Sindre Brekke Veltun

Prolonged double poling in cross-country skiing:

How does it affect performance and performance-determining variables?

Master's thesis in Physical Activity and Health
Supervisor: Dionne Noordhof
Co-supervisor: Knut Skovereng

June 2021

Master's thesis

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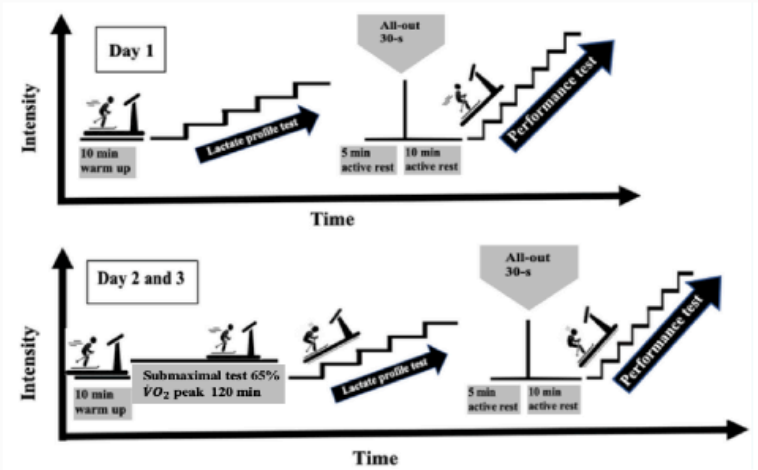
Kunnskap for en bedre verden

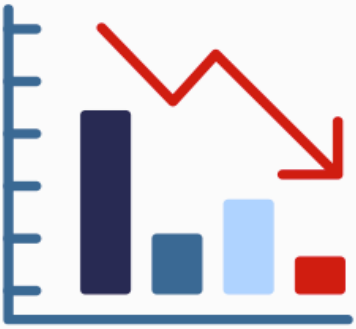
How does prolonged double poling effect performance and which variables are performance-determining ?

Rested state | **Fatigue state**

VS

The participants completed three test days in lab, consisting of different sport-specific performance tests performed from rested (day1) and fatigued state (day2 and 3) in double poling (DP)





Change in performance

Performance remained similar after 60 min as at rested state measurements, but decreased significantly with 4% after 120 min submaximal DP, which corresponded with a reduced efficiency at submaximal speed and shorter peak cycle length.

Performance-determining variables

$\dot{V}O_2$ -and GE at submaximal speed, cycle rate and cycle length assessed in rested state (D1) were significantly correlated to D3 performance and were substantially stronger related to D3 performance when they were assessed after 120 min submaximal DP (D3).

DP cycle rate

Take home message

Prolonged DP reduced performance in DP accompanied by a decline in efficiency and shorter peak cycle length. Cycle rate and efficiency determined from rested state (D1) were both significantly positively related to performance after prolonged submaximal DP (D3) and stronger correlation when determined after prolonged submaximal DP (D3).

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Finally, I would thank all the skiers that took part in the project. It has been interesting work with athletes at elite level and see how they have responded in the different tests. I hope their experiences during the project can be useful in their further training.

Abbreviations

XC	Cross-country
OLXC	Olympic cross-country
VSC	Visma Ski Classics
LXC	Long-distance cross-county
DP	Double poling
$\dot{V}O_2$	Voluntary oxygen uptake $\dot{V}O_2$
$\dot{V}O_2$max	Maximal oxygen uptake
$\dot{V}O_2$ peak	Peak oxygen uptake
LT	Lactate threshold
GE	Gross efficiency
PPO	30-s peak power output
TTE	Incremental time to exhaustion test
RPE	Rating of perceived exertion
D1	Day 1
D2	Day 2, after 60 min submaximal DP
D3	Day 3, after 120 min submaximal DP
Vpeak	Performance, peak speed, calculated as mean speed during the last minute before exhaustion TTE
Wmean	Mean power output attained during the 30-s PPO
LTspeed	Speed at lactate threshold

Abstract

Performance-determining variables are normally measured from a rested state, which may deviate from a fatigued state, like in the final part of a long-distance race. **Purpose**: investigate how performance decreases during prolonged DP and to investigate which physiological and biomechanical variables are performance determining after prolonged DP. **Methods**: Elite male cross-country skiers (n=10) completed three test days in the lab consisting of different sport-specific test; a blood lactate profile test, 30-s peak power output (PPO) test and an incremental time to exhaustion test (TTE) performed from rested state (day1: D1), after 60 min (day 2: D2) and 120 min (day 3: D3) submaximal DP. All tests were performed using the DP subtechnique. **Results**: DP performance (Vpeak: D1=19.31 km/h) was affected by prolonged submaximal DP, shown by a reduced performance after 120 min submaximal DP (Vpeak: 18.50 km/h, D3-D1: P=.046, d=-.78 and D3-D2; P =.019, d=-.76), without change in $\dot{V}O_2$peak. Which corresponded with higher $\dot{V}O_2$ and reduced gross efficiency (GE) at submaximal speed (10km/h) and decreased peak cycle length. GE (speed 12 km/h) and cycle rate (speed14km/h) assessed from rested state were related to performance D3 (GE: r= .73, P=.03 and cycle rate 14 km/h: r=.86, P=.001) and more closely related to D3 performance when they were predicted after prolonged DP (D3) (GE: r= .64, P=.032, and cycle rate 14 km/h: r=.93, P<.000). **Conclusions**: Prolonged submaximal DP reduced performance, which was accompanied by a reduced GE at submaximal speed and peak cycle length. GE and cycle rate predicted from rested state (D1) and fatigue state (D3) was related to performance in fatigue state (D3). However, performance should be determined in a sport-specific situation and further research are necessary.

Keywords: rested state, fatigue state, maximal oxygen uptake, gross efficiency, cycle rate, cycle length

Sammendrag

Prestasjons-bestemmende variable blir normalt målt fra utvilt tilstand, noe som kan avvike fra utmattet tilstand, som på slutten av en konkurranse i langløp på ski.
Hensikt: Å undersøke hvordan prestasjonen reduseres under langvarig staking og undersøke hvilke fysiologiske og biomekaniske prestasjons-bestemmende faktorer som er avgjørende for prestasjonen etter langvarig staking. **Metode**: Ti mannlige elite utøvere i langrenn fulførte tre testdager i lab, bestående av ulike idrettsspesifikke tester; laktat profil test, 30-sek maks test på stake ergometer og en tid til utmattelses test, som ble gjennomført fra hvile nivå (dag 1), etter submaksimal staking med varighet på 60 min (dag 2) og 120 min (dag 3), alle testene ble gjennomført i staking. **Resulta**t: Prestasjonen i staking (dag1= 19,31 km/t) ble redusert etter 120 min submaksimal staking (Dag 3= 18.50 km/t, Dag3-Dag1: P=.046, d=-.78 and Dag3-Ddag2; P =.019, d=-.76) som samsvart med en reduksjon i gross efficiency (GE) på submaksimal hastighet og maks stake-lengde per syklus, uten endring i $\dot{V}O_2$peak. GE (hastighet 10 km/t) og stake-frekvens (hastighet 14 km/t) estimert fra hvilenivå var sterkt relatert til prestasjonen dag3 (GE: GE: r= .73, P=.03 og stak-frekvens 14 km/h: r=.86, P=.001), men enda sterkere relatert til prestasjonen dag 3 når de ble estimert etter 120 min submaksimal staking (GE: r= .64, P=.032 og stake-frekvens 14km/t: r=.93, P<.000).
Konklusjon: Langvarig staking førte til dårligere prestasjon i staking, som samsvarte med redusert GE på submaksimal hastighet og lavere maks stake-lengde per syklus. Stake-frekvens og GE var relatert til prestasjonen utmattet tilstand (dag3) når de ble estimert fra hvile nivå (dag1) og etter 120 min staking (dag3). Basert på resultatene, burde prestasjonen bli estimert i idrettsspesifikke situasjoner og videre forskning er nødvendig.

Nøkkelord: uthvilt tilstand, utmattet tilstand, maksimalt oksygen opptak, gross efficiency, stake-frekvens, stake-lengde

Contents

Introduction

Cross-country (XC) skiing is one of the most complex endurance sports characterized by use of the upper and lower extremities in cyclic movements employing different subtechniques (1–3). Olympic XC (OLXC)-skiing competitions range from ~ 1.3-1.8 km sprint races (~ 3 minutes) to races of about 50 km (2-4 hours). The race terrain consists of one-third flat, one-third uphill and one-third downhill. Ten out of the twelve Olympic competitions are mass-start events (2,4), in which the outcome is often settled in a mass sprint. In addition to the Olympic mass-start events, there are since 2010 long-distance competitions. The Visma Ski Classics (VSC) pro tour in 2018/2019 consists of twelve long-distance XC (LXC) skiing competitions (5). In comparison to OLXC-skiing competitions, LXC-skiing races range from 40-90 km and are held on less hilly terrain (3,6). Double poling (DP) is the dominant subtechnique during classical-style LXC races, with the speed being generated exclusively through the poles (6–8).

Performance in OLXC-skiing is mainly determined by the performance oxygen uptake (; $\dot{V}O_2$ defined by maximal oxygen uptake [$\dot{V}O_2$max] and $\dot{V}O_2$ at lactate threshold LT), the O_2 deficit or anaerobic capacity and gross efficiency (GE) (1,2,4,9). In addition to a high aerobic capacity, it is important to be able, to utilize a high fraction of $\dot{V}O_2$max to produce velocity using varying subtechniques (4,10). The importance of the $\dot{V}O_2$max and GE has been emphasized in several studies as the main difference between national-level and world-class OLXC skiers (11,12). Further, GE and $\dot{V}O_2$max determined during treadmill roller skiing were closely related to on-snow sprint performance (13).The anaerobic energy contribution becomes less with increasing distance (2,9), but is still important during a final sprint (less than 2 min) (14), when its critical to produce high velocity(11). Despite different competition forms, there are close similarities between OLXC and LXC race events, both include races over several hours (50 km), competitions with mass start where the performance often is determined at the end of the race (in a mass sprint) and DP is a dominant subtechnique during classical-style. Despite an increasing interest around LXC skiing, only four studies (1,3,6,15) have focused on performance-determining variables in LXC-skiing

During the 2018/2019 season eight out of twelve VSC competitions were performed as prolonged submaximal DP followed by a high-intensity effort ending in a mas sprint (5). Performance is therefore often determined by the ability to produce a high power (velocity) when being fatigued (16). Studies indicate that performance decreases after prolonged exercise due to fatigue (1,17–19). Overall, the capability to prevent fatigue, utilize a high fraction of $\dot{V}O_2$max combined with a high GE is therefore crucial in long-distance event (1,9,19,20). It is known that performance is lower after a specific duration of moderate to high-intensity exercise (1,15,18,19) but it is unknown when the performance starts to decline. After 60 min submaximal cycling performance was significantly reduced, which was at least partly related to a decreased GE, without significant changes in $\dot{V}O_2$peak (19). In addition, Clark and colleagues observed a significant decline in power output after 80 min and 2 h cycling (21), which was not significantly related to reduced muscle glycogen levels (18,21). These studies indicate that performance decreases after prolonged exercise due to fatigue. Performance in LXC-skiing competitions is often decided at the end of the race, and when one knows that performance declines during prolonged exercise, it is critical to know when it starts to decline and which variables that are determining the performance when being fatigued.

Normally performance-determining variables are measured from a rested state (after a warm-up), which may deviate from a fatigued state, like in the final part of a LXC-race. The only study (1) that compared performance-determining variables in DP between a rested and fatigued stage (after 90 min prolonged DP) observed a significant lower performance in fatigue state. The decline in performance were corresponds with a decreased GE and shorter peak cycle length in DP, without a significant decline in $\dot{V}O_2$peak. The same variables were performance-determined in fatigue and rested state, but the magnitude of the correlation coefficient for biomechanical variables between rested and fatigue state were substantially smaller in fatigue state (1). After 48 km LXC race in DP , reduced cycle length was observed (15). However, cycle length has been shown to be related to GE and performance (1,13). The decline in performance after prolonged exercise may be due to lower GE (1,18,19,21) or aerobic-or anaerobic capacity.

Today's knowledge is based on performance tests performed in a rested state (2–4,6,9) which might not necessarily correspond to performance-determining variables in a fatigued state (1,15,18,19,21) As a whole it remains unclear when performance starts to decline and why it declines. Performance should therefore be predicted in a sports-specific situation like after prolonged exercise when it concerns long-distance competitions. The primary aim of this study is to investigate how performance decreases during prolonged DP and to investigate which physiological and biomechanical variables are performance determining after prolonged DP.

Methods

Participants

Ten elite male XC skiers (age 21 (2.9) year; body mass 74.4 (2.5) kg) volunteered to take part in this study, which was approved and registered by the Norwegian center for research data (NSD). Before the skiers participated, they received written information explaining the study protocol, purpose and potential risks associated to the study, and provided written consent. All skiers were familiar with treadmill roller skiing.

Skiers were asked to monitor their diet during the 24 h before the first test day and asked to replicate this diet before subsequent tests. During the 24 h before the tests athletes were asked not to drink alcohol and refrain from any high-intensity training (> 80% maximal heart rate). They were also asked to avoid caffeinated beverages during the last 3 h before every test day.

Experimental protocol

The participants completed three test days in the lab consisting of different sport-specific test. Participants performed a blood lactate profile test, 30-s peak power output (PPO) test and an incremental time to exhaustion test (TTE) every test day. These tests are mainly used in XC-skiing and have a high correlation to competition performance (22).On test day 2 (D2; 60 submaximal test) and day 3 (D3;120 min submaximal tes) the athletes completed a submaximal test before the blood lactate profile test, 30-s PPO and TTE-test (see Figure 1), the order of D2 and D3 was randomized for all athletes. The tests were carried out around the same time of the day (± 1 h separated by a minimum of 48 h and maximally four days) and under similar thermoneutral conditions (room temperature 19.3 °C (1.3) and 34.2% (5.9) humidity). All the tests and warm ups/recoveries were performed on roller skis in the DP subtechnique at a roller-skiing treadmill, except for PPO, which was performed on a DP ergometer. The protocol has been described previously in Noordhof et al. (1), but will be shortly outlined below (see Figure 1).

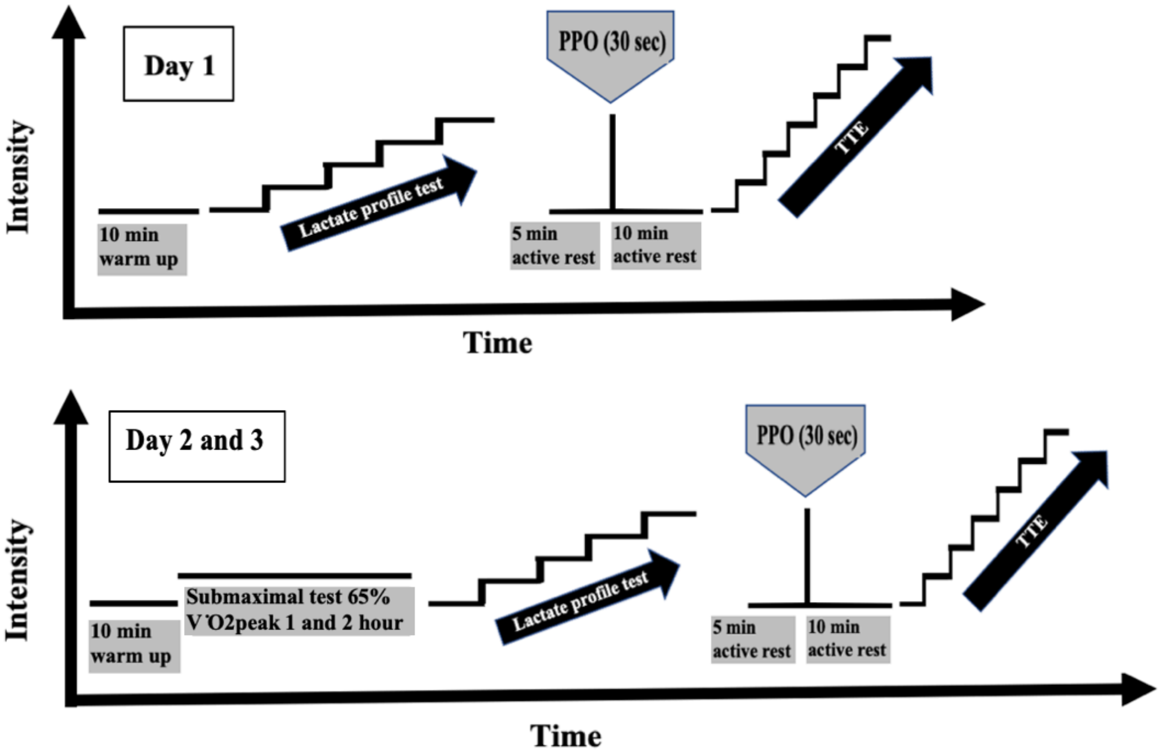

Figure 1: Overview of the study design. PPO:30-s peak power output test: TTE, incremental time to exhaustion test: $\dot{V}O_2$peak, peak oxygen uptake.

Test Day 1

The skiers warmed up for 10 min at low intensity on the treadmill, on an incline of 3% and speed of 12 km/h. Afterwards the participants carried out a blood lactate profile test at an inclination of 6% and a speed of 10 km/h, which was increased by 2 km/h every 5 min. During the final 2 min of each load respiratory data and heart rate were collected, the average of the last minute determined $\dot{V}O_2$, heart rate and respiratory exchange ratio (RER). After each 5 min load, the participants were asked to indicate their rating of perceived exertion (RPE) according to the Borg´s 6-20 scale (23) and a blood sample was taken from the fingertip to analyze blood [La$^-$]. The test finished when [La$^-$] reached ≥ 1.5 mmol·L^{-1} higher than [La$^-$] after the first load (10 km/h), RPE ≥ 16 or RER ≥ 1.00. Kinematic data were obtained using Oqus 400 cameras, from a 30-s period during the second minute of each load. After having completed the lactate-profile test, a 5 min active recovery was performed at a 3% inclination and a speed of 12 km/h, before performing the PPO.

The 30-s all-out PPO test was performed on a DP ergometer. The ergometers aero-resistance settings were set at the lowest level, to reduce poling time an make it resemble DP on snow (24). Poling force was measured continuously during the 30-s PPO by the ergometers software (PM5). During the first test, the athlete was allowed to decide his position in front of the ergometer. The distance between the athlete and DP ergometer was measured and repeated during subsequent tests. Directly after the PPO and before the TTE, the skiers performed 10 min of active recovery at a 3% incline and a speed of 12 km/h.

The TTE was performed to define aerobic capacity ($\dot{V}O_2$peak) and performance measured as peak speed (Vpeak). The test started at a 6% inclination and a speed of 10 km/h, which increased by 1 km/h, every minute, until exhaustion. The test was ended when the participants did not manage to continue or stopped themselves. Directly after the test ended [La^-] and RPE were determined. Respiratory data were continuously collected during the test.

Test Day 2 and 3

Before starting the submaximal test at a workload (speed) equal to 65% of $\dot{V}O_2$peak at a 6% incline, the participants performed the same warm-up routine as on the first test day (D1). The workload was determined individually by using the data collected from the TTE and blood lactate profile test performed on D1. $\dot{V}O_2$ heart rate and RER were collected during a 3 min period every 20 min (17-20, 37-40, 57-60,77-80, 97-100, 117-120) and calculated as average of the last two min. Directly after collecting the respiratory data, the treadmill was stopped for two min to take a blood sample from the fingertip to analyze glucose level and to drink (250 mL) isotonic sports drink (Enervit Sport, Milano, Italia). To maintain fluid balance during the submaximal tests the participants got to drink a total of 750 mL water added 45g carbohydrate (CHO) per hour (17). Standardized music (the same playlist) was played during the submaximal test, except during the respiratory data collection and a clock on the wall showed the time. The music and the watch were turned off immediately after completing the submaximal test. Directly after the submaximal exercise test, the participants performed the same protocol as on D1, except for the 10 min warm up (see Figure1).

Instruments and materials

Roller ski DP was performed on a 5 x 3 m motor-driven treadmill (Forcelink Technology, Zwolle, The Netherlands). A safety harness connected to the treadmill's emergency brake was used for security reasons. All skiers used the same pair of classic roller skis (IDT Sports, Lena, Norway) with type 2 wheels (rolling friction 0.018), to minimize variations in rolling resistance. Before all tests, the wheels were prewarmed during the warm up. All participants used their own ski poles corresponding with FIS regulations, with specialized carbide tips. Respiratory data were collected using open circuit spirometry system with a mixing chamber (Vyntus CPX; Erich Jeager GmBh, Höechberg, Germany) and heart rate data using a heart rate monitor (M400 Polar 208 Electro Inc., Port Washington, NY, USA). The metabolic system was calibrated prior to each test, according to the manufacturer's instructions. Blood lactate and glucose level from the fingertip were analyzed using a Biosen C-line lactate analyzer (EKF-Diagonostic GmbH, Barleben, Germany), which was calibrated automatically every hour. A Concept2 PM5 SkiErg (Concept2 Inc., Morrisville, VT, USA) was used for the PPO.

Three-dimensional kinematics were recorded by eight infrared Oqus 400 cameras (Qualisys´ motion capture, Qualisys AB, Göteborg, Sweden) placed around the treadmill to capture position characteristics of passive reflective markers (ø 14 mm) at a sampling frequency of 250 Hz and analyzed in acquisition software (Qualisys Track Manager) Oqus 400 cameras were calibrated before each test according to the manufacturer's. Further analysis was performed in Matlab (R2019a). The markers were placed on the poles (5 cm from lower egdge of the pole on posterior side) with double sided tape (3M, St. Paul, MN, USA).

Data analysis

Performance (Vpeak: mean speed reached during the last minute before exhaustion) and aerobic capacity ($\dot{V}O_2$peak = average of the three highest 10-s consecutive measurements) were defined during the TTE-test. Anaerobic capacity (upper-body power) (25,26) was determined as the average power output during the entire 30-s PPO-test. Furthermore, speed at lactate threshold (LTspeed) was estimated as the speed corresponding to the exact lactate value [La$^-$] at threshold. The speed was calculated based on a linear relationship between the closest speed below and above the exact lactate value [La$^-$].

The work rate was calculated as the sum of the power against gravity (P_g) and rolling friction (P_f). P_g is the product of mass (body mass + mass of equipment) gravitational acceleration, sin α (the angle of treadmill) and velocity of the treadmill belt. P_f is the product of the friction coefficient (0.02), mass (body mass + mass of equipment), gravitational acceleration, cos α (the angle of treadmill) and velocity of the treadmill belt. The aerobic metabolic rate was defined as the product of mean $\dot{V}O_2$ (L/min) multiplied with the oxygen equivalent using the mean RER and the standard conversion tables (27).

GE was determined during the lactate profile test and submaximal test from the average $\dot{V}O_2$ and RER data using Equation (1) as long as RER ≤ 1.00.

$$\text{GE (\%)} = \frac{\text{Work rate (W)}}{\text{Metabolic rate (W)}} \text{ X } 100 \qquad (1)$$

Kinematic data were analyzed using reflecting markers, calculated as mean from a 30-s period. Cycle time was determined as the time between each poling plant and cycle rate was defined as number of poling plants per minute. Cycle length was calculated by multiplying cycle time and treadmill speed (m/s). Peak cycle length was determined during the TTE-test, using the highest mean obtained from a 30-s period collected in the middle part of each load (from 15 to 45-s) and was not necessarily reached at the highest speed.

Statistics

All data from each test day were tested for normality, by visual inspection of Q-Q plots together with a Shapiro-Wilk test. Data were normally distributed and presented as mean (±SD). A one-way repeated measures ANOVA was used to compares performance and performance-determining variables between days. The assumption of sphericity define the main effect size of prolonged submaximal DP and Eta squared (η2) define the effect size of prolonged DP. The effect size of day-by day comparisons were calculated using Cohen's D ($d = \frac{M_1 - M_2}{\sqrt{s_1^2 + s_2^2/2}}$) (28). Relationships between performance and performance-determining variables ($\dot{V}O_2$peak, GE, lactate threshold, cycle length and cycle rate) across test days were assessed using Pearson product-moment correlation coefficients. Confidence intervals for the corresponding correlation coefficients were determined by converting r into Fisher z score and the corresponding standard error from which the lower and upper value of the confidence interval can be transformed back to correlations coefficient. The accounts of correlation coefficient and effect size were explained by subsequent scale: .1-3 small; .3-5 moderate; .5-7 large; .7-.9 very large; .9-.10 nearly perfect. All statistical tests were carried out using SPSS (version 26;IBM SPSS Statistics, Chicago, IL). Statistical significance was set at an alpha level of <0.05.

Results

Ten athletes completed all testes, but due to a technical problem the data of the 30-s PPO-test (D1 and D3) of one athlete was excluded from data analysis. In addition, the same athlete missed respiratory data collected during the lactate threshold (D1) and incremental test (D3), and was therefore excluded.

Submaximal DP tests

During prolonged submaximal DP (60 and 120 min) a non-significant main effect of day on $\dot{V}O_2$ and GE was found ($\dot{V}O_2$: F (1,8) =3.27, P=.16, η^2=.23 and GE: F (1,6) =3.22, P=.12, η^2=.35, see Figure 2). However, a significant main effect of duration on relatively intensity (60 min; F (2,18)= 8.23, P=<.001, η^2 =.58 and 120 min; F (1.8,16.3)=10.26, P=.002, η^2=.53) and GE (60 min; F (2,16)=9.5, P=.002, η^2=.54 and 120 min; F(5,40)=8.2, P=<.001, η^2=.51) was found (Figure 2), without a significant effect on blood glucose level (60 min: F (2,18)=11.63, P=.001, η^2=.59 and 120 min: F (2.25,20.29)=4.03, P=.03; η^2 =.31).

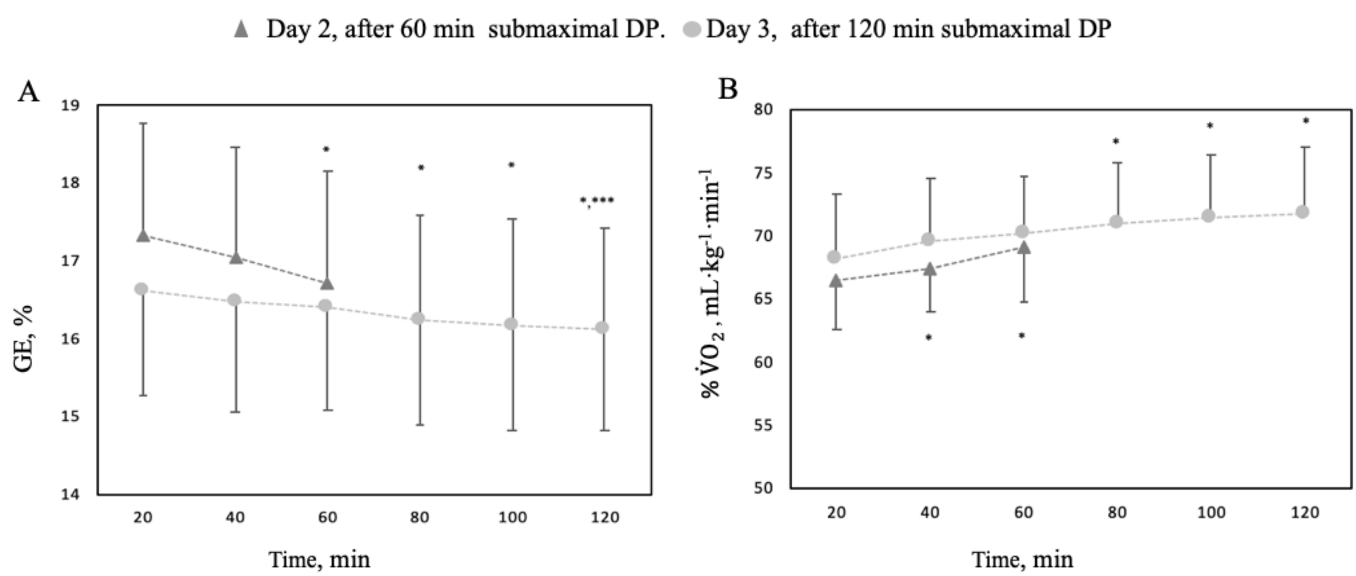

Figure 2: Change in GE (A) and $\dot{V}O_2$ during submaximal double poling (B). Data are presented as mean (SD). ; ▲, Day 2, 60 min submaximal DP; ●, Day 3, 120 min submaximal DP; *, different from 20 min (P=≤..01); ***, different from 60 min (P=≤..01)

Difference in performance between days

There was a significant main effect of prolonged submaximal DP on performance (Vpeak) (F (2,18) = 5.12, P =.017, η^2=.36). Day-by-day comparisons showed no significant difference in performance between D1 (rested state) and D2 (after 60 min prolonged submaximal DP) (Vpeak: D1=19.31 km/h (1.17) and D2 =19.28 km/h (1.12)). However, after 120 min prolonged submaximal DP (D3), performance (Vpeak: 18.50 km/h (0.99)) declined with 4% compared to D1 and D2 (D3-D; P=.046, d=-.78 and D3-D2; P =.019, d=-.76, see figure 3B).

Table 1: Main effect of prolonged submaximal DP (D1, D2, D3) on performance-determining variables

	N	F (df)	P	η^2
$\dot{V}O_2$ at 10 km/h	9	10.05 (2,16)	.001	.56
$\dot{V}O_2$ at 12 km/h	9	2.15 (2,16)	.15	.21
$\dot{V}O_2$ at 14 km/h	9	2.74 (2,16)	.095	.26
$\dot{V}O_2$peak	9	2.76 (2,16)	.093	.28
GE at 10 km/h	9	7.02 (2,16)	.006	47
GE at 12 km/h	8	1.75 (2,14)	.21	.20
GE at 14 km/h	7	2.54 (2,12)	.12	.30
Cycle rate at 10 km/h	8	1.63 (2,14)	.23	.19
Cycle rate at 12 km/h	8	1.99 /2,14)	.17	.22
Cycle rate at 14 km/h	8	2.05 (2,14)	.17	.23
Peak cycle rate	10	0.62(2,18)	.54	.06
Cycle length at 10 km/h	8	1.92 (2,14)	.18	.22
Cycle length at 12 km/h	8	2.17 (2,14)	.15	.24
Cycle length at 14 km/h	8	1.71 (2,14)	.22	.20
Cycle length peak	10	3.84 (2,18)	.041	.30

Abbreviations: N, number of practitioners; F, F-ratio of sphericity assumed One-way repeated measures ANOVA; η^2, partial eta squared;

Day-by-day difference in performance-determining variables

The effect of prolonged submaximal DP on physiological and biomechanical performance-determining variables is presented in Table 1, Figure 3 and 4. There were observed a significant main effect of prolonged submaximal DP for $\dot{V}O_2$ and GE at submaximal speed (10km/h) and peak cycle length. A no significant day-by-day difference between D1 and D2 (D2-D1) was observed for all performance-determining variables. As shown in Table 1 there was a significant main effect of prolonged submaximal DP on $\dot{V}O_2$ and GE at a submaximal speed of 10 km/h. Significantly higher $\dot{V}O_2$ values were observed on D3 compared to D1 and D2. The effect sizes for D3-D2 and D3-D1 changes in $\dot{V}O_2$ were considered large (D3-D2: -2.6 $mL \cdot kg^{-1} \cdot min^{-1}$ (1.6), P=.0001, d=.69 and D3-D1: -2.4 $mL \cdot kg^{-1} \cdot min^{-1}$ (2.0), P=.008, d=.59, Figure 3B). In addition, GE on D3 at 10 km/h was significantly lower than on D1 and D2 (D3-D1: -.87 % (0.1) P=.050, d= -.73, and 3-D2: -.88 % (0.001) P= .0011, d=-93, Figure 3A). Prolonged submaximal DP had a significant effect on anaerobic capacity (F (2,16) =3.8, P= .044, η^2=.32). However, no significant differences between days were found, despite a large effect size for the D3-D1 change (23.4 W (32), P=.069, d=-.66, see Figure 4). There was a non-significant main effect of prolonged submaximal DP on speed at LT (F (1.23, 11.09) =2.15, P=.17, η^2 =.19). A significant main effect of prolonged submaximal DP on peak cycle length was observed (see Table 1), where the effect size for the D3-D2 difference was considered very large (P=.017, d=-.75) and even larger correlation coefficient for D3-D1(P=.067, d=-.79, Figure 3C). Otherwise, there was no significant effect of prolonged submaximal DP on biomechanical performance-determining variables observed (see Table 1).

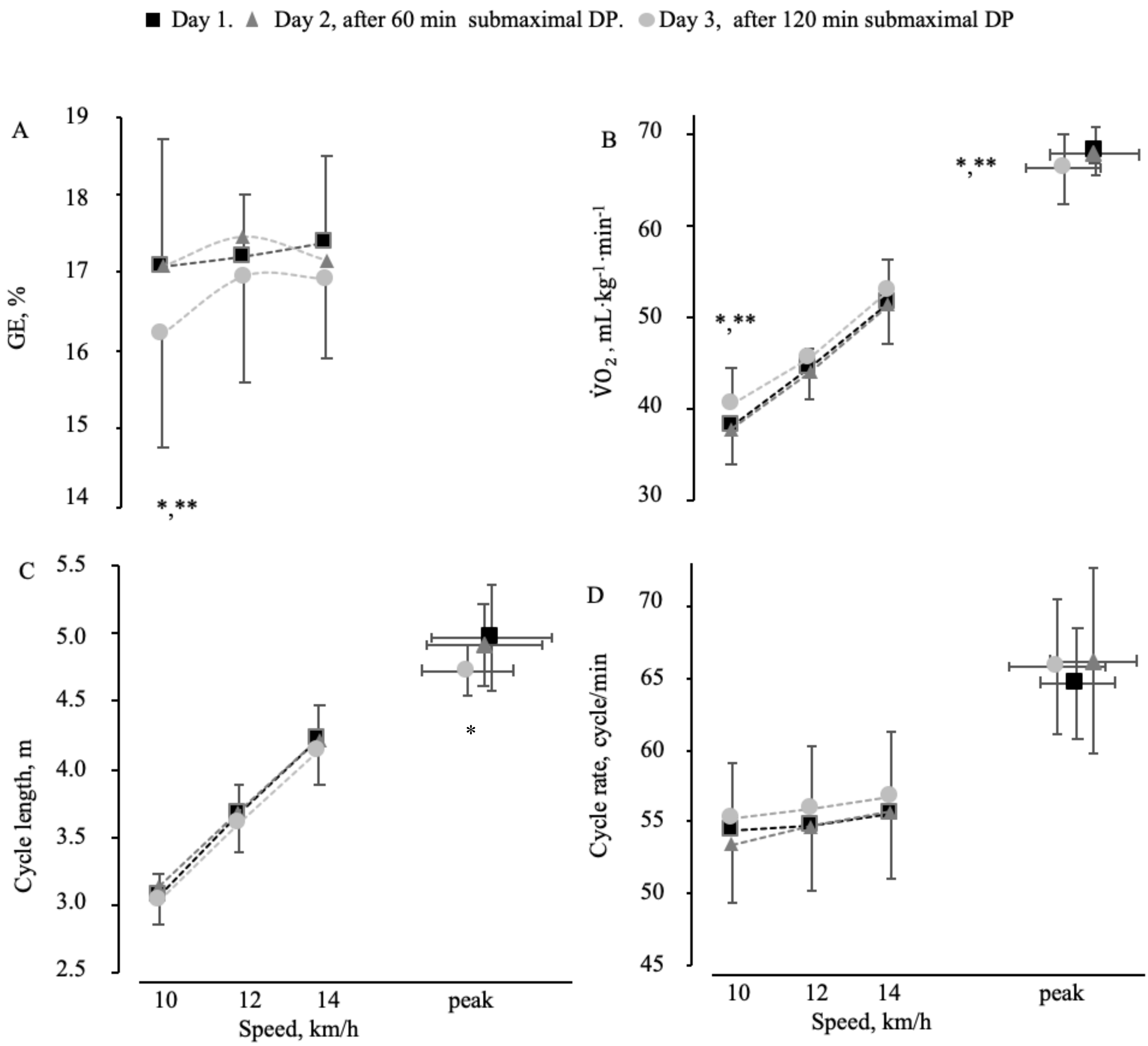

Figure 3: GE (A), $\dot{V}O_2$ (B), cycle length (C), cycle rate (D). Data are presented as mean (SD).; ■, Day 1; ▲, Day 2, after 60 min submaximal DP; ● , Day 3, after 120 min submaximal DP. Physiological and biomechanical data at 10 to 14 km/h measured during the course of the blood lactate profile test and TTE (peak values). Peak cycle rate and cycle length were defined as the highest values, which was not necessarily at the highest speed. *Significantly different from Day 1(P<.05); ** Significant different from Day 2 (P<.05). For GE only seven practitioners are included due to missing data

Correlations between performance-determining variables and performance

The relationships between performance-determining variables estimated at different speed and performance are presented in Table 2 and Figure 5. $\dot{V}O_2$ at submaximal speeds (12km/h) estimated D1were large negatively correlation to performance D3 and very large related when assessed after prolonged submaximal DP (D3). A similar observation was observed for GE (speed: 12km/h), where GE was stronger correlated to performance D3 assessed in fatigue state (D3) compared with rested state (D1). Cycle rate at 10 km/h had a very large correlation coefficient to performance D3 and determined D1 and was nearly perfect related to performance D3 assessed D3.

Table 2: Relationship between physiological and biomechanical performance-determining variables and performance (peak speed reached during the TTE)

		D1 performance-determining variables and D3 performance	D2 performance-determining variables and D3 performance	D3 performance-determining variables and D3 performance
	N	r (95%CI), P	r (95%CI), P	r (95%CI), P
$\dot{V}O_2$ at 10 km/h	9	-.56(-.89;.17) .058	-.46(-.86;.29).1	-.60(-.90;.11) .045
$\dot{V}O_2$ at 12 km/h	9	-.63(-.91;.06) .034	-.53(-.88;.21) .071	-.71(-.93; -.09) .017
$\dot{V}O_2$ at 14 km/h	9	-.56(-.89;.17) .058	-.46(-.88;.21) .055	-.56(-.89;.17) .058
$\dot{V}O_2$peak	9	.31(-.45;.81) .31	.49(-.26;.87) .091	.13(-.58;.73) .37
GE at 10 km/h	9	.55(-.18;.89) .064	.68(.03;.93) .015	.59(-.12;.90) .048
GE at 12 km/h	9	.64(-.04;.92) .032	.67(.03;93) .025	.73(.13;.94) .03
GE at 14 km/h	8	.45(-.37;.88) .13	.57(-.15;.90) .055	.56(-.24;.91) .075
Wmean	9	-.63(-.91;.06) .035	.28(-.77;.51) 23	.17(-.56;.75) .33
LTspeed	10	.44(-32;.87) .17	.66(.06;.91) .018	.50(-.19;.87) .086
Cycle rate at 10 km/h	9	.80(.21;.96) .008	.84(.40;.97) .002	.87(.49;.97) .001
Cycle rate at 12 km/h	9	.84(.40;.97) .003	.88(.52;.97) .001	.84(.40;.97) .002
Cycle rate at 14 km/h	9	.86(.40;.97) .001	.81(.32;.96) .004	.93(.64;.99) <.000
Cycle length at 10 km/h	9	-.81(-.96; -.36) .007	-.83(-.96; -.37) .003	-.86(-.97; -.45) .002
Cycle length at 12 km/h	9	-85(-.97; -.35) .004	-.88(-.97; -.52) .001	-.84(-.97; -.41) .002
Cycle length at 14 km/h	9	-.85(-.97;-.44) .002	-.8(-.96; -.29) .005	-.93(-.99; -.67) .000
Peak cycle length	10	-.55(-.88;.12) .049	.-.53(-.89;.05) .056	-.14(-.7;.54) .35

Abbreviations: GE, gross efficiency; Wmean, mean Watt at 30-s PPO; LT, lactate threshold; N, number of practitioners; P, P value Pearson product-moment correlation coefficient 1-taled.

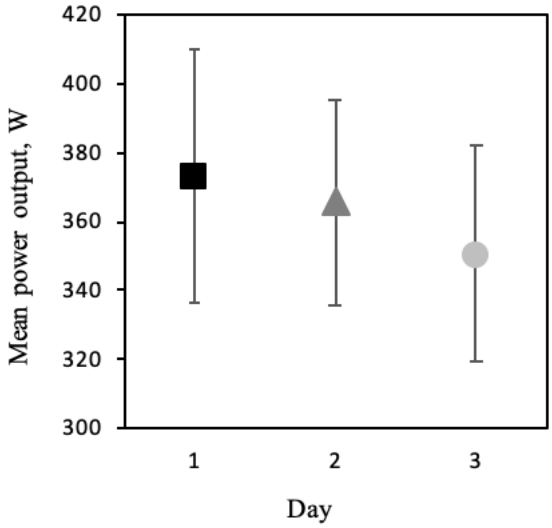

Figure 4: Change in mean power output during the 30-s PPO test. Data are presented as mean (SD).; ■, Day 1; ▲, Day 2, after 60 min submaximal DP; ● Day 3, after 120 min submaximal DP.

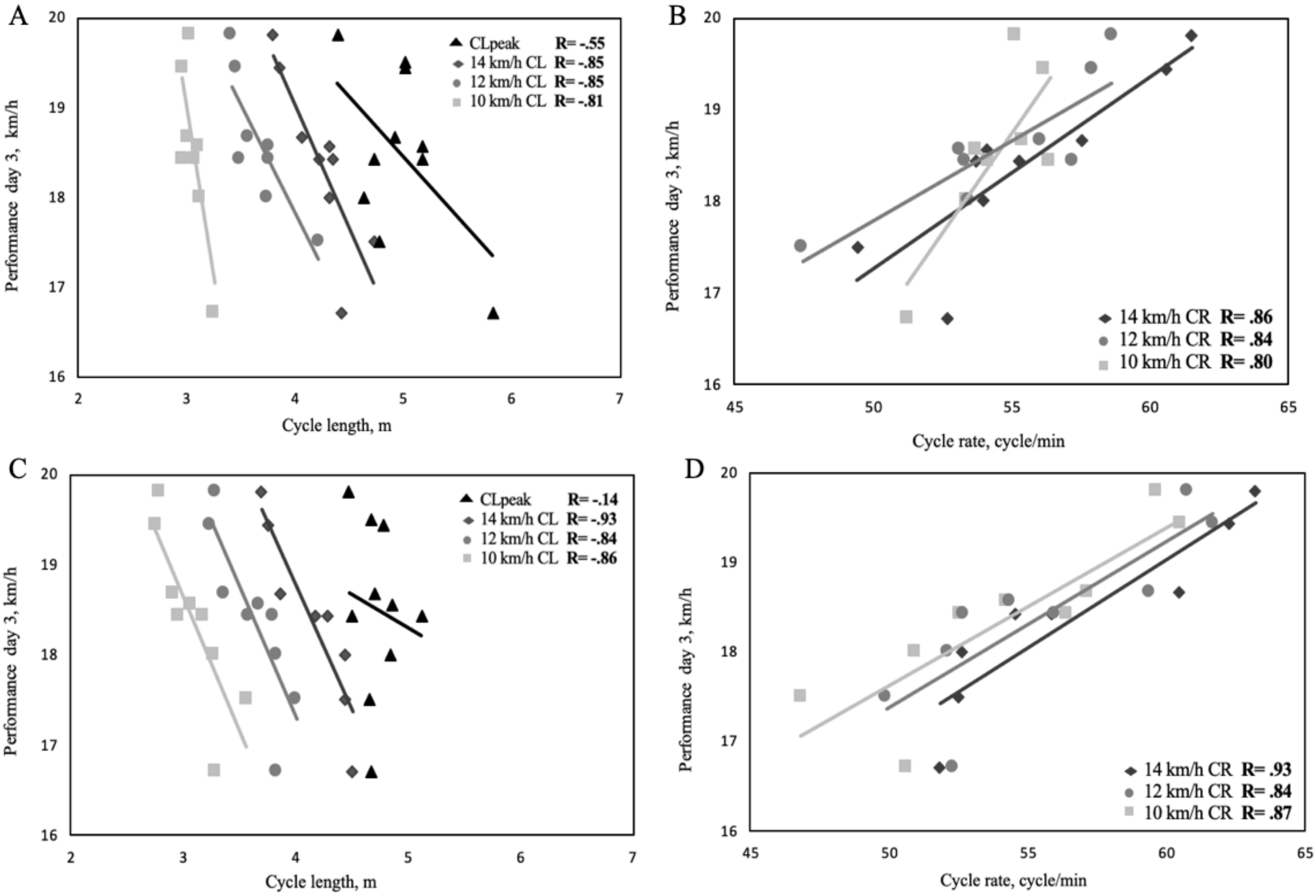

Figure 5: Relationship between cycle length (A) and cycle rate (B) day 1 and performance day 3 and relationship between cycle length (C) and cycle rate (D) day 3 and performance day 3. Data points represent individual athletes at different speeds and the lines represent the regression. Biomechanical data were collected during the blood lactate profile test, and peak values determined during TTE. R, R value Person product-moment correlation. P<.05 for all correlation coefficients excepted CLpeak (D1 and D3). CLpeak, peak cycle length.

Discussion

The purpose of the current study was to investigate how performance decreases during prolonged DP and to investigate which physiological and biomechanical variables are performance determining after prolonged DP. The main findings are that, (1) DP performance (Vpeak) after 60 min submaximal DP (D2 Vpeak= 19.28 km/h) showed no significant difference from the rested state (D1 Vpeak =19.31 km/h), but decreased significantly with 4 % after 120 min submaximal DP (Vpeak= 18.5 km/h), which corresponded with a higher $\dot{V}O_2$ and reduced GE at a submaximal speed and decreased peak cycle length; (2) $\dot{V}O_2$-and GE assessed from rested state (D1, speed 12 km/h) were significantly correlated to performance after prolonged submaximal DP (D3), but more closely related when they were predicted after prolonged DP (D3). Similarly, development was observed for the biomechanical performance-determining variables where the correlation coefficient between cycle rate and cycle length assessed from rested state (D1, speed 14km/h) and performance after prolonged submaximal DP (D3) were very large, but the correlation coefficient were even stronger (nearly perfect) when assessed after prolonged DP (D3).To our knowledge, this is the first study to demonstrate how prolonged submaximal DP for longer than 90 min affected DP performance, when compared with rested state measurement.

The current study explained for the first time how DP performance changed during prolonged submaximal DP with duration up to120 min. Submaximal DP for 60 min at an intensity of 65% $\dot{V}O_2$peak had no significant effect on DP performance, with may be explained by the relatively low intensity. A cycling study(19), observed a decline in performance after 60 min submaximal cycling, which is in contrast to current study. These difference in responds to prolonged exercise may be explained by reduced fatigue resistance due to lower level athletes participating in the cycling study. However, reduced DP performance in elite XC-skiers is demonstrated already after one heat in a simulated sprint competition(20), in a sprint the intensity is considerable higher than in the present study. Submaximal DP for 120 min (D3), had very large effect on DP performance compared with rested state (D1) and 60 min submaximal DP (D2) which result in a considerable decline in DP performance. During prolonged submaximal DP, the relative intensity increased (from 66 % to 72% of $\dot{V}O_2$peak) accompanied by reduced GE (see Figure 2). Despite an increasing relative intensity during prolonged submaximal DP, blood glucose level was not affected and therefore did not explain the reduced DP performance after prolonged submaximal DP (D3). There was a small non-significant effect of prolonged submaximal DP on $\dot{V}O_2$peak which indicates that the ability to reach a high aerobic capacity remained similar after prolonged exercise compared to from a rested state, as shown in previous studies (1,18,19).

The decreased DP performance after 120 min DP coincided with an increased $\dot{V}O_2$ and reduced GE at submaximal speed (speed 10 km/h) and lower peak cycle length (see Figure 2A, 2B and 2C) compared to D1 and D2. These findings are in line with another DP study (1) who also observed similar decline in GE (at speed 10km/h) after 90 min submaximal DP at an intensity of 65% $\dot{V}O_2$peak, as observed as in the present study after 120 min submaximal DP (D3-D2). In contrast to presented study Noordhof et al. (1) also demonstrated a reduced GE and increased $\dot{V}O_2$ at submaximal speed 12 and 14km/h, which can possibly be explained by number of participants (1). Overall this result may indicate a higher metabolic cost to produce the same work load when being fatigued. Furthermore, another XC-skiing study (29), where the skating technique was performed observed a decline in GE and cycle length at a submaximal speed already after short high-intensity exercise. Similarly, was shown in a cycling study (19) where reduced performance after 60 min submaximal cycling was related to a significant decline in GE

To our knowledge this is the first study to demonstrate a main effect of prolonged submaximal DP on anaerobic capacity. Despite a 6% decline in anaerobic capacity and large day-by day effect size (D3-D1; d=-.66), the decline did not reach statistical significance. Comparable cycling studies (18,19) observed a reduction in power after prolonged submaximal cycling in a 30-s and 3 min all-out test (18,19), affected by central fatigue (18). Several XC-skiing studies have investigated changes in upper-body power after simulated sprint competition or short-term high intensity DP in elite skiers (30–33). Observations from previously (30–33) and currently study indicate that upper-body muscle fatigue affects DP power/anaerobic capacity. Furthermore, muscle fatigue due short-term high intensity DP (30) led to decreased cycle length, accompanied by reduced work per cycle (30).

Reduced peak cycle length was demonstrated in the current study after 120 min (D3) submaximal compared with the rested state (D1) (see figure 3C), which is in line with previous findings (after 90 min submaximal DP and 48 km DP race) (1,15). In addition Noordhof and colleagues (1) observed a decline in cycle length and an increased cycle rate at a submaximal speed (10 km/h) after 90 min submaximal DP, while in the present study no significant effect of prolonged submaximal DP on cycle length and cycle rate at submaximal speeds was found, despite similar effect sizes, with may be explained by the difference in the number of participants.

As assumed form previous studies (1,13) $\dot{V}O_2$ and GE were the main physiological performance- determining. The correlation coefficient between D1 $\dot{V}O_2$-and GE at 12 km/h and performance after prolonged submaximal DP (D3) were smaller than the correlation coefficient between D3 $\dot{V}O_2$-and GE at 12 km/h and performance D3. Furthermore, the relationship between $\dot{V}O_2$ – and GE at submaximal speed assessed (D2) and performance in fatigue state (D3) were similar when all were determined after prolonged submaximal DP (D3). Cycle rate and cycle length were the main biomechanical performance-determining variables. The were observed a very large relationship between cycle rate and cycle length assessed at speed 14km/h D1 and performance after prolonged DP (D3), but the correlation coefficient were nearly perfect between cycle rate and cycle rate at 14 km/h determined in fatigue state (D3) and performance D3. These results indicate that prediction of performance-determining variables should be assessed in a sport-specific situation, like after prolonged exercise when concerns long-distance race.

Performance after prolonged submaximal DP was non-significant related $\dot{V}O_2$peak, which are in contrast to previously research (1). Furthermore, the relationship between GE and performance are in line with previous studies where GE was related to performance(13) and explained 31% of the variance in the decline in performance after prolonged submaximal DP (1). In contrast to previous study (1) the relationship between cycle rate and performance had positive correlation coefficient and opposite for the cycle length determined in rested state and after prolonged submaximal DP. To our knowledge, this relationship between performance and biomechanical performance-determining variables are showed for the first time. Sandbank et al. (11,12) found longer cycle length in World class XC sprinters compared with national level sprinter explained by lower capacity of force production for national level skiers, than word class skiers. However, participation in the currently study and Noordhof et al. (1) were similarly and shouldn’t explained the opposite effect of biomechanical performance-determining variables on performance.

Methodological considerations
It can be changing to estimate the constant speed for the prolonged submaximal DP and for some athlete the speed corresponds to an intensity a bit above 65% of $\dot{V}O_2$peak. The reason why, can be, that the athlete had a very good day at D1 and therefore overestimates his capacity, in contrast to the athlete had a bad day at D1 the speed during the prolonged submaximal DP may be too low and therefore under estimate the effect of prolonged submaximal DP. However, changes in performance were calculated athlete by athlete and not between athletes. For that reason, the results shouldn't be affected by error in estimating of the speed. In addition, prolonged submaximal DP at constant speed and incline are not competition specific, but was evaluated as the best way to standardized for all participants and performed in a previously study (1).

Overall performance and performance-determining variables were not difference between D1 and D2. This result can be due to training and familiarization with treadmill roller skiing. However, the athletes were familiarized with roller skiing and the order of D2 and D3 was randomized, thus effects should be limited. Furthermore, an incremental TTE test in the laboratory might differ from competition performance, even though previous studies indicate that laboratory tests are sports specific and predict performance well (13,22).

Finally, a limitation of this study is that XC-skiers did not want take part in the study due to COVID-19 virus because of risk and uncertainty around the XC season. Therefore, only ten athletes participated in the study. This low number of participants may have had large effects on the results and can possibly some of the differences compared to the literature. Because of the COVID-19 pandemic, the data collection was performed at two different time points, before and after the XC season (November and April). Performing two separate data collections might have resulted in different amounts of motivation and shape between the two groups of athletes. However, the aim of this study was to compare performance assessed from rested state and after prolonged DP within each subject and not between participant. Therefore, two different data collection should not be limiting the conclusions.

Conclusions

The current study provide new knowledge of how prolonged submaximal DP affects performance and performance-determining variables. Performance was unchanged after 60 min submaximal DP but decline significantly after 120 min submaximal DP, which was accompanied by a decreased GE at 10 km/h and peak cycle length, without changes in $\dot{V}O_2$peak. Furthermore, $\dot{V}O_2$ -and GE at submaximal speed, cycle rate and cycle length assessed in rested state (D1) were significantly correlated to D3 performance and were substantially stronger related to D3 performance when they were assessed after 120 min submaximal DP. Performance should therefore be determined in a sports-specific situation, like after prolonged exercise when concerns long-distance race.

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