

THERMOREGULATORY RESPONSES IN CROSS-COUNTRY SKIERS

A FIELD STUDY

Mariann Sandsund¹, Øystein Wiggen¹, Hilde Færevik¹, Lars Karlöf², Randi E. Reinertsen¹

1) SINTEF Technology and Society, Trondheim, Norway

2) SWIX SPORT AS, Oslo, Norway

Contact person: Mariann.Sandsund@sintef.no

INTRODUCTION

Outdoors activities, such as cross-country skiing, may expose the human body to severe thermal stress during training and competitive events in the winter season. Cooling affects all aspects of muscular performance (1), and cold has a profound effect on the functional properties of skeletal muscle. When exercise intensity is high enough to maintain core temperature, but skin cooling is still present, a change in muscle temperature is also likely, and this may reduce mechanical efficiency and thus increase the total energy cost (2, 3). The physiological alterations from cold exposure may lead to earlier onset of fatigue, producing negative effects on endurance time to exhaustion (4, 5).

Low air resistance is important in many athletic events where speed is crucial (6), including cross-country skiing. This has led to clothing becoming thinner and more tight-fitting, such as the cross-country ski-suits used by competition skiers. Cold and windy ambient conditions can affect physical performance and result in impaired skiing performance (7). Few studies have measured thermoregulatory responses in cross-country skiers during training and competition.

The objective of this study was to investigate thermoregulatory responses in well-trained cross-country skiers wearing racing suits during a field study that simulated a 10 km cross-country skiing race. We hypothesised that exposure to cold and convective heat loss due to body movement would reduce the subjects skin temperatures, and predicted that the front surface of the body, which is exposed to the highest wind speeds, would have the greatest fall in temperature.

METHODS

Subjects. Eight healthy male cross-country skiers (age 26 ± 2 yr; height 181 ± 5 cm; weight 74 ± 5 kg) with a maximum oxygen uptake (VO_{2max}) of 71.8 ± 5.7 ml · kg⁻¹ · min⁻¹ volunteered for this study. The study was approved by the Regional Committee for Medical Research Ethics, Central Norway and the Norwegian Data Inspectorate.

Weather conditions. The field tests were performed in Norway on five different days in January to March 2009. On these days, the ambient temperature measured at the start/finish area of the race ranged between -3.2° C and -8.3° C, relative humidity was 50-75% and wind speed 0.2 - 3.4 m · s⁻¹.

Protocol. Before the simulated ski race the subjects met at the laboratory and were fitted with thermistors (YSI, Yellow Springs Instruments, $\pm 0.15^\circ\text{C}$) for measurements of rectal- and skin temperatures every second minute. Skin temperatures were measured at six sites (forehead, chest, back, upper arm, front and back thigh). Mean skin temperature (MST) was calculated according to Teichner et al (8).

The subjects dressed in clothing consisting of a long-armed pullover and long underwear trousers worn under a cross-country skiing suit, together with gloves and head gear. An extra pair of trousers and a jacket were worn during the warm-up period. The subjects brought their own shoes and skis.

They were then taken to the cross-country stadium where an individual warm-up period commenced immediately; this was followed by a 10 km ski race. Five subjects used the classic and three subjects the skating technique during the test. Individual variations in technique and performance meant that the time to finish ranged from 24 to 34 minutes. Heart rate (f_c) was measured continuously during the tests (Polar Electro OY, Kempele, Finland).

Before start, after the warming up period and at the end of the test, the subjects were asked to rate their subjective evaluation of thermal sensation on an 11-point scale (extremely cold to extremely hot)(9).

In order to determine the subjects' maximal oxygen uptake ($\text{VO}_{2\text{max}}$) and maximal heart rate ($f_{c\text{max}}$) a laboratory test consisting of running on a motor-driven treadmill (Woodway) at 6° (10.5%) uphill gradient was also performed. After a warm-up period a test was performed with stepwise increments in exercise intensity until the subject was exhausted and the $\text{VO}_{2\text{max}}$ was reached.

Data analysis. The time used on the simulated ski race differed among the participants. Most of the results are therefore presented as individual data using descriptive statistics. Mean values and standard deviations are presented for some group data. A paired t-test was used to compare the lowest individual skin temperatures during the race. In three subjects the rectal probes fell out during the ski race. Rectal temperatures are therefore presented for only five of the subjects.

RESULTS

The results for one subject showing all individual temperatures, MST and rectal temperature during the warm-up and the test period are presented in Figure 1. The same subjects' f_c is presented in Figure 2. During the laboratory test this subjects' $f_{c\text{max}}$ was measured at $206 \text{ beats} \cdot \text{min}^{-1}$, which means that the work load during the race was approximately 89%. For the whole group the exercise intensities represented $88 \pm 3\%$ (range 83-94%) of the subjects' $f_{c\text{max}}$.

During the warm-up period, when the subjects were wearing extra trousers and a jacket, the MST remained stable. During the tests, when they wore only the cross-country ski-suit the MST declined $6.3 \pm 2.0^\circ\text{C}$; from $28.3 \pm 1.2^\circ\text{C}$ at the end of the warm-up period to $22.1 \pm 1.9^\circ\text{C}$ at the end of the race. The lowest individual temperatures measured were on the forehead, front thigh and chest, while the highest temperatures were measured at the back and upper arm (Table 1). Significantly lower temperatures were measured on the chest and front of the thigh than on the back and back thigh, respectively.

The core temperature, measured as rectal temperature, rose with increasing exercise intensity, rising by 1.6°C from $37.1 \pm 0.2^{\circ}\text{C}$ at the start of the warm-up period to $38.7 \pm 0.3^{\circ}\text{C}$ at the end of the test (n=5).

Test persons subjective evaluations of thermal sensation of the body were neutral before the start of the warm-up and increased to slightly warm after the warming up period and close to warm at the end of the test.

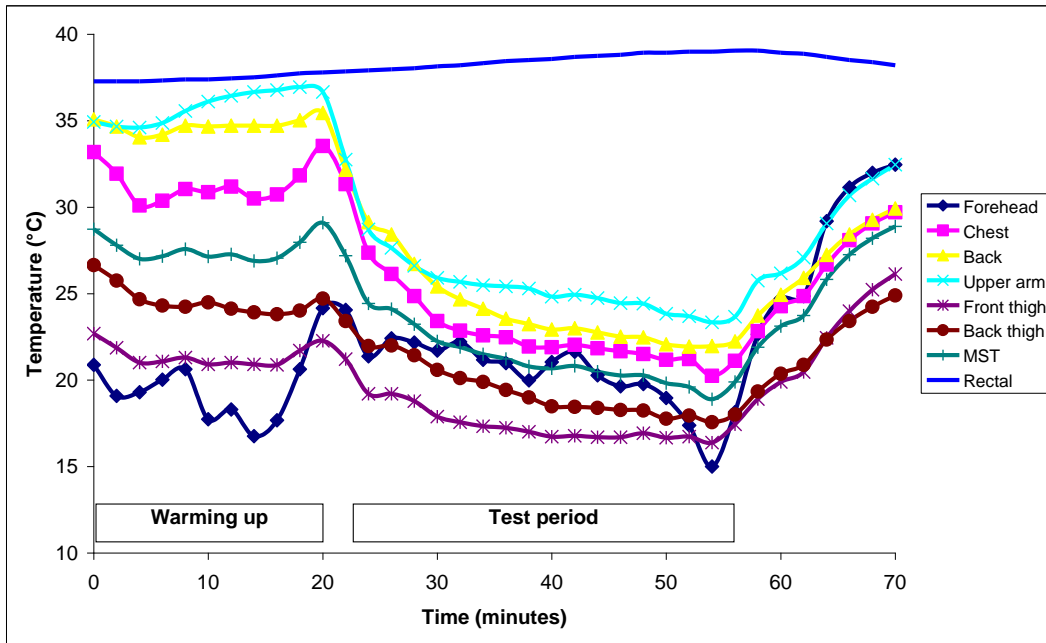


Figure 1. Rectal and skin temperatures for one subject during the warm-up and test periods. Ambient temperature at the start/finish area was -8.3°C .

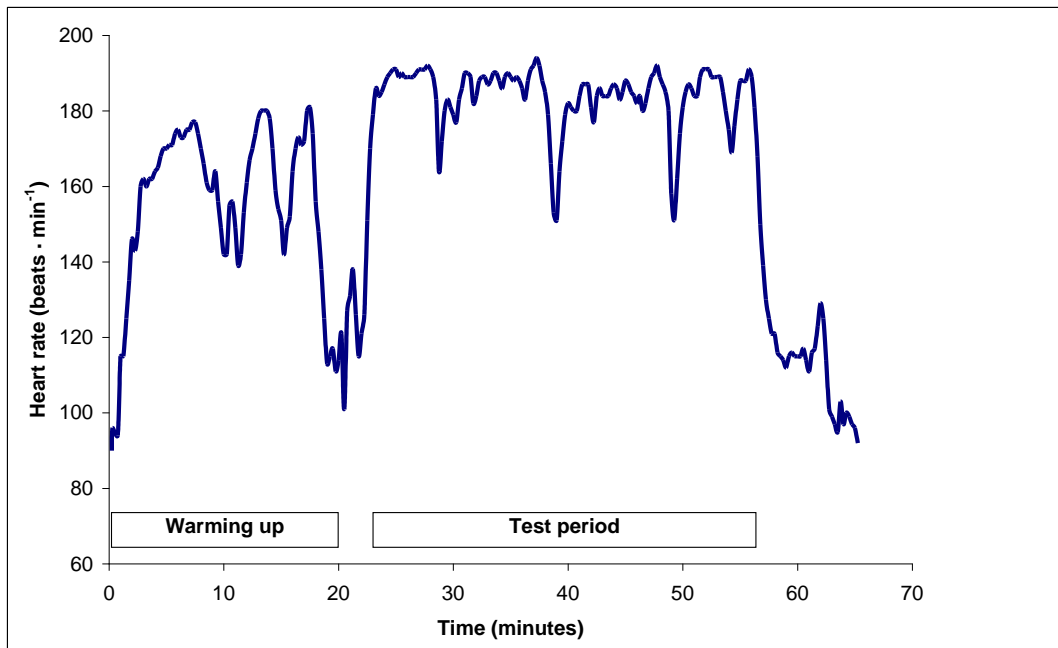


Figure 2. Heart rate shown for one subject (same subject as in Fig. 1) during the warm-up and test periods. Ambient temperature at the start/finish area was -8.3°C .

Table 1. Lowest skin temperatures measured in each subject during the test (n=8).

<i>Test subject</i>	<i>Forehead</i>	<i>Chest</i>	<i>Back</i>	<i>Upper arm</i>	<i>Front thigh</i>	<i>Back thigh</i>
1	18.6	23.7	24.7	21.2	18.3	20.7
2	18.7	21.3	29.3	24.3	21.2	21.6
3	15.0	20.2	21.9	23.3	16.4	17.6
4	21.6	17.3	24.7	25.8	22.5	24.1
5	13.4	20.9	24.5	25.0	18.8	20.8
6	20.2	22.4	22.5	25.9	21.4	24.3
7	20.0	19.9	26.9	25.9	22.1	23.6
8	17.4	19.4	21.0	20.5	18.3	20.0
Mean ±	18.1	20.6	24.4	24.0	19.9	21.6
SD	2.8	1.9	2.7	2.1	2.3	2.3

DISCUSSION

During the tests the subjects were working at a mean of 88% of their f_{cmax} which increased the heat production and caused a rise in the rectal temperature. Although core temperature rose, all skin temperatures fell. At two of the six skin sites the mean temperatures were lower than 20° C, with the lowest temperature measured on the forehead which in some subjects was partly uncovered during the ski race due to movement of the cap. However, all the skin temperatures were lower than those usually measured in a neutral state (28-32°C)(10). The significantly lower temperatures on the chest and front thigh compared with the back and back thigh reflect a considerable heat loss from the front surface of the body and a higher rate of convective heat loss due to the high racing speed. Low skin temperatures and a high core temperature produced subjective evaluations of the thermal state of the body that were closer to neutral than the low skin temperatures might have suggested.

It is well established that cooling affects muscular performance (1, 5), but to what extent performance deteriorates will vary, depending on the type, duration and intensity of cold exposure (11). This study of cross-country skiers wearing racing suits demonstrated that skin temperatures fell during the 24-34-minute exercise period. The MST in this study was also lower than that recorded in the study of Oksa et al. (12), which led to a deterioration of muscular performance. The least degree of cooling which is sufficient to degrade muscular performance has not been identified (1). However, it has been shown that relatively slight cooling may be sufficient to significantly decrease muscular performance and its components (12), and it has been suggested that skin cooling alone may be sufficient to cause a decrease in the force production of a muscle (13). Other studies have shown that time to exhaustion is affected by ambient temperature, and was significantly shorter in subjects exercising on a bicycle at -20 than at 20° C (11). Running on a treadmill at -15° C also reduced time to exhaustion compared to 23°C in cross-country skiers (5).

Aerobic performance at various ambient temperatures has also been studied by several authors. An optimal range of temperatures of 3-11°C for moderate-intensity exercise has been reported (14, 15). However, none of these studies involved cross-country skiers operating at high intensity and wearing cross-country ski-suits.

CONCLUSIONS

This study demonstrated that cold exposure (-3 to -8°C) reduced skin temperature during a simulated cross-country skiing race in spite of increased heat production. The clothing used did not prevent skin cooling, especially on the front of the body, which was particularly exposed to cold and wind because of the high speeds involved during the race. The cross-country ski-race suit should be improved in order to provide sufficient thermal protection during competition in a cold environment. Further investigations must also focus on limiting values for cold and wind exposure, related to physical performance in cross-country skiers.

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