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AVIATION MEDICINE

HUMAN TOLERANCE TO ACUTE EXPOSURE TO
SIX PERCENT CARBON DIOXIDE IN AIR AND IN OXYGEN

PROJECT NUMBER 21-1402-0001
REPORT NUMBER 1

PROJECT REPORT

THIS REPORT CONCERNS....
the acute respiratory effects of inhaling CO_2 in air and in oxygen.

IT IS FOR THE USE OF....
flight surgeons and aeromedical research personnel.

ITS APPLICATION FOR THE AIR FORCE....
concerns the problems of acute CO_2 toxicity and sealed cabins.

HUMAN TOLERANCE TO ACUTE EXPOSURE TO SIX PERCENT CARBON DIOXIDE IN AIR AND IN OXYGEN

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Contract No. AF 33(038)–13244

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Air University
USAF SCHOOL OF AVIATION MEDICINE
RANDOLPH FIELD, TEXAS

March 1953

PRECIS

OBJECT:

To establish the physiological effects of carbon dioxide under conditions met with in present-day aircraft; also to furnish information of value in research related to levels that may be obtained in sealed cabins.

SUMMARY:

1. Thirty-one humans, all male, ranging in age from 21 to 43 years of age, were exposed acutely at a ground level altitude of 5,000 ft. to 6.0 ± 0.2 percent CO_2 using A-14 oxygen masks and diluter demand oxygen regulators.

2. Twenty-six subjects breathed CO_2 in air and 24 individuals inhaled CO_2 in O_2. Nineteen subjects served in both the air and O_2 groups.

3. All but one subject completed a 16-minute period of inhaling CO_2 without any alarming symptoms. The subjective symptoms were noted and summarized. In 84 percent of 50 man-exposures, individuals detected the beginning of breathing CO_2 by other than the effect on respiration.

4. A card-sorting test was administered during the experimental period. Errors and the speed of card sorting were not influenced significantly by inhaling CO_2.

5. The mean expiratory minute volume rose from 12 liters/min. to about 38 liters/min. for the group inhaling CO_2 in air and from near 11 liters/min. to approximately 30 liters/min. for the group breathing CO_2 in O_2. The rise was slower for the latter group, but tended to approach the former near the end of the experiment.

6. The actual and percentage changes, minute by minute, in the averages for the expiratory minute volumes, tidal volumes, respiratory rates, and pulse rates were noted and summarized. The percentage rise in the tidal volume was higher than that for the respiratory rate, indicating that an increase in tidal volume, on the average, plays a more significant role in adapting to CO_2 than does the rise in respiratory rate.

7. The average alveolar pCO_2 determined during the 16th minute of inhaling CO_2 was 11 mm.Hg above the average of 32 mm.Hg found after 5 minutes of air breathing.

8. The minute by minute changes in alveolar pCO_2 for typical experiments using a mouthpiece were presented.

9. The results were discussed and the advisability of requiring aircrew indoctrination in the effects of acute CO_2 inhalation was emphasized.

HUMAN TOLERANCE TO ACUTE EXPOSURE TO SIX PERCENT CARBON DIOXIDE IN AIR AND IN OXYGEN

INTRODUCTION

The tolerance of humans when acutely exposed to CO_2 has not been thoroughly investigated from the viewpoint of aviation medicine. White (1) reviewed the literature in 1948 and, from the data available, estimated the time tolerance curves applicable to humans (2, 3). The purpose of the current investigation was to study the effect of an approximate sea level equivalent of 5.0 percent CO_2 dry,* which is equivalent to a pCO_2 of 36 mm. Hg BTPS and which is calculated to be about 6 percent CO_2 at 5,000 ft.

METHODS

Equipment used

Male subjects, between 21 and 43 years of age, were exposed to gas mixtures using four diluter demand regulators (AN6004–1 with diluter off). Two regulators in parallel delivered air and the other two gas mixtures containing CO_2. The paired regulators delivered a peak flow in excess of 300 liters/min. ambient at the line pressure used. By using a 3-way valve between the regulators and the mask hose, a shift from air to CO_2 mixtures could be made without the knowledge of the subject. A-14 masks, equipped with microphones, were used and fitted carefully to each subject. The masks were modified by plugging one exhaust port and sealing a 1-inch tube in the other. This tube was connected to a 600-liter, water-sealed, chain-compensated, recording spirometer. A 3-way stopcock adapted for use with a syringe was sealed into the outer wall of the mask distal to the exhaust valve. This made it possible to obtain syringe samples of the exhaled gas. The microphone was connected to an amplifier and loud-speaker through a spring switch which the subjects closed when speaking.

The gas mixtures were obtained commercially and were analyzed using the Scholander micro gas analyzer (4). One gas was compressed air, the other two contained 6.0 ± 0.2 percent CO_2, one in air and the other in O_2.

Experimental procedure

No attempt was made to have the subjects in a basal condition. Each subject was seated in a chair and fitted with a mask. He was allowed to breath air for 5 to 8 minutes and then was shifted to the CO_2 mixture. A performance test involving card naming and sorting was begun 3 minutes before the CO_2 exposure. CO_2 was inhaled for 16 minutes during which time the subject continued the card test except for at least a 1-minute period (8th-10th min.) during which time the ventilation was recorded without the subject speaking, and during the 16th minute when the last alveolar gas sample was obtained. The subject was then shifted to air and recordings of the ventilation were continued until the pre-CO_2 level was approximated. Haldane-Priestley alveolar air samples after a normal expiration were taken immediately after the fitting of the mask, just before shifting to CO_2, and during the 16th minute of breathing the experimental gas mixture. When the experiment was finished, the subjects were questioned closely concerning their sensations and reactions.

Observations made

The respiratory rates, tidal volumes, and expiratory minute volumes were determined from the continuous spirometric records. Pulse rates were checked manually at periodic intervals. The alveolar gas samples were analyzed in duplicate with the Scholander technique. A card-sorting test employed by Hoffman, Clark, and Brown (5) during the second world war to determine the time of useful consciousness during hypoxia was used in the present study as an objective assessment of changes in performance. In the procedure the subject picked up a card, named it, and then placed the card in one of four slots in a box, each slot being labeled with one of the four conventional card suits. Errors in naming or sorting cards were noted.

Received for publication on 31 May 1952.

*All percentages refer to the dry basis.

Each minute the time taken to sort five cards was recorded. Subjects were told that accuracy was the important thing and, though the time of card sorting would be noted, they were not to hurry, but to work at a speed they felt consistent with accuracy. Postexperimental interrogation of subjects was done, using a check list.

Several months after the CO_2 inhalations, a control was run on the card-sorting test during which 10 of the subjects inhaled compressed air for the entire experiment under conditions which simulated the CO_2 work in every other detail.

RESULTS

Performance data

Thirty-one subjects were used in this study. Twenty-six inhaled CO_2 in air, and 24 inhaled CO_2 in oxygen. Nineteen subjects were common to both groups.

One of the 31 subjects failed to complete the 16-minute exposure to CO_2. This subject reported dizziness, marked dyspnea, and a feeling "like I was going to faint . . . . I felt panicky." After 2 minutes and 22 seconds the subject, who was breathing CO_2 in O_2, was shifted to air because of the apparent urgency of symptoms. This subject had been in New Mexico (5,000 ft.) for only four weeks during the hot summer, having come directly from a temperate climate at sea level.

Figure 1 presents the data on the time of card sorting and shows the mean times each minute for sorting five cards for those breathing CO_2 in air and O_2 and for 10 control subjects who inhaled compressed air for the entire experiment. All of these last individuals had served previously as subjects in the CO_2 experiments. It is apparent that there was a slight trend downward in the time of card sorting throughout the experimental period. There was no significant difference between the CO_2 in O_2 and CO_2 in air groups. Since there was no slowing apparent in the sorting, one can believe that incoordination was not a prevalent factor. The objective observations made during the test also bear out the absence of motor difficulty. The control figures show a slightly faster rate of card sorting than in the CO_2 experiments.

Table I tabulates the mistakes made in the card-sorting test. Miscalling or misplacing a card was judged an error unless the mistake was spontaneously corrected by the subject. The CO_2 in air and O_2 data, along with the control figures, show the total number of errors each minute for the entire experimental period. The subject who did not complete the experiment is not included. However, he did not make any errors during the time studied. There was no apparent increase in the number of errors as the experiment progressed as one would expect if CO_2 were producing confusion. The total number of errors for the control, the air, and O_2 groups was 15, 12, and 10, respectively. The average error was 0.46 and 0.43 per subject for the air and O_2 groups, respectively, and 1.5 per subject in the control group. Although the latter error rate is 3 to 4 times as great as that for the CO_2 groups, it is felt that the slightly increased sorting rate, carelessness, and boredom were the significant factors in the control group and that subjects concentrated more intently when actually breathing CO_2. The data appear to follow a random distribution and the distribution of the number of errors made by a single person in any experiment was 0 to 3. No correlation with age was found.

Subjective symptoms and observations

In the 31 subjects during 50 man-exposures, there were 42 instances in which the beginning of CO_2 breathing was subjectively recognized by taste or smell. In one instance there was no report, and 7 subjects detected the CO_2 only as it increased breathing. Since CO_2 has been described as an odorless and tasteless gas, it is interesting that in 84 percent of the man-exposures, CO_2 was detected and described in such terms as *acid, ammonia, oily, metallic, sulfur, fruity,* and *sticky* by the subjects in recalling their sensations on beginning the CO_2 exposure. This recognition was about equal in the air and oxygen groups. On shifting from CO_2 to air, the taste and smell sensations were also common. These data are summarized in table II, as are other subjective symptoms.

Dyspnea was reported in all cases. All felt the difficulty of breathing to be *slight* or *moderate* except 5 who regarded the dyspnea as *severe.* Of the 19 subjects in both groups, 16 believed the dyspnea to be more severe in air than in O_2. The other 3 detected no difference. Of the 5 who noted severe dyspnea, one was a mild asthmatic in apparent good health; one was quite heavy; another, who was also overweight, became panicky and continued to hyperventilate markedly after being shifted back to air. A request from the observer to slow down was immediately obeyed. One subject has a marked scoliosis of the dorsal spine with past reports of partial atelectasis of the left lung. At present this subject has no apparent symptoms relevant to the deformity and does mountain climbing without difficulty. The fifth subject was apprehensive from the beginning.

Of the 2 subjects who reported subjective difficulty with vision, one claimed seeing a third slot on one side of the card-sorting box between the two slots actually present; the other reported a transient blurred vision. None of the subjects gave objective signs of visual difficulties. They saw and named cards accurately and about half were spot-checked during the CO_2 breathing with a standard visual acuity chart.

By "difficulty of movement," in table II, is meant the *subjective* feeling of difficulty in sorting cards during the experimental period. The data on the time of sorting and the opinion of the observers bear out the fact that objectively there was no incoordination and no one was clumsy.

Headache was a slightly more common symptom in the CO_2 in air group. In only one case was the headache severe; in most cases it was

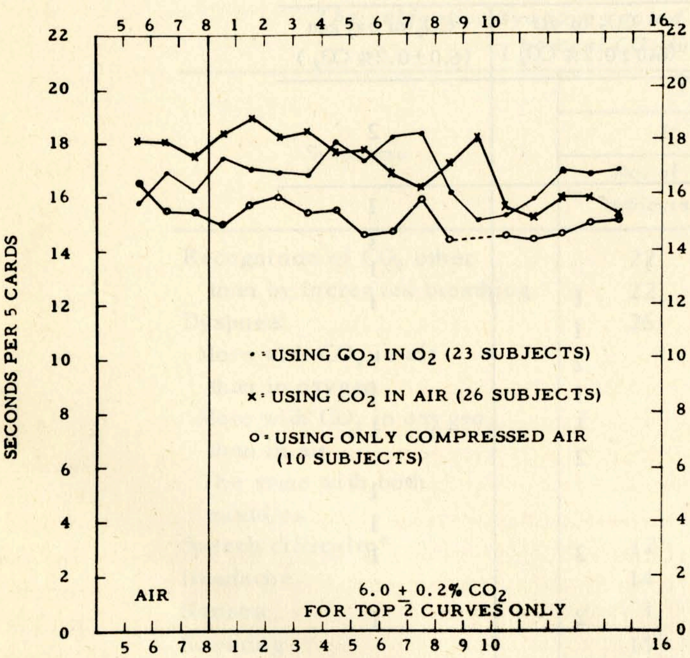

FIGURE 1

Minute by minute means of the times taken by subjects to sort five cards when breathing compressed air and 6.0 ± 0.2 percent CO_2 in air and in O_2.

mild and of very short duration. In all but one instance the onset of the headache was after breathing CO_2. Occurrence *soon* after the shift back to air was the rule.

As for the feeling of difficulty with speech, it can be said that no subject objectively showed any deterioration. Understanding of speech over the intercommunication system was always adequate. The subjects apparently believed the stress of dyspnea made talking more difficult. Many stated the experience of breathing CO_2 when talking was more of a strain than during the period when card sorting was discontinued. Subjects did tend to speak more rapidly when breathing CO_2, and they maintained a higher expiratory minute volume when talking. Note the drop in lung ventilation between the 9th and 10th minutes in figure 2.

Other subjective sensations deserve mention. A feeling of fatigue was common; *fogginess* was reported; feelings that reactions were *slowed down* and that more *concentration* was required during card sorting when breathing CO_2 were prevalent. Most subjects volunteered the information that they felt better after the first few minutes of the exposure were past.

The post-exposure interrogation revealed no significant aftereffects of the experiments and allowed the subjects to say whether or not they thought they might drive a car or pilot a plane adequately. It is of interest to note that of the 26 subjects breathing CO_2 in air, 18 believed the CO_2 would not influence driving or piloting at all; 6 felt their performance would not be up to par; and for 2 subjects there was no report. In the CO_2 in O_2 group, 17 of 24 felt the CO_2 would not interfere with driving or piloting; 6 believed the CO_2 would deteriorate their performance; and in 1 case there was no report. Eight subjects were or had been pilots and all of these felt they could fly safely.

Most subjects were of the opinion that breathing the CO_2 in air over a 16-minute period was close to a marginal concentration for safe operation of an automobile or an airplane. All agreed, and many suggested that all pilots should be exposed to CO_2 as an indoctrination procedure.

Physiological data

Figure 2 shows the average and the range of the individual observations for the expiratory minute volumes, minute by minute, for all subjects in the CO_2 in air and O_2 groups. The variation among individuals was large, and more marked during the CO_2 breathing. The mean figures leveled off fairly well after about 10 minutes of exposure to CO_2. However, there was a late rise in the CO_2 in O_2 group toward the end of the experimental period with only a small difference between the groups at the 15th minute. The data suggest that the presence of O_2 may defer the rise in expiratory minute volume.

The third pair of curves in figure 3 gives the mean changes, minute by minute, in the expiratory minute volume for the 19 subjects who served in both groups. The air and oxygen groups also here show a difference, though less marked than was apparent in the massed results. The difference between the two groups is statistically significant, with a probability of less than 0.001 that chance is involved. The barometric variation during the experiments ranged from 622 to 638 mm.Hg and averaged 629 and 630 mm.Hg for the O_2 and air groups, respectively. It will be noted in figure 3 that recovery of the ventilation takes place between the 3d and 5th minutes after shifting from CO_2 to air.

A plot of the ventilation data against age shows no definite relationship. Figure 4 gives the figures for the maximal expiratory minute volumes obtained during CO_2 inhalation as a function of age.

Figure 5 shows the average expiratory minute volumes from the 11th to the 15th minute of CO_2 breathing plotted against age.

Figure 6 shows the average minute-by-minute changes in the respiratory rates along with the

TABLE I

Total number of errors made during the card-sorting test by 10 subjects breathing compressed air, 26 subjects breathing compressed air followed by 6.0 ±0.2 percent CO_2 in air, and 23 subjects inhaling compressed air followed by 6.0 ±0.2 percent CO_2 in O_2.

Minute number	Air without CO_2	CO_2 in air (6.0 ±0.2% CO_2)	CO_2 in oxygen (6.0 ±0.2% CO_2)
		Number of errors	
6			
7			2
8	1		
1			1
2	2		1
3	1		1
4		1	1
5	1	1	
6		2	
7		1	1
8	1	1	1
9		2	
10			1
11	2		1
12	2	2	1
13	1		
14	3	2	1
15	2		
Total errors last 15 minutes	15	12	10
Error rate in mistakes per subject	1.5	0.46	0.43

individual range each minute for the two groups during the experiment. There was a tendency for the rate to rise during the CO_2 breathing; this tendency was less marked for the CO_2 in O_2 group. Following the 10th minute the rates tend to level off after a rise of about 3 to 4 per minute and 1 to 2 per minute for the CO_2 in the air and O_2 groups, respectively. Results for the 16th minute were low because of the voluntary control of breathing to obtain the alveolar gas sample. The rise after shifting to air after the 16th minute was probably partly a reflection of the gas sampling procedure.

Figure 3 shows the mean results obtained on the 19 subjects common to both groups for tidal volume, expiratory minute volume, respiratory rate, and pulse rate. It is interesting to note that during CO_2 breathing the data for the CO_2 in O_2 group consistently fell below those for the CO_2 in air group. It is apparent that there was a slight rise in pulse rate for those breathing CO_2 in air, and that the subjects adapted to CO_2 by an increase of respiratory rate and tidal volume to almost triple the expiratory minute volume. On the average, an increase in tidal volume was more significant than the rise in respiratory rate, as may be seen from table III.

Table III summarizes the mean figures for expiratory minute volume, tidal volume, respiratory, and pulse rates, and shows the percent change in the data at periodic intervals compared with the pre-CO_2 level.

In table IV are given the mean alveolar CO_2 data for all experiments along with the range in the figures noted in each group. The results are segregated to show the data for all subjects in the air and O_2 groups and for those who served in both groups. It will be noted that the range between the maximal and minimal figures for each group is quite large; this is partly due to experimental errors and to the subjects' lack of experience with respiratory experiments. The averages for the alveolar partial pressures in each time period are almost the same for each group. The mean rise in the alveolar pCO_2 found during the 16th minute of breathing 6.0 percent CO_2 compared with that after breathing air for 5 minutes was 11 mm.Hg for both the CO_2 in air

TABLE II

The subjective symptoms noted during the inhalation of 6.0 ± 0.2 percent CO_2 in air and oxygen•

Symptoms	CO_2 in air, 26 subjects: No. of subjects	CO_2 in air, 26 subjects: Percent		CO_2 in oxygen, 24 subjects: No. of subjects	CO_2 in oxygen, 24 subjects: Percent
Recognition of CO_2 other	22				
than by increased breathing	22	85		20	83
Dyspnea:	26	100		24	100
More with CO_2 in air					
than in oxygen			16		
More with CO_2 in oxygen					
than in air			0		
The same with both					
mixtures			3		
Speech difficulty*	12	46		4	17
Headache	14	54		10	42
Nausea	1	4		0	0
Sweating	15	58		15	63
Visual difficulty*	2	12		0	0
Hearing difficulty	0	0		0	0
Difficulty of movement*	13	50		4	17
Faintness	0	0		1	4

*See "Results."

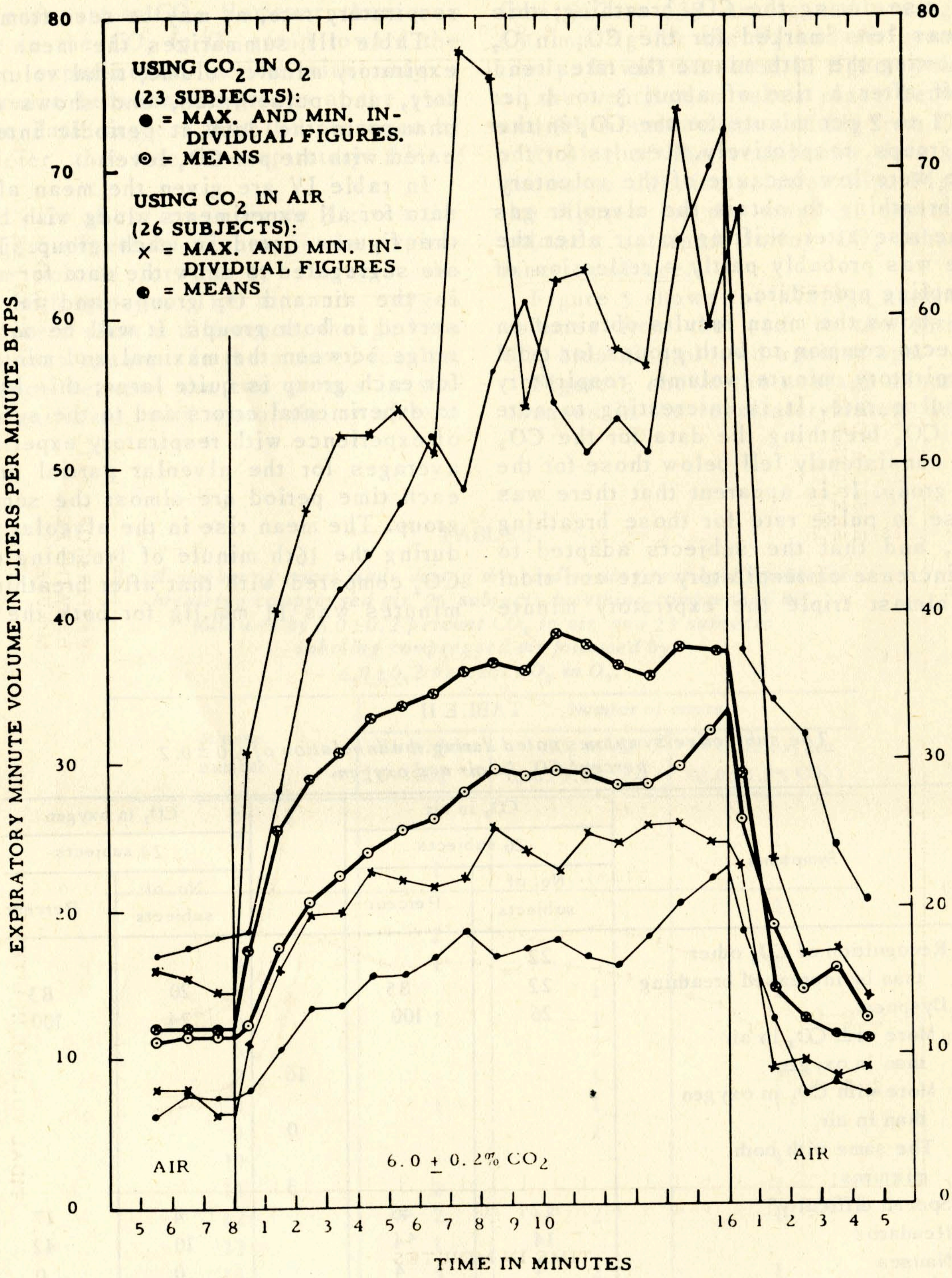

FIGURE 2

The mean expiratory minute volumes and the range of single observations for subjects before, during, and after breathing 6.0 ± 0.2 percent CO_2 in air and in O_2.

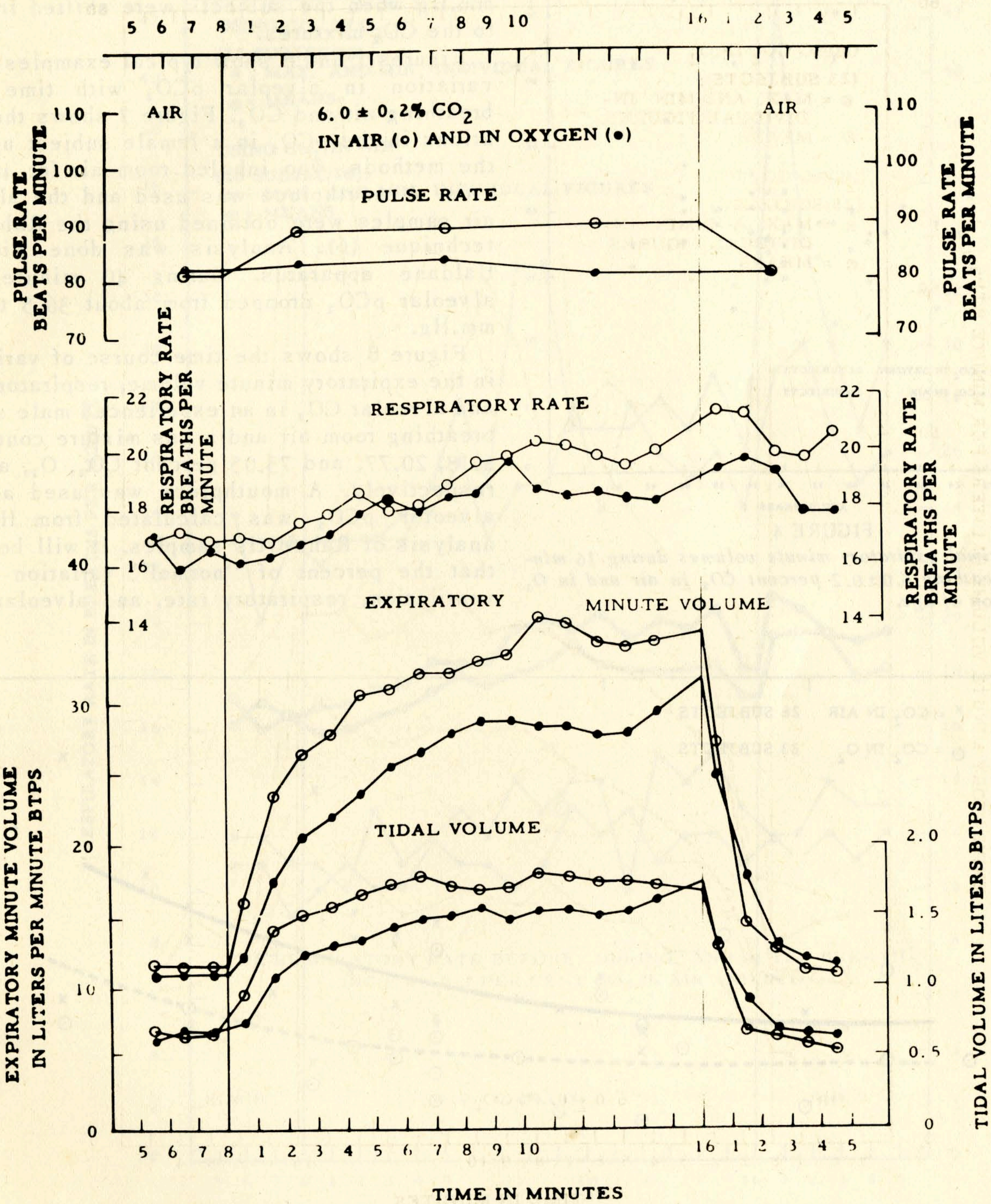

FIGURE 3

The mean data for the pulse and respiratory rates, the tidal volumes, and expiratory minute volumes for 19 subjects before, during, and after breathing 6.0 ±0.2 percent CO_2 in air and in O_2.

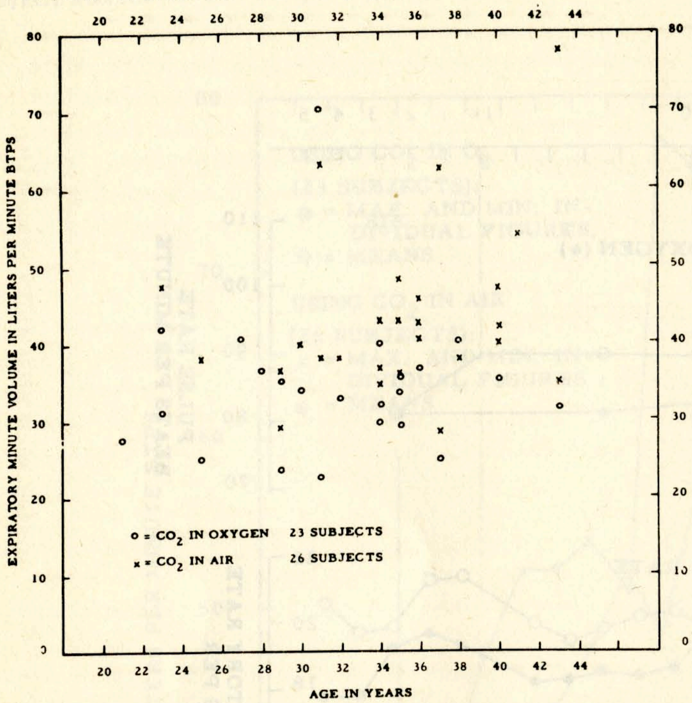

FIGURE 4

The maximal expiratory minute volumes during 16 minutes of breathing 6.0 ± 0.2 percent CO_2 in air and in O_2 as a function of age.

and CO_2 in O_2 groups. The pCO_2 in the inhaled dry gas rose from near 0 to an average of 36.7 mm.Hg when the subjects were shifted from air to the CO_2 mixtures.

Figures 7 and 8 show typical examples of the variation in alveolar pCO_2 with time when breathing air and CO_2. Figure 7 shows the variations in the pCO_2 in a female subject used to the methods, who inhaled room air for 40 minutes. A mouthpiece was used and the alveolar air samples were obtained using the Rahn-Otis technique (6). Analysis was done with the Haldane apparatus. During 40 minutes, the alveolar pCO_2 dropped from about 36.5 to 35.5 mm.Hg.

Figure 8 shows the time course of variations in the expiratory minute volume, respiratory rate, and alveolar CO_2 in an experienced male subject breathing room air and a gas mixture containing 6.18, 20.77, and 73.05 percent CO_2, O_2, and N_2, respectively. A mouthpiece was used and the alveolar pCO_2 was calculated from Haldane analysis of Rahn-Otis samples. It will be noted that the percent of "normal" variation in the ventilation, respiratory rate, and alveolar pCO_2

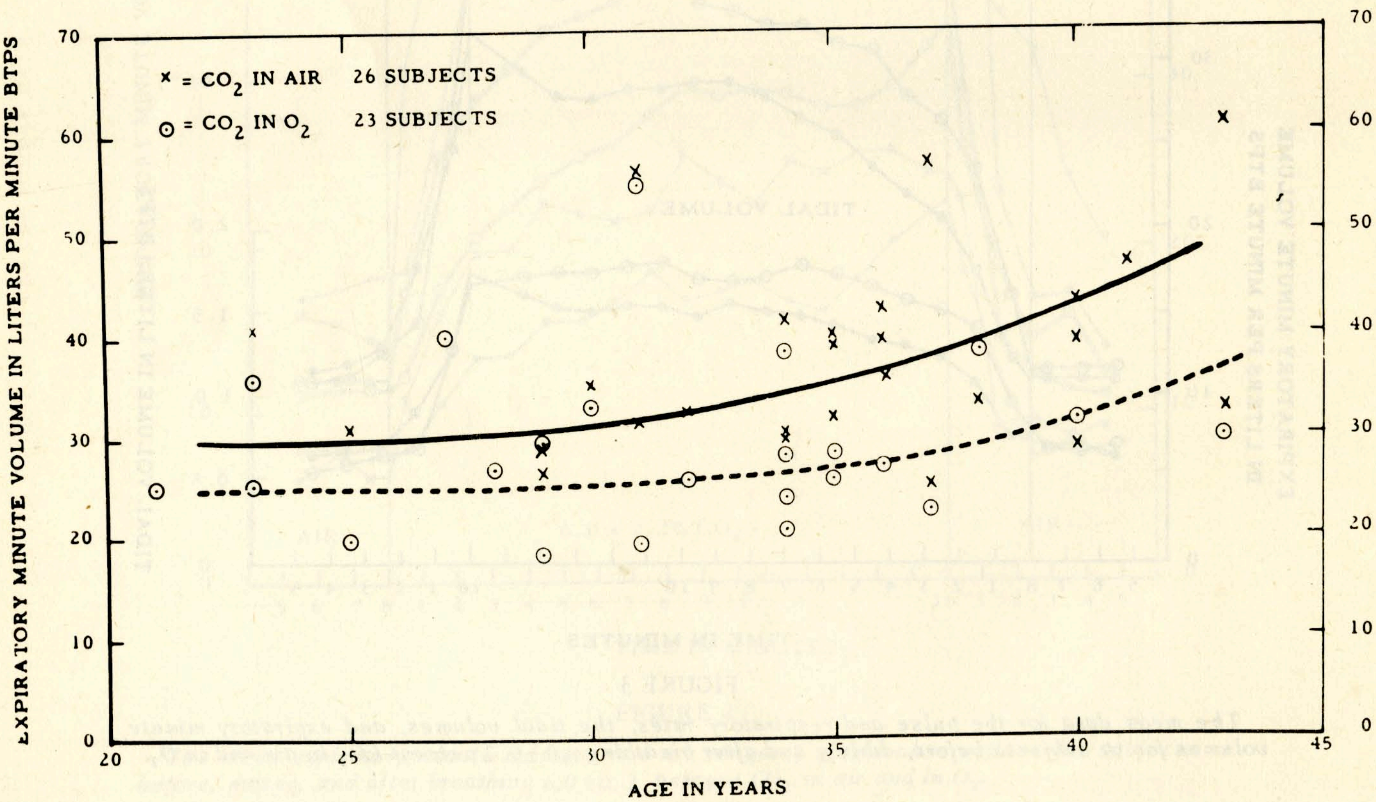

FIGURE 5

The relation between age and the average expiratory minute volumes taken for the 11th to the 15th minutes, inclusive, for subjects inhaling 6.0 ± 0.2 percent CO_2 in air and in O_2.

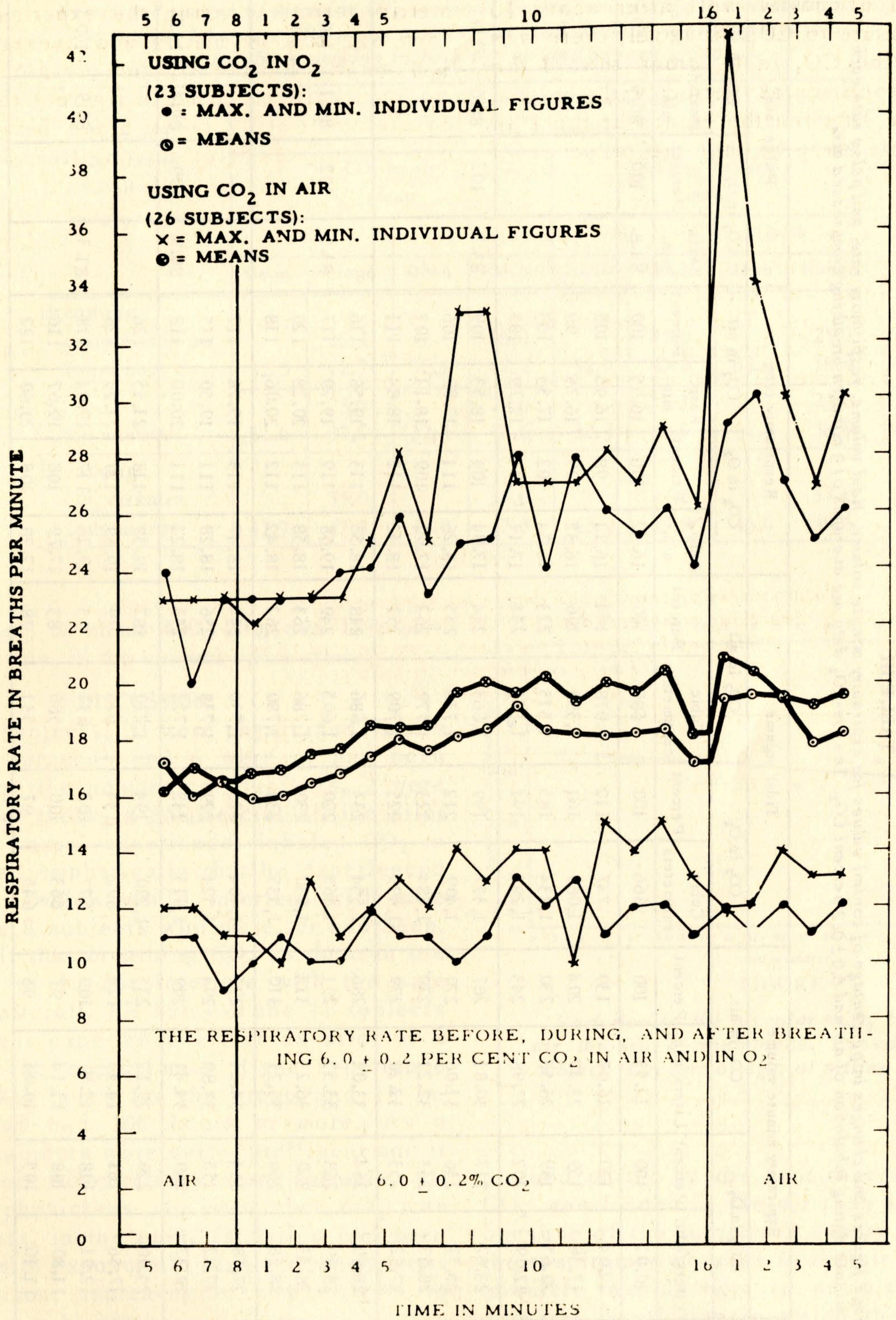

FIGURE 6

The average and range of respiratory rates for subjects breathing air and 6.0 ± 0.2 per cent CO_2 in air and in O_2.

TABLE III

The average figures and changes in percentage of control values for expiratory minute volume, tidal volume, respiratory rate, and pulse rate each minute during inhalation of air and 6.0 ± 0.2 percent CO_2. The pre-CO_2 data are averages of 3 minutes breathing compressed air.

Minute number for air and CO_2 breathing	Expiratory minute volume				Tidal volume				Respiratory rate				Pulse rate			
	CO_2 in O_2		CO_2 in air		CO_2 in O_2		CO_2 in air		CO_2 in O_2		CO_2 in air		CO_2 in O_2		CO_2 in air	
	Liters/min.	Percent	Liters/min.	Percent	Cubic centimeters	Percent	Cubic centimeters	Percent	Resp./min.	Percent	Resp./min.	Percent	Beats/min.	Percent	Beats/min.	Percent
Pre-CO_2	10.92	100	11.53	100	666	100	680	100	16.42	100	16.95	100	81.8	100	80.9	100
CO_2 1	12.04	110	16.07	139	747	112	978	144	16.11	98	16.95	100				
2	17.38	159	23.47	204	1,065	160	1,398	206	16.32	99	16.75	99				
3	20.65	189	26.56	230	1,234	185	1,515	223	16.74	102	17.53	103				
4	22.09	202	27.98	243	1,291	194	1,573	231	17.11	104	17.79	105				
5	23.67	217	30.81	267	1,327	199	1,663	244	17.84	109	18.53	109	83.1	102	88.6	110
6	25.72	236	31.06	270	1,409	212	1,736	255	18.26	111	17.89	106				
7	26.57	243	32.21	279	1,484	223	1,779	262	17.90	109	18.11	107				
8	27.62	253	32.20	279	1,499	225	1,709	251	18.42	112	18.84	111				
9	28.80	264	33.01	286	1,554	233	1,686	248	18.53	113	19.58	116				
10	28.69	263	33.55	291	1,465	220	1,695	249	19.58	119	19.79	117	83.5	102	89.1	110
11	28.43	260	36.23	314	1,530	230	1,786	263	18.58	113	20.28	120				
12	28.28	259	35.71	310	1,535	231	1,780	262	18.42	112	20.06	118				
13	27.78	254	34.21	297	1,504	226	1,730	254	18.47	113	19.78	117				
14	27.87	255	33.89	294	1,524	229	1,738	256	18.28	111	19.50	115				
15	29.37	269	34.41	299	1,613	242	1,721	253	18.21	111	20.00	118	80.8	99	89.4	111
Post CO_2 1	25.00	229	27.12	235	1,290	194	1,270	187	19.38	118	21.35	126				
2	17.56	161	14.33	124	892	134	673	99	19.69	120	21.29	126				
3	12.91	118	12.59	109	677	102	631	93	19.28	117	19.94	118	81.3	99	80.9	100
4	11.80	108	11.14	97	663	100	566	83	17.79	108	19.67	116				
5	11.46	105	10.94	95	645	97	531	78	17.78	108	20.60	122				

TABLE IV

Means and ranges of alveolar CO_2 tensions before, and during the inhalation of 6.0 ±0.2 percent CO_2 in air and oxygen (16th minute) for all subjects and for those serving in both the air and oxygen groups.

Time and gas mixture inhaled when sample taken	Partial pressure of alveolar CO_2 in mm.Hg							
	CO_2 in air group				CO_2 in oxygen group			
	All		Both		All		Both	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Breathing compressed air 1st minute	32.3	26.1 42.2	32.9	26.1 42.2	32.9	25.0 40.6	31.8	25.0 38.4
5th minute	31.6	23.0 37.6	32.1	23.0 37.6	32.3	23.0 38.9	32.1	23.0 38.9
Breathing CO_2 mixture 16th minute	42.7	35.0 47.8	43.0	35.0 47.8	43.2	37.6 49.8	43.0	37.6 48.6

was a maximum of about 470, 200, and 123, percent, respectively, in the subject under study.

DISCUSSION

Of the 31 subjects, 20 were physicians. Seven were flight surgeons and 6 were or had been pilots. Among the nonmedical subjects, 2 were pilots. One of these, a commercial airline pilot with 12,000 hours' experience, inhaled CO_2 in air and stated emphatically that he experienced no symptoms which would interfere with safe piloting. The 8 subjects who were, or had been, pilots all felt that breathing CO_2 as done in the experiments would not interfere with the safe handling of aircraft. All but 3 of the 31 subjects had had flight experience either as pilot or a passenger. The approximate flight experience totaled 22,500 hours for the group and 15 individuals had had 100 hours or more. As a whole, the subjects were quite intelligent and it was felt their observations were reliable, although the physicians all knew that CO_2 was toxic and that, in the past, fatalities had been associated with exposure to high concentrations. For this reason, apprehension was a factor in several of the subjects.

The alveolar data on the pCO_2 show an average rise which is essentially the same for both the air and O_2 groups in spite of the difference in the alveolar ventilation as judged by the expiratory minute volume figures. This may be explained partly by the fact that more metabolic CO_2 was formed in the air than in the O_2 group because of the increased energy expenditure of the respiratory muscles in the air group. Another possible explanation is an alteration in the cerebral circulation in which the vasoconstrictive effects of oxygen might play a part. This possibility is consistent with the findings of Kety and Schmidt (7) who reported a decrease of 13 percent in cerebral blood flow in man which was associated with inhaling 85 to 90 percent

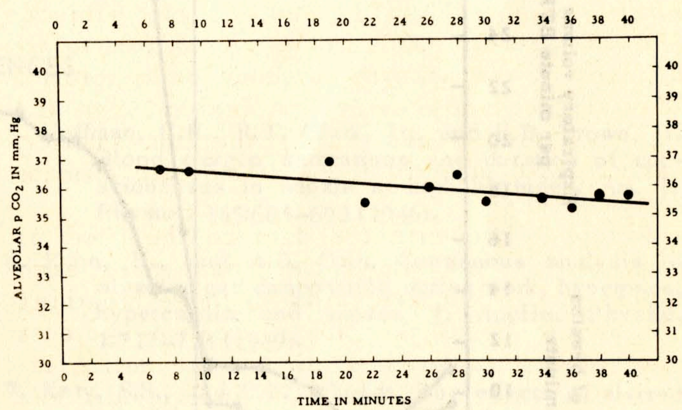

FIGURE 7

Variation in the alveolar pCO_2 breathing room air through a mouthpiece. Experienced female subject, 37 years of age, at sitting rest.

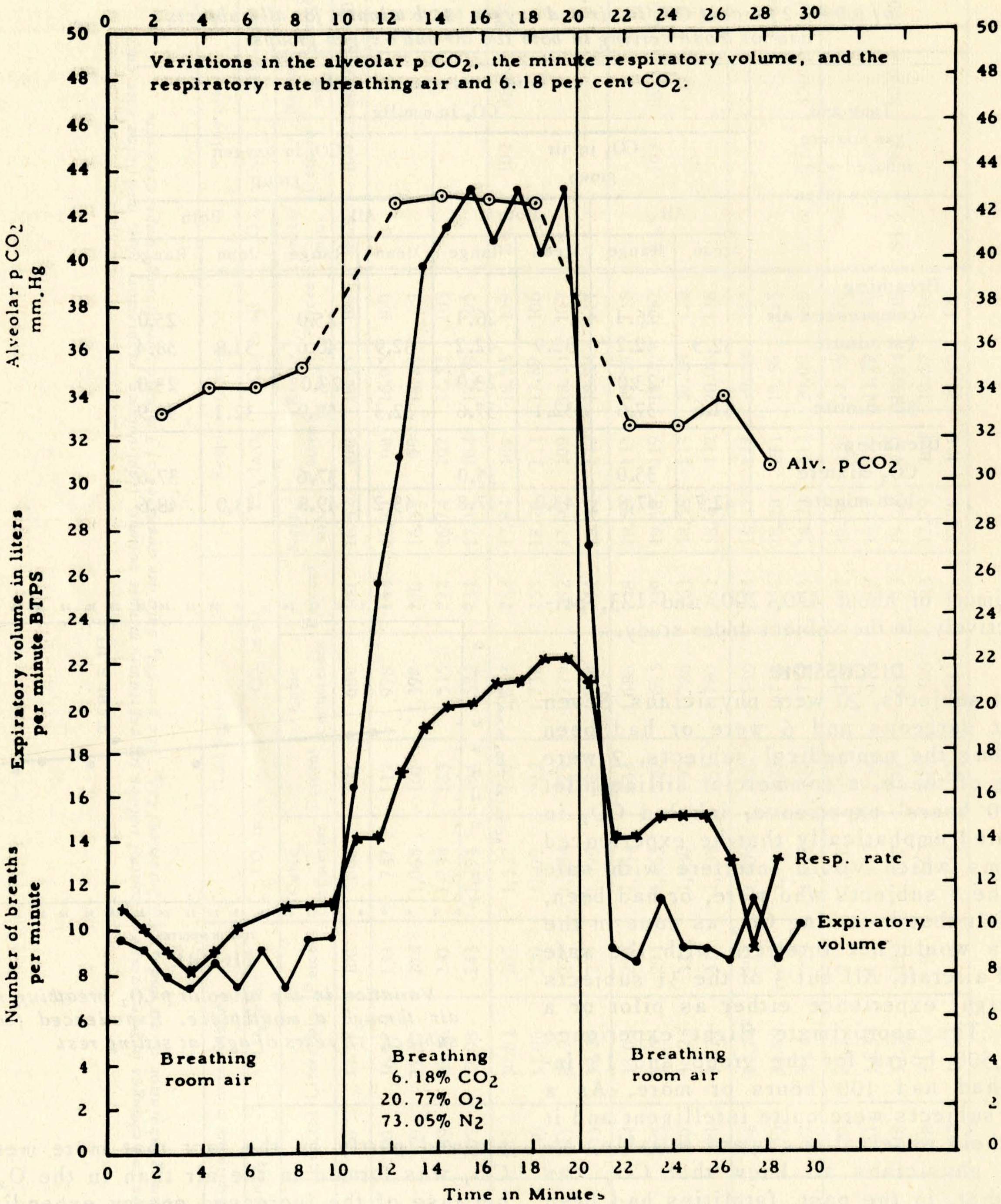

FIGURE 8

Variations in the expiratory minute volumes, respiratory rates, and alveolar pCO_2 breathing room air and while inhaling a gas mixture containing 6.18, 20.77, and 73.05 percent CO_2, O_2, and N_2, respectively. Experienced fasting male subject, 35 years of age, breathing through a mouthpiece at sitting rest.

O_2 at near sea level. The difference between the respiratory effect of CO_2 in air and in O_2 is now under careful study and will be reported in a later paper.

The average pCO_2 breathing air prior to CO_2 inhalations was 32.3 and 32.9 mm.Hg for the 1st minute for the air and O_2 groups and 31.6 and 32.3 mm.Hg for the 5th minute for the two groups, respectively. These figures are close to those for individuals acclimatized to 5,000 ft., reported by Rahn and Otis (8), who summarized data from several sources in the literature. When the common hyperventilation, using masks (9), is considered, the data from the present study and those cited in the literature are practically identical.

It is interesting to note that Rahn and Otis (6), working at near sea level, reported a rise in the alveolar pCO_2 of 11 mm.Hg when the inhaled pCO_2 was 34 mm. of Hg. In this study at near 5,000 ft. the inhaled pCO_2 was close to 35 mm. Hg on the average with a mean rise in alveolar pCO_2 to 11 mm.Hg at the end of the CO_2 breathing period.

The fact that in 84 percent of the man-exposures CO_2 was detected by a sensation of taste or smell, and that all subjects noted a stimulation of breathing, makes it apparent that a very high percentage of individuals can detect CO_2 at the concentration studied in the early stages of exposure. Certainly the interests of safety in aviation demand that all aircrewmen should be indoctrinated concerning the physiological and toxicological effects of CO_2. This opinion also recognizes the thesis that *every* pilot should be aware of *every potential hazard* associated with flying any given aircraft.

ACKNOWLEDGMENTS

Acknowledgment is made of the assistance of Miss Elizabeth Roorbach, Donald Hudson, Dominic Bellino, William Osburn, and Mrs. Blanche Bailey in the analysis of data and the preparation of illustrations and tables.

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