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**Maximal Work Capacity and Performance Depends Warm-up Procedure and Environmental but not Inspired Air Temperatures**

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##### ABSTRACT

**Lindberg, A-S, Malm, C, Hammarström, D, Tonkonogi, M**. Maximal Work Capacity and Performance in Cold and Warm Environmental and Inspired Air Temperatures. **JEPonline**2012;15(1):26-39. The purpose of this study was to compare peak (VO2 peak) and maximal (VO2 max) oxygen uptake, physical performance, and lactate accumulation [la-] in warm versus cold environments. The influence of inhaled air temperature and different warm up modes on these variables as well as arterial oxygen saturation (SaO2%) and pulmonary function were also studied. Two studies were performed. In study A, 10 males performed maximal exercise tests on a bicycle at +20°C and -12°C. In study B, 8 elite cross-country skiers performed maximal cross-country skiing tests at +13.7ºC. Different warm up modes (continuous and intermittent) and different temperatures of the inhaled air (-8°C and +13°C) were used. In study A, we found significantly higher VO2 peak, peak carbon dioxide (VCO2 peak), peak ventilation (VE peak) and respiratory exchange ratio (RER) in +20°C compared to -12°C. In study B, we found significantly lower SaO2% at the end compared to the beginning of the maximal performance test. Time to exhaustion (Tex) was significantly longer using intermittent warm up irrespectively of inhaled air temperature. In conclusion, we found that VO2 max was affected by different environmental temperatures but not by different temperatures of the inhaled air and that intermittent warm up increased Tex without affecting VO2 max.

**Key Words**: Asthma, Arterial desaturation, Cold, Cross-country skiing, Oxygen uptake

# INTRODUCTION

Physical performance is affected by the surrounding temperature, with decreased muscle function (24,25) and work capacity (21,36) in cold environment. The additional effects of wind and water will further enhance the heat transfer from the body (2,17), which will consequently affect physical performance (17). Cold exposure causes superficial and limb blood vessels to constrict in order to conserve heat, which reduces heat loss by reducing the difference between skin and environmental temperature (15).

In cross-country ski racing a very high VO2 max is important for success (3). Laboratory VO2 max testing at room temperature is a common way to predict performance and evaluate training-effects in cross-country skiers (7,12,16,32). The effects of cold climate on submaximal oxygen uptake (VO2sub) and VO2 max during exercise is relatively well documented, but results are inconsistent: VO2 max remained unchanged (23,29,31), decreased (21) or increased (27) in the cold climate while VO2sub remained unchanged (29;23) or increased (21,30,31). Comparisons between different studies are difficult due to variations in study designs (e.g., different environmental temperatures). In the current study, cold is defined as temperatures below 0°C. In a review, Jett et al. (11) concluded that when investigating the effects of cold exposure on metabolism during exercise, the variety of factors shown to exert influence must be systematically isolated, controlled, and examined (e.g., training status of the subjects, duration and intensity of resting pre-exercise exposure to cold conditions, duration and intensity of cold exposure during exercise, and the insulation of clothing. Doubt et al. (6) reported that VO2 during exercise is generally higher in the cold compared to warm, but that the difference decreases as the workload increases. Higher VO2sub in cold environment is reported to be caused by thermogenesis which will cause a greater contribution of the anaerobic glycolysis at the beginning of exercise (2). Jett et al. (11) explains that at near maximal power output, it is likely that increased thermogenesis is no longer necessary due to the metabolic heat production of exercising muscles, thus leaving VO2 max unaffected by the cold.

Even though the environmental temperature differs between studies, the general consensus is that Tex during VO2 max testing is reduced in cold compared to warm environments (21,23,27,29). Exercise induced bronchospasm and other asthmatic symptoms in cold climate are common problems among cross-country skiers (13,20,26,33), with a prevalence as high as 42% to 80% (13, 26). The mechanism of exercise induced bronchospasm/asthma is not absolutely clear, but exercise intensity and duration of exercise are important determinants of the severity of exercise induced asthma (1). Regardless, asthmatic problems may cause increased work of breathing (22) during exercise (17) and, therefore, decrease exercise performance due to decreased oxygen saturation (SaO2%) (19). The majority of healthy people maintain SaO2% above 95% even at maximal effort, while elite endurance athletes can reach levels under 90% SaO2% which can limit VO2 max (4,5,9,28). Exercise induced arterial hypoxemia (EIAH), has been defined as a SaO2 below 95% or 3% to 4% < rest (5,19). EIAH at maximal effort has been found in runners (4), bikers (9, 28), rowers (5) and in cross-country skiers using diagonal technique, but not with double pooling technique (10). All of these studies are carried out in room temperature.

Sandsund et al. (31) found that bronchodilator by β2 agonist may increase forced expiratory volume in 1 sec (FEV1) but not ventilation, VO2 max or time to exhaustion in non-asthmatic cross country skiers. In healthy, non-asthmatic people ventilation is not a limiting factor for VO2 max (17). It has also been shown that the warm-up procedure can influence subsequent airway function during heavy exercise (18). However, we have not found that the effects of different warm-up modes on physical performance in cold climate have been investigated previously.

Physiological performance tests of cross-country skiers are usually made in a laboratory with an ambient temperature around +20°C, but their competitive performance takes place at lower temperatures, normally -5°C to -15°C. Therefore, the purpose of this study was to compare VO2 peak, maximal performance, and lactate accumulation in warm versus cold environment. The influence of inhaled air-temperature and different warm up modes on arterial saturation, VO2 max, pulmonary function, lactate accumulation, and performance-time were also studied.

# METHODS

## Testing Conditions

Two studies were performed with different environmental conditions and different subjects included. To specify the actual intervention, we named the intervention group A-12, A+20, B+14con, B+14int, B-8con and B-8int based on the type of intervention, as described below.

In the first study (A), each subject performed 2 tests; once in a climatic chamber with the temperature at -12°C, relative humidity 80%, and wind 1.5 m/sec (A-12) and once in a room with an air temperature of +20°C, relative humidity 20%, and no wind (A+20). In the second study (Study B) each subject performed 4 tests; every test was performed in a room with a temperature of +13.9 ± 0.3°C but with different warm up modes (Tables 1 and 2). Two of the tests were executed with warm inhaled air (+13.7 ± 0.4°C); one test prepared with continual (B+14con) and one with intermittent (B+14int) warm up. Two tests were executed with cold inhaled air (-7.6 ± 0.4°C); one test was presided with continual (B-8con) and one with intermittent warm up (B-8int).

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| Table 1. Continual warm up session for 20 min with different temperature of the inhaled air (+13.7 ± 0.4°C and -7.6 ± 0.4°C) in a warm environment (+13.9 ± 0.3°C).   |  |  |  | | --- | --- | --- | | **Speed (km•h-1)** | **Incline (°)** | **Time (sec)** | | **8.5** | 3 | 240 | | **9.0** | 4 | 240 | | **9.5** | 5 | 240 | | **10.0** | 6 | 240 | | **10.5** | 7 | 240 | |

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| Table 2. Intermittent warm up session for 20 min with different temperature of the inhaled air (+13.7 ± 0.4°C and -7.6 ± 0.4°C) in a warm environment. (+13.9 ± 0.3°C).   |  |  |  | | --- | --- | --- | | **8.5** | **3** | **240** | | **9.0** | 4 | 240 | | **9.5** | 5 | 240 | | **10.0** | 6 | 240 | | **11.0** | 10 | 30 | | **11.0** | 3 | 75 | | **11.0** | 10 | 30 | | **11.0** | 3 | 75 | | **11.0** | 10 | 30 | |

## Subjects

In study A, 10 healthy males volunteered to participate in this study after receiving a verbal and written explanation of the test procedure. Subjects with any heart disease, lung disease or obvious on going infection (virus or bacterial screening was not made) were excluded. Mean (±SD) age, height, and body weight were 37 ± 5 yrs, 181 ± 7 cm, 79.2 ± 6.2 kg, respectively, and mean VO2 max of 4.17 L•min-1 (range 44 to 61 mL•kg-1•min-1).

In study B, 8 healthy national and international male cross-country skiers accustomed to VO2 max testing volunteered to participate. Mean (±SD) age, height, and body weight were 21 ± 5 yrs, 181 ± 8 cm, 75.2 ± 9.2 kg, respectively. VO2 max was 5.03 L•min-1 with a range 60 to 81 mL•kg-1•min-1. Written and verbal instructions regarding the study and possible risks and discomfort were given prior the tests. The tests were conducted in accordance with the World Medical Association Declaration of Helsinki regarding human subjects. Ethical permission was granted by the local ethical committee at Dalarna University, Falun, Sweden (2006-03-31).

## Procedures

### Instrumentation

In both studies, the O2 and CO2 gas analysers (Jaeger Oxycon Pro, Intramedic AB, Bålsta, Sweden) were calibrated in relation to known gases (Air Liquid, Alpha mix) with a two point calibration prior to each test. Volume calibration was automatically conducted with constant flow of 0.3 and 2.0 L•sec-1. The system is regularly calibrated for airflows up to 10 L•sec-1 by manual calibration. In study A, environmental temperature and relative humidity were checked with GMH 3330 and GMH 3160-12 (Svenska termoinstrument AB, Täby, Sweden). During the VO2 tests, a two way Y-valve, mouthpiece, nose clip and tubes were connected to the subjects with a headgear (Hans Rudolph Inc, Kansas City, USA). Pulmonary function was assessed by forced vital capacity (FVC) and forced expired volume in one second (FEV1) with a Jaeger Oxycon Pro in the second study only. Heart rate was registered with Polar heart rate monitor S810 (Polar Electro Oy, Kempele, Finland). In the second study, temperature of the inspired air was measured with a thermistor (Termometerfabriken Viking AB, Eskilstuna, Sweden) located at the inspiring valve. Bodyweight of the subjects was measured with a flat-scale (Seca Corporation, Hanover, USA). During the second study, arterial saturation was measured on the fingertip using a pulse-oximeter (Datex-Ohmeda, Luiseville, USA) synchronized to the Oxycon Pro. Lactate-accumulation was analysed with Biosen 5130 and Biosen 5140-1506 (EKF-Diagnostic, Magdeburg, Germany). The bicycle tests were performed on a Monark 828E (Monark ecercise AB, Varberg, Sweden), and the cross-country skiing tests were performed on a motor driven treadmill (Refox, Falun, Sweden). In the first study, concentration of capillary haemoglobin concentration in blood (B-Hb) was analyzed with a B-Hemoglobin Fotometer (Hemocue AB, Ängelholm, Sweden).

### **Experimental Design**

During both studies, restrictions regarding food and exercise prior to the tests were given. In study A, the subjects were instructed not to exercise the day before, no hard training 3 days before and not to do any unaccustomed exercise 4 days before each session. In study B, the subjects were told to standardize training and content of food on their own. Each subject signed a medical check-up and body weight was checked before each session in order to calculate correct VO2 and VCO2 values.

In study A, each subject performed two maximal exercise ramp tests on a bicycle ergometer in random order at the same time of the day on two separate days, 2-7 days between the tests. The subjects wore the same clothing during both sessions apart from gloves, which were used in the climatic chamber only. Prior to and 1 min after each test capillary blood was sampled from a fingertip. The 15 min warm up took place in the warmer area (20°C) at the same self-chosen intensity during both sessions. Immediately after entering the climatic chamber the subjects performed a maximal ramp test. The tests started at 100 W and each min the resistance was increased by 25 W until exhaustion. The test stopped when the subjects were unable to keep up the 60 rpm cadence. The physiological parameters measured during cycling were VO2 peak, peak heart rate (HR peak), VE peak, VCO2 peak and RER. Values were calculated as 30-sec means for each variable. Other variables registered were Tex, [la-]b and B-Hb.

In study B, each subject performed four maximal cross-country skiing ramp-tests until exhaustion. Tests were performed in random order but at the same time of the day on four different days, 1-7 days between the sessions. The subjects wore the same self-chosen clothes in all sessions. After each test, fingertip capillary blood was sampled at 1, 5, and 10-min. The tests were administered with 2 different modes of warm up: continual and intermittent cross country skiing for 20 min (Tables 1 and 2) and 2 different temperatures of the inhaled air. Each test started 5 min after the warm up. The maximal exercise ramp test started at 11 km•h-1 and with 4° inclines which then increased 1° each min during the test. The test stopped when the subject stopped at voluntary exhausted. FEV1 and FVC were measured prior to and at 5 min after the maximal ski test. Physiological parameters measured during the ramp tests were VO2 max, maximal heart rate (HR max), maximal ventilation (VE max) maximal carbon dioxide production (VCO2 max), RER, SaO2%, [la-]b, and performance time (Psec).

## Statistical Analyses

The data are presented as mean ± standard deviation. Statistical analyses were performed using JMP (SAS Institute, USA). Differences between tested conditions were investigated with repeated measurement ANOVA and paired t-test.

# RESULTS

Physical and physiological characteristics of the subjects and maximal exercise test results from study A are presented in Table 3. We found that VO2 peak (P<0.05), VCO2 peak (P<0.01), RER (P<0.05) and VE peak (P<0.05) were significantly higher in session A+20 compared to A-12 (Table 3, Figure 1) while HR peak, [la-]b, B-Hb and Tex were not significantly different between sessions (Figure 2).



**Figure 1. Peak oxygen uptake (VO2 peak) was significantly higher in room (A+20) compared to cold (A-12) environment (P<0.05). Boxes show median and 75% CI. Whiskers at 95% Confidence Interval (CI).**



**Figure 2. Time to exhaustion (Tex) was the same in warm (A+20) and cold (A-20) environment. Boxes show median and 75% CI. Whiskers at 95% CI.**

There was a significant correlation between results in warm and cold (A+20 vs. A-12) environment regarding VO2 peak (mL• kg-1•min-1, R2 = 0.43, P = 0.02), VO2 peak (L•min-1, R2 = 0.35, P = 0.04) and Tex (sec; R2 = 0.64, P = 0.03).

**Table 3. Physiological maximal exercise test results from study A. Tests were made in a room-temperature of 20°C (A+20) and -12°C (A-12).**

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Group** | **B-Hb**  **g•l-1** | **VO2 peak**  **ml•min-1** | **VO2 peak**  **mL•min-1•kg-1** | | **VCO2 peak**  **mL• min-1** | **RER** | **VE**  **L•min-1** | **HR peak**  **beats•min-1** | **[la-]b**  **mmol•l-1** | **Psec**  **Sec** |
| ***A+20*** | 152±9 | 4166±487\* | 52.7±6.1٭ | 4471±449٭٭ | | 1.07±0.04٭ | 175±25٭ | 180±10 | 12.1±1.5 | 623±96 |
| ***A-12*** | 152±10 | 3869±352\* | 48.9±5.5\* | 4093±379\*\* | | 1.06±0.05\* | 156±23\* | 177±13 | 11.2±2.5 | 614±90 |

N=10. B-Hb: Hemoglobin concentration, VO2 peak: Peak oxygen uptake, VCO2 peak: peak carbon dioxide production, RER: respiratory exchange ratio, VE: expired minute ventilation, HR peak: Peak heart rate, [la-]b : lactate concentration in blood. Psec: Performance time. Significance between A+20 and A-12 ٭P<0.05 ٭٭P<0.01

**Table 4.** Physiological maximal exercise test results from study B. Every test was made in a room temperature of +13.9°C. Two of the tests executed with +13.7°C temperature of the inhaled air prepared with continual warm up (B+14con) or intermittent warm up (B+14int). Two of the tests were executed with cold -7.6°C temperature of the inhaling air, prepared with a continual warm up (B-8con) or with intermittent warm up (B-8int).

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Group** | **VO2 max**  **mL•min-1** | **VO2 max**  **mL•kg-1•min-1** | **VCO2 max**  **mL•min-1** | **RER** | **VE**  **L•min-1** | **HR max**  **beats•min-1** | **SaO2**  **%in** | **SaO2**  **%max** | **[la-]b**  **mmol•l-1** | **Psec**  **Sec** |
| **B+14con** | 4970±616 | 66.1±2.9 | 5524±910 | 1.11±0.06 | 160.8±21.8 | 193±7 | 97.0±0.7 | 93.8±3.7§ | 9.6±2.9 | 401±61.6 |
| **B+14int** | 5092±573 | 67.3±3.4 | 5767±839 | 1.13±0.04 | 164.7±16.1 | 194±4 | 97.9±0.7 | 95.5±4.2 | 9.3±2.7 | 435\*†±75.2 |
| **B-8con** | 4925±564 | 65.4±2.3 | 5260±776 | 1.07±0.06 | 159.4±15.0 | 193±5 | 97.1±0.5 | 95.5±3.4 | 9.3±1.6 | 394†‡±53.8 |
| **B-8int** | 5020±518 | 66.8±2.5 | 5636±660 | 1.12±0.04 | 166.4±14.3 | 195±4 | 96.8±2.0 | 93.5±5.7 | 9.9±2.0 | 451\*‡±752 |

N=8. VO2 max: maximal oxygen uptake, VCO2 max: maximal carbon dioxide production, RER: respiratory exchange ratio, VE: expired minute ventilation, HR max: maximal heart rate, SaO2%: arterial saturation of the blood before (SaO2%in) and in the end of the maximal exercise test (SaO2%max), [la-]b : lactate concentration. Significance between B-8int and B+14con ٭P<0.05. Significance between B+14int and B-8con †P<0.05. Significance between B-8int and B-8con ‡P<0.05. §Significant between Max and Initial values (P<0.01)

Physical and physiological characteristics of the subjects and maximal exercise test results from study B are presented in Table 4. We found in warm environment and with continuous warm up (B+14con) that SaO2% was lower at the end of the maximal exercise test than before (P<0.01). No significant differences in SaO2% between different warm up modes and temperatures of the inhaled air were found. Therefore, we also consolidated and analyzed these results together to compare SaO2% between initial and final work load. A significant difference (P<0.0001) was then found; 97.2 ± 0, 4% at initial work load compared to 94.6 ± 0.7% at the final work load (Table 4, Figure 3). Every test prepared with intermittent warm up resulted in longer Tex compared to the continual warm up (P<0.05). When inhaling cold air, Tex was 14.8% longer (P<0.05) with intermittent compared to the continual warm up (Figure 4). VO2 max, VCO2 max, RER, VE max, HR max, [la-]b, FEV1 or FVC were not affected by different warm up modes or different temperatures of the inhaled air (Tables 4 - 5).



**Figure 3. SaO2% was significantly lower (P<0.0001) after the maximal exercise test (94.6 ± 0.4%) compared to the initial work (97.2 ± 0.7%). Solid horizontal line indicates mean difference and dashed lines 95% CI. Vertical line is mean of mean of pairs on the x-axis. The 45-degree tilted square shows the frame of the tilted scatterplot of the original columns.**



**Figure 4.** When inhaling cold air, time to exhaustion (Tex) was significantly longer (P<0.05) with intermittent compared to the continual warm up, indicated with bracket (B-8con versus B-8int). Boxes show median and 75% CI. Whiskers at 95% CI.



Figure 5. Difference in VO2 max (mL•min-1) between Warm (20ºC) and Cold (-12ºC) environment plotted against the mean of mean. Solid horizontal line indicates mean difference and dashed lines 95% CI. Vertical line is mean of mean of pairs on the x-axis. The 45-degree tilted square shows the frame of the tilted scatterplot of the original columns.



Figure 6. Difference in Time to exhaustion (Tex; sec) between Warm (20ºC) and Cold (-12ºC) environment plotted against the mean of mean.

Table 5. Forced vital capacity (FVC) and Forced expired ventilation in one second (FEV1) in liter (L) before (Pre) and after (post) the maximal exercise test in study B. Tests were made in room temperature (+13.9).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **N=8** | **Pre FVC (L)** | **Post FVC (L)** | **Pre FEV1 (L)** | **Post FEV1 (L)** |
| **B+14con** | 6.0 ± 0.81 | 6.4 ± 0.81 | 4.8 ± 0.43 | 5.2 ± 0.50 |
| **B+14int** | 6.2 ± 0.76 | 6.2 ± 0.88 | 4.9 ± 0.4 | 5.0 ± 0.59 |
| **B-8con** | 6.2 ± 0.82 | 6.4 ± 0.88 | 4.9 ± 0.47 | 5.1 ± 0.48 |
| **B-8int** | 6.3 ± 0.72 | 6.4 ± 0.82 | 4.9 ± 0.33 | 5.1 ± 0.43 |

# 

# DISCUSSION

The main findings in study A were that VO2 peak, VCO2 peak, RER and VE peak were significantly higher in the warm session (A+20) compared to the cold session (A-12) without changes in any of the other variables. The higher VO2 peak in the warm environment compared to the cold environment is in agreement with the study by Oksa et al. (21), but disagrees with the findings regarding VO2 max where it has reported to be unaffected (23,29,31) or increased (27) by cold environment. A variation in VO2 max with different forms of exercise has been reported in the literature as a reflection of the quantity of muscle mass activated (11). Thus, studies using treadmill tests (11,29,31) cannot be compared with bicycle tests as was done in the present study. Treadmill running increases the possibility of reaching absolute VO2 max compared to bicycling. Patton and Vogel (23) used a mechanically braked ergometer bicycle and found VO2 max unaffected by cold environment. One reason might be that they used 2 to 3 kg of arctic clothing in the cold that may have affected their results by increasing work resistance, thus increasing the chance of reaching VO2 max. Also, when wearing heavy clothing, cooling of the body will most likely not occur during the short exposure of a max test of 8 to12 min and the only cold exposure will be via the inhaled air. In study A, the subject used the same clothing during both at cold and warm sessions (except gloves). Some researchers (2,6,11) have reported that VO2sub is generally higher in the cold environment and the reasons might be multifactor (e.g., thermogenesis, higher contribution of the anaerobic glycolysis, larger fraction of fast-twitch fiber recruitment, and respiratory heat loss). The difference in VO2 between warm and cold environment decreases as workload increases. This leaves VO2 max largely unaffected, while VO2sub and VO2 peak may be decreased in the cold environment.

In general, stroke volume is lower when exercising in a warm climate because arterial blood will be distributed to the skin and, therefore, unable to deliver its oxygen to the active muscles (17). Warming up prior to the exercise tests in study A was carried out at room temperature during both A+20 and A-12 and the maximal exercise test lasted for 600 to 700 sec, and subjects were exposed for different environmental temperatures only for a short time because the test started immediately after entering the climatic chamber. An increase in core temperature is necessary to reach VO2 max (36). Unfortunately rectal temperature was not investigated in study A, and we can consequently not draw any conclusions regarding the effects of body temperature on physical performance or VO2 max. Because of the short cold exposure, core temperature is probably not affected by the climate but only by the exercise. Hence, it not likely that the higher VO2 max in A+20 compared to A-12 was related to a higher core temperature.

In study A, [la-]b was the same in A+20 and A-12. Lactate was analyzed immediately and 5 min after the exercise test. One limitation is that during cold exposure peripheral vasoconstriction in the fingertip may occur, lactate samples from the fingertip may therefore not be representative of the body as whole (11). Jett et al. (11) suggests that when investigating metabolism or substrate utilization, the influences of environmental conditions have to be controlled. Also, duration and intensity of cold exposure at rest and prior to exercise, the degree of acclimation of subjects to cold conditions and the clothing status of the subjects have to be standardized. In future studies, a standardized definition of cold is also important if the purpose is to compare performance and physiological variables in relation to performance in winter sports.

In study B, physical performance time, measured as time to exhaustion (Tex) was higher using an intermittent warm up compared to a continuous warm up when inhaling cold air (Figure 4). It is interesting, and for the cross country skiers important in a competition that performance (e.g., Tex) was affected by different warm up models when inhaling cold air. The intermittent warm up resulted in a better Tex in the incremental maximal performance test compared to the continuous warm up. The reason for this finding may be that the intermittent warm up model activates the anaerobic system by breaking down creatine phosphate, increasing creatine, inorganic phosphate, and adenosine diphosphate in the working muscle cells without accumulating lactic acid due to the brief rest periods between the high intensity bouts (37). The high intensity bouts may have also contributed to a creatine phosphate recovery over-shoot (8,34,35). Maximal oxygen consumption (VO2 max), VCO2 max, RER, VE max, HR max, [la-]b, FEV1 and FVC were not affected by different warm up modes or different temperatures of the inhaled air. We have not found that the effects of different warm up modes on physical performance in cold climate have been investigated earlier.

In study B, we found significantly lower SaO2% at the end compared to the beginning of the exercise performance test. That is in accordance with Holmberg et al. (2007) using diagonal skiing. In 15 of the total of 32 tests in study B, cross-country skiers EIAH was reached with a mean SaO2% of 94.6 ± 0.7% including all of the tests. In 10 of the cases, the subjects reached moderate EIAH (SaO2% between 88% and 93%), 3 cases reached mild EIAH (SaO2% between 93% to 95%), and in 2 cases severe EIAH (SaO2% < 88%) according to the definition of Dempsey and Wagner (4). Dempesy et al. (5), Rice et al. (29), and Guenette et al. (9) all found EIAH in subjects tested on running and biking. Using pulse oximetry during exercise testing has the advantage that it provides for a continuous reading of the data. The drawback is that the evaluation is indirect and might be sensitive to an exercise induced reduction in skin blood flow at the onset of exercise or cold environment. All earlier studies investigating SaO2% were conducted in warm environments. The authors’ explanation for the observed variations in saturation during maximal effort in endurance athletes is not clear. However, if the subjects’ experienced vasoconstriction in the skin, then, this factor may influence SaO2% and help to explain the different findings.

For endurance athletes, the pulmonary system is not as developed as the cardiovascular system, possibly contributing to inequalities in ventilation-perfusion ratio within the lungs, shunting of blood and/or diffusion limitations (17). In study B, only the breathed air differed in temperature and even if VO2 max was equal in all four sessions we actually do not know if VO2 max was affected by EIAH. In one study, VO2 decreased by 2% for each 1% decrease of SaO2, at least when arterial desaturation exceeds 95% (19). In the present study, a weak but significant correlation (R= 0.11, p=0.037) shows that each 1% decrease in EIAH increased VO2 max by 1.5%, indicating a larger O2 extraction with higher VO2 max. The correlation between aerobic capacity in warm and cold environment suggests that testing winter sport athletes (e.g., cross country skiers) at room temperature will give results correlated to performance in competition, just at a slightly different level. However, looking at the large deviations from the regression line VO2 max (Figure 5) and time to exhaustion (Figure 6), it becomes evident that there are significant individual differences. Thus, one subject tested at room temperature may or may not perform equally in cold climate and testing winter sport athletes at room temperature can therefore be misleading.

# CONCLUSIONS

We found that VO2 maxwas affected by different environmental temperatures, but not by different temperatures of the inhaled air. Peak oxygen consumption (VO2 peak), VCO2 peak, RER and VE peak during biking were significantly higher at a room temperatures of +20ºC compared to -12ºC. Another finding was that before maximal cross-country skiing, intermittent warm up increased physical performance without affecting VO2 max, irrespectively of the temperature of the inhaled air.

In cross-country ski racing, a high VO2 max is important for success. Based on data from this study, testing VO2 max in room temperature will result in higher VO2 max than can actually be reach when competing in cold environments. Due to the large individual differences in performance and VO2 max, results relevant for competition can only be measured in competition environment. An intermittent warm up model is recommended for the athletes and testing in competition settings suggested for researchers and coaches.

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