HUMAN TEMPERATURE REGULATION DURING EUCAPNIC HYPOXIA

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INTRODUCTION

At altitude decreased inspired P_{O2} results in arterial hypoxemia. It is well known that hypoxemia alters the basic thermoregulatory responses to cold challenge. In animals, hypoxemia delays the onset of shivering (1), decreases the maximal shivering response (2-4) and inhibits nonshivering thermogenesis (3). Hypoxemia is also associated with increased core temperature (T_{co}) cooling in conscious cats (2). In humans, hypoxemia elicits peripheral vasodilation (with consequent increases in skin temperature and surface heat loss) and inhibits heat production (5, 6). The effects of hypoxemia on total heat balance are not so clear. Core temperature has been demonstrated to either remain constant (6) or decrease (5, 7) during hypoxic cold exposure. There are several limitations to previous work on the effects of hypoxia on human thermoregulation. First, the hypoxic stimulus has not been isolated from that of arterial hypocapnia subsequent to hypoxic hyperventilation. Second, little is known of the thermoregulatory effects of hypoxia during heat challenge. Therefore this study was performed to determine the effects of eucapnic hypoxia on T_{co} thresholds for warm and cold thermoregulatory responses as well as the rate of core cooling during mild cold stress.

METHOD

In eight subjects, we used the protocol of Mekjavic *et al.* (8) to determine the T_{co} thresholds for sweating, peripheral vasoconstriction and shivering, following exercise in 28°C water. Esophageal temperature was used as an indicator of T_{co}. Subjects 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 occured. 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 vasoconstriction 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. Subjects performed two randomly ordered trials each on separate days. During the control trial, the inspirate was humidified room air. For the eucapnic hypoxia trial, subjects inspired a humidified gas mixture (12% O_2/balance N_2) with C02 added to the inspirate to maintain the end-tidal CO_2 concentration at baseline levels. Paired t-tests were used to test for significant differences between conditions.

RESULTS

Eucapnic hypoxia lowered the T_{co} thresholds for shivering by (mean±SE) 0.19 ± 0.04°C ($P<.0.05$), and vasoconstriction by 0.14 ± 0.07°C ($P<0.05$), but had no significant effect on the T_{co} threshold for sweating (Table 1). Eucapnic hypoxia increased the post-exercise T_{co} cooling rate by 0.45 ± 0.18°C/hr ($P<0.05$) (Table 1). The sizes 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 unchanged by eucapnic hypoxia.

Table 1. Effect of eucapnic hypoxia on human thermoregulation (*, P<0.05).

		Baseline Tes	Sweating Threshold	Vasocon-smction Threshold	Shivering Threshold	Null Zone Size	Tes Cooling Rate
CONTROL	Mean	37.01	0.21	0.18	-0.44	0.64	-1.38
	SD	0.25	0.12	0.21	0.28	0.22	0.85
HYPOXIA	Mean	37.11	0.05	-0.05	-0.62	0.67	-1.83
	SD	0.15	0.33	0.30	0.25	0.20	0.72
A (Control	Mean	-0.11	0.16	0.14	0.19	-0.02	0.45
-Hypoxia)	SE	0.09	0.10	0.07	0.04	0.12	0.18
	t	-1.17	1.62	**2.08***	**5.08***	-0.19	**2.54***

CONCLUSIONS

Eucapnic hypoxia significantly decreased the thresholds for cold thermoregulatory responses. Although the absolute decreases in thermoregulatory thresholds were small (0.14 and 0.19°C for vasoconstriction and shivering respectively), the core cooling rate increased by ~33%. These data are consistent with previous work in animals and humans which demonstrated that hypoxia promotes cutaneous vasodilation (6, 7) and reduces cold-induced shivering (4, 9). The quantitatively small effect of eucapnic hypoxia on thermoregulatory thresholds is not surprising. Gautier *et al.* (2, 3) demonstrated a large inhibition of shivering during hypocapnic hypoxia in cats. This effect was reversed by restoring end-tidal C02 concentrations to normal. It is possible that hypocapnic hypoxia (which would be experienced at altitude) would produce an even greater effect on thermoregulatory control and core temperature cooling rate in humans.

REFERENCES

1. Blatteis C.M. and Lutherer L.O. 1973, Cold-induced thermogenesis in dogs: it's reduction by moderate hypoxia, ***J. Appl.*** *Physiol.* 35(5), 608-612.

2. Gautier H., Bonora M., Schultz S.A. and Remmers J.E. 1987, Hypoxia-induced changes in shivering and body temperature, ***J. Appl.*** *Physiol.* 62(6), 2477-2484.

3. Gautier H., Bonora M. and Remmers J.E. 1989, Effects of hypoxia on metabolic rate of conscious adult cats during cold exposure, ***J. Appl.*** *Physiol.* 67(1), 32-38.

4. Giesbrecht G.G., Fewell J.E., Megirian D., Brant R. and Remmers J.E. 1994, Effects of hypoxia on thermoregulatory responses to isolated cutaneous and body core cold stimuli in conscious rats, ***J. Appl.*** *Physiol.* in press.

5. Cipriano L. and Goldman R.F. 1975, Thermal responses of unclothed men exposed to both cold temperatures and high altitudes, ***J. Appl.*** *Physiol.* 39(5), 796-800.

6. Blatteis C.M. and Lutherer L.O. 1976, Effect of altitude exposure on thermoregulatory response of man to the cold, *J.* ***Appl.*** *Physiol.* 41(6), 848-858.

7. Robinson K.A. and Haymes E.M. 1990, Metabolic effects of exposure to hypoxia plus cold at rest and during exercise in humans, ***J. Appl.*** *Physiol.* 68(2), 720-725.

8. Mekjavic I.B., Sundberg C.J. and Linnarsson D. 1991, Core temperature "null zone", *J.* ***Appl.*** *Physiol.* 71(4), 1289-1295.

9. Kottke F.J., Phalen J.S., Taylor C.B., Visscher M.B., Evans G.T. Effect of hypoxia upon temperature regulation of mice, dogs and man. ***Am.*** *J. Physiol.* 153, 10-15.

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