COLD-INDUCED ADAPTATIONS FOLLOWING A 225 km SCIENTIFIC EXPEDITION IN ARCTIC CONDITIONS

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INTRODUCTION

Research in cold physiology usually focuses on physiological responses of healthy normal subjects exposed to a single stressor (cold temperature) during short term controlled studies. In order to better understand responses to long term exposure to cold in the field (i.e., that may be encountered by adventurers, explorers, military personnel, or any workers in a cold environment) long term field measurements are required under conditions where various other stressors such as malnourishment, dehydration, sleep deprivation, exhaustion and injuries (which can affect normal physiological responses to thermal extremes) may also occur. Continuous long term measurement of basic thermal parameters in field conditions is still an unresolved problem. For example, measurement of heart rate and core or skin temperature may be simple for a few hours in a laboratory setting, but difficult during a field trial of several weeks in a cold climate.

Two male subjects participated in a mid-winter 14 day (225 km) north-south unsupported ski trek on Lake Winnipeg (Canada). The scientific expedition had 3 main research components. First, local (finger and hand) and whole body cold response tests were conducted before and after the expedition. These tests were designed to document adaptation to intense short term cold exposure in terms of resistance to frostbite and hypothermia and recovery following cold exposure.

Second, portable data loggers were carried to make continuous measurements of heart rate (to estimate work intensity), skin and core temperatures. We are not aware of previous attempts to make similar measurements for an extended period in such harsh conditions. Third, various methods of estimation of energy expenditure were tested and compared. Full body composition analysis (done before and after the trip) combined with accurate dietary analysis provided one method of estimation of energy intake and output. Continuous heart rate data were also used to estimate energy output based on the heart rate to oxygen uptake relationship. Finally, isotope labeled water (deuterium, oxygen-18) was ingested during the trip. Isotope analysis of daily urine samples provided a third estimate of energy expenditure. Data for the latter two research components of the expedition will be discussed elsewhere.

METHODS

The two male participants were 36 and 38 yrs old, 185 and 183 cm tall, weighed 78.2 and 79.8 kg and had maximal oxygen consumption ($\dot{V}_{O2max}$) values of 47.7 and 43.2 $ml \cdot kg^{-1} \cdot min^{-1}$. The protocol was approved by institutional ethics committees and the participants gave informed consent. The study was divided into three segments: pre-expedition testing (3 days), traverse phase (14 days) and post-expedition testing (3 days). Anthropometric characteristics, aerobic capacity and physiological responses to the following standard cold tests were determined before and after the expedition

Systemic Cold Test (whole body cooling;). The objective of this test was to determine if the two weeks of cold exposure experienced during the traverse induced a systemic cold adaptation. In each test the subject rested nude (wearing only shorts and socks) for 2 h at an ambient temperature (T_a) of 10°C. Average skin temperature ($\overline{T}_{skin}$) and heat flows were determined from heat flux transducers (Concept Engineering) at 12 body sites. Rectal temperature (T_{re}), esophageal temperature (T_{es}), $\dot{V}_{O2}$ (measured with an open circuit technique) and heart rate were continuously measured. Following the cold stress the subject was rewarmed in water (39°C) until core temperature reached normal values (≥ 36.8°C).

Two local cooling tests of the isolated finger *(Frostbite Susceptibility Test)* and whole hand *(Cold Recovery Test)* were used to investigate if the two weeks of cold exposure induced a local cold adaptation of the hands. For each test, skin temperature was measured continuously on the ventral side of the tip of the middle finger with a fine gauge type-T thermocouple, and a thin latex glove was worn to waterproof the immersed finger and/or hand. T_{es} was also measured. At the beginning of both tests subjects, clothed in shirt and pants, rested in thermoneutral conditions (T_a=25°C, 40% relative humidity) for 60 min. First, the *Frostbite Susceptibility Test* consisted of immersing the 3 phalanxes of the middle finger of one hand in 5°C water for 30 min. A frostbite susceptibility index was then calculated (1). Second, the *Cold Recovery Test* consisted of immersing the other hand entirely in 10°C water for 30 min. Measurements were then taken during the 30 min recovery period. This test provides information on how the extremities are able to recover following a cold stress.

Since only two participants were studied no statistical analysis, other than the calculation of mean values over time, were performed.

RESULTS

General. During the 14 day trek, the mean ambient temperature was -32.5°C (night time lows ranging from -34 to -44°C, daytime highs ranging from -21 to -36.5°C, and windchill factors ranging from -31 to -64°C). The cold and windy environment, combined with the desolate terrain of rugged ice on the lake (which was 80 km wide at the widest point and 450 km long) provided a realistic simulation of travel conditions in arctic regions. The two subjects (**A** and B respectively) decreased % body fat by 4 and 3.9 %, lost 3.4 and 3.0 kg of fat mass, and lost 2.2 kg or gained 0.8 kg total body mass (Table 1).

Table 1. Subject characteristics and responses to 14 day trek.

	Subject **A**			Subject B		
	Pre	Post	Δ(%)	Pre	Post	Δ(%)
Wt (kg)	78.2	76.0	-3	79.8	80.6	+1
Body fat (%)	19.1	15.1	-21	15.7	11.8	-25
Body fat mass (kg)	14.9	11.5	-23	12.5	9.5	-24
Skinfold thickness 8 sites (mm)	143.6	107.2	-25	139.5	106.1	-24

Systemic Cold Test (whole body cooling;). Due to technical difficulties, this test was only performed by subject **A.** Following the expedition (post-expedition) $\bar{T}_{skin}$ was 0.9°C higher (32.8 vs 31.9°C) during rest at a T_a of 22°C. During the 2 h of cold exposure (T_a=10°C) however, $\bar{T}_{skin}$ was consistently lower (≈22 vs 23.3°C). There was a corresponding decrease in post-expedition $\dot{V}O_2$ (700 vs 880 ml·min^{-1}) and T_{es} (37.2 vs 37.5°C). These results are consistent with an insulative adaptation to the cold stress.

Cold Recovery Test (hand cooling;). Subject **A** had a lower finger temperature during rest under thermoneutral conditions. During the **30** min of recovery from cooling the whole hand in 10°C water, there were no post-expedition improvements in rewarming as finger tip temperatures rose from 10 to 23°C. However, the remainder of rewarming from 23 to 33°C was much slower in the post-expedition trial. These results provide further evidence of insulative adaptation. Note, the finger used for this test had not sustained significant cold injury (see below). Subject B demonstrated an immediate post-expedition improvement of recovery as finger temperatures in the post-expedition trial were 4-5°C warmer throughout recovery until reaching 32°C after ≈13 min of rewarming.

Frostbite Susceptibility Test (finger cooling). The finger used for temperature measurements on subject **A** had sustained 2° frostbite at the tip, Skin temperature (measured just proximal to the injured finger tip) was again lower during baseline measurements (27°C post-expedition vs 29°C). Following the expedition, a longer period of finger cooling (14 min post-expedition vs 7.5 min) was required before cold induced vasodilation (CIVD) occurred and the amplitude of skin warming during CIVD was less (5.5 to 7.5°C post-expedition vs 6.0 to 11.0°C). The frostbite susceptibility index increased from average *(5)* before the expedition to high (3) after the expedition. Results for subject B however, indicate an adaptation to decreased frost-bite susceptibility [the rating increased from average (6) to low (8) after the expedition]. Following the expedition CIVD occurred sooner (4 vs 8 min) and at a higher finger tip temperature (8.5 vs 6.5°C), with similar maximum temperatures (12.5 vs 13.0°C) attained.

CONCLUSIONS

This study demonstrates that adaptations to cold responses can occur in as little as 2 weeks of travel in extreme cold. Our observations of an insulative adaptation to whole body cooling with metabolic savings at the expense of lower core temperature, are in agreement with other studies (2). In a non cold-injured finger, a protective adaptation occurred with earlier CIVD during cold exposure and more rapid rewarming after cooling. In a cold-injured finger however, the CIVD response during cooling is delayed and there is no improvement in post-cooling recovery (even when measurements were made in non-injured areas of that finger).

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