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In Shackleton's trails: Central and local thermoadaptive modifications to cold and hypoxia after a man-hauling expedition on the Antarctic Plateau

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A B S T R A C T

Cold and hypoxia constitute the main environmental stressors encountered on the Antarctic Plateau. Hence, we examined whether central and/or peripheral acclimatisation to the combined stressors of cold and hypoxia would be developed in four men following an 11-day man-hauling expedition on this polar region. Before and after the journey, participants performed a static whole-body immersion in 21 °C water, during which they were breathing a hypoxic gas (partial pressure of inspired O_2: ~97 mmHg). To evaluate their local responses to cold, participants also immersed the hand into 8 °C water for 30 min, while they were whole-body immersed and mildly hypothermic [i.e. 0.5 °C fall in rectal temperature (T_{rec}) from individual pre-immersion values]. T_{rec} and skin temperature (T_{sk}), skin blood flux, and oxygen uptake (reflecting shivering thermogenesis) were monitored throughout. The polar expedition accelerated by ~14 min the drop in T_{rec} [final mean (95% confidence interval) changes in T_{rec}: Before = −0.94 (0.15) °C, After: − 1.17 (0.23) °C]. The shivering onset threshold [Before: 19 (22) min, After: 25 (19) min] and gain [Before: − 4.19 (3.95) mL min^{-1} kg^{-1}, After: − 1.70 (1.21) mL min^{-1} kg^{-1}] were suppressed by the expedition. T_{sk} did not differ between trials. The development of a greater post-expedition hypothermic state did not compromise finger circulation during the hand-cooling phase. Present findings indicate therefore that a hypothermic pattern of cold acclimatisation, as investigated in hypoxia, was developed following a short-term expedition on the South Polar Plateau; an adaptive response that is characterised mainly by suppressed shivering thermogenesis, and partly by blunted cutaneous vasoconstriction.

1. Introduction

Antarctica, the southernmost continent permanently covered with ice and snow, constitutes by far the coldest, and probably the most hostile area on the Earth surface. From the "*heroic era*" of Antarctic exploration of man's early attempts to venture inland to today's sojourners in scientific research stations placed across the continent, extensive human-based research has been conducted, suggesting that physiological adaptation to the extreme climate may occur (for review, see Wilson, 1965). Particularly in temperate residents, a hypothermic pattern of cold acclimatisation/habituation has often been detected, characterised by blunted shivering thermogenesis and cutaneous vasoconstriction, and ameliorated thermal discomfort (Budd, 1962; Butson, 1949; Goldsmith, 1960; Massey, 1959; Milan et al., 1961; Naidu and Sachdeva, 1993; Rintamaki et al., 1993; Wyndham et al., 1964).

During an arduous sledge journey into Antarctica however, aside from the extremely low ambient temperatures, a number of other environmental (i.e. wind chill, solar radiation, low humidity) and behavioral (i.e. physical and mental fatigue, sleep deprivation, malnutrition, dehydration) stressors are typically encountered (cf. Halsey and Stroud, 2012; Wilson, 1965). Such stressors may, independently and/or interactively, contribute to the adaptive responses. In particular, the Polar Plateau, which includes the Geographical South Pole, is located at an average elevation of ~3000 m above sea level (highest elevation 4093 m). The hypoxia encountered at such altitudes may constitute an independent stressor capable of modifying acute (cf. Cipriano and Goldman, 1975; Hemingway and Birzis, 1956; Johnston et al., 1996; Keramidas et al., 2014) and adaptive physiological adjustments to cold (cf. Blatteis and Lutherer, 1976; Keramidas et al., 2015a; Launay et al., 2006; Mathew et al., 1979; Savourey et al., 1997). Thus, following short-term residence at high altitude, metabolic heat production (Savourey et al., 1997) and shivering activity (Blatteis and Lutherer, 1976; Mathew et al., 1979) seem to be attenuated during whole-body cold-air stress. Indications of altitude-induced haematological acclimatisation have been reported following short- and long-term sojourns on the Antarctic Plateau (Guenter et al., 1970; Tikhomirov, 1973); yet, to our knowledge, no study has hitherto examined the

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thermoadaptive modifications to the specific conditions of this polar region, which includes both cold and hypoxia.

Accordingly, we sought to determine whether, and to what extent, central and/or local cold acclimatisation to a hypoxia-specific condition would be developed in a group of male lowlanders following an 11-day man-hauling expedition on the South Polar Plateau. To address this purpose, four expedition members underwent, pre and post journey, a static whole-body cold-water immersion, during which they were breathing a hypoxic gas mixture. In view of the recurring evidence that peripheral vasomotor reactions to cold are largely dependent on the whole-body thermal state (cf. Daanen et al., 1997; Flouris and Cheung, 2009; Keatinge, 1957; Werner, 1977), we also examined the effects of the polar journey on the finger cold-induced vasodilatation (CIVD) response during local cooling, while participants remained whole-body immersed and mildly hypothermic. We hypothesised that a hypothermic mode of acclimatisation/habituation, characterised by blunted shivering thermogenesis and cutaneous vasoconstriction, would appear during whole-body cooling. Moreover, based on results from short-term acclimatisation regimens to sustained cold (Naidu and Sachdeva, 1993; Purkayastha et al., 1993, 1992) and/or hypoxia (Felicijan et al., 2008; Keramidas et al., 2015a; Mathew et al., 1977), in which some levels of physical activity were performed, we anticipated that an enhanced finger CIVD reaction would prevail during hand cooling.

2. Materials and methods

2.1. Ethics approval

The experimental protocol was approved by the Humans Ethics Committee of Stockholm (2016/2328-31) and conformed to the standards set by the *Declaration of Helsinki*. Participants were informed in detail about the experimental procedures and gave their written consent.

2.2. Subjects

Four healthy, right-handed men [mean (range) age: 42 (18 − 52) years, height: 184 (179 − 188) cm] volunteered to participate in the study. They were nonsmokers, and had no history of any cardiovascular or pulmonary disease. All participants were lowlanders [three resided in Stockholm (altitude ~28 m), and one in Geneva (altitude ~375 m)], and had not sojourned at altitudes > 2000 m during the month preceding the study. They performed regular endurance exercise training (i.e. running, skiing), and were aerobically fit. Participants did not undergo any specific cold acclimatisation protocol prior to the journey, and had no previous experience with cold exposure experiments. Abstinence from caffeine, alcohol and exercise was requested for the 12 h preceding the experimental trials.

2.3. Study outline

All experimental trials were performed at the laboratory of the Department of Environmental Physiology, Royal Institute of Technology (Solna, Sweden). The pre-expedition trials were conducted 15–19 days before the journey to Antarctica. The post-expedition trials were carried-out two days after their return (R + 2) for two of the four participants, on R + 3 for one, and on R + 10 for the other. All trials were completed between December 2016 and January 2017. Testing was conducted by the same investigators, and at the same time of the day to ensure that the effect of diurnal variation was similar. The mean (standard deviation) ambient temperature, relative humidity and barometric pressure in the laboratory was 27.3 (0.2) °C, 34 (6)% and 770 (2) mmHg.

Prior to the whole-body immersion, participants were accustomed to the laboratory for ~30 min, while anthropometrical measures and instrumentation were conducted. Participants were dressed in swim pants. Each trial commenced with a 20-min baseline phase, during which they were lying supine on a gurney placed next to the water-tank. Aside from the first 10 min of the baseline phase, while they were breathing normoxic gas [fraction of O_2 (FO_2): 0.21; partial pressure of inspired O_2 (P_IO_2) corrected to body temperature and pressure saturated (BTPS): ~150 mmHg], participants were breathing a hypoxic gas mixture [FO_2: 0.135; P_IO_2: ~97 mmHg, BTPS; simulated altitude of ~3500 m] throughout the trial. Following the baseline phase, participants entered directly in the water-tank maintained at 21 °C temperature, and assumed a semi-reclined position within a few seconds. They were immersed to the level of the manubrium sterni; both arms were supported at the level of the heart above the water surface. They passively rested in this position until their rectal temperature (T_{rec}) dropped by 0.5 °C below individual baseline value (B-CWI phase). Subsequently, the right hand was covered with a thin plastic bag (thickness of 0.025 mm) and was immersed up to ulnar and radial styloids for 30 min (H-CWI phase) in a different water tank filled with 8 °C water. After the completion of the H-CWI phase, the hand was removed from the water, dried with a towel, if necessary, and a 15-min spontaneous hand-rewarming period ensued, while participants remained immersed in the tank and their hands were resting on the arm-support as in the B-CWI phase. The immersion was terminated earlier, in case the T_{rec} dropped by 2 °C from the baseline, or below 35 °C. After the immersion, participants were removed from the water-tank, placed supine in a well-insulated sleeping bag and monitored for a further 30-min whole-body rewarming period.

2.3.1. Polar expedition

The full expedition team consisted of 6 male members. After an overnight stay at the Union Glacier Camp (Ellsworth Mountains), they flew to the Polar Plateau (latitude: 88° 23´ S, longitude: 80° 03´ W; elevation ~2700 m above sea level). They man-hauled 189 km (~20 km day^{-1}) and reached the Geographic South Pole after 11 days. Each member pulled a fully loaded sledge (~70 kg at the beginning), and wore special lightweight insulated clothing. They slept ~8 h day^{-1} in nylon tents. They consumed ~6000 kcal day^{-1}, consisting of ~60% carbohydrates, ~25% fat and ~15% proteins; and drunk water from melted ice ad libitum. The highest recorded ambient temperature was − 20 °C and the lowest − 38 °C (mean recorded ambient temperature: − 27 °C). During the journey, participants' right-hand forearm and index finger skin-temperature, as monitored intermittently with thermistors and portable loggers (Talk 2, Tinytag, Gemini Data Loggers Ltd, Chichester, UK), ranged from 21.7 °C to 35.8 °C (mean: 29.5 °C) and from 12.0 °C to 34.6 °C (mean: 24.7 °C), respectively. The recorded altitude was ~2800 m above sea level (Ambit 3 Peak, Suunto, Vantaa, Finland), but the "*effective altitude*" was presumably considerably higher (i.e. lower P_IO_2, corresponding to ~3300 m; see West, 2001). Participants generally experienced thermal discomfort and physical exhaustion; none of them, however, suffered from hypothermia or frostbite. One of them presented symptoms of acute mountain sickness (i.e. headache, nausea, tiredness) during the first day at the Plateau, but he fully recovered thereafter and completed the journey.

2.4. Instrumentation

Body mass (accuracy 0.01 kg) was recorded with an electronic scale (Vetek, Väddö, Sweden). Body surface area (A_D) was derived from measures of body mass and height (Du Bois and Du Bois, 1916). Skinfold thicknesses were measured with a skinfold caliper (Harpenden, UK) at seven right-side locations: triceps, subscapular, chest, suprailiac, abdominal, front thigh, and midaxillary. Percent body fat was calculated according to the equation of Jackson and Pollock (1978).

Throughout the trials, subjects breathed through a low-resistance two-way respiratory valve (Model 2, 700 T-Shape; Hans Rudolph, Inc., Shawnee, OK, USA). The inspiratory side of the valve was connected via