Master's Thesis

Gender differences in work rate, physiological responses and kinematics during isolated upper body poling among cross-country skiers

- with a special focus on the influence of body composition and training patterns

Kenneth Myhre
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Kenneth Myhre
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ABSTRACT

Introduction: It has recently been shown that gender differences increase as the contribution from poling increases, indicating major differences in the capacity of the upper body betw males and females. Therefore, the aim of the present study was to compare aerobic capacities and anaerobic performance and efficiency during isolated upper-body poling in male and female performance-matched cross-country skiers. Additionally, body composition and training distribution was measured . **Methods:** Eight male cross-country skiers (age 20±3 yrs, body mass 77.1±7.0 kg, VO_{2max} 73.1±5.4 mL min^{-1} kg^{-1}) and nine female cross-country skiers (age 22±2 yrs, body mass 63.5±5.2 kg, VO_{2max} 64.5±4.2 mL min^{-1} kg^{-1}) completed three 4-min submaximal stages, a 3-min all-out test and a 30-sec modified Wingate test on a modified Concept2 SkiErg. Work rate and cycle rate were measured with the internal software of the ergometer, which in advance was validated with force and velocity measurements. Ventilatory variables were assessed by open-circuit indirect calorimetry. Body composition was measured using dual-energy X-ray absorptiometry. Training data from the last six months before testing were quantified based on training diaries. **Results:** Percentage gender differences in work rate, work per cycle and oxygen uptake increased as intensity increased ($P<0.05$). On the 3-min test, males achieved 95% higher work rate and 59% higher VO_{2peak} (L min^{-1}) (both $P<0.001$). On the 30-sec test, males performed 114% higher work rate ($P<0.001$). Comparison of regression lines showed no significant differences in metabolic rate-work rate relationship between genders at submaximal intensity ($P>0.05$). Males had 35% higher absolute lean mass in trunk and 59% more lean mass in arms (both $P<0.001$), and a greater percentage of total body mass localized to the upper body (61% vs. 57%; $P<0.001$). Total training hours or training in the different intensity zones did not differ between genders, but compared to females, males logged 113% more strength training and 35% more time in the classical technique on roller skies (both $P<0.05$). **Conclusions**: The differences in upper-body performance between male and female increased with increasing intensity. The differences in work rate was significantly higher than what could be explained by diversity in aerobic energy delivery, indicating that anaerobic capacity differentiates genders in upper-body exercise. This is further supported by the greater work per cycle and higher distribution of lean mass in the upper limbs among male skiers. Furthermore, training data indicated more upper-body strength and endurance training in males which might be one of the reasons for the relatively large differences in upper-body capacities.

Key words: aerobic capacities; anaerobic performance; cross-country skiing; double poling; efficiency; gender comparison

SAMMENDRAG PÅ NORSK

Innledning: Det har det nylig blitt vist at kjønnsforskjeller i prestasjon blant langrennsløpere øker desto mer overkroppen bidrar i framdriftsskapende arbeid. For å få en større forståelse rundt dette fenomenet, sammenligner denne studien aerob kapasitet, anaerob prestasjon og effektivitet under isolert overkroppsstaking blant mannlige og kvinnelige langrennsløpere matchet for prestasjoner i langrennssporet. I tillegg blir kroppssammensetning og treningsdata analysert. **Metode**: Åtte mannlige langrennsløpere (alder 20±3 år, kroppsmasse 77,1±7,0 kg , VO_{2max} 73,1±5,4 ml min^{-1} kg^{-1}) og ni kvinnelige langrennsløpere (alder 22±2 år, kroppsmasse 63,5±5,2 kg , VO_{2max} 64,5±4,2 ml min^{-1} kg^{-1}) gjennomførte tre drag fire-minutters drag på henholdsvis lav, moderat og høy submaksimal intensitet, en 3 minutters test av maks aerob kapasitet og en tilpasset 30 sekunders Wingate-test i et modifisert Concept2 SkiErg. Kraftutvikling og frekvens ble målt med ergometerets interne programvare, som på forhånd hadde blitt validert med kraft- og hastighetsmålinger ved hjelp av en kraftcelle. Gassutveksling ble målt ved hjelp av indirekte kalorimetri. Kroppssammensetning ble målt ved hjelp av DXA-skanning. Treningsdata fra de siste seks månedene før testing ble kvantifisert basert på treningsbøker. **Resultat**: Prosentvis kjønnsforskjell i kraftutvikling, arbeid per syklus, oksygenopptak økte med økende intensitet ($P<0,05$). På 3 min.-testen testen utviklet menn 95 % høyere kraft og nådde 59 % høyere VO_{2peak} (L min^{-1}) enn kvinner ($P<0,001$). På 30 sek.-testen hadde menn 114 % større kraftutvikling ($P<0,001$). Analyse av regresjonslinjer for sammenheng mellom metabolsk rate og kraftutvikling på submaksimal intensitet viste ingen signifikant forskjell mellom kjønnene ($P>0,05$). Menn hadde henholdsvis 35 % og 59 % mer muskelmasse i trunkus og armer ($P<0,001$), og en større andel av total kroppsmasse lokalisert i overkroppen (61 % vs. 57 % , $P<0,001$). Total treningstid var ikke forskjellig mellom kjønnene, men sammenlignet med kvinnene, trente menn 113 % mer styrketrening, og 35 % mer klassisk rulleski-trening ($P<0,05$). **Konklusjon**: Forskjellene i overkroppsytelse mellom menn og kvinner økte med økende intensitet. Forskjellene i kraftutvikling var større enn hva som kunne forklares med økning i aerob energileveranse, noe som indikerer at anaerob kapasitet kan være en faktor som skaper kjønnsforskjeller i overkroppsarbeid. Dette understøttes av større arbeid per syklus og større distribusjon av muskelmasse i armer og trunkus blant de mannlige skiløpere. Treningsdata indikerte dessuten mer overkroppsstyrke og -utholdenhetstrening blant menn, hvilket kan være en underliggende årsak til de relativt store forskjellene mellom kjønn i overkroppskapasitet i denne studien. **Stikkord**: aerob kapasitet; anaerob prestasjon; effektivitet; kjønnssammenligning; langrenn; staking

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INTRODUCTION

Cross-country skiing is a whole body endurance sport, where the athletes produce propulsion by combining upper body poling and leg push-offs over a great variety of distances (1.5-50< km), employing many different techniques over varied terrain. Cross-country skiing is an unique sport in the way that athletes need to adjust their technique with changing conditions, as choose of sub-technique alternates with speed and incline (Sandbakk, Ettema & Holmberg, 2012b). By changing techniques, the athletes are able distribute the work load in various ways between legs, trunk and arms during races and training sessions. To manage these challenges, both male and female cross-country skiers are characterized by high aerobic power when tested in leg and whole body exercises (Holmberg, Rosdahl & Svedenhag, 2007; Rusko, 1987; Saltin & Astrand, 1967). However, less is known about the requirements of upper body capacity in cross-country skiing, although a recent study suggested that the main reserve for further increase of aerobic performance of cross-country skiers lies in an increase of double poling aerobic capacity (Popov & Vinogradova, 2012).

During the last decades, cross-country skiing has developed in ways of better track preparation, shorter and steeper uphill parts and improved functional characteristics of the equipment (Sandbakk & Holmberg, 2014). Equipment and track improvement has given the athletes a greater opportunity to create propulsion by transferring force trough the poles to the snow by using muscles of the upper body, and firmer tracks, stiffer poles and better skis has directly led to higher competition velocity (Saltin, 1997; Sandbakk & Holmberg, 2014). Therefore, the double poling technique is now employed in parts of the tracks where the diagonal technique was earlier preferred, leading to an increase in the fractional use of double poling technique during races in classic technique (Lindinger, Stoggl, Muller & Holmberg, 2009). This is beneficial based on the fact that double poling is shown to be a particularly economical high speed technique (Hoffman & Clifford, 1992; Pellegrini et al., 2013). All together, this has resulted in an increased in demands of the upper body endurance capacities to perform well in cross-country skiing.

In historical perspective, the ratio when comparing running and double poling body peak oxygen uptake in elite cross-country skiers, has increased from 0.7 in the 1960s to above 0.9 in the late 1990s (Saltin, 1997). This development is probably brought about by more and intensified upper body training, because of increased demands on the upper body. More recently, Holmberg et al. (2006) found male elite skiers to reach 78% of their maximal oxygen uptake obtained during diagonal skiing when testing them in arm cranking. This indicates high upper body endurance capacity among skiers. As well as endurance, the higher speeds and equipment modifications in cross-country skiing has also increased the demands of strength and power in the upper body (Holmberg et al., 2005; Stoggl & Muller, 2009). Hence, skiers have also been compelled to put more emphasis on upper body strength and power training (Holmberg et al., 2005). Stoggl, Enqvist, Muller and Holmberg (2010) concludes that focus on increasing muscle mass in the trunk appears to be important for cross-country skiers, especially for peak speed and work economy in double poling. Losnegard et al. (2011) showed that heavy upper body strenght training added to a normal endurance training program for elite cross-country skiers lead to increased average power in a 5 min dobule poling test. Overall, these recent studies emphasize the general importance of the upper body for cross-country skiing performance (Holmberg et al., 2006; Losnegard et al., 2011; Popov & Vinogradova, 2012; Sandbakk & Holmberg, 2014; Stoggl & Muller, 2009), whereas previous studies further states that there are differences in neuromuscular and cardiovascular function between the upper and lower body during exercise (Calbet et al., 2005; Sawka, 1986). Therefore, to understand factors affecting cross-country skiing performance, further research of upper body function in cross-country skiers seems necessary.

It is known that among cross-country skiers, gender differences in performance and aerobic capacity increases as the contribution from upper-body propulsion (poling) increases (Sandbakk, Ettema & Holmberg, 2012a). The relative gender differences in performance associated with running, diagonal stride, G3-skating and double poling were found to be approximately 12%, 14%, 17% and 20% in speed and 54%, 58%, 62% and 67% in absolute work rates (Sandbakk, Ettema & Holmberg, 2012a). These increasing differences could not be explained totally by gender differences in VO_{2peak} or fat-free body mass (Sandbakk, Ettema & Holmberg, 2012a). In sports that requires somehow the same overall endurance capacity as cross-country skiing, such as running, cycling, speed skating and swimming, performance differences between males and females are approximately 10-12%, in both aerobic and anaerobic dominated diciplines (Coast, Blevins & Wilson, 2004; Joyner, 1993; Maldonado-Martin, Mujika & Padilla, 2004; Schumacher, Mueller & Keul, 2001; Seiler, De Koning & Foster, 2007). The major portion of gender differences in this cases was attributed to a higher VO_{2max} and lower percentage of body fat in men (Calbet & Joyner, 2010; Joyner, 1993). The athletes performing these sports does not have the same possibility to distribute work load in various ways between legs, trunk and arms as cross-country skiers, and we could therefore assume a more similar training impact between males and females on the same level in these sports. It might be questioned whether the differences between male and female cross country skiers continues to increase if upper body is totally isolated and, to what extent different physiological factors affects upper body performance in male and female skiers. A more in-depth, laboratory based study may gain deeper understanding of the factors that cause gender differences in upper body work across different work intensities.

One of the physiological factors that may influence gender differences, is the ability to convert metabolic energy into external energy, i.e. efficiency. When comparing male and female cross-country skiers at the same relative level, it was found that the metabolic rate - work rate relationship followed the same linear curve for both genders, meaning that the minor, non-significant differences in gross efficiency (i.e., work rate divided by metabolic rate) revealed was only caused by differences in work rates (Sandbakk, Ettema & Holmberg, 2012a). However, Sandbakk et al. (2010) demonstrated that efficiency were higher in international level compared to national level cross-country skiers when using the skating G3 technique, whereas Ainegren, Carlsson, Tinnsten and Laaksonen (2013) found international level senior cross-country skiers to have better skiing economy and higher gross efficiency compared with both the recreational skiers and junior elite skiers using the diagonal stride technique. Thus, gross efficiency in whole body work seems to differ between skiers at different performance levels, but not between genders at similar performance levels. When knowing that gender differences in upper body performance is greater than in leg and whole body performance (Sandbakk et al., 2010), it might be interesting to examine whether some of this variance could be explained by gender difference in upper body efficiency. Moreover, cross-country skiers have the possibility to increase speed by enhancing work per cycle and/or cycle rate, with longer a higher work per cycle being positively connected both to gross efficiency and performance in the skating technique (Sandbakk et al., 2010). In a former examination of double poling performance, male skiers were shown to execute longer cycle lengths (i.e., work per cycle) both at submaximal and peak speeds, whereas the cycle rate differed only at submaximal speed. Work per cycle was therefore considered the key differentiating factor with respect to double poling performance by males and females (Sandbakk, Ettema & Holmberg, 2012a). How work per cycle and cycle rate is affected by work rate alternations, and affect efficiency and performance in isolated upper body poling is, however, not yet examined.

An other factor that also might contribute to explain gender differences in performance, is differences in body composition. Findings indicates large variations in body composition among elite cross-country skiers (Haymes & Dickinson, 1980; Rusko, Havu & Karvinen 1978; Stoggl et al., 2010), compared to endurance sports like rowing and running where body composition seems to be more equal among successful elite athletes (Reilly et al., 1990). However, it is suggested that heavier but muscular athletes have an advantage, especially on flat terrain during races - where double poling is the main technique (Stoggl et al., 2010). This advantage was proven among male, but not among females in a 10 km classic style race (Bergh, 1987; Bergh & Forsberg, 1992). A recent study showed a positive relationship between absolute lean mass and performance and a relationship between overall race outcome and absolute lean mass in the arms among junior skiers in a 10-km skating distance race (Larsson & Henriksson-Larsen, 2008). In another recent study on relationships between body composition and peak speed in classic style cross-country sprint skiing, it was showed that body mass, trunk mass, and trunk lean mass all were factors that strongly determined double poling performance (Stoggl et al., 2010). The importance of body composition to gender differences in upper body poling remains to be elucidated.

The fact that differences when comparing genders is greater in the upper body compared to the lower body (Sandbakk, Ettema & Holmberg, 2012a), seems to be a distinctive characteristic of cross country skiing. Still, there is a general view that male and female cross-country skiers possess and requires the same overall training patterns with regards to training intensity distribution (Sandbakk & Tonnessen, 2012). This may be simplistic, when knowing that the athletes are able to select both technique and to what extent they put impact on the upper body versus the lower body during both endurance and strength training. Details are lacking in gender comparison of training data, so it is unclear whether the cause for gender differences in upper body function might be gender differences in actual training impact of the upper body versus lower body. More detailed insight in the actual gender differences of upper body training patterns is therefore of importance for understanding factors affecting performance in cross-country skiing, and for planning better and more customized upper body training programs for both male and female cross-country skiers.

To the best of our knowledge, no study to date has studied gender differences among cross-country skiers during isolated upper body poling. Therefore, the purpose of this study was to compare aerobic capacities and anaerobic performance between performance-matched high level male and female cross-country skiers during isolated upper body poling. Additionally, body composition and history of training was analyzed to provide further insight in underlying causes for possible gender differences in aerobic capacities and anaerobic performance. It was expected to find gender differences in work rate and oxygen uptake that exceeds what is earlier found when upper body was not completely isolated.

METHODS

Subjects

Eight healthy male and nine healthy female high level cross-country skiers volunteered to participate in the study. The characteristics of subjects´ are shown in Tab. 1. The athletes were matched for performance in skiing competitions relative to the best skier in the world of each gender based on International Ski Federation points (FIS-points). According to FIS, a skier's rank is relative to a 0 point standard established by the top ranked skier in the world, among males and females respectively. A skier's total points for a given race are determined by adding race points (from comparing the individual skier's time to the winner's time) and race penalty based on the five best competitors' FIS points in the competition (FIS, 2013).

Tab. 1. *Anthropometric characteristics, performance level (FIS-points) and maximal aerobic capacity for the eight male and nine female cross-country skiers in this study (mean ± SD).*

Variables	**Males**		**Females**	
	Mean	**SD**	**Mean**	**SD**
Age (years)	20.3	2.6	22.2	3.4
Body height (cm)	183	4	169	5**
Body mass (kg)	77.1	7.0	63.5	5.2**
FIS-points	102.6	22.7	102.8	24.0
VO_{2max} running (mL min^{-1} kg^{-1})	73.1	5.4	64.5	4.2**
VO_{2max} running (L min^{-1})	5.7	0.6	4.1	0.4**

Gender differences: **P<0.01

All skiers were fully acquainted with the nature of the study before signing written consent to participate. The athletes could at any time withdraw from the study and ask to have their data deleted, without consequences. The experimental procedures employed were pre-approved by the Norwegian Regional Ethics Committee, Trondheim, Norway.

The experimental design

The subjects completed three 4-min submaximal stages, one modified 30-s Wingate test and one 3-min all-out test during isolated upper body poling in a ski ergometer (Fig. 1). The tests were performed in a modified poling apparatus, where the athletes were able to keep a natural double poling position, but without having the possibility to use their legs. Here, performance in terms of work rate was measured, along with other physiological variables as oxygen uptake, heart rate and blood lactate concentration. Subsequent, cycle rate, work per cycle and metabolic rate was calculated. Additionally, VO_{2max} was tested during treadmill running to provide the possibility to compare upper body versus lower body capacity. Body composition were determined using dual-energy X-ray absorptiometry (DXA). In addition, a summary of individual training distribution from the last six months before testing was quantified, and the athletes answered a questionnaire based on the collected training data to provide further insight performed strength and roller ski training.

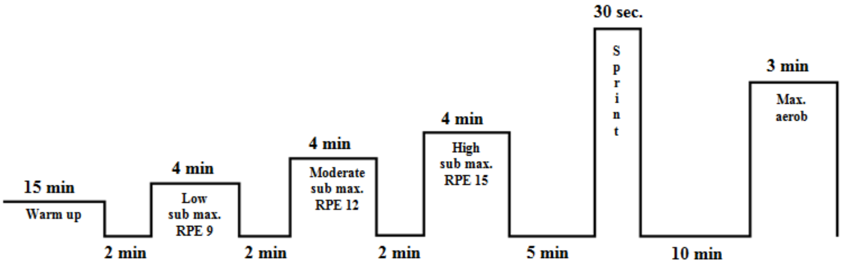

Fig. 1. *Test protocol overview for the isolated upper body tests in the poling ergometer*

Instruments and materials

All poling tests were performed in a Concept 2 SkiErg (Morrisville, NC, US). The flywheel resistance was sat on "1" for both genders. This was based on pilot testing that determined this level to provide an acceptable resistance compared to poling a in flat track on snow, and of methodological reasons to provide a most similar resistance for all athletes, as the flywheel adjustment on the Concept 2 SkiErg is not incremental. The running test was performed on a motorized treadmill (Woodway GmbH, Weil am Rein, Germany).

The subjects performed the entire test in a customized seat, to ensure that all measured work was performed by the upper body solely (Fig. 2). The seat allowed them to keep an upraised position, but their rear end was resting on a small seat so that their legs were unloaded, and their hip and feet were strapped immovable. Pilot testing of the setup, with EMG analysis of upper and lower extremities, showed no significant change in muscle activity in the legs from rest to activity, whereas upper body muscle activity was found to be in accordance with Holmberg et al. (2005) and Bojsen-Moller et al. (2010). The seat was modified with possibility to adjust elevation and distance from the ergometer, so the settings could be customized for each athlete. Settings aimed to comply with Holmberg et al. (2005), who stated that at the beginning of pole ground contact in the double poling technique, the angles in the elbow, hip, and knee joints were 104 ± 19°, 136 ± 14° and 150 ± 14°, respectively. Sitting on the bench, the subjects were able to perform a natural double poling motion with their upper body, without being able to use the lower extremities. Force and velocity values were measured at 1500 Hz sampling rate by a force cell (Noraxon U.S.A. inc, Scottsdale, AZ, US) mounted on the main rope in the ergometer. Movement frequency was chosen individually by each athlete, and cycle rate (Hz) was calculated using a motion capturing system (Qualisys AB, Gothenburg, Sweden) and analyzed in the Qualisys Track Manager Software (Qualisys AB, Gothenburg, Sweden).

Fig. 2. *Shows one cycle of isolated upper body double poling seated in the custom built seat*

Initial work rate on the submaximal stages was adjusted by a subjective fatigue scale ranging from 6-20, were 6 indicates no effort and 20 indicated maximal effort (Borg, 1982). The athletes were asked to report their perceived exertion for both the upper body muscular system and the cardiovascular system, in order to provide insight in possible differences in perceived stress of the two systems. At the submaximal stages, the athletes were told to work at an approximate given rate of perceived exertion for each stage, based on the Borg scale. In addition, physiological responses were measured to control for match on intensity on each stage for all athletes. At the all-out test, Borg scale was used to control for attained exhaustion.

Gas exchange values were measured by open-circuit indirect calorimetry using an Oxycon Pro apparatus (Jaeger GmbH, Hoechberg, Germany). Before each measurement, the VO_2 and VCO_2 gas analyzers were calibrated using high-precision gases (16.00±0.04% O_2 and

5.00±0.1% CO_2, Riessner-Gase GmbH & Co., Lichtenfels, Germany), the inspiratory flow meter was calibrated with a 3 L volume syringe (Hans Rudolph Inc., Kansas City, MO). Heart rate (HR) was measured with a HR monitor (Suunto t6d, Suunto OY, Vantaa, Finland), using a 5-s interval for data storage. Blood lactate concentration (BLa) was measured on 20 µL samples taken from the fingertip using a Biosen C-Line Sport (EKF Industrial Electronics, Magdeburg, Germany).

Test protocols, measurements and data collection

All testing sessions were completed within four weeks in October and November, approximately 1–4 weeks before the start of the national competition season.

Running test

Maximal oxygen uptake during running was performed on a motorized treadmill at a constant incline of 10.5%. The individual initial speed was increased by 1 km/h after 1 min of running, and thereafter by 0.5 km h^{-1} every minute until exhaustion or a plateau in VO_2 occurred. Running at 10.5% incline on a treadmill was regarded most relevant for testing VO_{2max} in cross-country skiers, according to Ingjer (1992). VO_2 and ventilation were monitored continuously, and the median of the three highest 10-s consecutive values was defined as VO_{2max}. A maximal level of effort was considered to have been attained, and the test was considered valid, if two of the following three criteria were met: (1) a plateau in VO_2 despite increased exercise intensity, (2) a RER value >1.10, and 3) a peak BLa >8 mmol/L (Bassett & Howley, 2000). Results from the running test are presented in table 1.

Double poling test

All poling tests started with a standardized low intensity warm-up consisting of 10 min running to ensure whole body circulation, and 5 min specific isolated upper body poling, both at approximately 60% of the athletes individual maximal heart rate. Thereafter, the skiers performed three 4-min submaximal stages, one modified 30-sec Wingate test and one 3-min all-out test to detect aerobic capacities, anaerobic performance and maximal specific power.

Submaximal tests

Physiological responses in connection with submaximal exertion were monitored during three 4-min stages of low, moderate and high intensity submaximal poling, with a 2-min rest between each stage. The intensity was adjusted by the Borg scale, and increased gradually from approximately 9 to 12 to 15 on the Borg scale, which represents low, moderate and high submaximal intensity, respectively. The subjects were instructed to maintain a steady pace through each stage. Watt was monitored in each stroke during the whole test, and work rate is presented as average values over the last three minutes. VO_2 and ventilation were monitored continuously and the median of the three highest 10-s consecutive values was defined as VO_{2peak}. BLa was measured immediately after completion of each session. The average heart rate during the last minute of each stage was also recorded. Gross efficiency was calculated as the work rate divided by the metabolic rate under steady-state conditions according to Sandbakk et al. (2010). Metabolic rate was calculated as the product of VO_2 and oxygen energetic equivalent and processed using a standard conversion table according to Peronnet and Massicotte (1991).

30-sec test

Following a 5 minute rest period, of which the last one minute was easy poling, the athletes performed a modified 30-sec Wingate test to determine anaerobic performance. To also predict the maximal power, the athletes were instructed to give maximum effort from the first stroke, and reach their maximum power as fast as possible. Watt was monitored in each stroke during the whole test, and average and peak values are presented. Specific power was calculated as the product of force and velocity, averaged over the 5 seconds of the 30-sec with highest watt, and referred to as peak watt. BLa was measured immediately after completion of the session.

3-min test

After a rest period of approximately 10 minutes, of which the last 5 minute easy poling, a 3-min all-out test was performed. The athletes were instructed to complete the stage to maximum exertion, to ensure that they took out their full potential. Watt was monitored in each stroke during the whole test, and performance is presented as average and peak values.

VO2 and ventilation were monitored continuously, and the average of the three highest 10-s consecutive values was defined as VO_{2peak}. BLa was measured immediately after completion of the session. The average heart rate during the last minute was also recorded. A maximal level of effort was considered to have been attained and the test was considered valid, if the athletes reached a plateau in VO_2 and ended the test totally exhausted (Borg scale 19-20), as evaluating RER values and BLa concentration was considered inaccurate during isolated upper body work.

Body composition

Body composition in terms of total mass, lean mass, fat mass, and bone mass content were analyzed for the whole body, trunk, legs and arms using the DXA software (Encore 2007, Version 11.4, General Electric Company, Madison, WI, US). Before each measurement, the equipment was calibrated using a phantom, and in accordance with the manufacturer's guidelines. The DXA scan was conducted by qualified personnel at St. Olavs Hospital, Trondheim, Norway. The various body segments were defined for further analyses and gender comparison as presented in Figure 3.

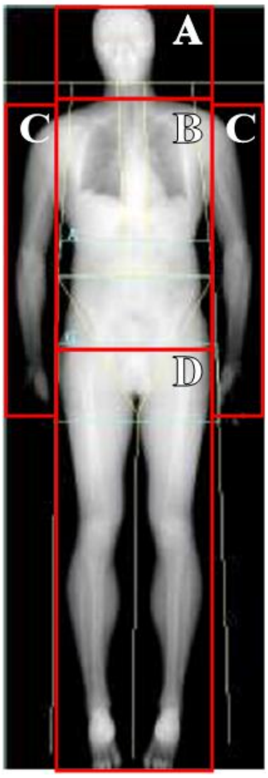

Fig. 3. *Showing the defined body segments used in this study, with* **A** *corresponding to "head and neck",* **B** *to "trunk",* **C** *to "arms" and* **D** *to "legs"*

Training data

Individual training data quantified by each athlete in their personal digital training diary (Olympiatoppens treningsdagbok, Lyymp AS, Norway) was submitted voluntary by the athletes. Intensity and type of exercise in the last six months prior to the testing was then compiled. In order to gather more information about the athletes` upper body strength and roller ski training in the same period, a questionnaire (appendix 1) based on collected training data was created using the "forms" application in Google Drive (Google Inc., Mountain View, CA, US), and distributed subsequent to the training data analysis. In the questionnaire, the athletes was asked especially to explain their classic roller ski training and strength training more in depth, and to rate the ratio of different types of strength training.

Statistical analysis

All data were checked for normality and presented as mean and standard deviation (mean ± SD). Independent samples t-test was performed to check for gender differences in RER, RPE, BLa, heart rate, training history and body composition. Levene's test for equality of variances was applied to control for variance homogeneity in these tests. The t-test procedure was also applied to test whether males and females had different intercepts regarding work rate – metabolic rate relationship. The coefficients and their respective standard errors were used to calculate the t-score, and the exact *P*-value was thereafter derived from the t-statistic, with the correct number of degrees of freedom.

2-way repeated measures ANOVA were applied to look for changes in work rate, work per cycle, cycle rate and oxygen uptake with gender as between subjects factor and with repeated measures on intensity as the within subjects factor. The Greenhouse-Geisser correction was used for epsilon < 0.75 to correct for inequality in variance. In cases where the 2-way ANOVA showed significant results, the independent samples t-test was applied to determine exact points of difference between genders. Bonferroni correction was used in cases where the same measurements were entered in to multiple comparisons. Statistical significance was set at an alpha level of < 0.05. Statistical tests were processed using SPSS 21.0 software for Windows (SPSS Inc., Chicago, IL, US) and Microsoft Office Excel 2013 (Microsoft Corporation, Redmond, WA, US).

RESULTS

Submaximal intensity

Physiological and kinematic variables for males and females are given in Table 2. No significant gender differences ($P > 0.05$) was found on the parameters for intensity (RPE, HR% of max, BLa, RER) on any of the stages. RPE did not differ significantly between the muscular and the cardiovascular system within each stage, neither between nor within genders. Males achieved significantly higher absolute work rate than females at all submaximal stages, with an average percent difference of 81% on low, 83% on moderate, and 89% on high submaximal intensities (all $P < 0.001$). The absolute oxygen uptake was significantly higher in males on all three submaximal stages, increasing from 53% via 58% to

63% at low, moderate and high submaximal intensity respectively (all $P < 0.001$). Normalized for total body mass, VO_2 differed significantly between males and females on each stage (all $P < 0.05$), with 25%, 29% and 33% higher values in males. In aerobic metabolic rate, males scored 53%, 59% and 62% higher than females (all $P < 0.001$). Metabolic rate showed a linear relationship with work rate both on individual basis, and for all subjects as shown in Figure 4. Comparison of the metabolic rate - work rate regression lines between males and females showed no significant difference ($P > 0.05$). When gross efficiency was interpolated at 80W submaximal intensity, a significant difference between genders was found, with mean values of 11.9 ± 1.5% for females and 13.3 ± 1.1% for males ($P < 0.05$).

A small but non-significant trend for gender differences was found on cycle rate at moderate and high submaximal intensity ($P = 0.09$ and $P = 0.08$), whereas there was clearly no difference at low intensity ($P = 0.61$). In percentage difference, females performed 3%, 10% and 10% higher cycle rate than males at low, moderate and high submaximal intensity respectively. In work per cycle, males achieved 86%, 102% and 107% higher values than females at low, moderate and high submaximal intensity (all $P < 0.001$).

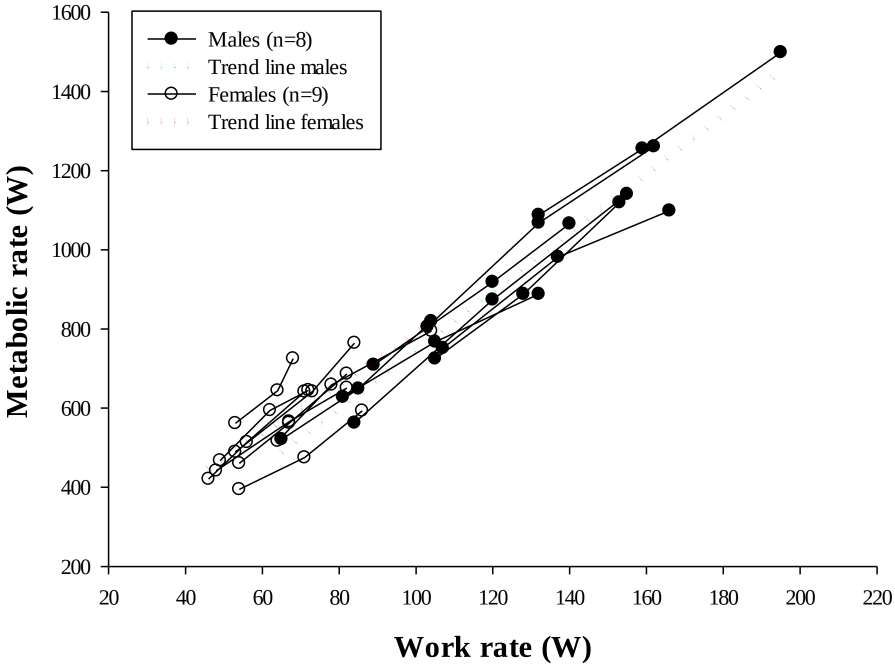

Fig. 4. *Metabolic rate plotted against work rate in male and female cross-country skiers during three 4-min stages of submaximal isolated upper body poling. Trend lines (green and red) are estimated based on the linear regression for males and females, respectively.*

Tab. 2. *Work rate, oxygen uptake (VO_2), respiratory exchange ratio (RER), blood lactate concentration (BLa,) aerobic metabolic rate and kinematics during three submaximal 4-min stages in eight male and nine female cross-country skiers (mean ± SD)*

	Submaximal stage 1				Submaximal stage 2				Submaximal stage 3			
	Males		Females		Males		Females		Males		Females	
Variables	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Muscular RPE	10.3	1.4	9.4	1.7	12.9	1.2	12.3	1.7	15.3	0.7	14.8	1.0
Cardiovascular REP	9.5	2.0	8.4	1.4	12.3	1.5	12.1	1.5	14.6	1.2	14.2	1.0
Absolute work rate (W)	96	20	53	7***	123	22	67	9***	151	27	80	9***
VO_2 (L min^{-1})	2.1	0.5	1.4	0.1***	2.6	0.5	1.7	0.2***	3.2	0.6	2.0	0.2***
VO_2 (mL min^{-1} kg^{-1})	27	5.1	21.7	2.3**	34.1	4.5	26.3	2.3***	41.0	5.6	30.8	2.2***
RER	0.92	0.04	0.91	0.05	0.95	0.03	0.96	0.05	0.98	0.04	1.01	0.03
Aerobic metabolic rate (W)	724	176	472	51***	925	184	582	62***	1111	211	686	65***
HR % of max	65	5	67	6	73	5	73	8	81	3	80	6
BLa (mmol/L)	2.7	0.7	2.6	0.6	3.8	0.9	4.0	1.0	6.0	1.3	5.9	1.3
Cycle rate (Hz)	0.64	0.07	0.66	0.08	0.65	0.08	0.72	0.07	0.69	0.07	0.76	0.08
Work per cycle (J)	149	32	80	11***	189	34	94	12***	218	39	105	12***

Gender differences: **$P < 0.01$, ***$P < 0.001$

3-min test

Physiological and kinematic variables for males and females in the 3-min test are given in Table 3. No significant gender differences ($P > 0.05$) was found on the parameters for intensity (RPE, HR% of max, RER) on the 3 min all-out test, except for lactate concentration, where males showed a 2.2 mmol/L higher value than females ($P < 0.05$). Males achieved 95% higher absolute work rate than females ($P < 0.001$), and 59% higher absolute VO_{2peak} (L min^{-1}) ($P < 0.001$). In relative VO_{2peak}, males reached a 34% higher value than females ($P < 0.001$). The oxygen uptake normalized for body mass during isolated upper body poling compared in percentage of relative VO_{2max} in running, was significantly higher in males than in females (77% vs. 65%; $P < 0.01$). This also entailed a greater percentage difference in oxygen uptake in upper body compared to lower body between males and females. During running, males reached a 13% higher oxygen uptake relative to body mass than females, whereas during isolated upper body poling the difference increased to 34%. No significant gender difference was found for cycle rate ($P = 0.07$), even if females on average used a 9% higher cycle rate than males. In work per cycle, males performed 112% better than females in absolute values ($P < 0.001$).

Tab. 3. *Work rate, oxygen uptake (VO_2), respiratory exchange ratio (RER), blood lactate concentration (BLa) and kinematics during the 3 minute all-out test in eight male and nine female cross-country skiers (mean ± SD)*

Variables	**3 min all-out**			
	Males		**Females**	
	Mean	**SD**	**Mean**	**SD**
Muscular RPE	19.4	1.1	19.3	0.5
Cardiovascular RPE	18.9	1.2	18.6	1.5
Watt	208	34	107	18***
VO_2 (L min^{-1})	4.3	0.7	2.7	0.3***
VO_2 (mL min^{-1} kg^{-1})	56.1	4.8	41.8	3.5***
RER	1.06	0.05	1.09	0.04
HR % of max	91	2	90	2
BLa (mmol/L)	13.3	2.2	11.1	1.5*
Cycle rate (Hz)	0.92	0.10	1.01	0.07
Work per cycle (J)	226	37	106	18***

Gender differences: *$P < 0.05$, ***$P < 0.001$

30-sec test

At the 30-sec test, a significant 114% differences in absolute work rate was found between males and females (329 ± 35W vs. 154 ± 19W, $P < 0.001$). In peak measured watt, a significant difference of 115% was recorded (389 ± 40W vs. 180 ± 21W, $P < 0.001$). No significant difference was found among males and females in the percent difference between average watt over the 30-s and peak measured watt (18 ± 3% vs. 18 ± 4%; $P = 0.17$). BLa did not differ significantly. No significant gender difference was found in cycle rate (1.32 ± 0.15 Hz vs. 1.26 Hz ± 0.15; $P > 0.05$). Work per cycle differed significantly with a 105% higher value in males (250 ± 26 J vs. 122 ± 15 J; $P < 0.001$)

Differences across intensities

Repeated measures ANOVA showed a main effect of gender on work rate, work per cycle and oxygen uptake normalized for body mass (all $P < 0.01$). A significant main effect was also found for intensity upon work rate, work per cycle and oxygen uptake normalized for body mass (all $P < 0.001$). Further, significant interaction effect between gender and intensity was found for work rate, work per cycle and oxygen uptake normalized for body mass (all $P < 0.01$). Follow-up t-tests identified significant gender differences on these three variables at all intensities ($P < 0.05$), as shown in Figure 5 A-C.

Cycle rate showed no main effect of gender (*P* > 0.05), while a significant main effect was found for intensity (*P* < 0.001), as well as a significant interaction effect between gender and intensity (*P* < 0.01). Follow-up t-tests showed significant gender difference in cycle rate increase between the low and the moderate submaximal stages, and between the 3-min test (shortened "max aerobe" in figure) and the 30-sec test (shortened "sprint" in figure), as shown in Figure 5 D.

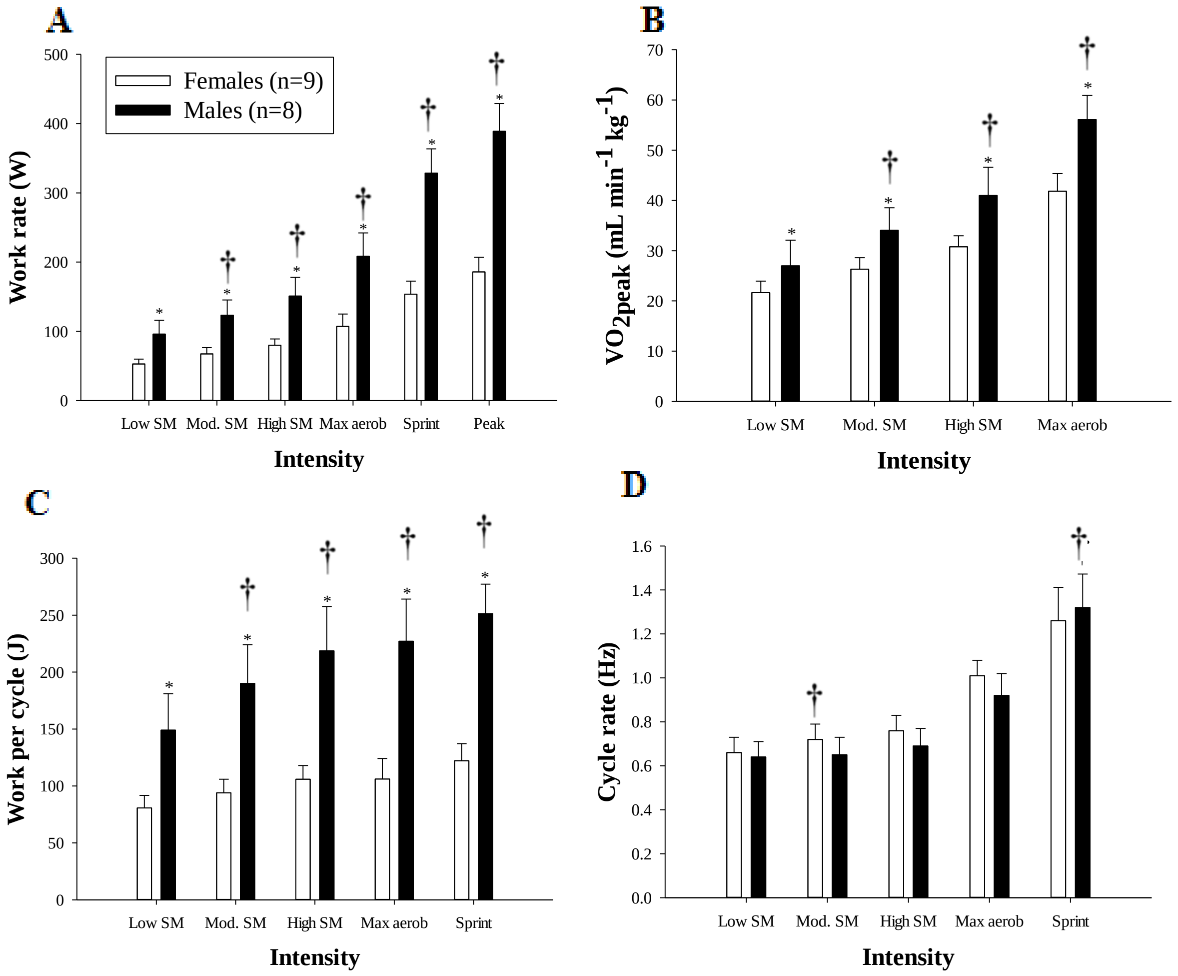

Fig. 4 A-D. *Showing gender differences in work rates, work per cycle, cycle rate and* VO_{2peak} *within and across intensities (SM = submaximal), between male and female cross country skiers.* *=*significant gender difference at current intensity (P < 0.05).* †=*significant gender difference in increase from the lower to current intensity (P < 0.05). P < 0.01 for intensity in all variables (A - D).*

Body composition

Fat mass, lean mass, and bone mass values for whole body, trunk and trunk plus arms from the body composition measurements are presented as absolute values in Table 4. Absolute body mass was significantly higher, 23%, in males compared to females ($P < 0.001$). Absolute lean mass was also significantly higher in males both in whole body, with a 34% difference ($P < 0.001$), and in upper body (trunk and arms) with a difference of 40% (42.4 kg vs. 30.4 kg; $P < 0.001$).

Tab. 4. *Dual-energy X-ray data for body composition (total lean mass, fat mass and bone mass content) presented in absolute values (kg), relative values for whole-body mass (% BM) and relative segmental masses (% SM) of arms, trunk and legs in eight male and nine female cross country skiers.*

	Males				**Females**			
				Total DXA mass				
	kg	**SD**	**% BM**	**SD**	**Kg**	**SD**	**% BM**	**SD**
Whole body	78.4	7.3			63.9	5.2***		
Arms	9.5	0.9	12.2	0.5	6.7	0.6***	10.4	0.4***
Trunk	38.0	4.2	48.4	1.7	29.8	2.9***	46.7	1.5*
Legs	25.8	2.7	33.0	1.9	23.0	2.0*	36.0	1.4**
Head and neck	5.0	0.3	6.4	0.5	4.4	0.2***	6.9	0.5
				Lean mass				
	kg	**SD**	**% SM**	**SD**	**Kg**	**SD**	**% SM**	**SD**
Arms	8.2	0.7	85.9	1.7	5.1	0.5***	76.8	4.2***
Trunk	34.3	3.7	90.1	1.4	25.3	2.4***	84.9	2.7***
Legs	21.7	2.3	84.2	2.6	16.9	1.3***	73.7	2.8***
Head and neck	3.5	0.2	70.0	1.0	3.1	0.2***	69.8	0.9
				Fat mass				
	kg	**SD**	**% SM**	**SD**	**Kg**	**SD**	**% SM**	**SD**
Arms	0.9	0.2	9.6	1.7	12.7	0.40**	19.0	4.3***
Trunk	3.0	0.7	7.8	1.5	3.9	1.0	13.0	2.8***
Legs	3.1	0.8	11.8	2.6	5.3	0.9***	22.8	2.8***
Head and neck	1.0	0.1	20.0	0.2	0.9	0.0***	20.1	0.2
				Bone mass content				
	kg	**SD**	**% SM**	**SD**	**Kg**	**SD**	**% SM**	**SD**
Arms	0.4	0.0	4.5	0.2	0.3	0.0***	4.2	0.4
Trunk	0.8	0.1	2.1	0.1	0.6	0.1***	2.1	0.3
Legs	1.0	0.1	4.0	0.2	0.8	0.1***	3.5	0.2***
Head and neck	0.5	0.1	10.0	1.2	0.4	0.1	10.1	1.1

*Gender differences:*P<0.05,* **$P < 0.01$, ***$P < 0.001$

Total mass in upper body (trunk and arms) were found to be significantly higher in males compared to females, with a difference of 30% (47.6 ± 5.0 kg vs. 36.5 ± 3.4 kg; $P < 0.001$). Males have significantly higher percent of their total body mass localized to their upper body with 61 ± 2%, whereas in females the same value were 57 ± 2% ($P < 0.001$). In lean mass, males also had a significantly higher percent of their total lean mass localized to their upper body (63 ± 2% vs. 60 ± 2%; $P < 0.05$). In absolute values, percentage gender differences in lean mass was increasing from legs via trunk to arms. Respective differences was 28% in legs, 35% in trunk and 60% in arms (all $P < 0.001$).

Training data

Training distribution for males and females respectively, are given in Table 5.Total training hours did not differ significantly between genders ($P > 0.05$), although males performed 7% more total training time in average. This difference was mainly caused by more than twice as much strength training among the male athletes ($P < 0.05$). Furthermore, male skiers trained significantly more in the classic technique on roller skis, with 35% more time spent in this technique the female skiers ($P < 0.001$). On the other side, females tended to perform more running than males, with 38% difference ($P = 0.056$).

***Tab. 5**. Total training separated in intensities and movement forms during the last 6 months before testing in eight male and eight female[1] cross-country skiers (mean±SD).*

Variables	Males				Females			
	Training hours	**SD**	**% tot. tr.**	**SD**	**Training hours**	**SD**	**% tot. tr.**	**SD**
LIT (<81% of HR$_{max}$)	277	45	76	6	278	58	82	5*
MIT (81-87% of HR$_{max}$)	14	5	4	2	13	4	4	1
HIT (>81% of HR$_{max}$)	18	7	5	2	19	6	6	2
Speed	10	5	3	2	8	6	2	2
Strength	42	25	12	6	19	10*	6	3*
Total	361	60	100	-	337	67	100	-
Classic roller skiing	96	12	26	4	71	26***	21	4**
Skate roller skiing	68	27	19	8	69	29	20	6
Running	104	22	29	9	144	47	43	10**
Other movement forms	93	48	17	7	53	22	15	6

*Gender differences: *P<0.05, **P<0.01, ***P<0.001. %.tot. tr. = % of total training; LIT = low-intensity endurance training; MIT = moderate-intensity endurance training; HIT = high-intensity endurance training.*

[1] *:one of the female athletes did not keep a training journal.*

In the questionnaire, when choosing which rolling friction they used most often for their roller ski wheels, males and females stated to use wheels with same friction, corresponding to the Swenor rubber wheels #2 (Sport Import AS, Sarpsborg, Norway). Males stated to implement roller ski sessions with double poling as the main technique once or more a week, whether females did the same only once a week or 1-3 times each month . Further, when ranking the distribution of double poling, kick double poling and diagonal stride during their roller ski training sessions (from 1 for the most used to 3 for the least used), females more often reported diagonal stride diagonal stride as the most (1) or second most (2) used technique than males. Males on their side, more often reported double poling and kick double poling as the two most used techniques, and nearly always diagonal stride as the least used technique during their classic roller ski training.

In their strength training sessions, males and females reported to have almost the same percentage distribution of their total strength training time divided between leg strength, arm strength and core strength and -stability training. Approximate distribution was 10%, 35% and 55%, for legs, arms and core respectively in both genders. The distribution of strength training sessions between endurance strength and maximal/explosive strength was about 75/25 for females, but 50/50 among males.

DISCUSSION

The current investigation was designed to compare gender differences in aerobic capacities, anaerobic performance and efficiency in performance matched male and female cross-country skiers during isolated upper body poling. The main finding were an increasing difference in upper-body performance between men and women with increasing intensity, which was substantially higher than what earlier showed during whole body exercises. The relationship between metabolic rate and work rate was not significantly different between genders, but gross efficiency at an interpolated submaximal load of 80W was significantly higher among males compared to females. Males reached significantly higher work rates than females through significantly greater work per cycle, whereas cycle rate did not differ significant although interesting trends were seen. Further, males had a higher distribution of lean mass in the upper limbs, and training data indicated more emphasis on upper body strength and endurance training among males.

Work rate, physiological responses and kinematics

On the poling test in this study, no significant gender differences was found on the parameters for intensity (RPE, HR% of max, BLa, RER) at any intensities. Because of a great difference between individuals and genders in absolute work rates and capacity, the procedure of comparing these variables was used as a basis to ensure a valid comparison between genders across different intensities, including the submaximal stages.

When having ensured a valid basis for comparing at all intensities, an interaction effect between gender and intensity was ascertained for work rate. Gender differences in work rate further increased from submaximal to maximal endurance to sprint. At the submaximal stages, males showed 81-89% higher external work rates than females, and the difference rose to 95% on the 3- min all-out test and 114% on the 30-sec test. Compared to an earlier study on cross country skiers (Sandbakk, Ettema & Holmberg, 2012a), were gender differences in absolute work rate was found to be 67%, 62%, 58% and 54% for double poling, G3 skating, diagonal skiing, and running respectively, gender differences in this study was clearly higher. The differences was also higher than what has earlier been found in leg and whole body exercise (Maldonado-Martin et al., 2004; Sandbakk, Ettema & Holmberg, 2012a; Schumacher et al., 2001). With regard to intensity, the consistently increase in gender difference with increasing intensity revealed here, stands in contrast to what Sandbakk, Ettema, Leirdal and Holmberg (2012) found when comparing genders using the G3 skating technique. In their study, gender differences in work rate increased from 39% at submaximal intensity to 62% at maximal aerobic intensity, but further only to 63% at maximal speed. To understand this divergent findings, we need to take a closer look at other underlying factors related to performance in upper body poling.

Previous investigations have partially attributed differences in performance between men and women to higher oxygen uptake (Calbet & Joyner, 2010; Joyner, 1993). In this study, males reached significantly higher VO_{2peak} in both absolute values and when normalized for body mass, and an interaction effect between gender and intensity was found in VO_2, meaning that gender difference rose with rising intensity. The percentage gender differences in absolute oxygen uptake was, however, not as high as the percentage difference in absolute work rates. Further, males also utilized a greater percentage of their VO_{2max} than females (77% vs. 65%), maybe because of more active muscle mass in males. For males, this difference was quiet similar as found by Holmberg et al. (2006) when comparing arm cranking and diagonal skiing in elite skiers (78%). The gender differences in VO_{2peak} during isolated upper body poling was higher than during running in the same subjects in this study (13% vs. 34%). The gender difference during running that was revealed here, is in accordance with gender differences in oxygen uptake observed in other endurance sports (Calbet & Joyner, 2010; Joyner, 1993) and for whole body work in skiers (Sandbakk & Ettema, 2013). Gender difference in VO_{2peak} during isolated upper body poling in this study is, in contrast, clearly higher. Therefore, the actual differences in VO_{2peak} revealed here is one explanatory factor for gender difference in performance during upper body poling, and for the more pronounced performance differences here compared to what other studies have showed. However, the gender differences in work rates was higher than what could be explained by diversity in aerobic energy delivery, meaning that differences in neither absolute or relative VO_{2peak} could explain the whole difference between genders in performance.

How efficient metabolic energy is converted to external energy, can be determined by comparing metabolic rate and work rate. A linear relationship between metabolic rate and work rate seems to be a rather common outcome independent of work type and work rate, as it is earlier showed both in cycling (Chavarren & Calbet, 1999; Moseley, 2004), and cross-country skiing (Leirdal, Sandbakk & Ettema, 2013; Sandbakk, Ettema & Holmberg, 2012a). The present study supports previous studies, as a linear relationship was found also in this case, and no significant difference between males and females regression lines was revealed. Despite this, when gross efficiency was interpolated at a submaximal load of 80W, a significant difference between genders was found. Whether this is the outcome of actual physical differences, or just an artefact of collected values and statistical tests is unclear. Therefore, it remains an uncertainty about possible differences between males and females in the effectiveness of the upper body, which should be more closely examined in future studies. When looking at gross efficiency in this study, we found values within the range of 12.5-15.1% among males and 9.4-14.6% among females. These values are slightly lower compared to what is earlier revealed in studies on roller ski skating (12.5-16.5%) (Leirdal et al., 2013; Sandbakk, Ettema, Leirdal & Holmberg, 2010) and cycling (~20%) (Ettema & Loras, 2009). The lower gross efficiencies during isolated upper body poling compared to these activities, might be a consequence of lower work rates and less amount of muscle mass activated during the movement in this case (Ettema & Loras, 2009). The fact that gross efficiency differed between genders in this case, might be because the skiers in this study are matched for performance relative to the best skier in the world of each gender while skiing on snow, but they might still differ in upper body performance level.

It is earlier demonstrated that a greater efficiency can be linked to higher work per cycle at a the same cycle rate among skiers (Sandbakk, Ettema & Holmberg, 2013). The males in this study exerted significantly higher work per cycle at the approximately same cycle rate, and this could contribute to affect the gross efficiency. On the submaximal intensities, females also tended to earlier start compensating by increasing cycle rate to reach higher work rates, as the percentage gender differences in this study grew significantly already from submaximal stage 1 to submaximal stage 2, and maintained on this level through the 3-min test. However, from the 3-min test to the 30-s test, males increased cycle rate significantly more than females, whilst the percentage increase in work per cycle were at the same level for both genders. The gender differences in work rate were therefore mostly due to a greater absolute work per cycle among males, but males also tends to have a greater range in cycle rate than females; they can choose a lower cycle rate at submaximal intensity, but have the potential to go higher when needed. Explosive strength and efficiency have recently been proposed as explanations for differences in work per cycle when using the G3 skating technique (Sandbakk et al., 2010; Stoggl et al., 2010). This might also explain what enable males to exert a higher work rate without increasing cycle rate in this study, as males here was shown to have a greater upper body lean mass, and better gross efficiency at submaximal intensity. Because average cycle rate on the 30-sec test was not significantly different between males and females, this may indicate a maximal threshold for cycle rate during isolated upper body poling, which here was reached at the 30-sec test. As an increase in work rate in cross-country skiing is characterised by increased work per cycle, and/or increased cycle rate (Lindinger & Holmberg, 2011; Sandbakk et al., 2010; Stoggl & Muller, 2009), females seems to have a potential to develop their upper body performance by performing a greater work per cycle.

Body composition

The current study revealed a higher total mass and total lean mass in both trunk and arms among males compared to women. Males also had a higher percent of total body mass localized to their upper body. One should of course be aware of the fact that lean mass values does not exactly correlate with muscle mass, although it is considered so in this study. This phenomenon applies particularly for the trunk, where the vital organs causes the values for lean mass to be somewhat higher than the actual value for muscle mass. With this in mind, we still consider the higher distribution of lean mass in the upper limbs among male skiers to entail a greater opportunity to create work. This because a greater lean mass allow males to gain advantage of a greater percentage of their total aerobic capacity, and it also provides them with a greater anaerobic capacity. The significantly higher percentage of VO_{2max} utilized, greater work rates and lactate accumulation in males during the 3-min test and the 30-sec test supports this assumption. This gives males an direct benefit in competitions, considering the fact that the best skiers in the world drives work rates considerably higher than what is required to elicit maximal oxygen consumption in parts of the track (Sandbakk & Holmberg, 2014). On the other hand, a higher total mass in the upper body among males compared to females, might also enable the males reach a higher work rate by using body mass and gravity to increase force in this actual motion.

An other interesting finding in this study is that percent differences between males and females in absolute lean mass was increasing significantly from legs via trunk to arms. In arms, the difference was more than twice as high in legs. A greater difference between genders in active muscle mass in this study compared what is likely in studies on leg and whole body exercise (Maldonado-Martin et al., 2004; Sandbakk, Ettema & Holmberg, 2012a; Schumacher et al., 2001), might also be an explanatory cause for the clearly higher gender differences in work rate in this study compared to earlier studies. The rising gender difference in lean mass from legs via trunk to arms also suggests that the importance of arm strength for performance in upper body poling should not be underestimated. On the other hand, during double poling force needs to be transferred across the trunk and out to trough the arms. Therefore, core strength and stability is also an important foundation for producing high external forces, because it facilitate the possibility to utilize arm strength optimally (Willardson, 2007).

In cross-country skiing, snow condition and the profile of the track influence whether the total body mass or a body mass normalized for lean mass is the best predictor for performance (Saltin, 1997). A hilly track and poor gliding favors the smaller skier, whereas skiing in tracks with superb gliding, and in flat terrain favors taller and heavier skiers. However, in isolated upper body work, the one can assume that both the absolute mass and the lean mass of the upper body contributes positively to the performance outcome.

Training data

Data from individual training dairies indicated more upper body strength and endurance training in males. Questionnaires based on quantified training data further strengthened that males put more focus on upper body maximal and explosive strength training, and use more of the double poling technique during training on roller skis. Additionally, we found that males spend more hours on strength training and on classic roller skis than females did, still if total training time was not significantly different. In total this constitutes a great difference between genders in time spent for upper body training and in training impact on the upper body. This might be an underlying reason for the greater differences found here, compared to in other sports where training patterns regarding choice of locomotion and local training impact is more similar between genders.

The complex nature of cross-country skiing, with a number of different techniques practiced in over varied terrain, entails a great variation in possible forms of movement during training. The fact that females uses roller skies with the same friction and train in the same tracks as males is likely to cause a lower velocity during training among females compared to males, because they are not as strong as males in overcome the resistance. Lower velocity further provides possible differences in choice of technique, as choice of technique relies on the actual velocity (Sandbakk, Hegge & Ettema, 2013). This may be the reason that males more often choose to, or is able to, use the double poling technique during roller ski training, and thereby puts more load on the upper body, whereas females to a greater extent choose techniques that puts load on their legs. On the other side, females use running quiet more in their training than males. The outcome of these differences in training patterns may be based individual strengths and weaknesses, and contributes to reinforce already existing physiologically differences.

In strength training, percentage distribution of training between leg strength, arm strength and core strength and -stability did not differ between genders. Based on the reports from the athletes training diaries, this means that males in average puts twice as much time in all these types of strength training compared to females. The fact that males in addition perform a greater percentage of their strength training as explosive and maximal strength training might further contribute to create gender differences in upper body performance. This, based on the fact that upper body power is known as an important determinant of classical skiing performance (Alsobrook & Heil, 2009). The fact that the resting concentration of the anabolic testosterone hormone is 10 to 20 times lower in females compared to males, gives males an further advantage in building muscles (Kraemer & Ratamess, 2003), which further is amplified by more strength training among males.

Regarding the training data, it could be questioned whether individually quantified data provides valid data for comparison. This question could always be discussed, but Sylta, Tonnessen and Seiler (2014) state that researchers can rely on the validity of self reported training data, as elite endurance athletes, including cross-country skiers, accurately self-report their training duration and intensity distribution. Still, training data, and subsequent athletes questionnaire does not provide an complete adequate and satisfactory objective measure for understanding what lies behind the hours recorded in the training diary. Potential for improvement lies in the accuracy of logging weight, repetitions and total load of strength training, and to obtain a better overview of technique distribution during training. At this points, there might exist different practices in the way keeping of training diaries among the athletes, and this fact complicates the attempt to compare performed training between individual athletes, and consequently genders. For further studies, it is important to be aware of the issues which exist, when comparing individually logged training data. Especially for strength training, which traditionally is logged as "hours" among cross-country skiers, the basis for comparing athletes is restricted. When knowing that today's Olympic cross-country skiers places a greater focus on upper-body power and more systematically perform strength training than before (Sandbakk & Holmberg, 2014), especially the way of logging strength training for cross-country skiers both in practice and research is worth to discuss in the near future.

Methodological considerations

The movement characteristics used in this study may not be directly comparable to double poling in cross country skiing. In the ski ergometer, the athletes potentially have a longer time to produce force (Linnamo, 2013), as the force production is not depending on the ground contact time, and does not depend on friction between skis and snow. Based on this, one can not directly compare tests in the ski ergometer with tests on roller skis or during skiing on snow (Holmberg et al., 2005; Lindinger & Holmberg, 2011). However, a similar muscle activity and fatigue load between Concept 2 SkiErg and skiing on snow, suggest that the SkiErg provides valid training and testing for skiers (Linnamo, 2013).

One of the major strengthens of this study, is the accordance of the average FIS-points between males and females. This provides a good and valid verification to assume that the athletes are at the same relative level compared to the best athlete in the world of each gender. From experience, this also suggests a similar level of training volume and dedication to their sports commitment. All though performance in the tests employed in this study does not necessarily reflect the actual difference between individuals during double poling on snow, the protocols are considered relevant for examining the gender differences in upper body performance among cross country skiers. This, because of the similarities of poling in the ergometer compared to poling on skis (Linnamo, 2013), and the skiers familiarity to this movement characteristics.

PRACTICAL IMPLICATIONS

The overall findings in this study suggested that female cross-country skiers on national level can achieve benefits in aerobic, anaerobic and strength capacities of the upper body by increasing the lean mass in upper body, and especially arms. It would also be interesting to perform the same test as applied in this study on elite athletes, to check if gender differences on elite level correspond to differences on national level or not.

Based on the findings in this study, we might suggest that female cross country skiers on national level should organized their strength training program systematically for the purpose of increasing upper body strength and power. Their training should further be monitored closely to ensure the desired progression. Regarding roller ski and on-snow ski training, female skiers on national level should consider adding more emphasis on upper body work, such as using double poling or G3 skating to a greater extent, to increase their upper body endurance. This can be done by choosing roller ski wheels with lower rolling resistance, or seek terrain which invites to more use of the double poling technique in both low, moderate and high intensity training.

Training patterns of both female and male cross-country skiers should be further be carefully analyzed and followed up. Coaches should ensure that desired properties are developed, and must in this context not forget to facilitate for development of the upper body. Focus on the importance of upper body training is especially important for coaches facing female cross-country skiers. Researchers, on the other hand, should do more in dept analysis of training patterns and actual content in each workout among cross country skiers, with particular focus on the impact on the upper body. This to gain more extensive understanding of actual performed training, and eventual gender differences in this area among cross country skiers.

CONCLUSION

The differences in upper body performance between men and women increased with increasing intensity, with the differences being significantly higher than what has been showed in leg- and whole body exercise. Gender differences in oxygen uptake increased with increasing intensity, and gender differences in VO_{2peak} was higher during upper body poling than during running. The relationship between aerobic metabolic rate and work rate did not differ significantly between genders. These results indicate that particularly anaerobic capacity differentiates genders in upper body exercise. The latter is further supported by the greater work per cycle and higher distribution of lean mass in the upper limbs among male skiers. In addition, individually logged training data also indicated more upper body strength and endurance training in males, which might be an underlying reason for the greater differences here compared to other sports.

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APPENDIX

Appendix 1:
Tolking av treningsdata i studiet "overkroppsarbeid i langrenn"

I forbindelse med tolking av treningsdagbok-data som vi har samlet inn gjennom studiet "overkroppsarbeid" i langrenn", ønsker vi å stille noen spørsmål som kan hjelpe oss til å få en litt grundigere forståelse av hva som ligger bak timene som er ført i treningsdagboka.
Vi setter stor pris på om du svarer på spørreskjemaet også selv om du ikke har sendt inn treningsdata i forbindelse med studiet. Alle svar er anonyme, og kan ikke spores tilbake til deg.

Har du spørsmål, ta kontakt med:
Kenneth Myhre (tlf. [redacted] / kenneth.myhre@student.hint.no) eller
Øyvind Sandbakk (tlf. [redacted] / oyvind.sandbakk@ntnu.no).

* Required

1. Angi ditt kjønn: *

○ Kvinne

○ Mann

SIDE 1: RULLESKI KLASSISK

Spørsmålene som følger gjelder trening på klassisk rulleski i perioden mai - oktober 2013.

2. Tenk på dine klassisk-turer på rulleski i perioden mai - oktober: *
ranger følgende teknikker ut i fra hvilken du vil si at du brukte mest (1) til minst (3):

	1	2	3
Diagonalgang	○	○	○
Dobbeltak med fraspark	○	○	○
Staking	○	○	○

3. Dersom du skal gjøre et anslag, hvor stor prosentandel av treninga di på klassisk rulleski vil du si har bestått av: *

staking? ☐*
dobbeltak med fraspark? ☐ *
diagonalgang? ☐*

4. Tenk på dine klassisk-turer på rulleski i perioden mai - oktober: *
Hvor ofte hadde du økter hvor STAKING utgjorde hoveddelen/var den mest bruke teknikken i løpet av økta?

○ Flere ganger i uka
○ En gang i uka
○ 1-3 ganger i måneden
○ Sjeldnere enn en gang per måned
○ Aldri

5. Hvilke(n) intensitet(er) hadde du på disse øktene hvor staking utgjorde hoveddelen? *
(du kan krysse av for flere alternativ)

☐ Lav intensitet (I1 - I2)
☐ Middels intensitet (I3)
☐ Høy intensitet (I4 - I5)
☐ Hurtighet

6. Hvilken rullemotstand brukte du OFTEST på dine klassisk-rulleski i denne perioden? *

○ Racinghjul eller tilsvarende
○ 1'er hjul eller tilsvarende
○ 2'er hjul eller tilsvarende
○ 3'er hjul eller tilsvarende
○ 4'er hjul eller tilsvarende
○ Vet ikke

7.Beskriv enkelt en eller flere klassisk rulleskiøkter du har gjennomført, som oppsummerer det du krysset av for over: *

☐

SIDE 2: STYRKETRENING

Spørsmålene som følger gjelder styrketrening i perioden mai - oktober 2013.

8. Hvor stor andel av styrketreninga di har i prosent vært: *
utholdende/stabiliserende styrke? ☐*
maksimal/eksplosiv styrke? ☐*

SIDE 3: STYRKETRENING

Spørsmålene som følger gjelder styrketrening i perioden mai - oktober 2013.

9. Hvor stor andel av dine styrketreningsøkter har i prosent vært: *

styrke på mage/rygg? *
styrke på armer? *
styrke på beina? *

10. Beskriv enkelt en eller flere styrkeøkter som oppsummerer det du krysset av for over: *

- beskriv i stikkordform hva du har brukt av øvelser, antall repetisjoner, intensitet, varighet og eventuelt mer.