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Faculty of Medicine and Health Sciences
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Human Movement Science
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Abstract

Introduction: Poling frequency (PF) in cross country skiing has been shown to affect gross efficiency (GE) and performance. However, there is limited knowledge about the relationship between individually manipulated PF in double poling (DP) and these parameters at different speeds and inclines. Therefore, the main purpose of this study was to investigate the effect of DP frequency at different speeds and inclines, on GE and physiological variables, and secondly how these parameters translate into performance. **Methods:** Seven regional to elite level cross country skiers performed 3 submaximal bouts (low, mod., and high intensity) and 1 performance time-to-exhaustion bout at two different inclines (3% and 8%) per day using the DP technique on roller skis on a big treadmill. Skiers were tested on three days separated by at least 48 hours, applying freely chosen frequency (FCF) on day 1 and a manipulated frequency (FCF-10 and FCF+10) at day 2 and 3. VO2, RER, and HR were measured continuously, and blood lactate concentration (BLa) and RPE were measured after each bout. **Results:** PF did not affect GE at any submaximal speed or incline. There was a tendency for FCF to have the highest GE at all intensities at both 3% and 8% incline. At submaximal bouts, GE significantly decreased and increased with power at 3% and 8% incline, respectively. FCF-10 caused significantly higher BLa levels than FCF+10. At 8% incline, a better performance was observed following FCF+10 compared to FCF. **Conclusion:** Results indicate that this present group of skiers tolerates fluctuations in PF within a certain range, without significant alterations in GE. Furthermore, GE decreased and increased significantly with power at 3% and 8%, respectively, potentially indicating the importance of poling power at increasing speeds.

Sammendrag:

Introduksjon: Stakefrekvens har vist seg å påvirke effektivitet og prestasjon i langrenn. Det er imidlertid begrenset kunnskap om sammenhengen mellom individuelt manipulert stakefrekvens og disse parameterne, ved forskjellige hastigheter og stigninger. På bakgrunn av dette var hensikten med studiet å undersøke effekten av stakefrekvens ved forskjellige hastigheter og stigninger, på effektivitet og fysiologiske variabler, samt hvordan dette overføres til prestasjon. **Metode:** 7 langrennsløpere på regional- til elitenivå gjennomførte 3 submaksimale drag (lav, mod. Og høy intensitet) og 1 prestasjonsdrag med tid til utmattelse på henholdsvis to forskjellige stigninger (3% og 8%) per dag. Skiløperne staket på rulleski på en stor tredemølle og ble testet 3 separate dager med minst 48 timer imellom. De anvendte sin foretrukne stakefrekvens (FCF) på dag 1 og staket med manipulerte frekvenser (FCF-10 og FCF+10) på dag 2 og 3. VO2, RER og HR ble målt kontinuerlig, og laktat og RPE ble målt etter hvert drag. **Resultat:** Stakefrekvens hadde ingen effekt på effektivitet på noen submaksimale hastigheter eller stigninger. Det var en tendens til at foretrukken frekvens (FCF) ga den høyeste effektiviteten på alle intensiteter på 3% og 8% stigning. På submaksimale drag hadde effektivitet en signifikant nedgang og økning med stigende intensitet på henholdsvis 3% og 8%. For FCF-10 ble det målt signifikant høyere laktatverdier enn FCF+10. På 8% stigning ble det observert en bedre prestasjon som følge av staking på FCF+10 sammenliknet med FCF. **Konklusjon:** Resultater indikerer at denne gruppen langrennsløpere tolererer endringer av stakefrekvens innenfor et begrenset omfang uten å få signifikante endringer i effektivitet. Videre kan nedgangen og økningen i effektivitet med intensitet potensielt indikere viktigheten av power i hvert stavtak ved økende hastigheter i staking.

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I would also like to thank the athletes that participated in my project. Your commitment and serious approach to the three days of testing has been crucial for the quality of this master thesis. I am very thankful for your volunteering, and it has been inspiring to meet and work with all of you. I hope the participation made some new experiences for you, and that this project can give you further knowledge on double poling. Hopefully, this project in coherence with other literature may be valuable for athletes that want to improve in cross country skiing, or more specifically, enhance their performance in double poling.

Finally, I have to thank all the employees at Senter for Toppidrettsforskning in Granåsen for the advice and inspiring conversations, as well as welcoming and including me in your working environment. I have really enjoyed this past year in company with you!

Thank you,

Vemund Øvstehage

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Abbreviations

DP	double poling
PF	poling frequency
CL	cycle length
GE	gross efficiency
G3	double dance technique in cross country skating
FCF	freely chosen frequency
FCF-10	refers to 10 poling thrusts per minute lower than freely chosen frequency
FCF+10	refers to 10 poling thrusts per minute higher than freely chosen frequency
LINT	low intensity
MINT	moderate intensity
HINT	high intensity
VO2	oxygen consumption
MR	metabolic rate
HR	heart rate
RER	respiratory exchange ratio
BLa	blood lactate concentration
RPE	rate of perceived exertion

1.Introduction

Double poling (DP) is one of the main techniques in cross country skiing classical style, and the use of it has become more dominant in the recent 10-15 years. Improvements in technique, upper-body capacity, equipment, and tracks, as well as higher speeds, have made DP develop substantially (1). It is now used in several uphill segments of the course, as well as in flat terrain where the speed is higher. DP makes up a considerable part of the distribution of classic techniques used during a race, especially in the longer Ski-Classics marathon races, where 10 out of 11 races in 2018 have been won by only DP (2).

DP is characterized by a cyclic movement pattern where the propulsive force is applied through the poles. The modern DP movement strategy is identified by higher pole forces applied during a shorter poling phase with smaller joint angles in the upper body and higher flexion and extension velocities (3). Therefore, the ability to translate a high level of energy into propulsive forces in a short amount of time is essential. In the same way as in regulation of thrusts in rowing or swimming, variations in poling frequency (PF) can be regarded as a gearing process (4), induced by continuous changes in PF and cycle length (CL). Especially with a lower PF at higher speeds, and thus longer CL, the importance of powerful thrusts is prominent.

In endurance sports, such as cross country skiing, there are three important factors that determine performance; Aerobic capacity, lactate threshold, and exercise economy (5).
As a consequence of mass starts and competition durations up to five hours, intensity and speed will fluctuate during a race, where the athletes work in submaximal intensity in a considerable part of the time. Furthermore, although there are differences in physical capacity among elite athletes, all of them are physical and technical well trained (6). Therefore, gross efficiency (GE) may be an important factor in differing athletes' performances (4).

Skiing technique has been proposed to have a great impact on GE in cross country skiing (4). GE is the ratio between metabolic rate (MR) and the total work generated, and can give a better understanding of how the external demands affect the physiological stress (7) at submaximal intensities. Thus, a higher efficiency equals a given amount of work generated, to a less energy cost.

In a study by Sandbakk and colleagues (4), on G3 skating, they showed that world-class skiers had a longer CL and a lower PF than national level skiers at similar speeds, as well as a lower MR and higher GE at the same work rate (WR). In another study on G3 skating by Leirdal et al.(8), they found GE at low frequency (FCF-10) to increase with power. In cycling, Foss and Hallén (9) also found a somewhat lower cadence than freely chosen, approximately FCF-10, to be the most efficient.

When double poling at 2-degree incline, Zoppirolli et al. (10) found high-level skiers to have a lower energetic cost, longer CL, and higher pole forces than regional-level skiers. A longer recovery phase and lower PF in DP, as a consequence of an increased CL, has been reported by Holmberg et al. (11) to relate to lower heart rate and blood lactate levels, as well as better performance. Lindinger and Holmberg (12) also found the oxygen uptake and heart rate to be lower at the two lowest fixed DP frequencies. Thus, a lower frequency seems beneficial to enhance GE and increase performance.

In addition to speed, the technique in DP may also be affected by terrain and external conditions. Thus, continuous variations in these parameters initiate adaptations of technique and variations in physiological demands. Stöggl and Holmberg (13) found DP at a steeper incline to be characterized by a more upright posture and distinctive utilization of the legs to create a greater vertical motion. Moreover, they found the elbow joints to be more flexed and the arms with a less maximal backward swing, accompanied by a 50% shorter swing time compared to DP on flat terrain. Danielsen et al. (14) showed that DP pole power at similar work rates was higher at lower gradients and that poling time and time-to-peak pole force was shorter. At the same time, pole force and the freely chosen PF were generally higher at steeper inclines for all work rates. In addition, a study by Dahl et al. (15) found GE in DP to be reduced at steeper gradients at the same external power output.

In the final part of a race, athletes switch to maximal speed with no necessity for metabolic efficiency. In a situation like this, it would be interesting to investigate how an energetic advantage would translate into performance at maximal intensity, as a consequence of the most efficient submaximal PF. Leirdal et al. (8) found no significant differences between FCF and FCF-10, but FCF+10 resulted in a poorer performance. Moreover, in cycling, Foss and Hallén (9) found the least efficient cadence to result in the best performance.

Lindinger et al. (16) observed DP speed to be controlled by an increase in both CL and PF. At high speeds, increased CL was achieved by increased mean peak pole force, although poling time and time-to-peak were reduced. When comparing fixed DP frequencies at three different speeds in flat terrain, Lindinger and Holmberg (12) found GE to decrease with higher frequencies at the two lower speeds, and GE to be higher at the to lower frequencies at the highest speed.

To the best of my knowledge, the effect of individually manipulated DP frequency on GE, at different inclines and intensities, has not been investigated. Therefore, the main purpose of this study was to investigate the effect of PF at different speeds and inclines on GE and physiological variables, and secondly how these parameters translate into performance. The hypotheses were that GE at submaximal intensities would be higher at the lowest frequency and that the freely chosen PF would result in the best performance at maximal intensity.

2. Methods

2.1 Participants

Nine regional- to elite-level skiers were recruited through ski teams or by email. Seven skiers completed all test days (Table 1). The data collection period was from the middle of December 2019 to the beginning of March 2020. All skiers participated in the study during their main season period, between competitions. The participants received a draft of the protocol when they were contacted, as well as information about the procedures and purpose of the study. On the first day of testing, the participants signed a written consent of participation and usage of research data. The study was registered and approved by Norwegian Social Science Data Services (NSD), as well as performed according to ethical standards established by the Helsinki Declaration of 1975.

Table 1. Characteristics of the 7 skiers

	Mean	±	SD
Age (years)	28	±	5.4
Body height (cm)	182	±	4.6
Body mass (kg)	76	±	5.2
Body mass index (kg/m^2)	23	±	0.86
VO2peak (ml/kg/min)	67.7	±	4.54
VO2peak (L/min)	5.147	±	0.37
Peak BLa (mmol/L)	11.37	±	2.18
Peak HR (beats/min)	183	±	9.8

VO2peak; peak oxygen uptake, peak BLa; blood lactate concentration peak, HR; heart rate

2.2 Experimental design

Each subject was tested on three occasions with a minimum of 48 hours of rest and low-intensity activity in between test days. For each subject, the three days of testing were completed within a period of seven days on average. The same test leader was testing each subject at all test days. The subjects were allowed to eat and drink as they wanted between the bouts, and nutritional intake was replicated during each day. They were not able to drink or eat at the actual stages. Each subject was tested at the same time of the day at all three test days and was encouraged to avoid high-intensity training prior to and between the test days. The inclines were randomized between subjects, but the order of inclines was similar for each of them, every day. The manipulated PF was randomized between the subjects and within each subject on day 2 and 3.

Prior to the main test period, an intensity scale at 3% and 8% incline was determined through pilot testing, calculation of WR, and discussion. A scale with increasing absolute intensities was created that could fit low (LINT), moderate (MINT), and high (HINT) submaximal intensity for each athlete, although they were on different physical levels. For 3% incline, the scale started at 13 km/h and ended at 23 km/h, increasing with 2 km/h per level, correspondingly ~19 watts. For 8% incline, the scale started at 7.5 km/h and ended at 12.5 km/h, increasing with 1 km/h per level, correspondingly ~20 watts.

All days of testing started with a 10 minutes warm-up where the subjects got used to 3% and 8% incline and tested the two first speeds on the intensity scale. The mouthpiece and poles were adjusted, and other equipment checked. The duration of breaks between the submaximal bouts was 2-3 minutes. Due to safety preparations, there was a few minutes longer break before the first performance bout started.

2.2.1 Day 1

Submaximal bouts

Day 1 was baseline day (Fig. 1), where the purpose was to determine which speed that was corresponding to LINT, MINT and HINT at 3% and 8% incline. The start speed was determined based on heart rate (HR) and feedback from the subject. The following blood lactate concentration (BLa) levels at LINT, MINT, and HINT could indicate if the scale was correct or not. The HINT bout was to be ending above 2.6 mmol/L. If the scale was set too low, the subject did two more bouts, one at each incline, to reach the correct lactate level, ending up doing six or eight submaximal bouts on day 1. If eight bouts were done, the last six were used for further analysis.

Performance bouts

The performance tests started at the next consecutive step on the intensity scale. After a five minutes bout, the speed increased by 1 km/h, continuing to increase every minute until exhaustion. The two maximal tests were separated by a break of 20-30 minutes, where BLa was measured after 20 minutes to verify if the rest period had been sufficient.

At each bout, the freely chosen frequency (FCF) of DP was measured by clicking on a metronome between the third and the fourth minute.

2.2.2 Day 2 and 3

Day 2 and 3 consisted of six submaximal and two maximal bouts on each day (Fig. 2), based on the intensity scale determined on day 1. The participants were instructed to target a PF as precisely as possible, using a metronome, creating a PF of FCF plus or minus 10 strokes per minute at each incline and intensity. The opposite PFs of day 2, were applied on day 3.

Performance bouts

The PF was only manipulated on the five minutes bout before the incremental time-to-exhaustion test. At the end of the five minutes bout, the metronome sound was turned off, and the subjects could apply a freely chosen poling frequency, going straight into the incremental stages. When the subjects reached the last speed of day 1, there was no further increment. Thus, the subjects went all out on the given speed until exhaustion.

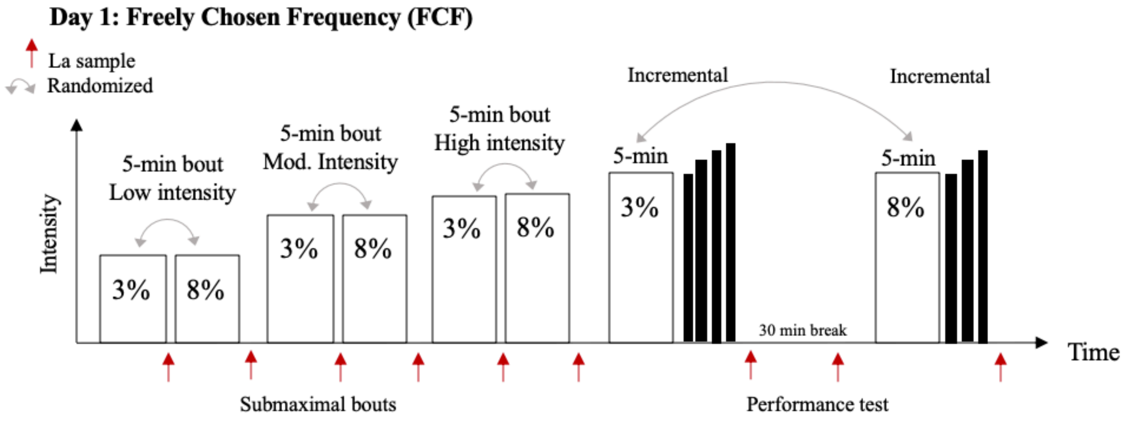

Figure 1: The protocol of submaximal and maximal bouts on day 1. Oxygen consumption and respiratory exchange ratio were measured continuously throughout each bout. The red arrows indicate when the BLa samples were taken. FCF was measured between minute 3 and 4 on each bout. HR was noted at the last minute of the 5 min. Bout at every intensity. RPE was measured after each bout using BORG’s scale.

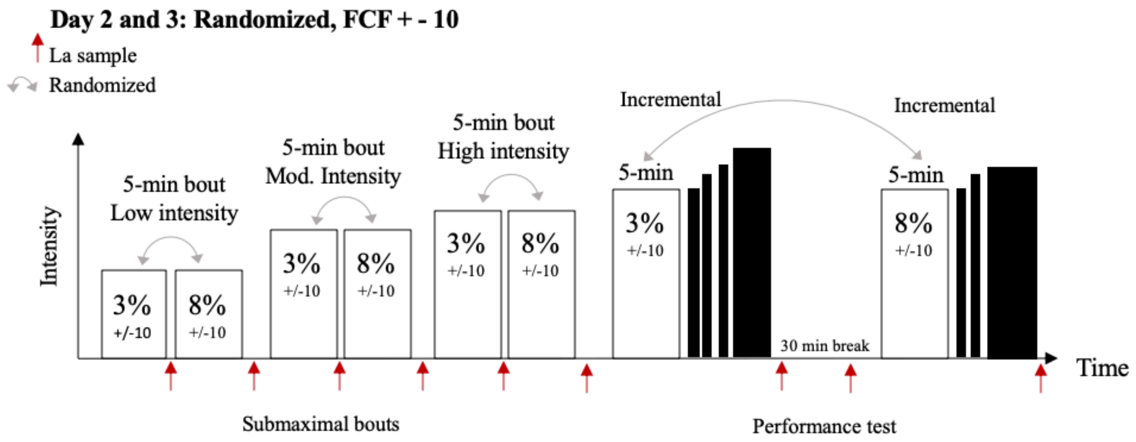

Figure 2: The protocol and design of submaximal and maximal bouts on days 2 and 3. Oxygen consumption and respiratory exchange ratio were measured continuously throughout each bout. The red arrows indicate when the BLa samples were taken. The manipulated frequency was given after 15 seconds until the end of the bout. HR was noted at the last minute of the 5 min. Bout at every intensity. On the maximal bouts, the manipulated frequency was turned off after the 5 min bout, when starting the incremental stages. RPE was measured after each bout using BORG's scale.

2.3 Equipment and measurements

The data collection was done in a laboratory with stable conditions (temperature 21, humidity ~30%) at NTNU - Senter for Toppidrettsforskning (SenTif). Swix Quantum 1 carbon ski poles (Swix, Lillehammer, Norway) with mounted carbide tips, were provided for all skiers, adjusted for individually preferred length, at ~30 cm lower than body height. The subjects used their own classical ski-boots. IDT classic roller skis with standard category 2 wheels (IDT Sports, Lena, Norway) and Rottefella binding system (Rottefella, Klokkarstua, Norway) was used by all subjects. A 3-by-5-meter motor-driven roller ski treadmill with a rubbery surface was used for all tests (S-mill, Motekforce Link, Amsterdam, The Netherlands), with a friction coefficient (μ) of 0.019, measured between wheel and rubber band of the treadmill.

In the process of finding (μ), one skier was rolling on the treadmill set in a horizontal position while holding on to a rope attached to another person in front of the treadmill. The rope was coupled to a load cell, which shows the friction force. The following equation was used to calculate μ: $\mu = Ffriction / F_N$

Respiratory variables were continuously measured through an open-circuit indirect calorimetry apparatus (Oxycon Pro, Jaeger GmbH, Hoechberg. Germany). A gas tank with a known gas concentration of 5% CO2 and 15% O2 (Riessner. Gase GmbH & Co, Lichtenfels, Germany), and the ambient air conditions, were used for calibration of the gas analyzers on each test day. A 3-liter syringe (5530series, Hans Rudolph Inc., Kansas City, MO, USA) was applied for manually calibration of the flow turbine (TripleV, Erich Jaeger GmbH, Hoechberg, Germany).

Blood lactate concentration was measured using Biosen C-Line Sport Lactate measurement system (EKF Industrial Electronics, Magdeburg, Germany), where a 5 μL blood sample was extracted from the subject's fingertip after each bout. Every hour the apparatus was calibrated with a standard concentration of 12- mmol μL. In total 10 – 12 lactate samples were collected on each test day. The timing of lactate measurements can be seen in Figure 1 and 2. Heart rate was measured continuously using a Polar V800 (Polar Electro Oy, Finland) with all subjects wearing a heart rate belt.

A metronome was used to measure and provide different poling frequencies (Tap Metronome, Version 1.2.1, by Dan Soper). At every maximum bout the subjects whore a safety harness attached to the ceiling, in case of an emergency situation. The rate of perceived exertion (RPE) was measured using BORG's RPE scale (6 – 20 scale) (17) and defined by the subject after each bout.

2.4 Data Analysis

Data analysis and calculations were done in Microsoft Excel (Microsoft Excel, 2020 Microsoft Corporation).

Oxygen consumption and RER

VO2 data in 10 seconds intervals were visually inspected. Relative and absolute oxygen consumption, as well as RER values, were calculated as last-minute average in every bout, to make sure the values were resulting from a steady state condition. Peak values were calculated from the last-minute average for the two performance bouts.

Metabolic rate

MR is the rate of whole-body energy input. It was calculated by the absolute oxygen consumption in liters per minute, multiplied by the kCal value corresponding to the RQ value (Péronnet and Maiscotte, 1991) (18). Furthermore, multiplied by the amount of kilojoule corresponding to 1 kCal, and divided by 60 to get joule per second, expressed in watt.

$$MR = \frac{VO2\ (L/\ min) \cdot kCal \cdot 4186\,J}{60}$$

Work rate

WR is the rate of work done against external resistance. For calculation of WR, work was decomposed into a vertical and horizontal component. When skiing on an inclined surface, N and mg are pulling in two different directions. On an indoor treadmill, the skier works against gravity and friction (rolling resistance), which means that he has to generate the same amount of work as the forces that are pulling on him. The vertical component was calculated by the skier's mass (m) times the gravitational acceleration (g) times velocity of the treadmill (v), multiplied by sinus of the angle of the treadmill. The horizontal component was calculated in the same way as the vertical component except multiplied by cosinus of the treadmill angle and then multiplied by the friction coefficient between the rubber band and roller ski. Finally, the two components were summed to the total work rate expressed in watt.

$$Work\ rate\ against\ gravity = \ m \cdot g \cdot v \cdot (sin\,\alpha°)$$
$$Work\ rate\ against\ friction = \ (m \cdot g \cdot v \cdot (cos\,\alpha°)) \cdot \ \mu$$

Gross Efficiency

The following equation was used to calculate GE:

$$GE = \frac{Work\ rate\ (W)}{Metabolic\ rate\ (W)}$$

Incline and speed

Treadmill inclination and speed were controlled from the control panel. Verification of the incline was done by an inclinometer placed on the flat surface on the side of the rubber band.

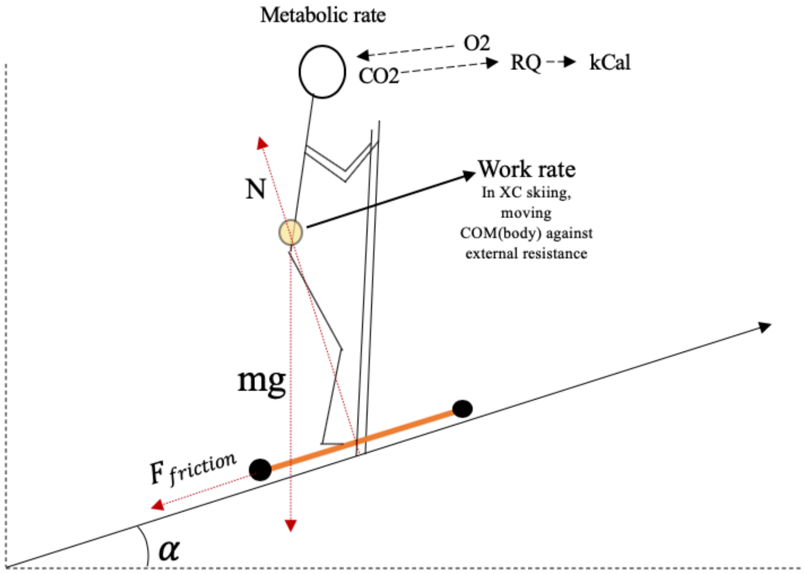

Figure 3. The relationship between the different components in the calculation of GE.

Performance

The time to exhaustion at the incremental stages was noted in seconds for every subject, to determine performance. Then the WR for every second of the performance was calculated, included the 5 min bout before the incremental stages, to see how many joules that were produced in total per subject in every poling condition. For the incremental stages, calculations of WR were adjusted for every 60 seconds when there was an increase in speed. The total amount of joules was divided by 1000 to get kilojoule.

2.5 Statistical Analysis

Submaximal bouts

All statistical analyses were performed using IBM SPSS Statistics (version 26, SPSS, inc, Chicago, IL). All statistical tests were done for 3% and 8% incline separately. A two-way repeated-measures ANOVA was done to check for possible differences in GE, MR, VO2, RPE, BLa, and HR between freely chosen and manipulated PFs and between submaximal intensities. A one way ANOVA was applied to check for possible differences in WR and FCF at different submaximal intensities.

Performance

To check for possible differences in time, work, RPE, VO2, V'E, BLa,, RER, and HR at the performance bouts, a one-way repeated measures ANOVA was done.

The level of significance was set at $p<0.05$ for all statistical analyses. Data are presented as mean ± standard deviation. When comparing means, effect sizes were evaluated by choens d. Magnitudes were interpreted as small: 0.2, moderate: 0.6, large: 1.2 (19)
Strength of association in one-way and two-way ANOVAs are indicated by Partial eta squared (η^2). Percentage points are indicated as 'pp' and refers to the difference between two percentage values.

3. Results

Seven subjects completed all test days, but one of them failed at one performance test at 3% incline. Thus, performance results at 3% are based on data from only 6 subjects.

3.1 Submaximal bouts

Gross efficiency

At 3% incline, a significant main effect of intensity was found (F(1.081,6.485)=7.787. p = 0.028, $\eta^2 = 0.565$), where GE decreased with power at all frequencies (Fig 4B). LINT showed a higher GE than MINT (0.2pp ± 0.98, p=0.041, d: 0.2) and HINT (0.7pp ± 1.00, p=0.029, d: 0.7). GE at MINT was higher than at HINT (0.5pp ± 0.83, p=0.035, d: 0.6). There was no significant main effect of frequency on GE (F(2,12)=8.889. p = 0.437, $\eta^2 = 0.129$) nor an interaction effect between intensity and frequency (F(4,24)=0.800. p = 0.537, $\eta^2 = 0.118$). A higher GE was observed following FCF compared to FCF-10 (0.4pp ± 0.99, p=0.272, d: 0.4) and FCF+10 (0.2pp±1.04, p=0.480, d: 0.2), but these findings were not significant.

At 8% incline, there was a significant main effect of intensity (F(2,12)=12.918 p = 0.001, $\eta^2 = 0.683$) where GE increased with power for all frequencies (Fig. 4D). Two pairwise comparisons showed a significant change in GE: LINT showed a lower GE than MINT (0.3pp ± 1.24, p=0.016, d: 0.2) and HINT (0.4pp ± 1.21, p= 0.007, d: 0.3). No significant main effect of frequency (F(2,12)=0.742. p = 0.497, $\eta^2 = 0.110$) or interaction effect with intensity (F(2.206,13.233)=0.101. p = 0.981, $\eta^2 = 0.017$) where found. GE following FCF was higher than FCF-10 (0.3pp ± 1.29, p= 0.372, d: 0.3) and FCF+10 (0.2pp ± 1.33, p=0.497, d: 0.2), but these findings were not significant.

A significant main effect was found for intensity on FCF at 3% incline (F(2,34.333)=14.045 p = 0.001, $\eta^2 = 0.701$) and 8% incline (F(2,17.714)=10.333 p = 0.002, $\eta^2 = 0.633$). Pairwise comparisons are presented in Table 2.

Table 2: Mean ± standard deviation for each intensity at submaximal intensities on 3% and 8% incline.

	3%incline			**8%incline**		
Condition	**Low**	**Moderate**	**High**	**Low**	**Moderate**	**High**
WR (W)	149.2 ±12.7	169.6 ±13.1*	189.6 ±13.7**	171.1 ±13.2	191.6 ±13.8*	212.1 ±14.4**
PF (FCF)	47 ±4.6	49 ±4.9*	51 ±4.6*	53 ±4.6	55 ±4.4*	56 ±4.3*

WR: work rate, PF: poling frequency, *Significantly different from low. **Significantly different from low and moderate

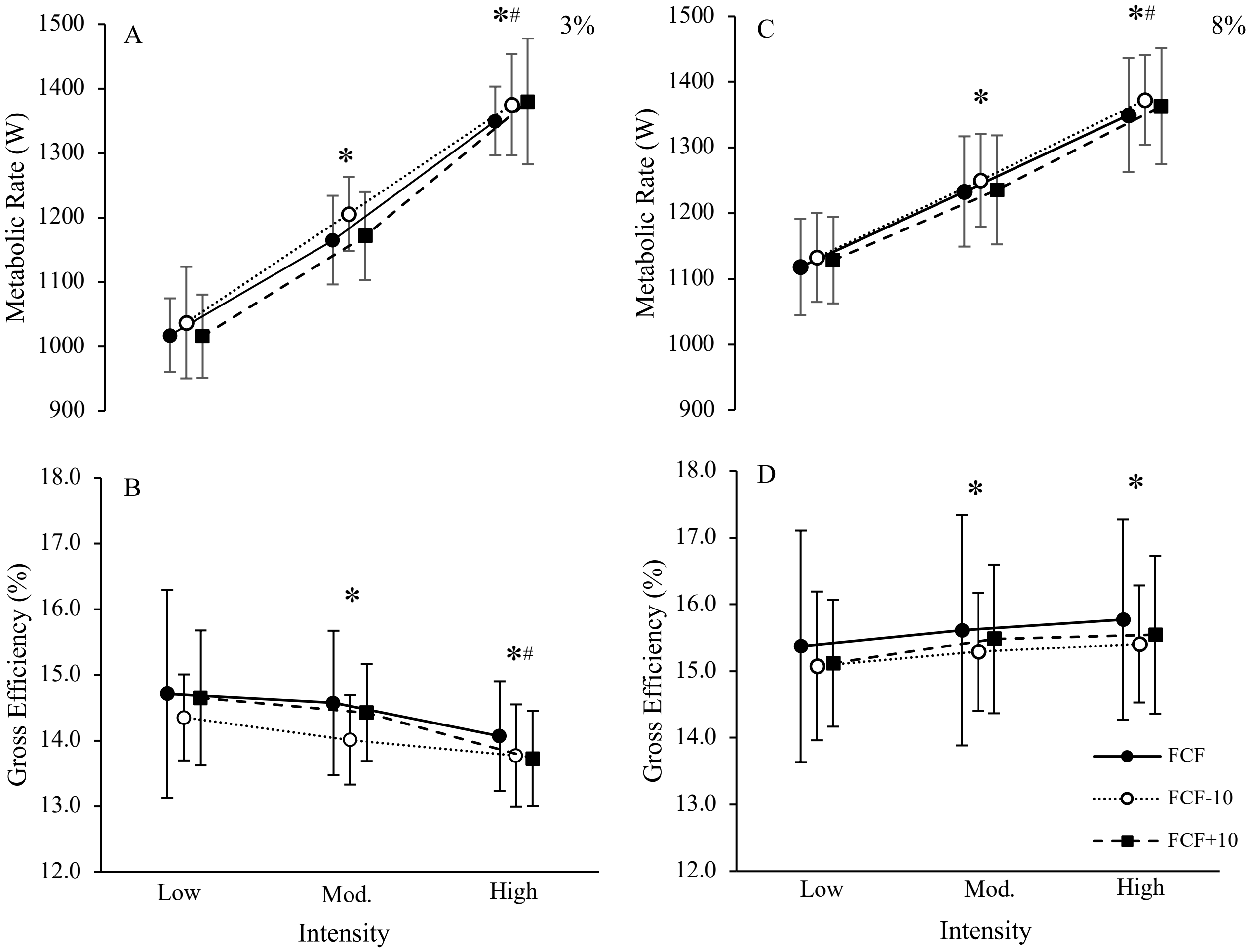

Figure 4.: Mean ± standard deviation for MR and GE in relation to intensity for the poling frequencies FCF, FCF-10 and FCF+10 at 3% incline (A/B) and 8% incline (C/D). ✻Significant difference from LINT. # Significant difference from MINT.

Blood lactate concentration

At 3% incline, there was a significant main effect of both intensity (F(2,12)=24.766, $p < 0.001$, $\eta^2 = 0.805$), and frequency (F(2,12)=18.656, $p = 0.007$, $\eta^2 = 0.565$) on BLa (fig. 5C). A 97.3% (1.8mmol/L ± 1.52, p=0.002, d: 1.2) higher lactate level was observed at HINT compared to LINT. FCF-10 had a significant 27.3% (0.64mmol/L ± 1.43, p=0.018, d: 0.5) and 14.5% (0.43mmol/L ± 1.47, p=0.043, d: 0.3) higher BLa than FCF and FCF+10, respectively.

At 8% incline, there was a significant main effect of intensity (F(2,12)=18.656, $p < 0.001$, $\eta^2 = 0.757$) (Fig. 5D). At HINT, skiers had a 77.9% (1.59mmol/L ± 1.49, p=0.004, d: 1.1) higher BLa than at LINT. A tendency for the main effect of frequency on BLa showed a somewhat higher p-value than 0.05 (F(1.103, 6.618)=2.075, p=0.197, $\eta^2 = 0.257$), but there was a significant 11.8% (0.35mmol/L ± 1.43, p=0.016, d: 0.2) higher BLa for FCF-10 compared to FCF+10.

Rate of perceived exertion (RPE)

There was a significant main effect of intensity on RPE (F(2,12)=84.517, $p < 0.001$, $\eta^2 = 0.934$) at 3% incline (Fig. 5E). HINT showed a 27.6% (3.14 ± 2.13, $p < 0.001$,d: 1.5) higher RPE score than LINT. A tendency for a main effect of frequency on RPE had a slightly higher p-value than 0.05 (F(2,12) = 84.517, p=0.099, $\eta^2 = 0.320$).

At 8% incline, a significant main effect of intensity (F(2,12) = 59.191, $p < 0.001$, $\eta^2 = 0.908$) was observed (Fig. 5F). The RPE score was 21.2% (2.62 ± 1.88, $p < 0.001$, d: 1.4) higher at HINT compared to LINT. A somewhat higher p-value than 0.05 was seen for the tendency for the main effect of frequency on RPE (F(2,12) = 1.926, p = 0.188, $\eta^2 = 0.243$).

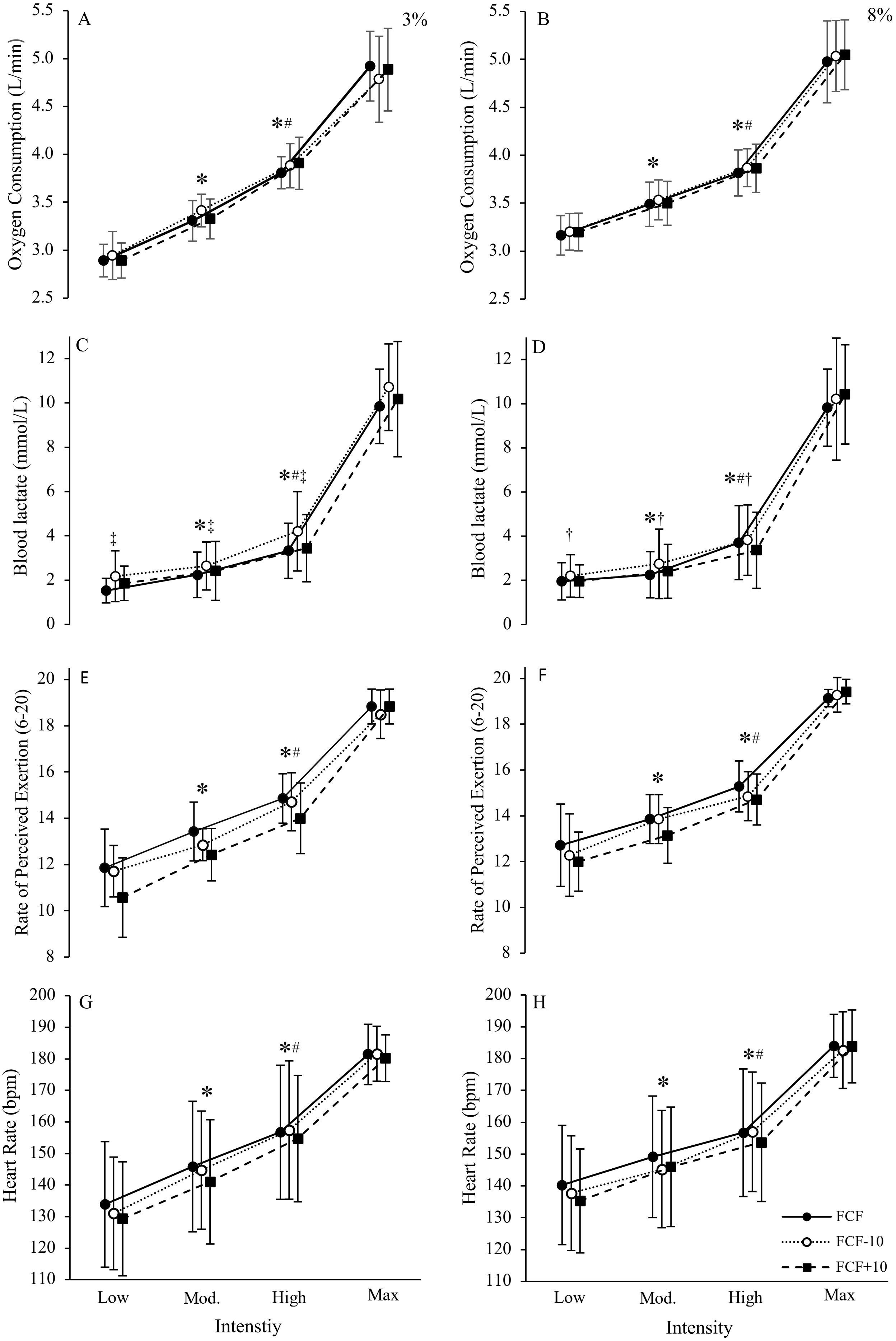
A
3%
B
8%
Oxygen Consumption (L/min)
5.5
5.0
4.5
4.0
3.5
3.0
2.5
*
*#
C
D
Blood lactate (mmol/L)
12
10
8
6
4
2
0
‡
*‡
*#‡
†
*†
*#†
E
F
Rate of Perceived Exertion (6-20)
20
18
16
14
12
10
8
*
*#
G
H
Heart Rate (bpm)
200
190
180
170
160
150
140
130
120
110
*
*#
FCF
FCF-10
FCF+10
Low
Mod.
High
Max
Intenstiy
Intensity

Figure 5: Mean ± standard deviation for absolute oxygen consumption (A/B), BLa (C/D), RPE (E/F) and HR (G/H) in relation to intensity for FCF, FCF-10 and FCF+10 at 3% and 8% incline. *Significant difference from LINT. # Significant difference from MINT. †Significant difference between FCF-10 and FCF+10. ‡ Significant difference between FCF – FCF-10, and FCF-10 – FCF+10.

3.2 Performance

At 3% incline, no significant main effect of frequency on performance- time (F(2,10) = 0.311, p= 0.740, $\eta^2 = 0.059$) or work (F(2,10) = 0.224, p= 0.803, $\eta^2 = 0.043$) were found, but there was a tendency for a better performance following FCF+10, compared to FCF and FCF-10 (Table 4, fig. 6A).

At 8% incline, no significant main effect of frequency on performance- time or work were found, but slightly lower significance levels, (F(2,12) = 3.769, p= 0.054, $\eta^2 = 0.386$) and (F(2,12) = 3.222, p= 0.076, $\eta^2 = 0.349$), respectively (Fig. 6B). Further, there was a tendency for FCF+10 to give the best performance. A significant difference between FCF+10 and FCF was observed, where performance time and work were 5.7% (29.0 ± 65.1, p=0.018 , d: 0.4) and 6.4% (8.2 ± 26.92, p=0.030 , d: 0.3) better at FCF+10, respectively. 6 out of 7 subjects performed better at FCF+10 than FCF, while 5 out of 7 subjects performed better at FCF+10 than FCF-10, although not significant.

Table 4: Mean peak ± standard deviation for the performance tests for FCF, FCF-10 and FCF+10 at 3% and 8%

	3% incline			**8% incline**		
Condition	**FCF**	**FCF-10**	**FCF+10**	**FCF**	**FCF-10**	**FCF+10**
Time (sec)	433 ± 96.7	440 ±159.4	461 ± 80.1	505 ± 73.6	518± 65.8	534 ± 57.3*
Work (kj)	93.0 ± 28.4	95.2 ± 40.3	98.6 ± 23.7	128.1 ±29.9	131.0 ±25.5	136.3 ±25.2*
VO2peak(ml/kg/min)	64.6 ± 4.6	63.8 ±3.3	64.5 ± 5.1	65.4 ± 5.4	66.5 ± 5.3	66.6 ± 4.0
V'E peak (L/min)	180 ± 9.0	182 ±13.2	180 ± 15.4	184 ± 14.6	185 ± 17.0	186 ± 15.4
MR peak (W)	1773 ± 134	1723 ±158	1760 ± 153	1797 ± 155	1815 ± 135	1825 ± 132
RER peak	0.98 ± 0.03	0.98±0.04	0.98 ± 0.03	1.01 ± 0.04	0.99 ± 0.05	1.02 ± 0.04

Time: Performance time, Work: kilojoules produced, VO2peak: peak relative oxygen consumption, V'E peak: peak ventilatory equivalent, MRpeak: peak metabolic rate, RERpeak: peak respiratory exchange ratio, *Significantly different from FCF.

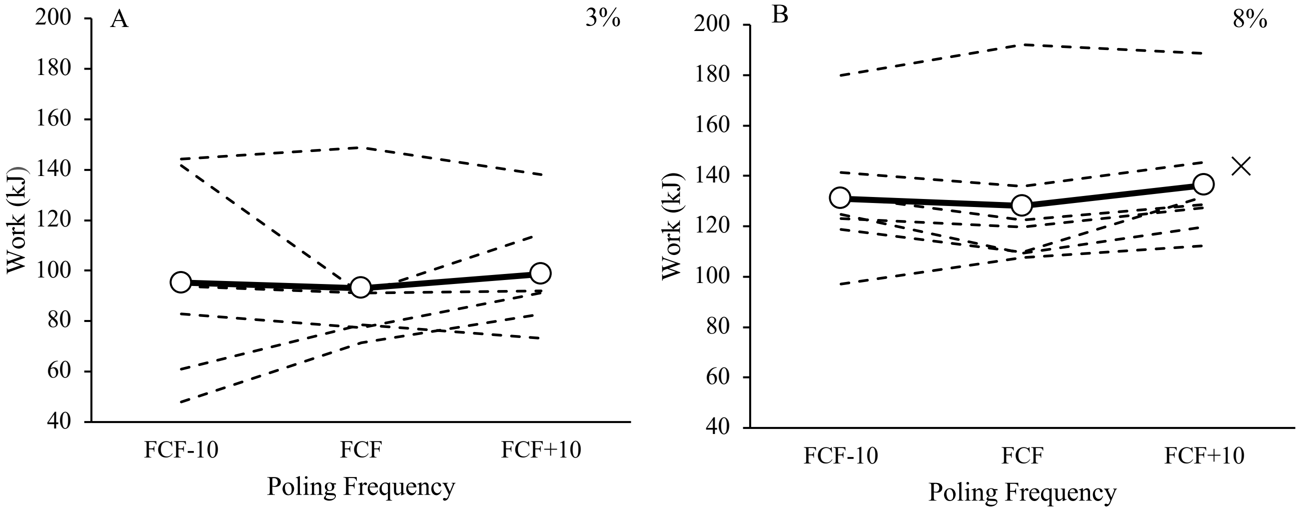

Figure 6: Performance quantified by work (kJ) for PF at 3% incline (A) and 8% incline (B).

--- Subjects. — Mean work per frequency. × Significant difference in performance between FCF and FCF+10.

4. Discussion

The purpose of this study was to investigate the effect of PF at different speeds and inclines on GE and physiological variables, and secondly how these parameters translate into performance. The main findings were that GE was not affected by PF at any speed or incline, where only a tendency for the highest GE following FCF was observed. However, FCF-10 led to higher BLa than FCF+10 at both inclines. Furthermore, GE significantly decreased and increased with power at 3% and 8%, respectively. Although FCF+10 led to a better performance than FCF, this difference was not predicted by submaximal GE measurements.

Submaximal bouts

In this present study, there was a tendency for FCF to be the most efficient PF at 3% incline at all intensities, as well as FCF-10 to show the poorest GE at LINT and MINT (Fig. 4A). There was also observed a tendency for a higher MR for FCF-10 at both inclines, except for HINT 3% (Fig. 4A/C). However, FCF-10 at HINT 3% led to significantly higher BLa compared to other PFs, which may indicate an increased anaerobic contribution and enhanced energy cost. The same relationship may partly explain the tendency of higher MR seen following FCF-10 at both inclines, where also higher BLa was observed compared to FCF+10 at 8% incline (Fig. 5C/D). In this present study, I did not measure exact anaerobic energy contribution, but a higher level of BLa may give an indication of increased physiological stress through enhanced anaerobic contribution.

In resemblance with findings by Leirdal et al. (8) for national level skiers in G3 skating, no effect of PF on GE was observed at submaximal intensities. However, contrary to this, a previous study on DP by Lindinger and Holmberg (12) found the lower frequencies to be more efficient at both lower and higher speeds in flat terrain. However, in their study, top elite athletes were tested, contrary to this present group of mostly regional-level skiers. Moreover, Sandbakk et al. (4) found a difference in GE in G3 skating, following a lower PF and longer CL at the same work rates for elite- compared to national level sprint skiers. Thus, it could be that skiers of a higher level are more capable of handling lower frequencies through better technique and more powerful poling thrusts, actually increasing their GE. Whereas national- and regional-level skiers are capable of tolerating lower frequencies without explicit changes in GE. Still, there is a tendency of lower GE at FCF-10 in this present study. A reason for these findings may be due to the protocol design.

The manipulated frequencies in my study were individually adjusted, but with a fixed range of manipulated frequencies (plus or minus 10). Leirdal et al. (8) manipulated PF the same way as in this study and found GE values ranging from 15 – 15.7%, which is in accordance with my findings on 8% incline. Lindinger and Holmberg (12) used no individual adjustment and applied fixed poling frequencies of 40, 60, and 80 poling thrusts per minute at 2% incline, where they found significant differences between all PFs at the two lower speeds. In my study, FCF at LINT for 3% and 8% were 47 and 53, significantly increasing with ~ 7% to HINT, placing them in between 40 and 60. Thus, one can argue reduced validity of fixed values because of the increase of FCF with power, and secondly, the fixed values used by Lindinger and Holmberg to be of a too wide range, creating unrealistically high PFs. At the same time, fixed values can also be logic for comparing certain frequencies, other than those related to FCF. However, one may assume that a PF of 40, 50, and 60 had caused results closer to what is presented in my study.

On the other hand, the individually adjusted system also has some challenges. An originally low FCF will cause a FCF-10 so low that it is difficult to complete, which could impact the results. Furthermore, 3%, high speed, high frequency, as well as, 8%, low speed, and low frequency, were reported to feel unnatural, stressful, and coordinatively challenging, although not statistically significant, causing the highest MR and BLa among PFs at the particular intensity (fig.4A/C, 5C/D). Thus, although PF is individually adjusted, unnatural poling patterns may appear fairly challenging.

It seems that regional level skiers are able to use different frequencies within a certain range without significantly affecting their GE. Being able to apply different PFs dependent of the situation, makes the skier more suitable for following the PF of the skier in front, which is beneficial in terms of reducing drag and easier adjustment of steady speed. However, when the speed of the peloton increases at leveled ground, a decrease in GE for this group of regional level skiers may occur, as well as potentially higher physiological stress at lower frequencies. An explanation for this may be the higher demand and lack of poling power.

At leveled ground, the ratio between poling phase and swing phase at FCF is approximately 1:3 (3), where FCF-10 and increasing speed further increase this ratio. Because of constant speed and less poling thrusts, the force per thrust needs to be higher to maintain speed. In other words, when the speed is high, the ground disappears quicker. Thus, the force has to be applied in a shorter amount of time. This requires an adequate angle of the pole plant as well as higher power per poling thrust. If the skier is in a lack of power, he must compensate with increased PF, and thus, there will be less time to reposition in the swing phase. Moreover, the initial position for the consecutive poling thrust will most likely be with a smaller hip angle and inadequate pole plant, reducing the possibility of applying enough power. Consequently, over time, this negative circle will make the energetic cost increase, causing GE to decrease.

Contrary to 3%, a significant increase in GE with power was observed at 8% incline for all intensities. At work rates of ~ 22 watts more (Table 2), there was also observed a tendency for higher GE values compared to 3% (Fig. 4D). The same relationship has been observed by Sandbakk et al. (20) in G3 skating, where the skiers execute a higher work rate at 8% than 2% incline, at similar MR. Moreover, in this present study, significant lower BLa was found for FCF+10 compared to FCF-10 (Fig. 5D), as well as a tendency for higher MR at FCF-10 (Fig. 4C). These differences may be explained by the enhanced pull of gravity the skier has to overcome (3), causing slower speeds at steeper inclines, more time to apply force on the ground through longer contact times, and thus better conditions for the muscles to work, resulting in higher force impulses and peak pole forces during the cycle compared to skiing at levelled ground (13). Thus, skiers of a lower level may beneficially use a higher PF to apply less force more frequently, in order to control lactate accumulation and physiological stress.

In this present study, there was a tendency for FCF to feel the most demanding at all submaximal intensities at both inclines (Fig. 5E/F), although it had the (insignificantly) highest GE. This is contrary to Foss and Hallén's (9) findings in cycling, where they found a tendency for the most efficient cadence to feel the second easiest cadence to execute. However, athletes were adjusting cadence by looking at a monitor/display, whereas in my study, I manipulated PF with a metronome. An explanation for my findings can be the potential effect of focusing on following a specific sound, which may make it feel easier to work on a given frequency. Clark et al. (21) found RPE to be lowered with 0.5 points when runners were listening to self-selected music, perhaps indicating an advantage of being able to focus on a type of audio. Although the metronome cannot be considered as music, an audio distraction might still help to switch focus. Furthermore, although not significant, FCF-10 was the second most demanding PF at every intensity potentially showing that a lower frequency is perceived harder to follow than a higher one. This is in accordance with the MR (Fig. 4A/C), HR, and BLa values (Fig. 5C/D/G/H).

Performance bouts

No differences in performance were found, except for a significantly better result following FCF+10 compared to FCF at 8% incline (Fig. 6B), but the effect was small. As discussed, a possibly lower level of force and power capacity among regional skiers may be a reason for a better performance following a higher frequency than a lower, especially at steeper incline. FCF+10 enables skiers to apply less force more frequently and may thereby make them sustain more energetically effective at high work rates, through better exploitation of their VO2 capacity. Thus, it seems that applying FCF+10 at 8% in the 5 minutes bout is beneficial to be better prepared for a further continuous increase in WR in a final sprint at FCF. It is also worth mentioning, although all values were not significant, that all physiological variables and RPE were highest at this particular condition. Therefore, one may assume that a higher frequency is more suitable for reaching maximum physiologic potential.

These findings are in contrast to those of Leirdal et al. (8) where they in a time to exhaustion test in G3 skating found all national level skiers to perform significantly worst in the FCF+10 condition. My results are more consistent with Foss and Hallén's findings in cycling (9), where a less efficient high cadence resulted in the best performance in a time trial, and a more efficient FCF only gave a moderate performance. Thus, this relationship may vary due to physical level, performance test and type of sport. However, in some occasions, the frequency an athlete chooses and/or the one with a lower physiologic cost at submaximal intensities, might not necessarily lead to the best performance.

Moreover, skiers reported a feeling of energetic excess related to the rapid change of frequency when entering the incremental stages, after double poling on FCF+10. These subjective reports are interesting considering a possible psychologic and physiologic effect of gearing when the speed increase, breaking up a somewhat monotonic poling pattern. On the other hand, regardless of previous PF, switching to FCF in a performance situation will most likely feel like a relief, when only focusing on winning.

At 3% incline, a larger dispersion in performance between the three frequency conditions for each subject was observed, compared to performances on a steeper incline (Fig. 6A/B). As previously mentioned, the short time for force generation may make performances more variable on 3%. Moreover, on average, it seems that the performances differ to a lesser extent compared to 8%. However, more similar results were observed within each subject at a steeper incline, although there was a tendency for these performances to be reported as more physically demanding and exhausting, potentially due to higher lactate accumulation. Lower speed and a longer poling phase at steeper incline may also contribute to more even results through favourable conditions for easier controlling different poling patterns coordinatively.

In addition to more similar performances, skiers also performed generally better at 8%. Skiers produced on average 35-38 kJ more at each PF compared to 3%. This may be due to the importance of the pull of gravity when calculating WR. For each 1 km/h increase in speed at the incremental stages, the difference in WR between 3% and 8% incline increases by ~10 watts, making skiers at 8% attain higher WR much quicker. Additionally, there is no drag when testing in a lab, which will influence the two conditions differently compared to outdoor skiing, where speed in flat terrain would also be limited by air resistance. Thus, it is interesting that skiers are able to sustain 70 – 80 seconds longer on average at the steeper incline. One may assume that the beneficial conditions at 8%, facilitating the muscles to maximize their potential, and perhaps better efficiency make up for the distinct increasing difference in WR. On the other hand, such differences make it difficult to compare performance on these inclines properly, which however, also is beyond the scope of this thesis.

Methodological considerations

It can be challenging to regulate the intensity of a heterogeneous group. Although they are all skiers at a high level, there are still differences in physical capacity, which have to be taken into consideration when designing the protocol. Therefore, I decided to regulate the intensity by absolute speed levels, adjusted relative to each subject and checked with BLa, HR, and RPE at each bout. Thus, the main challenge was to find the correct start speed. Consequently, it happened that a subject had a little too high concentration of lactate after the last submaximal bout. This may have affected the following submaximal bout at the consecutive incline or the performance bout. On the other hand, the trials were both randomized and similarly intensity-regulated at each day for every subject. Regulation only by absolute speed, and not relatively adjusted, may have caused a higher practical implication, as where skiers in a mass start follow the speed of the skier in front. Additionally, if I had applied an absolute speed, the conditions should have been more homogenous. However, it is important to note that this project wanted to compare GE at frequencies within each subject, not between different subjects. Therefore, a potentially too high or low adjusted intensity was similar each day, and thus consequences were minimal for the actual comparison.

Some factors may have affected the results. If the starting intensity was too high, there is a possibility that the anaerobic contribution has been too high at the last submaximal bout, thereby causing an increased energy cost and BLa, which may affect the GE. This may also cause GE to be somewhat overestimated since the oxygen consumption only reflects the aerobic metabolism. On the other hand, I made sure to start the athlete at one intensity level lower than expected, lowering the risk for an inappropriate intensity by making adjustments easier.

Secondly, if the subject had a bad day on day 1, its intensity levels and performance may have been set too low compared to the skier's actual capacity. Since day 2 and 3 are based on day 1, it will possibly create better results at manipulated PFs compared to FCF. However, FCF-10 and FCF+10 are compared to the same extent as to FCF in this project, which also is valuable data. Furthermore, there are considerations around the 20-30 minutes break between performance tests. Weltmann et al. (22) found 20 minutes recovery to be enough after a 5 min performance test in cycling, and to not affect the following test. For some subjects in my study, 20 minutes were enough, and others had up to 30. Anyhow, the duration of the break was similar at each test day for the same subject. Moreover, an effect of training may have influenced the results, where skiers potentially got more familiar with poling on manipulated frequencies, the frequently increments in speed, and the duration of the incremental stages. However, they were all used to perform at high intensity on roller-skis. Thus, effects might be limited.

Finally, when pilot testing, some athletes at the performance tests with FCF-10 reported that the speed suddenly got too high at 3% and made them quit, not the lack of oxygen. Therefore, to avoid this, the increase in speed on day 2 and 3 stopped where the athlete quitted on day 1. From there, the athlete had to keep on poling at constant speed until exhaustion.

Based on observations through this project, the ability to generate enough power is probably what differ athletes of high level in DP. Considering manipulation of PF, I wanted a manipulation that was big enough to make a potential difference, but still not bigger than practically realistic in a long-distance ski race. Thus, after pilot testing, the decision to manipulate the frequency by plus or minus 10, instead of 15 or 5, seems fair due to, for instance, 47 in FCF (Table 2) where FCF-15 leads to 32, which is a really hard PF to execute.

One of the main limitations of this study is the number of athletes. Due to the COVID-19 virus I got only complete data sets on seven subjects. Two more subjects had one and two test days left, and a few more were planned to participate. The consequences are mainly affecting the statistical analysis, where a larger number of participants could have caused potentially more significant and representative results. Another limitation is the timing of data collection, where most athletes were doing weekly competitions in their main season. This is also the reason why the data collection was ongoing during the COVID-19. Therefore, there were some challenges due to recruitment of the particular group of athletes that I preferred and to get them to come to the lab in certain weeks.

Future research within the same field should compare the effect of different DP frequencies on GE between two groups of regional/national level and elite level skiers at different inclines and intensities. It had also been interesting to look at many of the same parameters in DP after the athletes have been skiing for three to four hours outside. Thus, applying the same protocol as in this present study would have made it more physiologically realistic due to long-distance races.

5. Conclusion

In conclusion, GE was not affected by PF at any intensity or incline, indicating that this present group of skiers tolerates fluctuations in PF within a certain range without significant alterations in GE. GE decreased and increased significantly with power at 3% and 8%, respectively, potentially indicating the importance of poling power at increasing speeds. These findings may hopefully contribute to enhanced knowledge about PF in relation to GE and performance, as well as deliberately selected PF according to race-specific situations.

6. References

1. Stöggl T, Holmberg H-C. Force interaction and 3D pole movement in double poling: Force interaction and 3D in double poling. Scand J Med Sci Sports. desember 2011;21(6):e393–404.

2. Stöggl T, Ohtonen O, Takeda M, Miyamoto N, Snyder C, Lemmettylä T, mfl. Comparison of Exclusive Double Poling to Classic Techniques of Cross-country Skiing: Med Sci Sports Exerc. april 2019;51(4):760–72.

3. Holmberg H-C, Lindinger S, St??Ggl T, Eitzlmair E, M??Ller E. Biomechanical Analysis of Double Poling in Elite Cross-Country Skiers: Med Sci Sports Exerc. mai 2005;37(5):807–18.

4. Sandbakk Ø, Holmberg H-C, Leirdal S, Ettema G. Metabolic rate and gross efficiency at high work rates in world class and national level sprint skiers. Eur J Appl Physiol. juni 2010;109(3):473–81.

5. Hoffman J. Physiological Aspects of Sport Training and Performance. Second. University of Central Florida: Human Kinetics; 2014. 503 s.

6. Sandbakk Ø, Leirdal S, Ettema G. The physiological and biomechanical differences between double poling and G3 skating in world class cross-country skiers. Eur J Appl Physiol. mars 2015;115(3):483–7.

7. Ettema G, Lorås HW. Efficiency in cycling: a review. Eur J Appl Physiol. mai 2009;106(1):1–14.

8. Leirdal S, Sandbakk ø., Ettema G. Effects of frequency on gross efficiency and performance in roller ski skating: Frequency in roller ski skating. Scand J Med Sci Sports. juni 2013;23(3):295–302.

9. Foss □ivind, Hall□n J. Cadence and performance in elite cyclists. Eur J Appl Physiol. januar 2005;93(4):453–62.

10. Zoppirolli C, Pellegrini B, Bortolan L, Schena F. Energetics and biomechanics of double poling in regional and high-level cross-country skiers. Eur J Appl Physiol. mai 2015;115(5):969–79.

11. Holmberg H-C, Lindinger S, St??Ggl T, Bj??Rklund G, M??Ller E. Contribution of the Legs to Double-Poling Performance in Elite Cross-Country Skiers: Med Sci Sports Exerc. oktober 2006;38(10):1853–60.

12. Lindinger SJ, Holmberg H-C. How do elite cross-country skiers adapt to different double poling frequencies at low to high speeds? Eur J Appl Physiol. juni 2011;111(6):1103–19.

13. Stöggl TL, Holmberg H-C. Double-Poling Biomechanics of Elite Cross-country Skiers: Flat versus Uphill Terrain. Med Sci Sports Exerc. august 2016;48(8):1580–9.

14. Danielsen J, Sandbakk Ø, McGhie D, Ettema G. Mechanical energetics and dynamics of uphill double-poling on roller-skis at different incline-speed combinations. Ardigò LP, redaktør. PLOS ONE. 22. februar 2019;14(2):e0212500.

15. Dahl C, Sandbakk Ø, Danielsen J, Ettema G. The Role of Power Fluctuations in the Preference of Diagonal vs. Double Poling Sub-Technique at Different Incline-Speed Combinations in Elite Cross-Country Skiers. Front Physiol [Internett]. 21. februar 2017 [sitert 21. februar 2020];8. Tilgjengelig på: http://journal.frontiersin.org/article/10.3389/fphys.2017.00094/full

16. Lindinger SJ, StöGgl T, MüLler E, Holmberg H-C. Control of Speed during the Double Poling Technique Performed by Elite Cross-Country Skiers: Med Sci Sports Exerc. januar 2009;41(1):210–20.

17. Borg, 1982 Psychophysical bases of perceived exertion.pdf.

18. Péronnet F, Massicotte D. Table of nonprotein respiratory quotient: an update. Can J Sport Sci J Can Sci Sport. mars 1991;16(1):23–9.

19. Hopkins WG. A New View of Statistics [Internett]. A New View of Statistics. 2006. Tilgjengelig på: https://www.sportsci.org/resource/stats/effectmag.html

20. Sandbakk Ø, Ettema G, Holmberg H-C. The influence of incline and speed on work rate, gross efficiency and kinematics of roller ski skating. Eur J Appl Physiol. august 2012;112(8):2829–38.

21. Clark JC, Baghurst T, Redus BS. Self-Selected Motivational Music on the Performance and Perceived Exertion of Runners: J Strength Cond Res. desember 2018;1.

22. Weltman A, Stamford BA, Fulco C. Recovery from maximal effort exercise: lactate disappearance and subsequent performance. J Appl Physiol. 1. oktober 1979;47(4):677–82.