HUMAN TEMPERATURE REGULATION DURING ARTERIAL HYPERCAPNIA
INDUCED BY INHALATION OF 4% CO₂

Chad E. Johnston, Matthew D. White, Mingpu Wu,
Dwayne A. Elias and Gordon G. Giesbrecht

Laboratory for Exercise and Environmental Medicine
Health, Leisure and Human Performance Research Institute
University of Manitoba, Winnipeg, Manitoba, CANADA, R3T 2N2

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% CO₂ 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% CO₂ 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 vasoconstriction 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 trial, the
inspirate was humidified room air. For the hypercapnia trial, subjects inspired a humidified gas mixture of
4% CO2/20.9% O2/balance N2. 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/m²/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 VO₂. 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 vasoconstriction. 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.
REFERENCES


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