HUMAN TEMPERATURE REGULATION DURING ARTERIAL HYPERCAPNIA INDUCED BY INHALATION OF 4% CO_2

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INTRODUCTION

Carbon dioxide concentrations may be elevated in diving operations. Hypercapnia may affect basic thermoregulatory responses and predispose divers to hypothermia. Early animal studies have shown that inhalation of gas mixtures containing 3 to 10% CO_2 during cold exposure impairs thermal homeostasis by attenuating shivering and promoting heat loss through peripheral vasodilation (Stupfel 1974). The effects of hypercapnia in humans under similar conditions are less clear. Inhalation of 2.5 to 4% CO_2 mixtures have been reported to transiently suppress shivering without affecting core temperature (T_{co}) cooling rate (Bullard and Crise 1961, Lun *et al.* 1994), to increase cooling rate without affecting shivering (Wagner *et al.* 1983) or to have no significant effect on either shivering or core cooling (Lun *et al.* 1993). There are several limitations to previous work on the effects of hypercapnia on human thermoregulation. In addition to inconsistent results during cold stress, little is known about the thermoregulatory effects of hypercapnia during heat challenge. Also, the effects of hypercapnia on warm and cold response thresholds are unknown. Therefore, this study was performed to determine the effects of hypercapnia on core temperature thresholds for warm and cold thermoregulatory responses as well as the rate of core cooling during mild cold stress.

METHODS

In eight volunteers (6 male, 2 female), the protocol of Mekjavic *et al.* was used to determine the T_{co} thresholds for sweating, peripheral vasoconsmction and shivering, following exercise in 28°C water. Subjects ranged in age from 22 to 35 years (mean ± SD, 26.8 ± 4.5), in height from 1.59 to 1.82 m (1.75 ± 0.85) and in weight from 48 to 80 kg (68.2 ± 10.2). Esophageal temperature was used as an indicator of T_{co}. Subjects performed two randomly ordered trials each on separate days. During the control mal, the inspirate was humidified room air. For the hypercapnia trial, subjects inspired a humidified gas mixture of 4% CO_2/ 20.9% O_2/balance N_2. They were immersed to the clavicles in 28°C water, thus clamping skin temperature throughout the trial. They then performed underwater cycle exercise (50% maximum workload) for 25 minutes to elevate T_{co} and induce sweating. Subjects then cooled passively until shivering occurred. During cooling, the T_{co} cooling rate and the T_{co} thresholds for the following three thermoregulatory responses were determined. Sweating threshold was defined as the T_{co} when sweat rate (measured by a ventilated capsule on the forehead) fell to 50 $g/m^2/h$. The vasoconsmction threshold was defined as the T_{co} when fingertip blood flow (measured by a pulse oximeter based perfusion index) decreased substantially from baseline values. The shivering threshold was indicated by a sustained increase in VO_2. Core temperature thresholds for each response were reported relative to preimmersion baseline values. Paired t-tests were used to test for significant differences between conditions.

RESULTS

Hypercapnia lowered the T_{co} threshold for shivering from (mean ± SD) -0.35 ± 0.3 to -0.48 ± 0.4 °C ($P<0.05$), and significantly increased the post-exercise T_{co} cooling rate from 1.39 ± 0.9 to 1.74 ± 0.8 °C/hr ($P<0.05$). Hypercapnia had no effect on the T_{co} thresholds for sweating or vasoconsmction. The size of both the interthreshold range (range in T_{co} between sweating and vasoconstriction thresholds) and the thermoregulatory null zone (range between sweating and shivering thresholds) were also unaffected.

CONCLUSIONS

This study indicates that under conditions of mild cold exposure (immersion in 28°C water), hypercapnia decreases the threshold for shivering thermogenesis. This may be consistent with the transient inhibition of shivering during acute hypercapnia (Bullard and Crise 1961, Lun *et al.* 1994). The decrease in the shivering threshold may partly account for the greater T_{co} cooling rate during hypercapnia.

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