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Roles of nitrogen, oxygen, and carbon dioxide in compressed-air narcosis

C. M. HESSER, L. FAGRAEUS, and J. ADOLFSON

Department of Environmental Medicine, Karolinska Institutet, S-104 01 Stockholm, and National Defence Research Institute, S-104 50 Stockholm, Sweden

Hesser, C. M., L. Fagraeus, and J. Adolfson. 1978. Roles of nitrogen, oxygen, and carbon dioxide in compressed-air narcosis. Undersea Biomed. Res. 5(4): 391–400.—In an attempt to determine the roles of nitrogen, oxygen, and carbon dioxide in compressed-air narcosis, the effects on performance (mental function and manual dexterity) of adding CO_2 in various concentrations to the inspired gas under three different conditions were studied in eight healthy male volunteers. The three conditions were: (1) air breathing at 1.3 ATA; (2) oxygen breathing at 1.7 ATA; and (3) air breathing at 8.0 ATA (same inspired O_2 pressure as in (2)). By relating performance to the changes induced in end-tidal (alveolar) gas pressures, and comparing the data from the three conditions, we arrived at the following results and conclusions. A rise in O_2 pressure to 1.65 ATA, or in N_2 pressure to 6.3 ATA at a constant high P_{O_2} level, caused a significant decrement of 10% in mental function but no consistent effect on psychomotor function. A rise in end-tidal P_{CO_2} of 10 mmHg caused an impairment of approximately 10% in both mental and psychomotor functions. The results suggest that, at raised partial pressures, all three gases have narcotic properties, and that the mechanism of CO_2 narcosis differs fundamentally from that of N_2 and O_2 narcosis.

human subjects
nitrogen narcosis
oxygen narcosis
carbon dioxide narcosis
cognitive performance
psychomotor performance
hyperbaric air environment
end-tidal P_{CO_2}
ventilatory response to CO_2

For more than a century, it has been known that breathing air under raised ambient pressure may cause behavioral changes and signs and symptoms of narcosis. However, the mechanism of compressed-air narcosis is far from clear. In the past, a variety of different factors has been thought to be involved, such as the increased partial pressures of oxygen and nitrogen, carbon dioxide retention, pressure per se, and anxiety and claustrophobia (for a review, see Bennett 1966; Adolfson and Berghage 1974; Bennett 1975). It is now fairly well established that the major determinant is the increased nitrogen pressure, and that increased oxygen pressure, carbon dioxide retention, and other factors may contribute to the narcosis either directly or indirectly, by interacting with or modifying the nitrogen effect.

At present, there is no clear concept describing the relations among nitrogen, oxygen, and carbon dioxide effects in the production of compressed-air narcosis. Studies concerned with separate and combined effects of oxygen and nitrogen on behavior and psychomotor performance have indicated that raised pressures of oxygen alone may produce narcotic effects (Bennett and Ackles 1970; Adolfson, Fagraeus, and Hesser 1973; Thomas 1974; Smith and Paton 1976), and that nitrogen narcosis is potentiated by high oxygen pressures (Frankenhaeuser, Graff-Lonnevig, and Hesser 1963; Fenn 1965; Thomas 1974; Thomas, Burch, and

Banvard 1976). The role of carbon dioxide in compressed-air narcosis has been assessed by comparing the effects on performance of adding CO_2 to the inspired gas at normal and at raised ambient pressures (Case and Haldane 1941; Hesser, Adolfson, and Fagraeus 1971; Adolfson et al. 1973). In air breathing subjects, Case and Haldane (1941) found that an increase of the inspired CO_2 pressure to 30–40 mmHg had little or no effect on manual and arithmetic skill at atmospheric pressure, but caused a marked deterioration in performance at 10 atmospheres absolute (ATA). With somewhat higher inspired CO_2 pressure, most of the subjects became unconscious within five minutes at 10 ATA. In the two studies reported by Hesser et al. (1971) and Adolfson et al. (1973), performance was related to the changes in alveolar N_2 and CO_2 pressures induced by varying the inspired partial pressures of these gases simultaneously or separately while the partial pressure of oxygen was kept constant. In the first study, tests on mental and motor efficiency indicated that at 6 ATA the CO_2 component of compressed-air narcosis is negligible at alveolar CO_2 pressures below about 40 mmHg, and furthermore, that the N_2 and CO_2 effects on performance are simply additive at alveolar CO_2 pressures higher than 40 mmHg. In the second study, it was found that postural disturbances increased linearly with alveolar P_{CO_2} in conditions with low N_2 pressures (breathing air at 1 ATA or oxygen at 1.7 ATA), while at a high N_2 pressure (breathing air at 8 ATA), there was a parabolic relationship between body sway and alveolar P_{CO_2}, indicating that the CO_2 and N_2 effects on standing steadiness act synergistically at N_2 pressures higher than 6 ATA.

In the present investigation, we attempted to determine the roles of nitrogen, oxygen, and carbon dioxide in compressed-air narcosis in man by studying the effects on performance of adding CO_2 to the inspired gas under three different conditions. These conditions were: (1) air breathing at 1.3 ATA; (2) oxygen breathing at 1.7 ATA; and (3) air breathing at 8.0 ATA (same O_2 pressure as in (2)). By relating performance to the changes induced in alveolar N_2, O_2, and CO_2 pressures and comparing the data obtained in the three conditions, the relation of the nitrogen, oxygen, and carbon dioxide components in compressed-air narcosis at 8.0 ATA was assessed.

SUBJECTS, METHODS, AND PROCEDURE

Subjects

Eight healthy male volunteers between 23 and 47 years of age (average 32.4) participated in this study. Their heights ranged between 167 and 187 cm (average 177.9) and their weights between 64.0 and 90.0 kg (average 74.8). All subjects were trained divers and had participated in previous experiments of this type.

Methods

All experiments were conducted in a dry hyperbaric chamber. Each subject took part in three experimental sessions (Sessions 1, 2, and 3), which differed only with respect to ambient pressure and composition of inspired gas. Sessions 1 and 3 consisted of trials at ambient pressures of 1.3 (control) and 8.0 ATA, respectively, with the subjects breathing various mixtures of CO_2 and air; Session 2 was comprised of trials at 1.7 ATA with the subjects breathing various mixtures of CO_2 and oxygen. For technical reasons, the control experiments were performed at 1.3 ATA. The CO_2 concentrations of the four gas mixtures administered at each pressure were equivalent to approximately 0, 2, 4, and 6 percent, sea level pressure. The four gas mixtures used at each pressure were rotated among the subjects, while in the individual subject, gas mixtures with equivalent CO_2 concentrations were administered in the same order of sequence in all three sessions. Sessions 1 and 2 were run on the same day, with an intervening rest period of at least 60 min, while Session 3 was accomplished on a different day; the two experimental days were separated by 2 to 9 days. Four of the eight subjects started with Session 3. The order of Sessions 1 and 2 was also rotated. Inspired gas pressures and average chamber temperatures in the three sessions are given in Table 1.

The respiratory gases were stored in high pressure tanks located outside the chamber and directed into the chamber through pressure-reducing valves and regulators to 200-liter inspiratory plastic bags partially filled with water to secure saturation of the gases with water vapor. Via a mouthpiece, a low dead-space (10 ml) respiratory valve, and a large 3-way stopcock inserted between smooth bore tubings (i.d. 30 mm), the subject inhaled gas from one of the inspiratory bags; expired gas was collected in 200-liter expiratory bags. The resistive pressure offered by the inspiratory and expiratory circuits at a flow rate of 1.0 liter • s^{-1} amounted to approximately 0.9, 1.1, and 2.8 cmH_2O at ambient pressures of 1.3, 1.7, and 8.0 ATA, respectively. For the continuous recording of end-tidal CO_2 pressure, a special breath-by-breath end-tidal gas sampler (Brismar, Hesser, and Matell 1962) was used in connection with an infrared CO_2 analyzer (Capnograph, Godart) and an ultraviolet recorder (1508 Visicorder, Honeywell) located outside the chamber. The calibration of the analyzer was checked before and after each experimental session. Respiratory and calibration gases were analyzed in duplicate for O_2 and CO_2 by the micro-Scholander technique (Scholander 1947).

Two performance tests were used: (a) an arithmetic test for measuring mental function, and (b) the Vagland screwplate test for measuring manual dexterity. The arithmetic test was made up of four sets of 48 different arithmetic problems, each consisting of adding or subtracting the result of one-digit by one-digit multiplication from a two-digit number, such as 37+3•8= , 85−6•3= , etc. The subjects were instructed to multiply first, and then to add or subtract, and were asked to solve as many problems as possible in 2 min. The scores recorded consisted of the number of problems attempted as well as the number of correctly and incorrectly solved problems. The equipment used in the Vagland test (compare Adolfson 1967) consisted of a vertical aluminum plate on which 19 brass bolts were mounted in two rows. Each bolt (length 10 cm, diameter 8 mm) was fixed to the plate with two nuts separated by a brass tube (length 4 cm). The subject's task was to transfer as many bolts and nuts as possible from one side of the plate to the other in 6 min. Four scores were recorded for each bolt transferred completely with its two nuts, and one score was added for each additional nut completely screwed off or on. Since both the right and left hands and arms had to be used, the manual dexterity measured by this test can be defined as arm-hand performance under speed conditions (see Bachrach 1975).

TABLE 1

AMBIENT CONDITIONS AND INSPIRED GAS PRESSURES

Experimental Session	Ambient Pressure, ATA	Ambient Temperature, °C	Inspired Gas Mixture	Partial Pressures of Inspired Gases: Oxygen, ATA	Nitrogen, ATA	Carbon Dioxide, mmHg			
1	1.3	26.7	Air + CO_2	0.25	1.0	0	16	31	44
2	1.7	26.8	Oxygen + CO_2	1.65	—	0	15	27	42
3	8.0	27.7	Air + CO_2	1.65	6.3	2	16	30	50

Temperature and partial pressure values are average values.

On their first experimental day, the subjects were allowed to practice the two performance tasks for 1–2 h, or until a stable score level was obtained, to reduce or eliminate possible changes in performance resulting from practice rather than from changes in experimental conditions. A stable score level was usually achieved after 5–10 trials in the arithmetic test (compare Adolfson 1967), and after 3–9 trials in the Vagland test.

Procedure

The general design of the experiments was as follows. The subject arrived at the laboratory early in the morning and, after a medical examination, was allowed to practice the two performance tasks as described above. Together with an observer, the subject then entered the chamber, and the pressure was raised to either 1.3 ATA or 1.7 ATA in about one minute, or to 8.0 ATA in about two minutes. When the desired pressure had been reached, the subject sat in front of a table, put on a nose clip, and started to breathe the first CO_2 gas mixture. After a 3-min period, which was allowed for the chamber temperature to attain equilibrium and the subject to become adjusted to the new condition, the 2-min arithmetic test was performed. The subject then rested for one minute before taking the 6-min Vagland test. During the 3rd to 5th min of this test, expired gas was collected in one of the expiratory bags for the determination of the respiratory minute volume. Upon completion of the Vagland test, the observer turned the 3-way stopcock of the inspiratory circuit so that the subject was connected to the second CO_2 gas mixture. During the following 3-min period of adaptation to the new condition, the first inspiratory bag was emptied by the observer and then refilled with the third CO_2 gas mixture, while the expired gas collected during the preceding test period was emptied via a dry gas meter located outside the chamber. The same procedure was then repeated with the other gas mixtures. The last Vagland test was completed about 50 min after the start of compression, and was followed by decompression to atmospheric pressure according to standard air decompression tables. The total decompression time in the 8-ATA experiments was 300 min. Except for one case of mild bends in the left shoulder, no signs or symptoms of decompression sickness occurred. In the 1.3-ATA air experiments, exposure to the gas mixture with the highest CO_2 concentration caused mild headache in five out of eight subjects.

RESULTS

Pulmonary ventilation ($\dot{V}_E$) and end-tidal P_{CO_2}

With no CO_2 added to the inspired gas, $\dot{V}_E$ averaged about 15 liters $\cdot$ min^{-1} (BTPS) in all three experimental conditions (Sessions 1–3), while end-tidal P_{CO_2} (Table 2) was somewhat higher at 8.0 ATA air than at 1.3 ATA air or 1.7 ATA O_2 ($P < 0.01$). The addition of CO_2 in equivalent concentrations to the inhaled gas caused smaller increases of $\dot{V}_E$ and, as a consequence, larger increases of end-tidal P_{CO_2} when the inspired partial pressures of oxygen and/or nitrogen were increased. Thus the ventilatory response to CO_2 ($\Delta\dot{V}_E/\Delta$end-tidal P_{CO_2}) decreased from 2.27 (liter $\cdot$ min^{-1})/mmHg at 1.3 ATA air, to 1.43 (liter $\cdot$ min^{-1})/mmHg at 1.7 ATA O_2, and to 0.75 (liter $\cdot$ min^{-1})/mmHg at 8.0 ATA air (compare Fagraeus and Hesser 1970), while $\dot{V}_E$ at an end-tidal P_{CO_2} of 50 mmHg averaged about 49, 42, and 29 liter $\cdot$ min^{-1} (BTPS) in the three sessions at 1.3, 1.7, and 8.0 ATA, respectively.

Performance tests

Mean values and standard deviations for all performance test scores obtained in the three sessions are given in Table 2. Performance scores in percent of control values (air breathing at 1.3 ATA) in the three conditions and at different end-tidal CO_2 pressures are shown in Fig. 1 (*left panel*) for the arithmetic test (problems attempted), and in Fig. 2 for the manual dexterity test.

An analysis of variance of the data obtained in Sessions 1 and 2 indicated that an increase of the inspired O_2 pressure from 0.25 to 1.65 ATA caused a significant effect on arithmetic skill ($P < 0.01$) but no consistent effect on manual dexterity, while increases of the inspired and end-tidal CO_2 pressures produced significant changes of the scores in both tests ($P < 0.01$). No significant oxygen-carbon dioxide interaction could be demonstrated. The oxygen effect on arithmetic skill consisted of decrements in both speed and accuracy of performance. Thus the

TABLE 2

EFFECTS ON END-TIDAL P_{CO_2} AND PERFORMANCE TEST SCORES OF ADDING CO_2 IN VARIOUS CONCENTRATIONS TO THE INSPIRED GAS

Condition	Inspired P_{CO_2}, mmHg		End-Tidal P_{CO_2}, mmHg	Arithmetic Score		Vagland Screwplate Test Score
				Attempted	Correct	
1.3 ATA air	0	M	34.0	27.8	25.1	54.1
		SD	3.8	8.1	8.5	9.9
	16	M	37.6	27.1	25.4	51.6
		SD	3.1	6.9	6.6	10.6
	31	M	42.4	25.4	23.3	51.5
		SD	2.0	7.1	7.7	12.0
	44	M	50.8	23.3	21.8	47.5
		SD	1.0	8.4	7.8	10.7
1.7 ATA O_2	0	M	32.3	24.3	22.1	53.5
		SD	3.4	8.1	8.6	8.7
	15	M	35.9	23.6	21.1	50.6
		SD	2.8	7.6	7.9	9.6
	27	M	40.7	23.5	21.4	52.4
		SD	2.4	6.7	7.2	10.3
	42	M	50.0	19.9	17.8	47.6
		SD	1.1	8.7	8.9	12.4
8.0 ATA air	2	M	35.1	21.3	17.3	51.6
		SD	3.2	8.1	8.2	8.8
	16	M	39.4	23.8	19.4	53.1
		SD	2.6	10.3	11.3	6.8
	30	M	45.7	17.9	14.4	48.6
		SD	2.7	8.3	8.2	5.8
	50	M	57.9	12.3	10.1	42.8
		SD	1.8	6.1	5.5	9.0

Values are means (M) ± SD ($n = 8$).

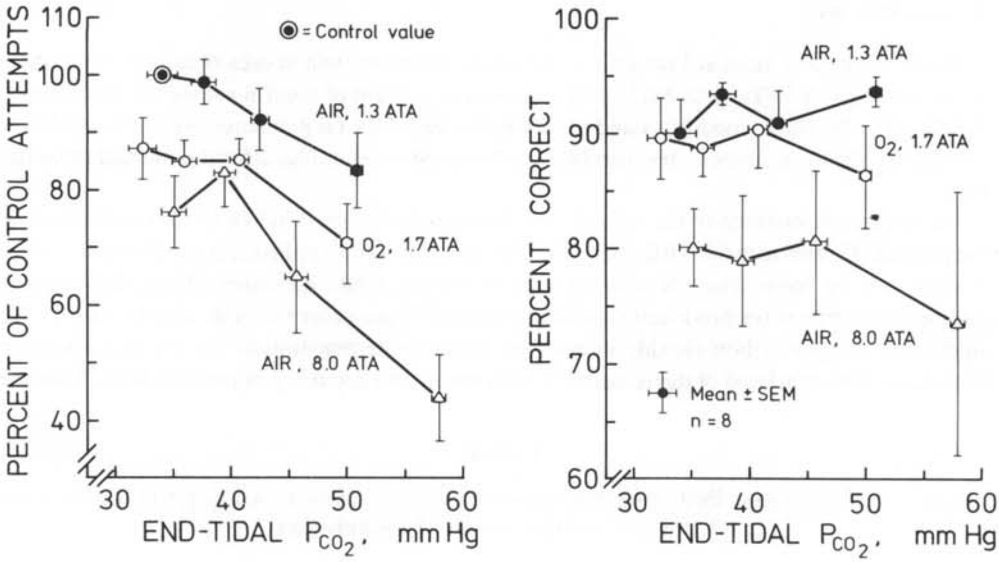

Fig. 1. Separate and combined effects of raised partial pressures of O_2, N_2, and CO_2 on cognitive performance (arithmetic test). *Left panel:* number of arithmetic problems attempted, in percent of control values obtained during air breathing at 1.3 ATA. *Right panel:* number of correctly solved problems in percent of problems attempted.

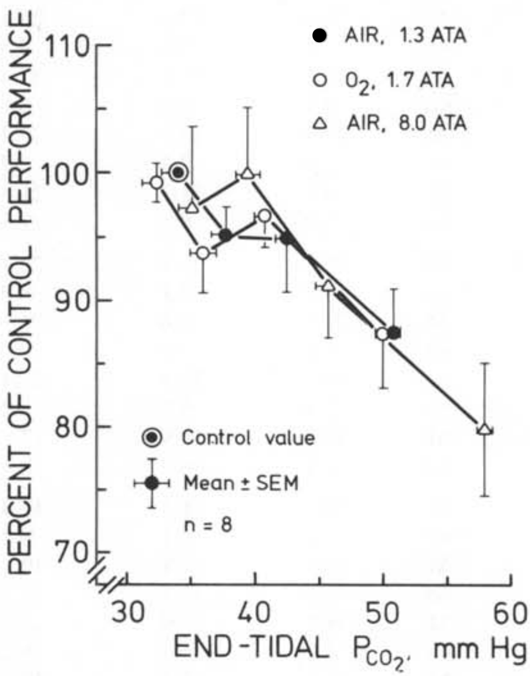

Fig. 2. Separate and combined effects of raised partial pressures of O_2, N_2, and CO_2 on psychomotor performance (Vagland screwplate test for manual dexterity); values are number of scores in percent of control values obtained during air breathing at 1.3 ATA.

number of problems attempted decreased by approximately 10% (Fig. 1, *left panel*), and the number of problems solved correctly dropped from about 92% at 1.3 ATA air to 89% at 1.7 ATA O_2 (Fig. 1, *right panel*). The CO_2 effect consisted of a progressive decrement in performance with gradual increases of the inspired and end-tidal CO_2 pressures, both at 1.3 ATA air and at 1.7 ATA O_2. In both conditions, the number of arithmetic problems attempted decreased by approximately 17% (Fig. 1), and the scores in the Vagland test by 12% (Fig. 2) when the inspired P_{CO_2} was raised to about 43 mmHg and the end-tidal P_{CO_2} rose from about 35 to 50 mmHg; both reductions were statistically significant ($P < 0.05$).

A statistical analysis of the data from Sessions 2 and 3 revealed that arithmetic skill, but not manual dexterity, was affected significantly ($P < 0.01$) when the inspired N_2 pressure was raised to 6.3 ATA at a constant P_{O_2} level of 1.65 ATA. As shown in Fig. 1, the nitrogen effect on arithmetic performance consisted of a decrement of approximately 10% in both the number of problems attempted and the number of correctly solved problems. A significant CO_2 effect was obtained in both tests ($P < 0.01$); it consisted of a progressive deterioration of performance with increasing inspired and end-tidal CO_2 pressures. With a rise in end-tidal P_{CO_2} from about 35 to 58 mmHg in the air experiments at 8.0 ATA, the number of arithmetic problems attempted decreased from a mean value of 21.3 to 12.3 (Table 2), or by an average of 37%, while the mean scores in the Vagland test decreased from 51.6 to 42.8 (17%). No significant interaction between the nitrogen and carbon dioxide effects could be demonstrated by performance scores.

DISCUSSION

It is well known that man's performance and efficiency in hyperbaric air may be affected not only by the raised partial pressures of the inspired gases, but also by other factors such as anxiety, environmental temperature, adaptation, practice effects, and learning (for a review, see Bachrach 1975). To reduce or eliminate the influence of such interfering variables, special measures were taken in the design of the experiments. Trained divers with previous experience of hyperbaric air experiments were used as test subjects, and the chamber temperature was kept constant at a comfortable level by a heat exchanger. Before starting the experimental sessions, the subjects were allowed to practice the performance tasks until stable score levels were obtained. Moreover, the sequence of exposure to the three different ambient pressure levels was rotated among the subjects, as was the sequence of exposure to the four inspired CO_2 concentrations used at each pressure. In this way, any possible effects of fatigue and adaptation were reduced when mean changes of performance scores were calculated for the group of subjects.

Oxygen and nitrogen effects

The performance measures employed in the present study revealed that raised partial pressures of oxygen and/or nitrogen clearly impaired cognitive ability, but had no significant effect on manual dexterity. These observations support the notion of Kiessling and Maag (1962), that the degree of performance decrement in hyperbaric air is directly related to the complexity of the task and that "the neural structures which support reasoning and immediate memory show greater functional impairment than do those supporting simple motor coordination and choice reactions." This would also explain the fact that in our present study a rise of the inspired P_{O_2} to 1.65 ATA caused a significant 10% decrement in mental function (arithmetic test), while in a previous study (Frankenhaeuser, Graff-Lonnevig, and Hesser 1960), a rise of the inspired Po_2 to 3 ATA produced only a slight and insignificant decrement in psychomotor function (tests on simple and choice reaction times and mirror drawing). In recent years there has been increasing evidence that raised pressures of oxygen may cause a depression of the central nervous system, either directly by producing narcosis-like effects similar to those of high pressures of nitrogen and other inert gases (Bennett and Ackles 1970; Bennett and Dossett 1973; Adolfson et al. 1973; Smith and Paton 1976), or by potentiating the narcotic action of inert gases (Frankenhaeuser et al. 1963; Fenn 1965; Thomas 1974; Thomas et al. 1976).

When the inspired nitrogen pressure was raised to 6.3 ATA at a constant O_2 pressure, arithmetic performance decreased by an average of 10%, i.e., to the same extent as was observed when the inspired oxygen pressure was raised to 1.65 ATA (Fig. 1, *left panel*). This suggests that for producing equivalent degrees of decrement in mental function, the rise in nitrogen pressure has to be 3 to 4 times greater than that in oxygen pressure and, hence, that oxygen is 3 to 4 times as potent a narcotic as nitrogen. This tallies rather well with the suggestion of Paton (1967), that for mice the ratio of the anesthetic pressures of N_2 and O_2 should be approximately 2.6.

Carbon dioxide effects

When evaluating CO_2 effects on performance, the measured variables should be related to the changes occurring in alveolar (end-tidal) rather than in inspired CO_2 pressure, since alveolar Pco_2 reflects changes of Pco_2 in arterial blood and hence in the central nervous system more closely than does inspired Pco_2 (compare Hesser et al. 1971). This is further emphasized by the present observation that with equivalent inspired CO_2 concentrations, the end-tidal Pco_2 rose to higher levels at 8 ATA than at 1.3 ATA.

In contrast to the effects of oxygen and nitrogen, the effects of CO_2 on performance were statistically significant not only in the arithmetic test but also in the Vagland test for manual dexterity. Both mental and psychomotor functions were thus impaired by approximately 10% in all three experimental conditions when the end-tidal Pco_2 was increased by 10 mmHg (Figs. 1 and 2). Studies on the narcotic action of various gases have shown that the ratio of narcotic or anesthetic potency of CO_2 and N_2O approximates 4:1 (McAleavy, Way, Altstatt, Guadagni, and Severinghaus 1961), and that of N_2O and N_2 30:1 (Miller, Paton, Smith, and Smith 1973; Lambertsen, Gelfand, Peterson, Strauss, Wright, Dickson, Puglia, and Hamilton 1977; Örnhagen 1977). From these figures it can be calculated that CO_2 has at least 120 times the narcotic potency of nitrogen. Our data would suggest that the narcotic potency of CO_2 is even greater, i.e., several hundred times as great as that of nitrogen.

Most theories concerning the mechanism of inert gas narcosis are based on the fact that, in general, there is a good correlation between lipid solubility and narcotic potency of inert and other narcotic gases (for a review, see Bennett 1975). Oxygen and carbon dioxide are about 2 and 13 times as soluble, respectively, as nitrogen (Dittmer and Grebe 1958) and therefore should be approximately 2 and 13 times as potent a narcotic. The narcotic potency observed in the present study agrees fairly well with these figures in the case of oxygen, while carbon dioxide was found to be more than 30 times as narcotic as predicted by the lipid theory. This suggests that the mechanisms underlying the narcotic action of O_2 and N_2, on the one hand, and of CO_2, on the other, are different. Further support for this view is given by the fact that with CO_2, significant effects on performance were obtained in both the cognitive and psychomotor tasks, while with O_2 and N_2 significant effects occurred only in the cognitive test. A possible explanation for the high narcotic potency of CO_2 would be that CO_2 effects on performance, like most of the physiological biochemical effects of CO_2, are mediated by hydrogen ions (H^+). Evidence for this conception is found in the observations of Eisele, Eger, and Muallem (1967), that in dogs the anesthetic effect of CO_2 correlates better with the pH of the cerebral extracellular fluid than with arterial P_{CO_2}. This does not exclude the possibility that CO_2 has narcotic effects that act in accordance with the lipid solubility theory, but which are masked by H^+-induced narcosis occurring at far lower P_{CO_2} levels.

CONCLUSION

Impairment of mental function in man produced by acute exposure to raised air pressure (8.0 ATA) is due to the combined narcotic effects of high nitrogen and oxygen pressures, while the role of CO_2 as a causative factor is negligible as long as the alveolar (arterial) P_{CO_2} does not exceed 40 mmHg. However, in conditions with hypoventilation and consequent CO_2 retention, the role of the CO_2 component in compressed-air narcosis increases markedly with the rise in CO_2 pressure.

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The present address of Dr. Fagraeus is Department of Anesthesiology, Duke University Medical Center, Durham, N.C. 27710.—*Manuscript received for publication June 1978; revision received September 1978.*

Hesser, C. M., L. Fagraeus, and J. Adolfson. 1978. Les roles de l'azote, de l'oxygene, et de l'oxyde de carbone dans l'intoxication a l'air comprime. Undersea Biomed. Res. 5(4): 391–400.—Pour préciser les rôles de l'azote, de l'oxygène, et de l'oxyde de carbone dans l'intoxication à l'air comprimé, nous avons étudié les effets sur la fonction metale et sur la dextérité manuelle de l'oxyde de carbone dans le mélange gazeux respiratoire. Les sujets, 8 volontaires males normaux, ont respiré 3 mélanges: (1) air à 1,3 ATA; (2) oxygène à 1,7 ATA; et (3) air à 8,0 ATA (pression de l'oxygène inspiré identique à celle de l'oxygène à 1,7 ATA. Nous avons examiné les rapports entre la performance et les altérations des pressions gazeuses alvéolaires à la fin de la respiration, et comparé les résultats des trois mélanges respiratoires. Nous concluons que 1) l'augmentation des pressions de l'O_2 jusqu'à 1,65 ATA, et de l'azote (N_2) jusqu'à 6,3 ATA avec une P_{O_2} constante et élevée, a causé une baisse significative de 10% de la fonction mentale, mais n'a pas exercé d'effet consistent sur la fonction psychomotrice; et 2) une hausse de 10 mmHg de la P_{CO_2} à la fin de la respiration a causé une baisse de 10% des fonctions mentales et psychomotrices. Ces résultats nous font penser qu'à des pressions partielles élevées, les trois gaz exercent des effets intoxicants, et que le mécanisme de l'intoxication par co_2 diffère d'une facon fondamentale de ceux des intoxications à l'azote et à l'oxygène.

sujets humains
intoxication à l'azote
intoxication à l'oxygène
intoxication à l'oxyde de carbone
performance cognitive
performance psychomotrice
milieu d'air hyperbare
P_{CO_2} de la fin de la respiration
résponse ventilatoire à co_2

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