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Perception of thermal comfort during narcosis

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Mekjavić IB, Passias T, Sundberg CJ, Eiken O. Perception of thermal comfort during narcosis. Undersea & Hyperbaric Med 1994; 21(1):9–19.—We examined the perception of thermal comfort in six male subjects immersed in water at 28°C (study I) and 15°C (study II), breathing either room air (AIR) or a normoxic mixture containing 30% N_2O (N_2O). Immersions were terminated if esophageal temperature (T_{es}) decreased by 2°C from resting levels or to 35°C. At regular intervals, subjects rated their perception of thermal comfort on a 21-point scale (thermal comfort vote, TCV; +10 = very, very hot, 0 = neutral, -10 = very, very cold). For similar decreases in T_{es} from resting preimmersion values (mean ± SD = −0.90° ± 0.13°C and −0.92° ± 0.15°C during the AIR and N_2O trials in study I, and −0.90° ± 0.22°C and −0.89° ± 0.27°C during the AIR and N_2O trials in study II), subjects perceived the immersions as less cold during the N_2O trials. The median TCVs for the AIR condition of −5 in study I and −7.75 in study II, were significantly lower than those reported by the subjects for the respective N_2O conditions (−1.75 in study I and −5.5 in study II). It is concluded that behavioral adjustments required for maintaining thermal balance may be diminished during narcosis due to the altered perception of thermal discomfort. Assuming that the effect of inert gas narcosis on thermoregulatory responses is similar to that of N_2O, then combined with the significant attenuation of heat gain mechanisms by anesthetic gases, the attenuation of the perception of thermal comfort may represent a significant factor in the etiology of hypothermia observed in compressed air divers.

temperature regulation, thermal comfort/discomfort, thermal pleasure/displeasure, cold water immersion, hypothermia, diving

In light of evidence that hyperbaric nitrogen attenuates behavioral thermoregulation in mice, and that this effect is also observed with subanesthetic doses of nitrous oxide (1, 2), a similar effect of inert gas narcosis on divers exposed to compressed-air environments cannot be excluded. In high heat-loss environments, appropriate behavior may maintain internal body temperature stable, but if such responses are not initiated in a hyperbaric environment, this may precipitate the development of hypothermia.

Under normal conditions, core temperature may fluctuate by 0.7°C without initiating the responses of shivering and sweating (3). This range of core temperatures, absent of shivering and sweating, has been defined as the null zone (3). During narcosis induced with inhalation of 30% N_2O, the null zone is widened (4) suggesting a loss of "fine" regulation of core temperature. The widening of the null zone arises from a shift of the core threshold temperature for shivering to lower values, whereas the core threshold temperature for sweating remains unaltered. The only responses available to counteract decreases of skin and core temperatures, while the core temperature remains in the range of the null zone, are vasoconstriction and behavioral responses. In high heat-loss environments, such as experienced during cold water immersion or hyperbaric air environments, the protection against further cooling of the core temperature offered by the constrictor response is minor compared to that which may be initiated with appropriate behavioral responses. Thus, in the presence of an anesthetic agent, reliance on behavioral responses for the maintenance of normal body temperature, especially in the region of the null zone, is much greater.

The present study examined the effect of subanesthetic doses of N_2O on perception of thermal comfort during progression to hypothermia. For the purpose of relating the findings of the study to compressed air diving, the premises of the study were that: a) inhalation of 30% N_2O induces narcosis, and b) the effects of N_2O narcosis are equivalent to the effects exerted by hyperbaric nitrogen. In terms of behavioral responses, N_2O is considered to be a good substitute for hyperbaric nitrogen (5). Studies by Fowler and coworkers (6, 7) and Biersner (8) have demonstrated that N_2O and hyperbaric nitrogen exert identical narcotic effects on memory, auditory perception, and other functions involved in skilled performance. Biersner (8) has suggested that the effects of 30% N_2O on specific performance tasks is analogous to the narcotic effect of air at a depth of 210 fsw. Most research to date has focused on the effect of narcosis, whether induced with hyperbaric nitrogen or N_2O, on complex behavior such as cognitive, reaction time, and dexterity. Behavioral responses are also essential for maintaining thermal balance in high heat loss environments, and since thermoregulatory behavior relies on thermal perception and reflects the perception of thermal comfort (9), it was hypothesized that the results of the present study may offer some insight into the potential effects of inert gas narcosis on behavioral temperature regulation in divers.

METHODS

The effect of narcosis induced with inhalation of 30% N_2O on the perception of thermal comfort during exposure to high heat loss environments was assessed in two separate studies. Both studies involved head-out immersion of subjects and allowed their core temperature to cool to mildly hypothermic levels. In study I the water temperature was maintained at 28°C, whereas in study II the water temperature was 15°C. Subjects participating in these studies were requested to participate in two trials; in one trial they inspired room air (AIR), and in the other a normoxic gas mixture containing 20.9% O_2–30.0% N_2O–49.1% N_2 (N_2O). In both studies the breathing mixture was humidified by passing it through a room temperature bath. Also, the N_2O and AIR trials were interspaced by at least a week, and the order in which the trials were conducted was alternated among the subjects. The effect of N_2O on core temperature cooling rate and shivering thermogenesis has been reported elsewhere (4, 10).

Both studies received approval by appropriate Institutional Ethics Review Boards. Study I was conducted at the Karolinska Institute (Stockholm, Sweden) and study II at Simon Fraser University (Burnaby, Canada).

Subjects

The subjects were 11 healthy males, non-medicated, and of above average fitness level as determined from an incremental exercise protocol. Subjects in both studies were physically active year-round, thus their experiences with cold exposure were in general very similar.

All subjects were requested to refrain from exhaustive exercise and any alcoholic beverages for 24 h before the experimental trials. Experiments were scheduled so that subjects completed both conditions in each study at the same time of day, and in the postabsorptive state. With the exception of one subject, who participated in both studies, the subject groups for the two studies were different. Only subjects whose esophageal temperature was displaced by a minimum of 1°C during either the AIR or N_2O trial were included in the present analysis. This a priori requirement eliminated several subjects from each study.

Six male subjects participated in both studies. Their physical characteristics are given in Table 1.

Protocol

Subjects remained immersed for a maximum duration of 130 min in study I and 60 min in study II. Experiments were also terminated in the event that esophageal temperature decreased to 35°C or by 2°C from preimmersion levels. Although the main aim of the studies was to evaluate the effect of N_2O on autonomic responses during cooling, subjective assessment of the perception of thermal comfort was incorporated in the measurement procedure, to gain insight into the possible effects

Table 1: Characteristics of Studies I and II. Values are Means (SD)

	Study	
	I	II
Subjects		
Number	6	6
Mass, kg	76.0 (8.5)	69.6 (7.1)
Height, m	1.82 (0.06)	1.75 (0.06)
Age, yr	28.7 (3.3)	27.8 (4.5)
Protocol		
Water temperature, °C	28	15
Maximum immersion time, min	130	60
Protocol while immersed		
Exercise: intensity, % max	50	–
Exercise: duration, min	30	–
Rest: duration, min	100 (postexercise)	60

on behavioral thermoregulation. The particulars of each study are given below and are summarized in Table 1.

Study I

The main purpose of the study was to examine the effect of N_2O on the core thresholds for shivering and sweating and the magnitude of the null zone. Once immersed in the 28°C water, subjects were instructed to exercise on an underwater cycle ergometer for 25–30 min at a rate equivalent to 50% of their maximal workrate. After the exercise period, subjects rested in the tank for an additional 100 min. The initial exercise period was sufficient to elevate esophageal temperature (T_{es}, °C) and initiate a steady rate of sweating from the forehead. Since attainment of a steady rate of sweating was required for a parallel study (4), the duration of exercise varied from 25–30 min. During the 100-min recovery period, the water was well agitated, causing a gradual decline in core temperature and eventually instigating a shivering response.

Study II

This study (10) was designed primarily to assess whether the attenuation of the shivering response observed in study I persisted in the presence of a greater thermal stimulus from the skin region, and with a more substantial cooling of the core region. After a resting period, subjects were immersed rapidly in a tank of water maintained at 15°C.

Measurements

Esophageal temperature (T_{es}, °C)

In both studies, core temperature was assessed with an esophageal thermistor probe (YSI 702, Yellow Springs Instruments, Yellow Springs, OH) inserted to a depth corresponding to the level of the intervertebral space between T8 and T9 and in close proximity of the myocardium (11). Esophageal temperature was measured at minute intervals throughout the immersions. The observed rates of change of T_{es} ($\dot{T}_{es}$, °C/h) in the AIR and N_2O trials were compared with a paired t test.

Thermal comfort vote (TCV)

The perception of thermal comfort was obtained at 10-min intervals in both studies. Subjects were requested to rate their perception of thermal comfort on a 21-point scale, with 0 indicating thermoneutrality (+10: very, very hot; +8: very hot; +6: hot; +4: moderatley hot; +2: warm; 0: neither warm nor cold (neutral); −2: cool; −4; moderately cold; −6: cold; −8: very cold; −10: very, very cold) as suggested by Enander et al. (12). Subjects in both studies were given identical instructions, because the investigator administering the test was present in both studies. The subjects in study I (conducted in Sweden) were all bilingual, thus they all understood the protocol and the scale on which they had to rate their perception of thermal comfort. Subjects were not instructed to distinguish between core and cutaneous thermal comfort.

Perceptions of thermal comfort reported in the AIR and N_2O trials at a T_{es} 1°C lower than preimmersion values ($\Delta T_{es} = -1$°C) were compared with a Wilcoxon signed-rank test. After each trial, subjects were interviewed by the same investigator to record any other sensations they might have experienced.

Oxygen Uptake ($\dot{V}O_2$, liter/min)

Oxygen uptake was estimated indirectly, by measuring inspired ventilation and the O_2 and CO_2 content of the mixed expired gas. Details of the instrumentation have been described previously (4,10).

RESULTS

In both studies subjects were interviewed after each experiment, and they all reported that they perceived the immersions more comfortable when inspiring the gas mixture containing 30% N_2O. Without exception, all subjects also reported that inhalation of 30% N_20 induced a feeling of euphoria during the rest and immersion periods.

The perceptions of thermal comfort reported by each subject during the 28° and 15°C immersions are presented in relation to the relative decrease in esophageal temperature from preimmersion levels in Figs. 1 and 2. As evident, all subjects reported a higher thermal comfort vote at any given T_{es} during the N_2O trials. During the cooling period, skin temperature (T_{sk}) was clamped at a level slightly higher than that of the surrounding water; thus the results decribe the perception of thermal comfort as a function of core temperature at two levels of T_{sk}. The subject populations for the two studies were different, thus direct comparison of the results obtained in studies I and II is not possible.

It was previously reported that N_2O inhalation attenuated heat production, as reflected by $\dot{V}O_2$, during progressive cooling in both 28°C (4) and 15°C (10) water. To compare whether the degree of attenuation of $\dot{V}O_2$ was similar to that observed for thermal perception, the relative decrease in the reported thermal comfort votes during the N_2O trials was compared to the relative decrease in $\dot{V}O_2$ at approximately $\Delta T_{es} = -1$°C. TCVs were recorded at 10-min intervals, and since the rate of cooling of T_{es} varied among the subjects, it was not possible to derive a TCV at exactly 1°C below preimmersion values for all subjects.

During the 28°C immersion, for an average 0.9°C decrease in T_{es}, both $\dot{V}O_2$ and TCV were significantly altered by inhalation of 30% N_2O (Table 2); $\dot{V}O_2$ was attenuated by 28%, whereas the rating of thermal discomfort was reduced by 63%. Similarly, a significant attenuation of $\dot{V}O_2$ and TCV was also noted during the N_2O trial in study II. In contrast to the 28°C immersions (study I), the degree of N_2O-induced attenuation of $\dot{V}O_2$ (32%) and the rating of thermal discomfort (30%) was similar during immersion in 15°C water.

Over the range of T_{es} for which TCV measurements were recorded, T_{es} cooling rates between the AIR and N_2O conditions in study I were not significantly different, averaging $-0.92° \pm 0.17$°C/h in the AIR and $-0.96° \pm 0.35$°C/h in the N_2O condition.

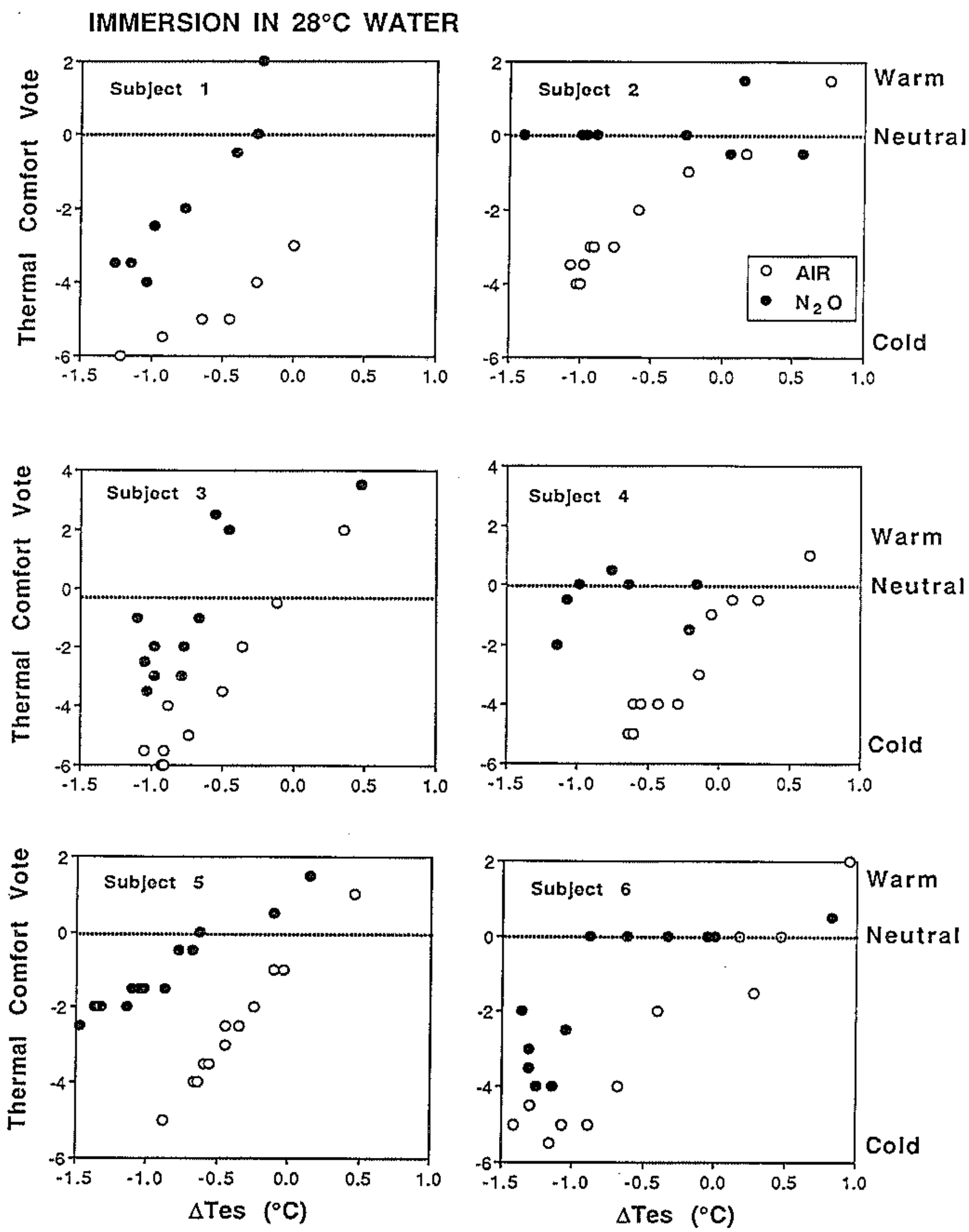

FIG. 1—Perception of thermal comfort (TCV) as a function of the displacement in T_{es} from resting preimmersion values (ΔT_{es}) during immersion in 28°C water.

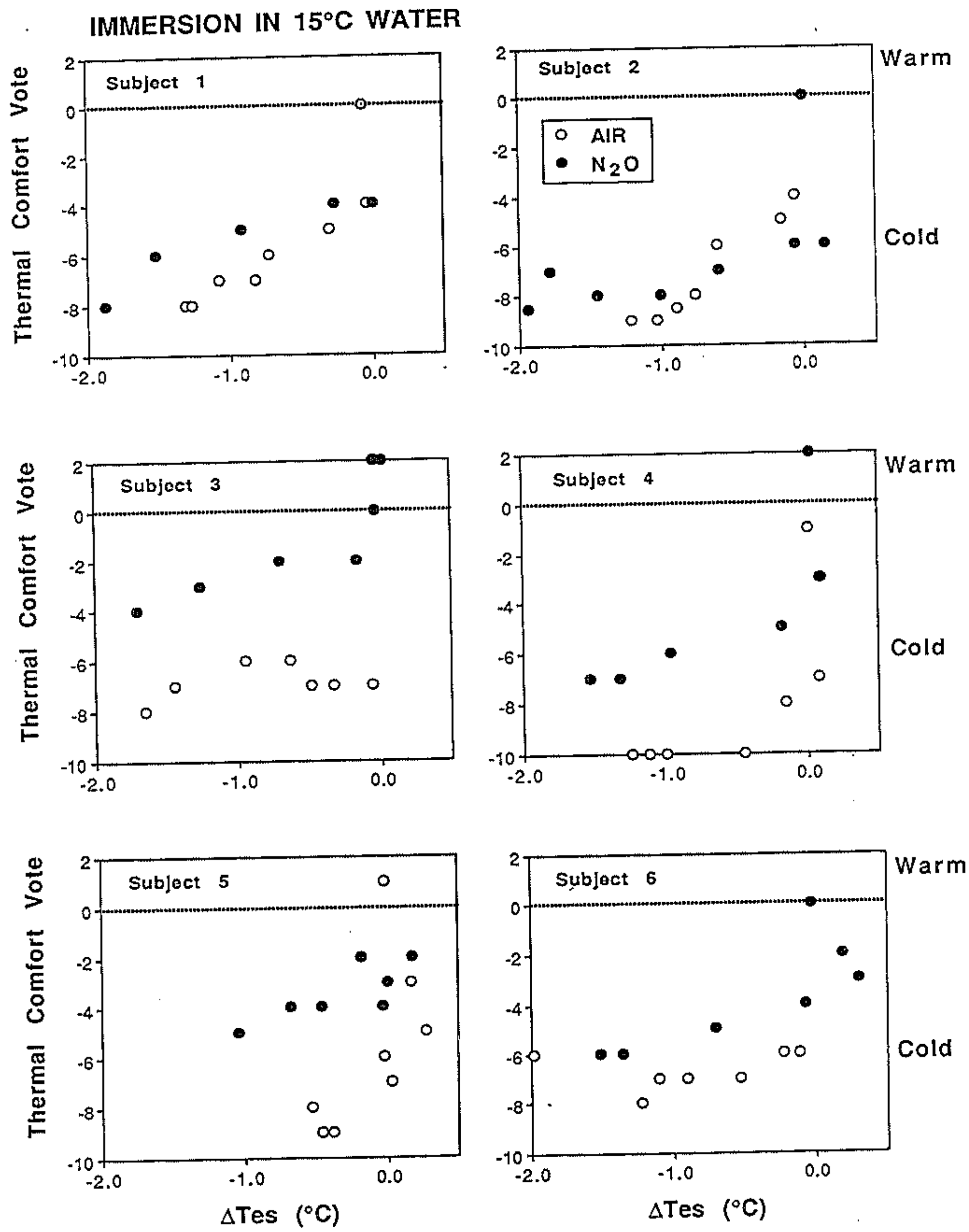

FIG. 2—Perception of thermal comfort (TCV) as a function of the displacement in T_{es} from resting preimmersion values (ΔT_{es}) during immersion in 15°C water.

Table 2: Comparison of Perception of Thermal Comfort and Oxygen Uptake During AIR and N_2O Trials for Immersions in 28° and 15°C Water, for Similar Decreases in T_{es} (ΔT_{es})

		AIR	N_2O	
Study I: 28°C water				
ΔT_{es}, °C	mean (SD) =	−0.90 (0.13)	−0.92 (0.15)	n.s.
$\dot{T}_{es}$, °C/h		−0.92 (0.17)	−0.96 (0.35)	n.s.
$\dot{V}O_2$ liter/min		0.68 (0.11)	0.55 (0.08)	*
TCV, ND	median =	−5	−1.75	**
Study II: 15°C water				
ΔT_{es}, °C	mean (SD) =	−0.90 (0.22)	−0.89 (0.35)	n.s.
$\dot{T}_{es}$, °C/h		−1.02 (0.35)	−1.47 (0.44)	*
$\dot{V}O_2$ liter/min		1.24 (0.29)	0.85 (0.35)	*
TCV, ND	median =	−8	−5.5	**

Key: ND = non-dimensional; n.s. = no significant difference between AIR and N_2O conditions; asterisk = significant difference at 0.05 level (paired *t* test test); double asterisk = significant difference at 0.05 level using non-parametric statistics (Wilcoxon signed-rank test).

In contrast, the T_{es} cooling rate of −1.47°C/h in the N_2O condition in study II was significantly greater than the T_{es} cooling rate of −1.02° ± 0.35°C/h observed in the AIR condition.

DISCUSSION

The present findings demonstrate that the perception of thermal discomfort is diminished during narcosis induced with inhalation of 30% N_2O. This attenuation was evident at two levels of T_{sk}, representing mild (28°C water) and strong (15°C water) peripheral cold receptor stimulation, and in both circumstances the attenuation persisted during cooling of core temperatures to mildly hypothermic levels. The following discussion examines the observed effects of N_2O, a non-volatile anesthetic gas, on the perception of thermal comfort, from the perspective of the known effects of anesthetic gases on central and peripheral neural structures, and the contribution of central and peripheral thermoreception to behavioral temperature regulation. Finally, the effect of narcosis on autonomic and behavioral temperature regulation must be examined in terms of the possible contribution to the etiology of hypothermia in divers.

Temperature regulation, and the perception of temperature and thermal comfort, rely on central and peripheral thermal sensory information. Autonomic and behavioral thermoregulation require the unimpaired integrated activity of all components of the thermoregulatory system: sensors situated in skin and core regions, extrahypothalamic and hypothalamic neural structures involved in processing thermal information emanating from thermal sensors, and the effector organs. Any non-thermal factors that affect the sensor-to-effector pathway will influence the autonomic and behavioral responses to thermal disturbances and may thus compromise thermal stability of the internal environment.

Narcosis is one such non-thermal factor that has been demonstrated to suppress shivering thermogenesis (4, 10, 13) and render the regulation of body temperature coarse. The main site of action of anesthetics seems to be the synaptic junction. This was demonstrated quite elegantly by Davis (14), who showed that inhaled anesthetics attenuate the afferent signals passing via the polysynaptic reticular formation to a greater degree than the ones transmitted by the oligosynaptic medial lemniscus pathway. Thus, the more synapses are involved in a particular pathway, the greater will be the distortion of the information and consequently the response elicited by this neural pathway. Based on these observations, and lack of findings of significant effects of inhalation anesthetics (halothane and N_2O) in concentrations used in clinical practice, on cutaneous sensors and action potential propagation in peripheral nerve fibers and long fiber tracts of the CNS (15, 16), it may be postulated that thermal perception is attenuated primarily as a result of N_2O acting on synaptic transmission of central regions involved with temperature regulation. The evidence presented by Coleshaw et al. (17), that subanesthetic doses of N_2O inspired by euthermic subjects do not affect cutaneous thermal perception from a hand immersed in water baths ranging from 22° to 32°C, further supports the notion that N_2O-induced alterations of perception of thermal comfort are predominantly due to an action of N_2O centrally.

Although the perception of thermal comfort is dependent on both core and skin temperature (18, 19), since T_{sk} in studies I and II was maintained constant throughout immersion, the increase in the perception of thermal discomfort during the course of the immersions can be attributed to the decreasing temperature of the core. It has been demonstrated that hypothalamic temperature is the dominant factor in eliciting thermoregulatory behavior (20), thus the increasing thermal discomfort in both studies was most likely mediated by a decreasing hypothalamic temperature.

In the present study the subjects were not given the opportunity to respond behaviorally to the imposed thermal stresses, but could only rate the magnitude of their discomfort with the thermal environment. Assuming that behavioral responses to a thermal stimulus rely on perception of thermal comfort and discomfort, our observations may be extrapolated to suggest that in the presence of an anesthetic agent core temperature displacements would not be defended with appropriate behavioral responses.

The overall effect of narcosis on temperature regulation is essentially a widening of the null zone (4). In essence, narrow-band regulation is replaced with a more broad-band regulation (21, 22). Satinoff (21) has suggested that progressive widening of the null zone may be expected with removal of higher structures in the thermoregulatory neuraxis, indicating a hierarchical arrangement of parallel integrative systems involved with temperature regulation. As discussed earlier, anesthetic agents act primarily on synaptic connections, thus the greater the number of synapses in the pathway of a particular thermoregulatory response, the greater the effect of narcosis. This would suggest that higher centers would be impaired first due to their polysynaptic pathways (21), and regulation of body temperature is taken over by lower centers, which do not have the capability of narrow band regulation because of their simpler neural arrangement.

The manner (i.e., site and mode of action) in which narcosis is induced with N_2O may be quite distinct from that of hyperbaric nitrogen, and thus studies examining the effects of anesthetics on autonomic function in humans may not be applicable to compressed air diving. Nevertheless, Pertwee et al. (1) have demonstrated that the effects of hyperbaric N_2 and N_2O on behavioral thermoregulation in mice are quite similar, with the exception that N_2O has a much greater narcotic potency than hyperbaric nitrogen. Both gases elicited changes in behavior which promoted the development of hypothermia in mice. Assuming that similar changes in behavior, as a result of an attenuation of the perception of thermal discomfort, occurs with exposure of divers to hyperbaric nitrogen, as was observed with inhalation of N_2O, then it is most likely that the hypothermia observed in divers may be attributed not only to the physical characteristics of the hyperbaric environment enhancing heat loss, but also to an inhibition of behavioral thermoregulation. Similarly, if hyperbaric nitrogen also suppresses the shivering response, then the combined inhibition of autonomic and behavioral thermoregulation would render divers susceptible to the development of hypothermia. In many dive situations, the divers must regulate their thermal environment. To date, hypothermia observed in divers has been attributed to their inability to respond appropriately to displacements in ambient and body temperatures, a consequence of the effects of hyperbaric nitrogen and pressure (23). The present discussion has presented arguments favoring a central effect of narcosis, essentially attenuating autonomic and behavioral responses aimed at maintaining thermal stability. In high heat loss environments, such as hyperbaric air environments, this will result in progressive cooling of the core region, without initiation of appropriate behavioral responses to reduce the heat loss.

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