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THE EFFECTS OF OXYGEN DEPRIVATION (HIGH ALTITUDE) ON THE HUMAN ORGANISM

By

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The views expressed in this report are those of the writer and not necessarily of the Bureau of Air Commerce or the Department of Commerce.

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THE EFFECTS OF OXYGEN DEPRIVATION (HIGH ALTITUDE) ON THE HUMAN ORGANISM

Ross A. McFarland*

I. The Necessity of Studying the Effects of High Altitude in Aviation.

The most important physical variables which affect the human organism while in flight in the modern commercial aeroplane appear to be vibration, noise, ventilation, temperature, rate of ascent and descent, and altitude. The zones of passenger comfort and discomfort in these and other variables are shown graphically in Figure 1 (from Bassett). With the possible exception of rate of descent and altitude, these factors have been brought well within the so-called comfort zone. Their elimination as unpleasant aspects of flying will soon be brought about by the skill of technical engineering. The most important physical variables which remain to be controlled appear to be the physiological and psychological impairment resulting from the lack of oxygen available for the organism at high altitude and the action of sudden changes in barometric pressure on the eardrum of the middle ear. These two problems are also intimately tied up with engineering skill, for their solution lies in the development of supercharged cabins. This equipment, however, will not be available for some time, and many doubt the practicability of such procedures for flights of short duration in domestic air transportation.

This report is concerned with the effects of the diminished partial pressure of oxygen encountered while in flight at high altitudes on the

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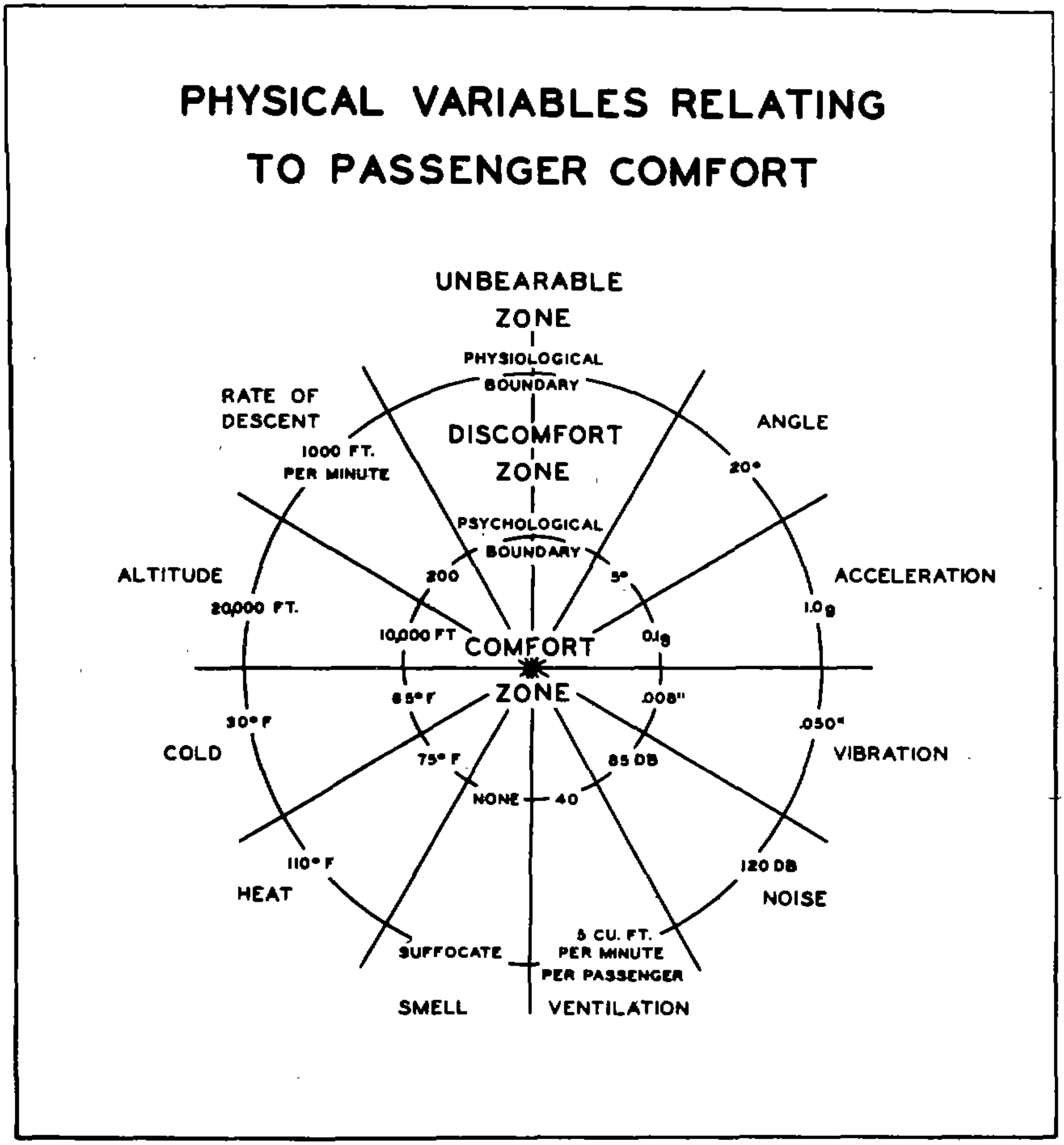

FIG. I (BASSETT)

average flying population. The development of the human organism has, for the most part, taken place relatively close to sea level. There are millions of people who have become acclimatized to altitudes as high as 8,000 to 14,000 feet in the mountainous regions of the Andes, the Alps, and the Himalayas. However, transporting the human body by aeroplane to similar altitudes, even though for short periods of time, cannot help but have marked effects on various organic functions. In spite of the amazing capacity of the human organism to adjust to sudden changes in the physical environment, whether it be extremes in temperature, in humidity, in the ionization of the air, or in the barometric pressure and the consequent alteration in the available oxygen supply to the tissues, the problem demands thorough scientific analysis. The eventual success of commercial air transportation, in competition with other means of travel, appears, among other things, to be intimately associated with maintaining a relatively normal organism during, and at the end of each flight.

Physiologists have been interested in the effects of high altitude for many years. A number of extensive investigations have been carried out during varying periods of acclimatization in mountain expeditions, notably those of Haldane, Henderson and Schneider (18) to Pike's Peak (1911), of Barcroft et al (2) to the Peruvian Andes (1922) and of Dill et al (17,38) to the Chilean Andes (1935). In the Alps extensive investigations have been carried out by Mosso (51), Zuntz (70) and Loewy (40). More recently Hartmann (29) has made studies at very high altitudes in the Himalayas. There is also an extensive amount of data available from the experiments of the physiologists and psychologists who selected the pilots for altitude flying during the World War with the rebreather apparatus and low pressure chamber.

In addition, there is an extensive literature dealing with many specialized aspects of the effects of oxygen deprivation in chamber experiments with rebreathing devices and with Douglas bags. Although the data from all of these sources are relevant, the experimental procedures have not duplicated the specific rates of ascent and altitudes which are experienced by passengers during the average flight on the domestic air lines.

In this report, therefore, an attempt has been made to observe the physiological, biochemical, and psychological changes associated with varying rates of ascent and lengthsof exposure to altitudes of 10,000 to 18,000 feet. Approximately 200 subjects, varying in age from 18 to 72 years, were tested individually. For the most part they were of average physical fitness, with the exception of the group of psychoneurotics whose chief complaints related to chronic exhaustion and fatigue. On account of convenience and expense, the experiments have been carried out in a low oxygen chamber at sea level. These findings have been compared with the data from a limited number of experiments in a low pressure chamber and during actual flights at high altitude. Thus far we have attempted to study only the effects of the most important variable of high altitude, namely, the diminished partial pressure of oxygen. Further experiments should be carried out during actual flights to high altitude to observe whether the changes in total pressure will give results significantly different from those obtained from alteration in the partial pressure. It is also important to determine whether the psychological effects of flying due to fear, etc., will significantly alter the data obtained from chamber studies at sea level.

II. The Physical Factors of the Environment at High Altitude.

The air which is inspired at sea level contains, by volume, and on the dry basis, 20.93 per cent of oxygen (O_2), about 78 per cent of nitrogen (N_2), 0.04 per cent of carbon dioxide (CO_2), and about 1.0 per cent of the inert gases, argon, neon, xenon, krypton and helium. Since oxygen constitutes about one-fifth of the air, the partial pressure of oxygen alone, therefore, is 159 mm. Hg. As one rises above the level of the sea, the pressure of the atmosphere falls (barometric pressure) so that at any given altitude the concentration of gases in a given volume of air is reduced. At 19,000 feet, for example, although the composition of the air is unaltered,[1] the total atmospheric pressure and the partial pressure of oxygen are reduced one-half. The partial pressure of oxygen in the lungs is less than half that at sea level; also atmospheric air becomes saturated with water vapor at 37° C., as it reaches the alveoli of the lungs regardless of the barometric pressure. Thus 47 mm. of pressure must be deducted from the 760 mm., giving us dry air in the depth of the lungs at a pressure of 713 mm., a reduction of about 6% at sea level. When the barometric pressure is one-half normal, the diluting effect of water vapor will be twice as great as at sea level. There is a reduction of oxygen percentage from that in the atmosphere to that in the alveoli (due to

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[1] In the recent stratosphere experiments of Captain Stevens, sampling of the atmosphere indicated that the composition of the air is practically unchanged up to an altitude of approximately 14 miles.

dilution by the residual air of the lungs) of one-fourth or even one-third. We have, therefore, at sea level in the alveoli an oxygen percentage of 14 to 15, and an oxygen pressure of 103 mm. Hg on the average. The partial pressure of the oxygen of alveolar air normally is greater than that of the blood stream, resulting in a flow of oxygen from the alveoli into the blood where it is held in combination in the blood cells by means of hemoglobin.

Table 1 shows altitude in relation to the barometric pressure, the partial pressure of oxygen in the atmosphere, the partial pressure of oxygen in the alveolar air, and the percentage of oxygen available for the organism.

Table 1

Altitude	Barometric Pressure (mm. Hg)	O_2 Pressure (mm. Hg)	O_2 Pressure in Alveolar Air (mm. Hg)	Equivalent % O_2 in Air Diluted With N_2 at Sea Level
Sea level	760	159	103.0	20.93
6,000	602	126	78.0	16.58
10,000	506	106	63.5	13.94
14,000	444	93	53.0	12.23
18,000	380	80	45.0	10.46
22,000	328	71	36.0	9.03
28,000	253	53	20.0	6.97
30,000	230	47		6.33

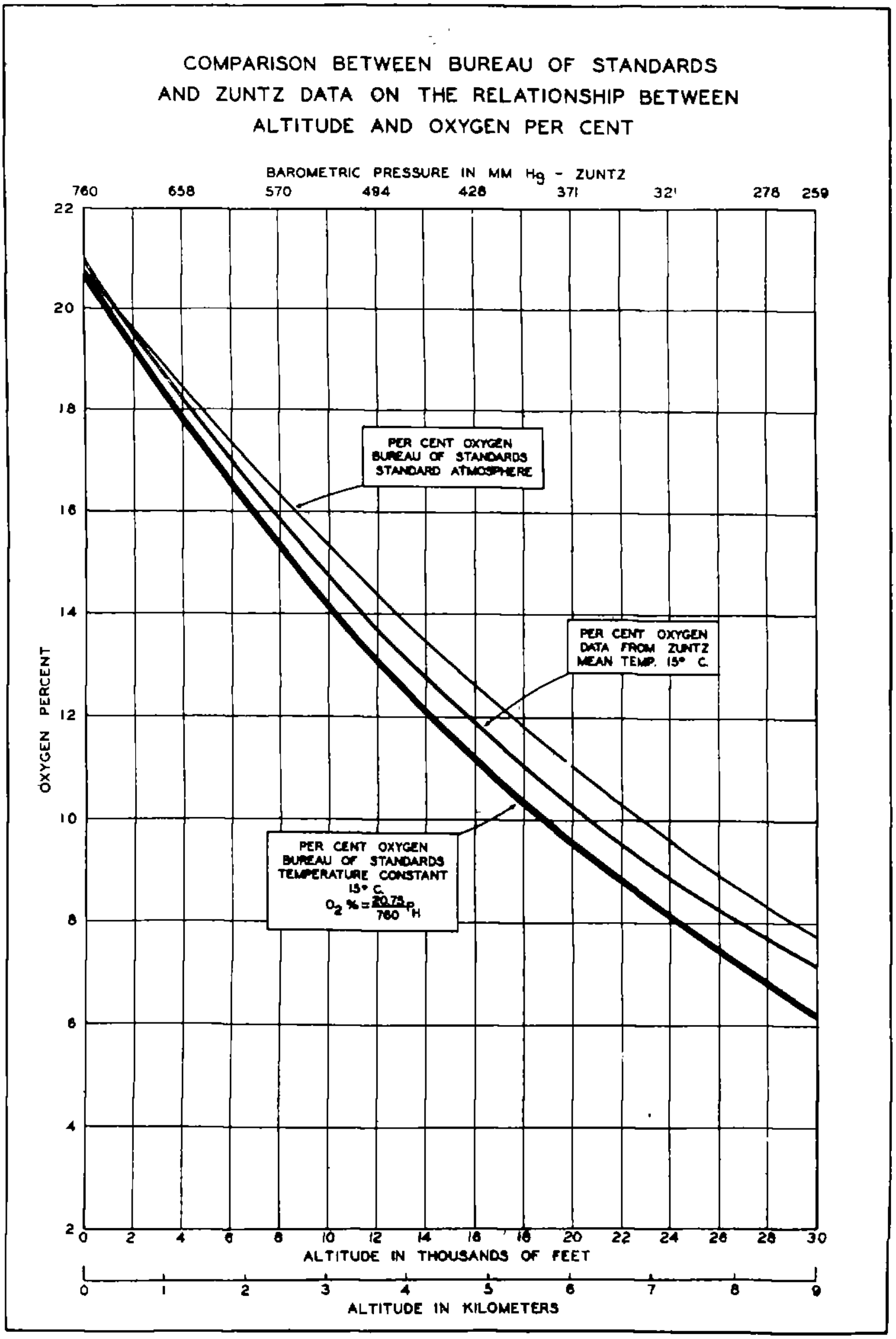
The relationship between altitude, barometric pressure and the percentage of oxygen available for the organism is shown in Table 2, both for the standard atmosphere and at a constant temperature of 15° Centigrade (data from U. S. Bureau of Standards). A comparison between the U. S. Bureau

Table 2

Bureau of Standards

Relation of Altitude, Pressure and Oxygen

Altitude Feet	Air Temperature °C	Pressure mm.Hg.	Temperature Constant, 15° C.	Standard Atmosphere
0	15.0	760.0	20.75	20.75
1,000	13.0	732.9	20.01	20.15
2,000	11.0	706.6	19.29	19.56
3,000	9.1	681.1	18.60	18.99
4,000	7.1	656.3	17.92	18.43
5,000	5.1	632.3	17.26	17.88
6,000	3.1	609.0	16.63	16.63
7,000	1.1	586.4	16.01	16.82
8,000	-0.8	564.4	15.41	16.31
9,000	-2.8	543.2	14.83	15.81
10,000	-4.8	522.6	14.27	15.32
11,000	-6.8	502.6	13.72	14.84
12,000	-8.8	483.3	13.20	14.38
13,000	-10.8	464.5	12.68	13.93
14,000	-12.7	446.4	12.19	13.49
15,000	-14.7	428.8	11.71	13.05
16,000	-16.7	411.8	11.24	12.63
17,000	-18.7	395.3	10.79	12.22
18,000	-20.7	379.4	10.36	11.82
19,000	-22.6	364.0	9.94	11.43
20,000	-24.6	349.1	9.53	11.05
21,000	-26.6	334.7	9.14	10.68
22,000	-28.6	320.8	8.96	10.32
23,000	-30.6	307.4	8.39	9.97
24,000	-32.5	294.4	8.04	9.63
25,000	-34.5	281.9	7.70	9.30
26,000	-36.5	269.8	7.37	8.97
27,000	-38.5	258.1	7.05	8.65
28,000	-40.5	246.9	6.74	8.35
29,000	-42.5	236.0	6.44	8.03
30,000	-44.4	225.6	6.16	7.76
31,000	-46.4	215.5	5.88	7.48
32,000	-48.4	205.8	5.62	7.20
33,000	-50.4	196.4	5.36	6.94
34,000	-52.4	187.4	5.12	6.68
35,000	-54.3	178.7	4.88	6.43
36,000	-55.0	170.4	4.65	6.15
37,000	-55.0	162.4	4.43	5.86
38,000	-55.0	154.9	4.23	5.59
39,000	-65.0	147.6	4.03	5.32
40,000	-55.0	140.7	4.01	5.08



COMPARISON BETWEEN BUREAU OF STANDARDS
AND ZUNTZ DATA ON THE RELATIONSHIP BETWEEN
ALTITUDE AND OXYGEN PER CENT
BAROMETRIC PRESSURE IN MM Hg - ZUNTZ
760
658
570
494
428
371
321
278
259
OXYGEN PERCENT
PER CENT OXYGEN
BUREAU OF STANDARDS
STANDARD ATMOSPHERE
PER CENT OXYGEN
DATA FROM ZUNTZ
MEAN TEMP. 15° C.
PER CENT OXYGEN
BUREAU OF STANDARDS
TEMPERATURE CONSTANT
15° C.
$O_2\% = \frac{20.73}{760} P_H$
ALTITUDE IN THOUSANDS OF FEET
ALTITUDE IN KILOMETERS

FIG. 2

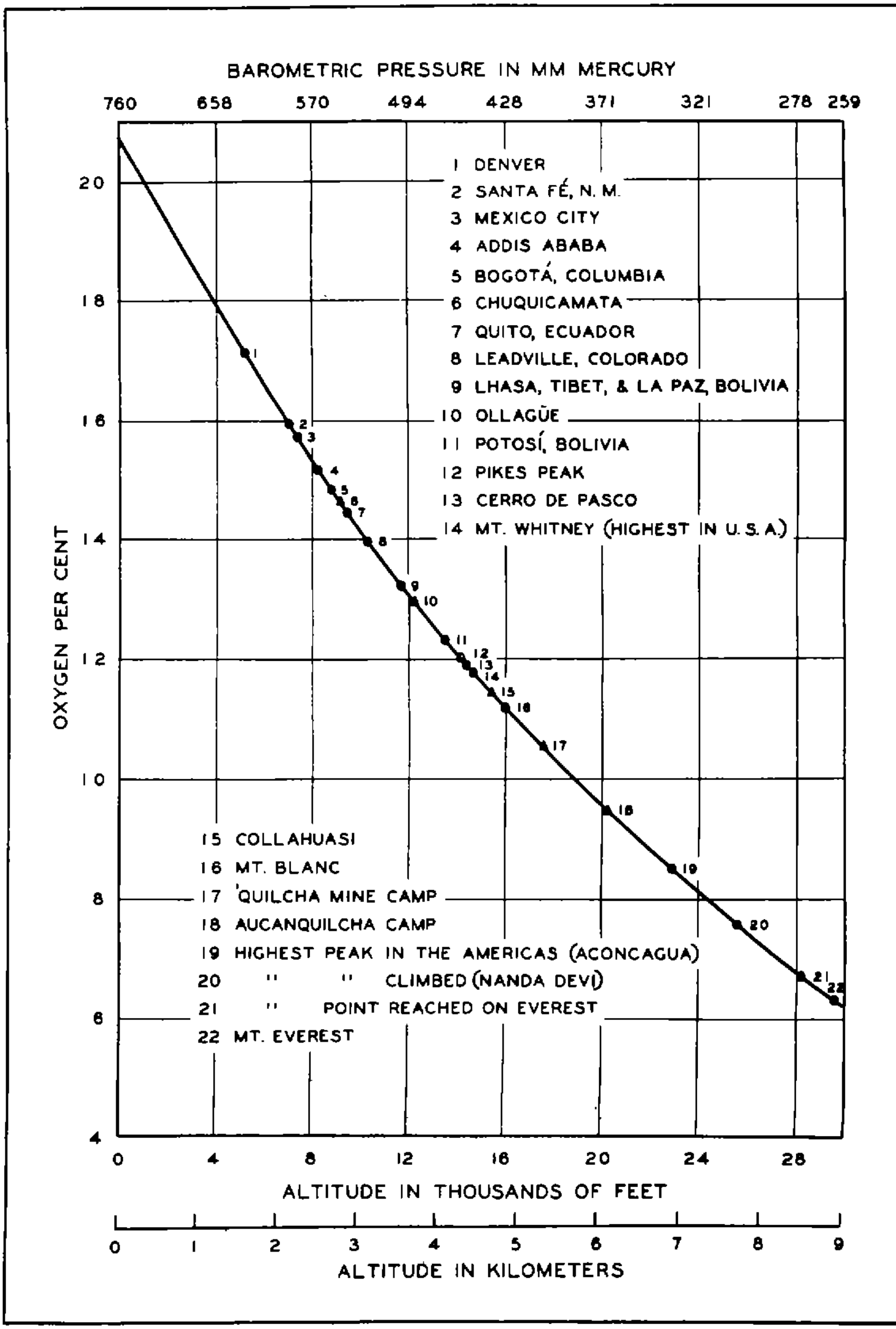
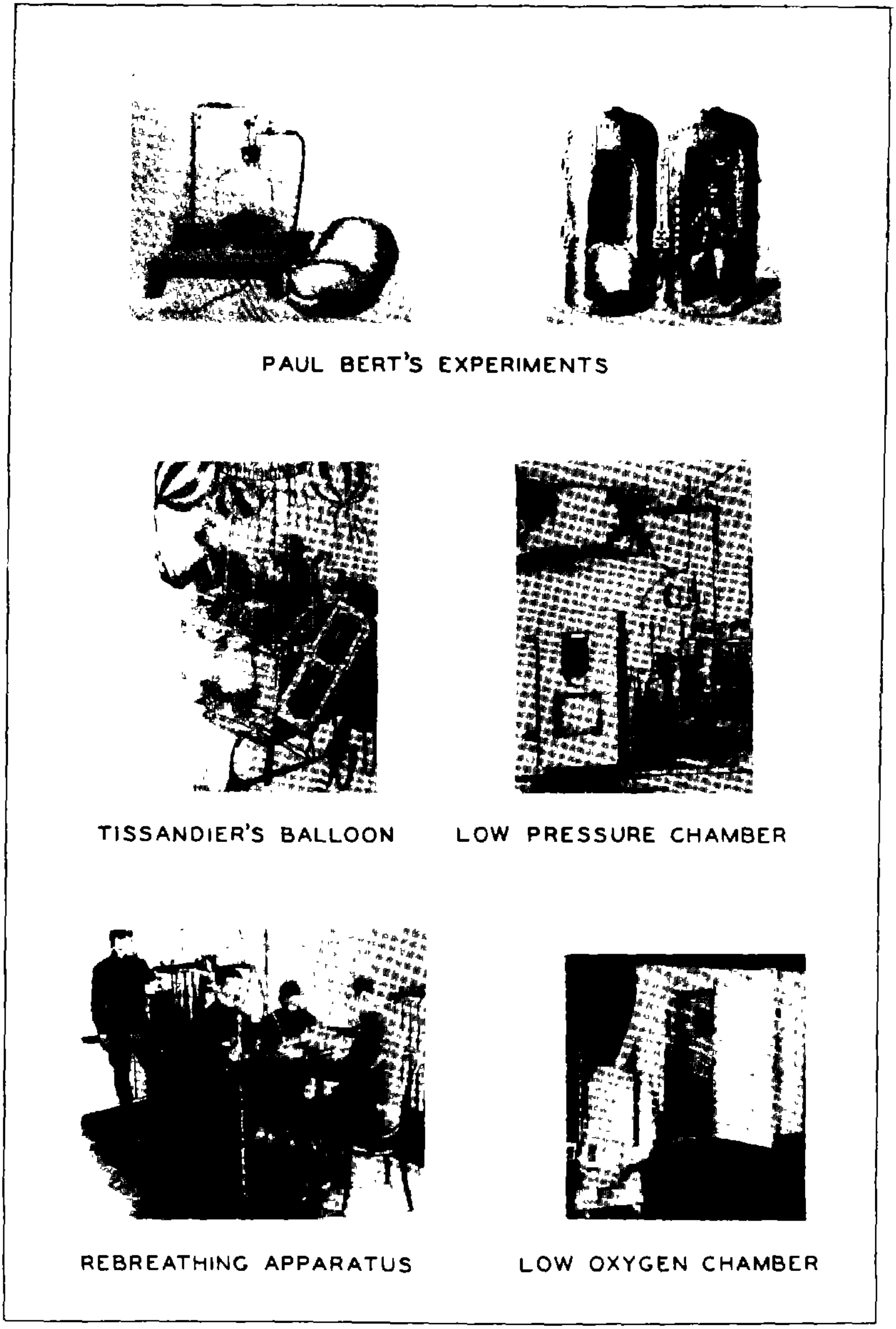


FIG. 3. (CHILEAN EXPEDITION 1935)

of Standards data and the Zuntz data of the relationship between altitude and oxygen per cent is shown graphically in Figure 2. At 14,000 feet, for example, where the barometric pressure is 490, the percentage of oxygen available for the organism at 15° Centigrade is only 12. A number of well known cities and mountain peaks have been charted in Figure 3 in relation to the various stations established by the International High Altitude Expedition to Chile (1935). (Cf. 38,44.)

The original contention of Paul Bert (1878) has been amply verified by subsequent research; namely, that the important factor in high altitude which causes the abnormal symptoms in the organism is the diminution, not in the mechanical or <u>total</u> pressure, but in the diminished <u>partial</u> pressure of the atmospheric oxygen and the consequent decrease in the alveolar oxygen and oxygen saturation of the arterial blood. In other words, he demonstrated quite conclusively that the physiological action of oxygen and other gases depends on their partial pressures. In a series of experiments on animals (chiefly sparrows) (Figure 4), Bert proved that death was due either to increased pressure of carbon dioxide or to diminished pressure of oxygen. At ordinary pressure, and with ordinary air enclosed in the vessel (Figure 4), death occurred when the oxygen percentage fell to about 3.5 or when the carbon dioxide reached 26 per cent. At half the ordinary pressure, 7.0 was the fatal oxygen percentage, so that the partial pressure of oxygen was the same; and so on down to pressures of a third and even a fourth of an atmosphere. The cause of death depended simply on whether 3.5 per cent of an atmosphere of oxygen or 26 per cent of an atmosphere of carbon dioxide was reached first. The mere mechanical



PAUL BERT'S EXPERIMENTS

TISSANDIER'S BALLOON

LOW PRESSURE CHAMBER

REBREATHING APPARATUS

LOW OXYGEN CHAMBER

FIG. 4

pressure had no observable influence. Bert repeated these experiments on himself under less extreme conditions and obtained similar results. If, for example, he breathed excess oxygen from outside the chamber through a tube (Figure 4), but varied the barometric or total pressure in the chamber, he remained normal until simulated altitudes of 30,000 to 35,000 feet were reached. These findings have been verified on numerous occasions by Haldane (28A), Schneider (65), and others, and it is generally accepted that the ill effects of altitude are primarily due to the diminished oxygen pressure.

The above interpretation of the cause of mountain sickness was challenged by Mosso (51) twenty years later (1898), who maintained that as a physical consequence of the low atmospheric pressure more carbon dioxide was washed out of the blood in the lungs (acapnia) and that this was the most important cause of mountain sickness. Subsequent research has clearly established the fact, however, that the excessive loss of carbon dioxide which occurs at low atmospheric pressure is due to the increased breathing caused by the lack of oxygen. Acapnia, therefore, although an important contributing cause, is only a secondary result of the lowered oxygen pressure. Cf. Haldane (28A), Henderson (30), and Schneider (54).

A number of experimenters have verified Bert's conclusions that even while breathing excessive quantities of oxygen life cannot be maintained much beyond 35,000 feet altitude. Recently L. Hill (33) has observed that even while breathing 100 per cent oxygen loss of consciousness occurs in men and monkeys when the barometric pressure falls to approximately 115 mm. Hg or 45,000 feet. Marked motor incoordination as judged by handwriting tests, and general physiological and psychological deterioration begin in the neighborhood of 35,000 to 40,000 feet.

In order to keep a person in an environment similar to that at sea level while in flight at high altitude, as far as oxygen is concerned, one need only increase the percentage of oxygen in the inspired air, for the partial pressure of oxygen is correspondingly increased. In other words, to maintain a partial pressure of oxygen in the inspired air equivalent to 159 mm. Hg at the various altitudes, the percentage of oxygen should be increased in the proportions indicated in Table 3 and Figure 5/[(7)] In practice, while in flight at high altitude, these percentages should be greatly increased, since no allowance for ventilation and wastage has been made.

Table 3

Altitude in Relation to Barometric Pressure and Percentage of O_2 Needed to Maintain 159 mm. Hg in the Inspired Air

Altitude (in feet)	Barometric Pressure (mm. Hg)	O_2 Per Cent Needed
0	760	21.0
10,000	530	30.2
15,000	440	36.4
20,000	375	42.7
25,000	315	50.8
30,000	260	61.6
35,000	220	72.8

It is on this principle that the various types of oxygen supply apparatus used in altitude flights are constructed. By decreasing the percentage of oxygen (barometric pressure being unchanged) the partial pressure of oxygen is decreased. This is the method employed in the rebreather or altitude classification test at sea level. On the contrary, by increasing the

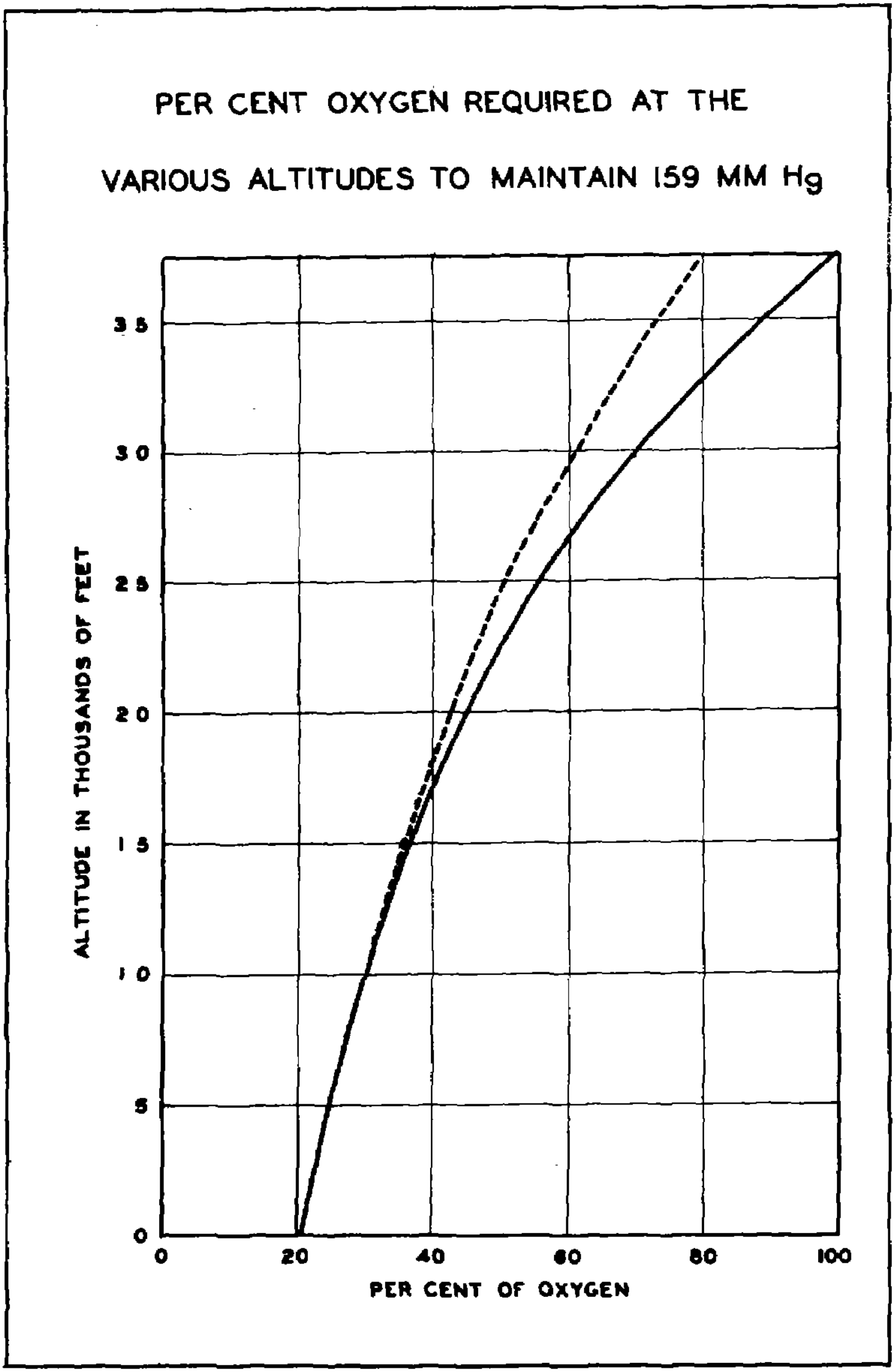


FIG. 5. (BEYNE AND CLARKE)

percentage of oxygen in the inspired air, the partial pressure is increased. At 40,000 feet, for example, the barometric pressure is 148 mm. Hg and the partial pressure of the oxygen of the atmospheric air is 32 mm. Hg--too low, of course, to sustain life. If by use of an oxygen supply apparatus the percentage of oxygen in the inspired air is increased from 21 per cent to approximately 80 per cent, then the partial pressure of the oxygen of the inspired air would be .80 x 148, or 118.4 mm. Hg, a pressure capable of sustaining life indefinitely.

III. Description of the Various Methods Used in Studying the Effects of Oxygen Want (Anoxia). *

A great deal of the confusion which exists relative to the effects of oxygen deprivation is probably due to the interpretation of data obtained with different experimental procedures. The results may vary, therefore, not because of the different effects of oxygen want produced by reducing the total pressure as contrasted with the partial pressure, but due to differences in the length of exposure, i.e., whether the various mechanisms of acclimatization have had a chance to take place. Also, in experiments of short duration the subject may be able to compensate by exerting greater effort. Before attempting to state the extent to which data obtained by the various methods are comparable, a brief description of the essential features of each will be discussed.

1. Mountain expeditions. The most satisfactory way of studying the effects of oxygen want over any extended period of time is to arrange to live at high altitudes in mountainous regions, as in the Alps or the Andes. Provided exposure to cold, excessive fatigue from climbing, etc.,

*The word anoxia is preferable to anoxemia because the latter term refers to oxygen lack in the blood alone. (52)

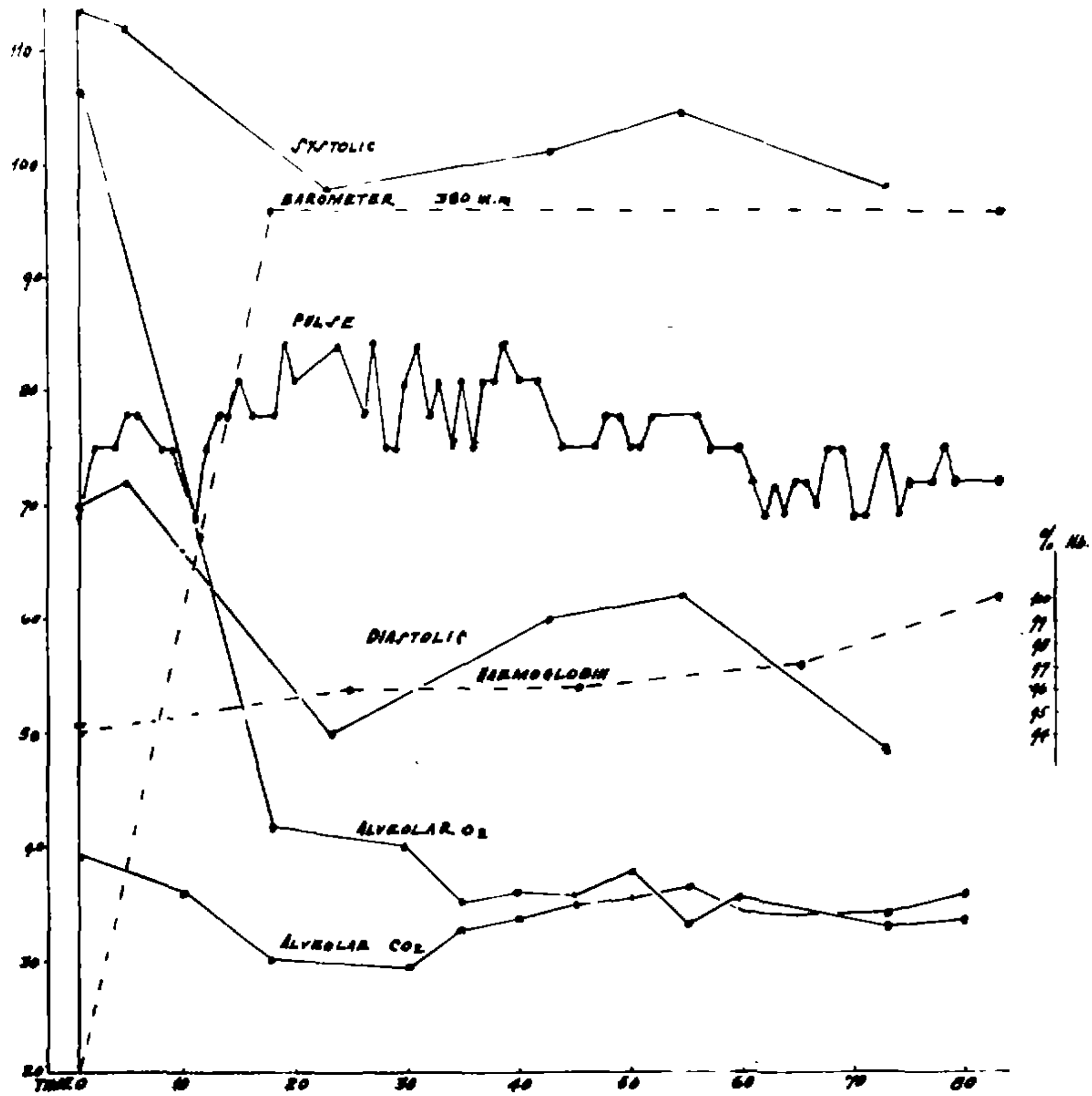
can be controlled, the mechanisms of acclimatization relating to the decreased oxygen pressure can be observed with great precision. Following the initial period of mountain sickness one becomes adjusted to the lack of oxygen and remains fairly comfortable while at rest. The highest altitudes to which man can become permanently acclimatized appear to be in the neighborhood of 18,000 feet as observed in the mining communities of South America (44).

2. The low pressure chamber. In the low pressure chamber both the pressure of the air and the concentration of oxygen can be altered so that the atmospheric conditions existing at high altitude can be simulated precisely at sea level. By means of a vacuum pump, the total pressure can be reduced corresponding to the precise atmospheric conditions at high altitude. If the percentage of oxygen is kept constant, the amount of oxygen available for the organism will decrease in the same fashion is in a aeroplane climb. A valve system automatically regulates air intake and admits a stream of fresh air to the chamber. In simulating ascent, the air is pumped out faster than it is allowed to enter, and in simulating descent, the pump is turned off and air is admitted at any desired rate. Any altitude may be maintained as long as desired. From the point of view of reproducing precisely the atmospheric conditions encountered during an aeroplane ascent, this procedure probably is the most satisfactory. These chambers are not simple to operate efficiently, particularly if it is desired to regulate not only the ventilation but temperature and humidity also. One of the low pressure chambers used in testing pilots for altitude tolerance during the World War at Mineola, Long Island, is shown in Figure 4. The results of a typical experiment in this chamber at 18,000 feet is shown in Figure 6. Cf. Air Service Medical (65).

3. The low oxygen chamber. In low oxygen chambers the supply of oxygen, or the partial pressure, is diminished by diluting air with nitrogen, leaving the total pressure the same as in the normal atmosphere at sea level. The oxygen pressure can be reduced at the desired rate by running in nitrogen from a cylinder through a flow meter simulating the reduction in oxygen pressure during a flight to high altitude. A motor blower unit may be used to circulate the air. The temperature and humidity may be controlled by blowing the contents of the chamber over ice so as to cool and dry the air; or preferably, an air conditioning unit may be installed so as to control automatically these variables. The accumulation of carbon dioxide is prevented by placing soda lime in the air circuit. A low oxygen chamber simplified in design and operation by Barach (4) is shown in Figure 4. This type of chamber is frequently used in clinical medicine in syndromes involving anoxia, such as pneumonia, emphysema or cardiac disorders. The per cent of oxygen in the inspired air is increased from 21 to 40-50 per cent. They are easy to operate, and are quite spacious and comfortable for experimental purposes. The expense is considerable, however, due to the supplies of nitrogen and oxygen which are necessary to maintain the desired experimental conditions. In this experiment, most of the tests were carried out in a chamber similar to the one shown in Figure 4.

4. The rebreathing apparatus. This method involves the use of a rebreathing machine such as the one devised by Henderson and Pierce (1) for testing the tolerance of aviators for high altitude flying during the World War. A photograph of this apparatus is shown in Figure 4. With this procedure the subject breathes over and over again the same air with the carbon

dioxide absorbed by soda lime. The oxygen is gradually absorbed by the subject and it is thereby reduced from 21 to 6 or 7 per cent. The average subject usually reaches the limit of his capacity to withstand the effects of oxygen deprivation in 20 to 25 minutes. The time at which various changes occur in respiration, pulse, and blood pressure is noted. The results from two typical experiments with this apparatus are shown in Figure 7 (subject in "poor training") and Figure 8 (subject exceptionally good). By analyzing the air in the tank at the end of the run, the altitude which the subject is supposedly able to stand is determined. A series of psychological tests given during the experiment on the rebreather involve: (1) choice reaction times to a series of lights; (2) control of the speed of a motor with the foot from auditory cues; and (3) the regulation of an ammeter from visual cues. Since all three of these tests are applied throughout the experiment, signs of deterioration usually show up in one or more of the tests. The chief criticism of this procedure is that the experiment takes place too rapidly and the subject, by exerting great effort, may be able to withstand the effects of the acute oxygen want for short periods of time until the final stages of deterioration. These experiments probably were successful in eliminating physically unfit pilots, but a false impression was given as to the altitudes at which aviators could remain for any length of time and maintain their physical and mental capacities. Flack (19) devised a somewhat similar apparatus for testing pilots in the Royal Air Force. This same principle of gradually absorbing the oxygen available and thus constantly reducing its percentage is widely used in physiological research on specialized aspects of anoxia. The hindrance involved to the subject from the rebreathing



—N. E. F., June 7, 1918. Taken to 380 mm. (18,000 feet) in 18 minutes in the low-pressure chamber and maintained at that level. This case illustrates the interrelation of the pulse rate, respiration, and oxygen-carrying capacity of the blood.

FIG. 6. (AIR SERVICE MEDICAL)

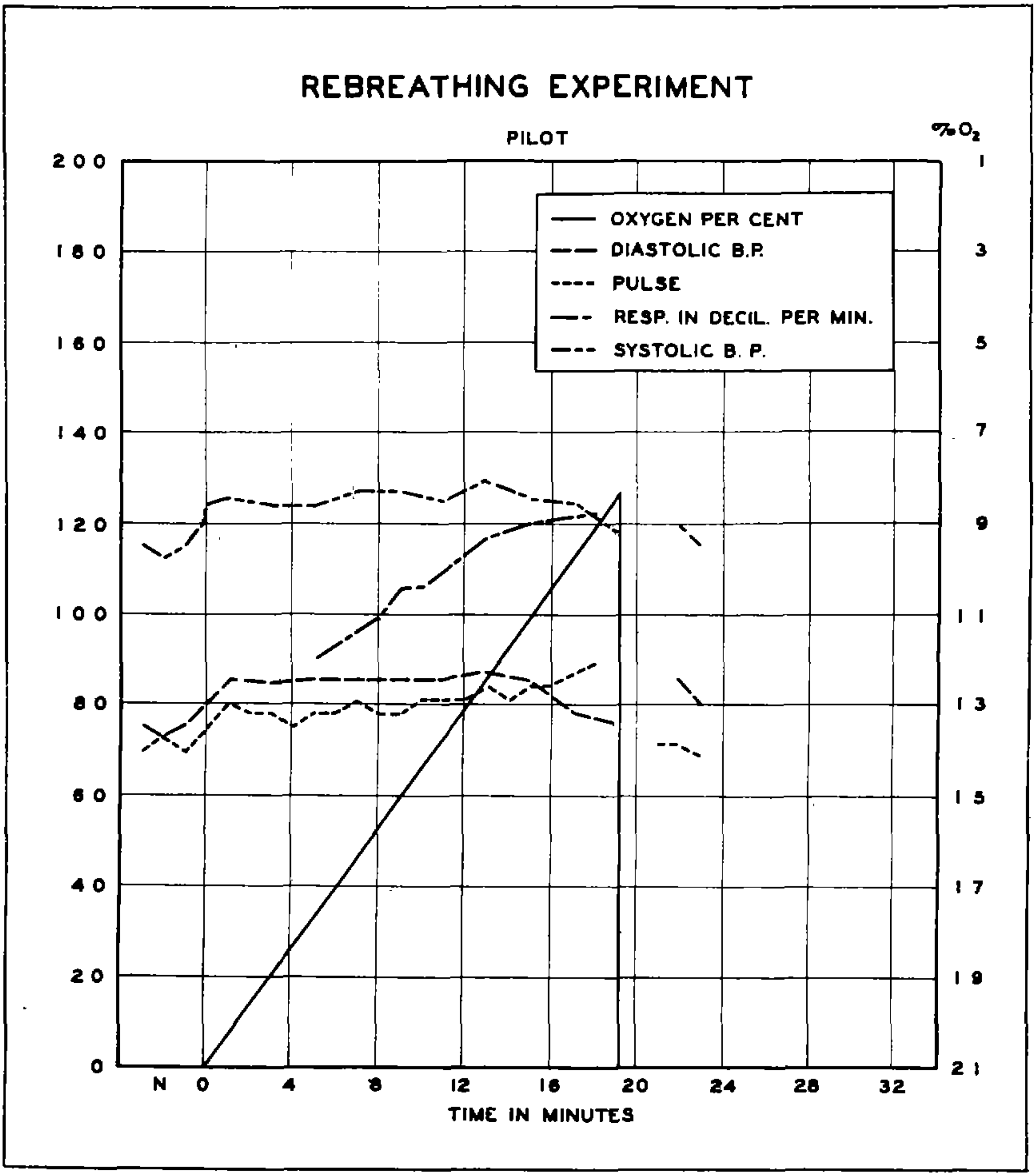


FIG. 7. (AIR SERVICE MEDICAL)

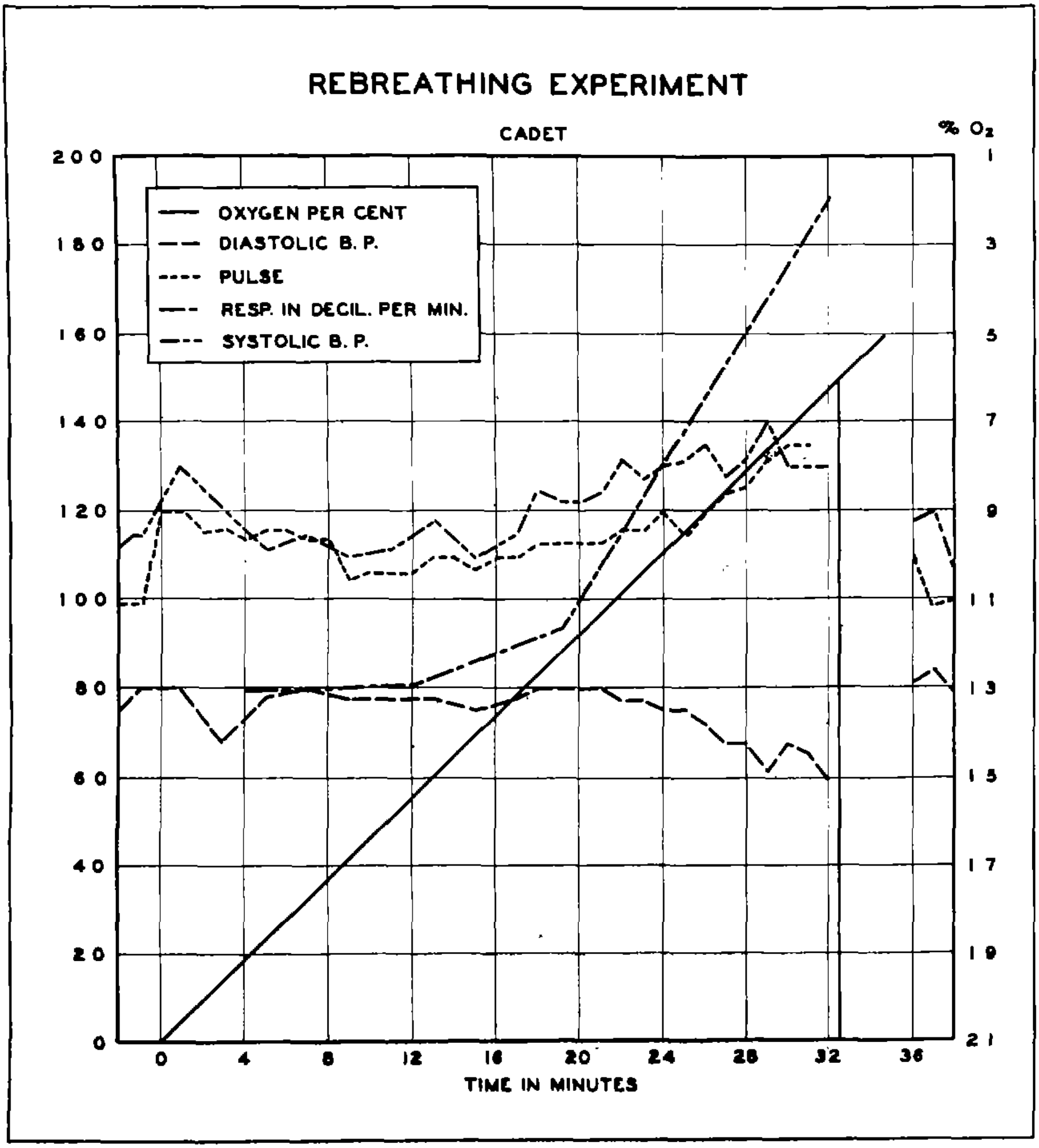


FIG. 8. (AIR SERVICE MEDICAL)

apparatus, mouthpiece, etc., is disadvantageous for experiments involving psychological tests. More recently, Christensen and Krogh (15) have recommended for testing pilots the use of a rebreather of 200 liters' capacity and containing 13 per cent oxygen to begin with. Since it takes 7 or 8 minutes to lower the oxygen percentage by 1 per cent with this procedure, from 30 to 40 minutes elapse before the oxygen is reduced to 7.6 per cent, where collapse may be anticipated in the average subject. The reduction of oxygen pressure is, therefore, more gradual, making it possible to observe the reactions of the subjects over longer periods of time.

5. The Douglas bag procedure is a fairly satisfactory method for studying specialized aspects of anoxia during short durations in the laboratory. The oxygen concentration can be determined for any desired percentage by running compressed air and nitrogen into the bag through a gas meter. If a 1,000 liter Douglas breathing bag is used, the supply may be sufficient to last for two hours with the concentration remaining the same throughout the experiment. The subject, with the nose clipped, breathes the oxygen mixtures from the bag into the room through a mouthpiece. It is difficult, however, to simulate the gradual reduction of oxygen pressure experienced during flights to high altitude by this method, and the mouthpiece tends to distract the inexperienced subject in taking psychological tests.

6. Flights to high altitude by aeroplane or balloon. The early balloon ascents by the meteorologist, Glaisher (25), and the balloonist, Coxwell (1862), and the French scientists Croce-Spinelli, Sivel and Tissandier (1875), friends of Paul Bert, first called attention to the striking symptoms of diminished oxygen pressure on the human mind and body (Figure 4). Although

their accounts of the effects of altitude were based on subjective reports, subsequent research under more controlled conditions has verified their general observations relating to sensory and mental impairment. This method is obviously impractical for scientific research relating to the human problems of modern air transportation.

The most direct attack upon the physiological and psychological effects of altitude in commercial air transportation would be to carry out experiments under actual flight conditions. By such a procedure the conditions could be controlled relating to rate of ascent, height attained, length of exposure, etc. The chief obstacle to such experiments, if they were to be carried out with large numbers of subjects over prolonged periods of time, would be the expense of maintaining and operating one of the most recent and best equipped planes used in commercial aviation. If planes of the most recent design and construction were not used, the vibration, noise, lack of space, and other distractions possibly would give rise to as much impairment in the psychological and certain of the physiological measurements at moderate altitudes as would the lowered oxygen pressure. Chamber studies at sea level are desirable if one wishes to separate the relative effects of oxygen deprivation from the effects of many of the other variables of flying, such as vibration, emotional excitement, sudden movements of the plane, etc. Experiments at sea level, however, cannot be entirely substituted for ones under actual flying conditions at high altitude. It is important to determine, for example, among many other things, whether the emotional excitement and various mechanisms of acclimatization tend to facilitate or handicap the average person's reaction to diminished oxygen pressure while in flight.

IV. Are the Results from These Various Methods Comparable?

In attempting to analyze the effects of oxygen want on passengers while in flight on commercial air transport planes, it is important to determine how much of the experimentation can be carried out in low oxygen and low pressure chambers at sea level and how much must be carried out while in the air. The following tentative conclusions based upon the data thus far available may be stated:

1. The original contention of Paul Bert, verified by such authorities as Haldane (28A), Barcroft (2A), Y. Henderson (32), Schneider (65), and more recently, by an extensive series of experiments in Germany (11), appears to be well founded; namely, that the important effects of high altitude result from the diminished partial pressure of oxygen. If one is interested primarily in the effects of diminished oxygen pressure at high altitude for a given altitude, rate of ascent and length of exposure, the essential conditions can be reproduced by reducing the total (barometric) pressure (pressure chamber) or by reducing the partial pressure or percentage of oxygen by diluting air with nitrogen (low oxygen chamber and Douglas bag).

2. The psychological effects, i.e., sensory, motor and mental deterioration, have been practically the same with all of the methods mentioned above when rate of ascent and length of exposure have been held constant. This also assumes that the subjects have not been seriously impeded by face masks, mouthpieces, etc. The results of the rebreathing experiments during the World War are not comparable and imply a false (too high) ceiling, since the subject tended to overcome the effects of oxygen want for short periods of time by exerting greater effort. The data from chamber studies are more comparable since adequate controls can be run and the subject is unhampered by mouthpieces, etc.

3. A number of authors have suggested recently that there are certain differences in the physiological responses to changes in the total pressure (low pressure chamber) as contrasted with the partial pressure (low oxygen or nitrogen dilution experiments). Kaiser (36) believes that under the latter conditions: (a) the circulatory responses are different; (b) one does not build up a tolerance for anoxia by repeated exposures; (c) the after-effects are more serious, lasting for a number of days or weeks; (d) the loss of consciousness precedes severe cramps, while during a change in total pressure the reverse order follows; and (e) in calculating the partial pressure of oxygen and corresponding altitudes that a subject can tolerate, the altitudes are at least two kilometers higher than that which actually can be reached at high altitude. It should be kept in mind that Kaiser's experiments were carried out at the extremes or critical levels of oxygen want. These differences, if true, are probably of less significance at more moderate altitudes, i.e., 8,000 to 18,000 feet.

Another physiological difference in the response to decreased barometric pressure which might not be present in nitrogen dilution experiments has been brought forward by Mateeff (43). He has suggested that the decrease in barometric pressure tends to expand the entire vascular bed, thereby reducing the pressure on the circulatory system. If the vascular system within the abdominal cavity expands owing to the general elasticity of the area, part of the effective pressure in the heart will be lost to other more rigidly confined vascular areas, the brain particularly suffering by the disturbed distribution of blood. Since the circulatory responses to moderate altitudes are not extreme, this can hardly be of great significance during short exposures of several hours' duration. Furthermore, the vascular area is filled with a liquid that cannot expand at a constant pressure; hence, there could be no change in the vascular area without a change in volume of the circulating blood. This has not been demonstrated in man, except possibly after long acclimatization. The expansion of gases in the abdomen and the possible impairment of the digestive processes under conditions of low barometric pressure as contrasted to changes in partial pressure alone may be of some significance, especially if gas forming foods have been ingested previous to the experiments.

It is also possible that the changes in inter-cranial pressure are different under lowered barometric pressure as contrasted with nitrogen dilution experiments. Armstrong, for example (personal communication), has reported marked changes in intra-cranial pressure in goats under lowered barometric pressure at very high altitudes. The needle was placed in the cisterna magna. The alterations were first observable around 16,000 feet, while the increase was 400 per cent at 25,000 feet. The administration of 100 per cent oxygen had no effect in decreasing the pressure. However, it is not desirable to make direct applications from the results obtained on animal subjects to human subjects. Also, it is well known from the studies of Schmidt (58,59), Lennox (39), Gibbs (23) and others (24) (16) that oxygen want under any condition gives rise to cerebral vasodilatation and increased blood flow, which could cause an increase in intra-cranial pressure. In general, although certain physiological differences may occur in experiments involving changes in the total pressure as contrasted with those of nitrogen dilution alone, the differences appear to be of minor significance at moderate altitudes.

4. The most important variable which appears to have given rise to markedly different reactions at similar reduced oxygen pressures relates to rate of ascent and length of exposure, or the length of time during which the oxygen pressure has been lowered and maintained at a constant level. As indicated above, the rebreathing experiments during the World War gave rise to the impression that altitudes of approximately 18,000 feet could be tolerated without oxygen because no serious impairment was manifested in many of the subjects until just previous to collapse at very high altitudes. The results from chamber studies over longer periods of time, where the subjects are unaware of the changes in the oxygen pressure and do not compensate by exerting greater effort, have indicated considerably lower altitudes in order to remain within margins of safety.

Marked differences also appear to be present in comparing the effects of altitude when attained by flight in an aeroplane as contrasted with a motorcar or railroad train. The winding railroad track or motor road of the average mountain route, as contrasted with the aeroplane in smooth air (also the absence of continual disturbances of the visual fields), may partially account for the fact that one rarely sees typical mountain sickness in an aeroplane at altitudes where it may be first observed on mountain railways.

To the question, can the data obtained at sea level be applied to the effects encountered while in flight at high altitude, it may be answered that the results obtained thus far seem to indicate that for corresponding rates of ascent and lengths of exposure the physiological and psychological effects are quite comparable, whether the oxygen deprivation is brought about by reducing the total pressure or by nitrogen dilution. In fact, as indicated above, there are certain advantages to be obtained from chamber studies at sea level, in that the effects of oxygen want alone can be separated from the effects of vibration, noise, emotional excitement and rough air. However, experiments at sea level cannot be entirely substituted for those carried out while in the air because some subjects may improve due to acclimatization, while others may deteriorate due to the emotional response to the more realistic setting.

V. Important Variables of High Altitude in Aviation.

The response of the average passenger on a commercial air transport plane to the lowered oxygen pressure encountered while in flight may be influenced by a large number of important variables. Since these various factors are of such great importance in understanding the physiological and psychological changes associated with successful acclimatization, a number of the more important ones are listed below. In the experiment which will be reported later, the rate of ascent in relation to the altitudes where the effects are first manifested and where the effects appear to become marked (i.e., between 10,000 feet and 20,000 feet) have been studied in a large group of subjects varying in age and physical fitness.

1. Height attained. At what altitude is the average passenger first affected physiologically and psychologically? Where are the effects marked, and at what altitude are the effects dangerous?

2. Rate of ascent. What rate of ascent is most advantageous so that mechanisms of acclimatization can be brought into action in the average passenger? For example, is it possible to take passengers to 12,000 feet in 1 hour and 15 minutes without serious distress, while in 15 minutes serious impairment is manifested? What are the effects of sudden loss of pressure or a very rapid rate of descent, other than on the middle ear?

3. Length of exposure. At what altitude can one become comfortably acclimatized so that no ill effects are manifested following the exposure, and at what altitude does definite deterioration set in after a certain number of hours, even though an initial adaptation appears to be taking place? For example, even though the average passenger is able to adjust to 10,000 feet or 12,000 feet for 3 to 4 hours, does he show definite ill effects after 6 to 8 hours?

4. Amount of physical exertion. At what altitude does a stewardess, a pilot, or a cameraman manifest symptoms of anoxemia, as contrasted to the passenger who sits quietly during a flight?

5. Roughness of the air and movements of the plane. In what way or ways does rough air accentuate the effects of a lowered oxygen pressure, or does "airsickness" become more acute when combined with the effects of anoxia at high altitude?

6. The physical characteristics of the individual. Since one of the most striking features of the response of a group of passengers to high

altitude is the great diversity of reactions, what are the most significant factors? In a group of 200 subjects, for example, several may collapse at 10,000 or 12,000 feet, while others may not collapse until 24,000 feet is reached. What sort of a distribution curve could be constructed so as to establish safe altitudes of operation for the entire flying population? A number of important variables appear to be:

(a) Age--chronological age contrasted with physiological age;

(b) Tolerance due to repeated flights;

(c) Amount of regular exercise each day or week;

(d) Degree of fatigue previous to flight;

(e) Number of hours of sleep the previous night;

(f) The kinds of food ingested;

(g) The amount of alcohol or narcotics previous to the flight;

(h) Emotional adaptation, freedom from worry, mental conflicts, etc.;

(i) Degree of relaxation or the reverse, i.e., muscular tension;

(j) Clinical anomalies, such as cardiac disorder, anemia, asthma, malaria, metabolic disturbances, tuberculosis, etc.

VI. The Physiological Responses of the Organism to Lack of Oxygen and Excess Carbon Dioxide.

There is no storage of oxygen in the body, unlike many other chemical substances necessary to maintain life, such as carbohydrate. In emergencies of oxygen want, the release of red cells (oxygen carriers) by the spleen and bone marrow may be considered as a storehouse in a limited sense. In man the blood is really the only storehouse for oxygen, and its capacity is very limited. Hence the body lives a hand-to-mouth existence with respect to its oxygen supply. When the available supply of oxygen is shut off, there is loss of consciousness within a minute or two. Many physiologists estimate that the deterioration of the cortical tissue due to oxygen lack is so profound that recovery is impossible after 8 to 10 minutes. The lower centers of the brain and the spinal cord may survive after one-half hour or more of oxygen deprivation. The efficiency of one's body is dependent upon the constancy of the internal environment, i.e., the regulation of temperature, water, oxygen, the hydrogen-ion concentration, etc. Since man's higher nervous faculties developed due to the constancy of these organic processes, an extreme variation in any one of them, particularly the oxygen percentage, will produce striking effects on the nervous system and other tissues of the body. The seat of oxidation is the living cell and the quantity of oxygen taken up by the cells is conditioned primarily by the degree of activity of the organism.

The use of breathing, of course, is to obtain supplies of oxygen for the tissues and to get rid of the carbon dioxide, thereby maintaining the proper balance of gases in the blood. The air in the alveoli is brought into proximity with the lung capillaries, thus providing for the exchange of gases between the blood and the air. There is a reduction of oxygen in the alveoli (lungs) to an average of 14 per cent, due to dilution by the residual air in the lungs. The average composition of carbon dioxide in the alveoli is 5.5 per cent. The venous blood which comes to the lungs gives off carbon dioxide and takes up oxygen until it comes into equilibrium with the air of the alveoli. On account of the pressure of oxygen in the alveoli being greater than that in the blood, oxygen is absorbed into the blood by diffusion. Slight alterations in the alveolar carbon dioxide pressure cause great changes in breathing. In the case of exercise, for example, more oxygen is absorbed by the tissues and a greater amount of carbon dioxide is given off. Increased breathing takes place immediately so as to wash out the excess carbon dioxide and restore the equilibrium. Table 4 shows the average amount of carbon dioxide produced per person during the various conditions of activity (69).

Table 4

Condition	CO_2 in cubic centimeters per minute (0° C. and 760 mm. Hg)
Rest--in bed	.197
Rest--standing	.264
Walking--2 m.p.h.	.662
Walking--3 m.p.h.	.922
Walking--4 m.p.h.	1.399
Walking--5 m.p.h.	2.39
Heavy labor	4.78

During vigorous exercise the demand for extra oxygen by the tissues is met by a number of important physiological changes, the chief ones being: (1) a very great increase in lung ventilation; (2) a large increase in the output of the heart per minute; (3) a rise in the arterial pressure so that the blood flows in greater volume per minute through the expanded capillaries of the region where activity requires a greater oxygen supply; (4) heightened rate of diffusion or exchange of gases in the capillaries of the lungs and of the contracting muscles; and (5) a slight increase in number of the red corpuscles. Thus the rate of breathing will vary: (1) in proportion to the degree of activity of the body, i.e., the metabolic rate; and (2) with the reaction of the blood; i.e., so as to maintain the appropriate oxygen tension in the blood.

Breathing appears to be controlled automatically by the respiratory center, a small area located in the medulla oblongata at the base of the brain. If this center is destroyed, all rhythmical respiratory movements cease, or, if these cells are totally deprived of oxygen within 8 to 10 minutes, the destructive changes are so great that they do not recover. The intimate connection between the nervous and chemical control of breathing is shown by the activity of the respiratory center, since its functioning depends, among other things, upon the composition of the gases in the blood circulating through it.* During anoxia with a decreased percentage of available oxygen, or during exercise with an increased percentage of carbon dioxide, the arterial blood visits, among other places, the respiratory center, the carotid sinus and carotid body. (It has been shown that the carotid body is especially sensitive to asphyxial or anoxemic blood.**) The excess carbon dioxide acts as a stimulus, and the cells discharge more nerve impulses to the muscles of respiration so that their action is more vigorous. Thus the increased ventilation of the lungs pumps out the extra carbon dioxide until the proper balance is again reached. The heart rate, which also increases, exposes the blood more often in a given length of time to the alveolar air. Thus more oxygen is supplied to the deficiency of the respiratory, cardiac, and vasomotor centers of the medulla (69).

The extraordinary sensitiveness of the respiratory center can be demonstrated by the fact that an increase of only 0.22 per cent carbon dioxide in the alveolar air will cause the ventilation of the lungs to be increased 100 per cent. Excess carbon dioxide in the inspired air beyond the normal

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*For an authoritative account of the regulation of respiration by the blood gases, cf. L. J. Henderson. Blood: A Study in General Physiology. Yale University Press, New Haven, 1928, and R. Gesell. The Chemical Regulation of Respiration. Physiol. Rev., 5:551, 1925.

**Heymans, C., Bouckaert, J. J., et Regniers, P. Le Sinus carotidien. Doin, Paris, 1933.

0.04 per cent has noticeable effects, since the rise in alveolar carbon dioxide hinders elimination of the excess carbon dioxide. There is increased breathing with full and rapid pulse with 4 per cent carbon dioxide, and compensation is still more difficult with a further rise; at 6 per cent, headache and mental confusion develop. Toxic effects appear with higher percentages; the heart slows; consciousness is lost; the breathing becomes feeble and finally ceases. Experimental work indicates that the variations in ordinary breathing are due to an increased production of carbon dioxide. For example, when the carbon dioxide percentage of the inspired air was increased, the lung ventilation increased as is shown in Table 5 (69).

Table 5

Per Cent CO_2	Average Respiratory Volume (liters)	Per Cent of Increase in Lung Ventilation
.03	6.3	—
1.00	8.3	32.0
2.00	11.3	79.5
4.00	19.4	207.9
6.00	32.7	418.6
8.00	46.6	639.0

The amount of oxygen which can be carried by the blood is dependent upon the quantity of hemoglobin located in the red cells. In its ordinary form, oxyhemoglobin is a bright red color and contains oxygen which it readily parts with in the tissues. It then becomes reduced hemoglobin, which is of a purplish color and which in turn absorbs oxygen from the air in the alveoli. The arterial blood in normal subjects at sea level contains from 94 to 96 per cent of its hemoglobin in the oxygenated form and only 4 to 6 per cent in the reduced form. Under resting conditions the blood is from 60 to 85 per cent saturated.*

*For authoritative discussions of hemoglobin and oxygen in relation to high altitude, cf. Peters, J. P., and Van Slyke, D. D. Quantitative Clinical Chemistry (Chapter 12). Williams & Wilkins, Baltimore, 1931, and Dill, D. B. Life, Heat and Altitude. Harvard University Press C[illegible]brid[illegible] 193[illegible]

The amount of oxygen taken up by the blood depends upon the partial pressure of oxygen in the alveolar air, the temperature of the blood, the concentration of salts in the blood and the hydrogen-ion concentration of salts in the blood (carbon dioxide tension). During rest the whole blood volume passes through the lungs about once per minute, and it may pass as often as ten times during exercise. When the arterial blood is imperfectly saturated, the condition which develops is called <u>anoxemia</u>. It is indicated by the bluish color of the skin and lips (<u>cyanosis</u>).

VII. The Physical and Psychological Responses of the Organism while in Flight at High Altitude.

The most important physiological changes associated with the diminished barometric pressure at high altitude (Figure 9) are as follows: (a) stimulation of the respiratory center and an increase in the pulmonary ventilation; (b) a decrease in the alveolar oxygen and carbon dioxide tensions (Figure 9; also Figure 10 from Haldane (31A) and Figure 11 from Schneider (65)); (c) dilatation of the alveoli favoring a more efficient respiratory exchange; (d) an initial increase in the heart rate and blood pressure and an increase in cardiac output, followed by a gradual return to normal while at rest; (e) an increase in the amount of hemoglobin in the circulation (cf. Figure 12 from Haldane (31A)); (f) a decrease in the arterial oxygen saturation associated with the fall in alveolar oxygen tension (Figure 9); and (g) changes in the acid-base equilibrium--the initial effect being one of alkalosis associated with the excess elimination of carbon dioxide. Sudden and extreme anoxemia depresses the activity of the respiratory center so that a delayed effect may be the retention of carbon dioxide and consequently an acid reaction in the blood (cf. McFarland (44)).

The psychological changes follow closely the rapidity and severity of the physiological alterations in the organism. If anoxemia is produced suddenly, as during an aeroplane ascent, the most striking effects are on the

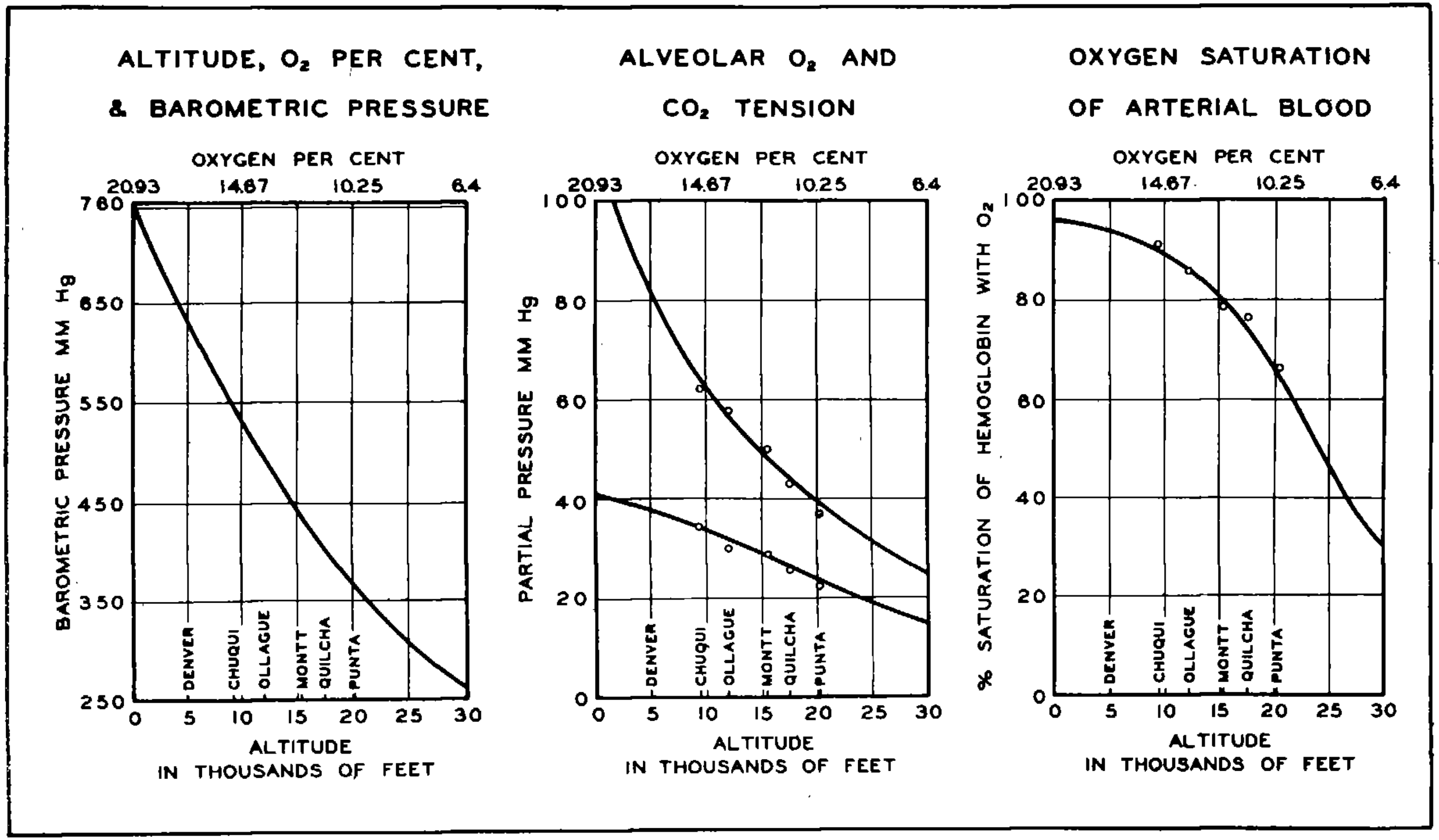

ALTITUDE, O_2 PER CENT,
& BAROMETRIC PRESSURE
OXYGEN PER CENT
20.93
14.67
10.25
6.4
BAROMETRIC PRESSURE MM Hg
760
650
550
450
350
250
DENVER
CHUQUI
OLLAGUE
MONTT
QUILCHA
PUNTA
0
5
10
15
20
25
30
ALTITUDE
IN THOUSANDS OF FEET
ALVEOLAR O_2 AND
CO_2 TENSION
OXYGEN PER CENT
20.93
14.67
10.25
6.4
PARTIAL PRESSURE MM Hg
100
80
60
40
20
0
DENVER
CHUQUI
OLLAGUE
MONTT
QUILCHA
PUNTA
0
5
10
15
20
25
30
ALTITUDE
IN THOUSANDS OF FEET
OXYGEN SATURATION
OF ARTERIAL BLOOD
OXYGEN PER CENT
20.93
14.67
10.25
6.4
% SATURATION OF HEMOGLOBIN WITH O_2
100
80
60
40
20
0
DENVER
CHUQUI
OLLAGUE
MONTT
QUILCHA
PUNTA
0
5
10
15
20
25
30
ALTITUDE
IN THOUSANDS OF FEET

FIG. 9

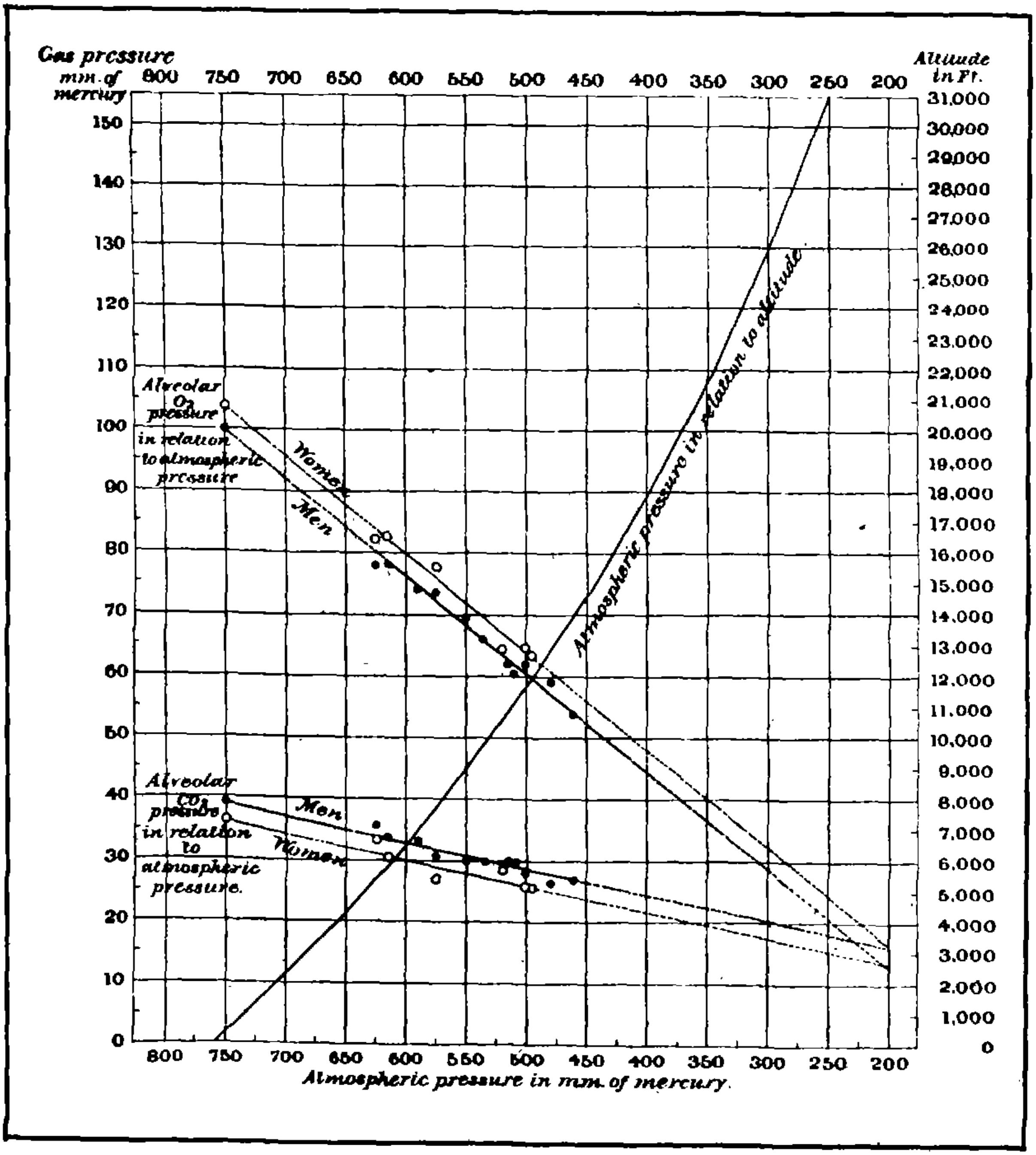
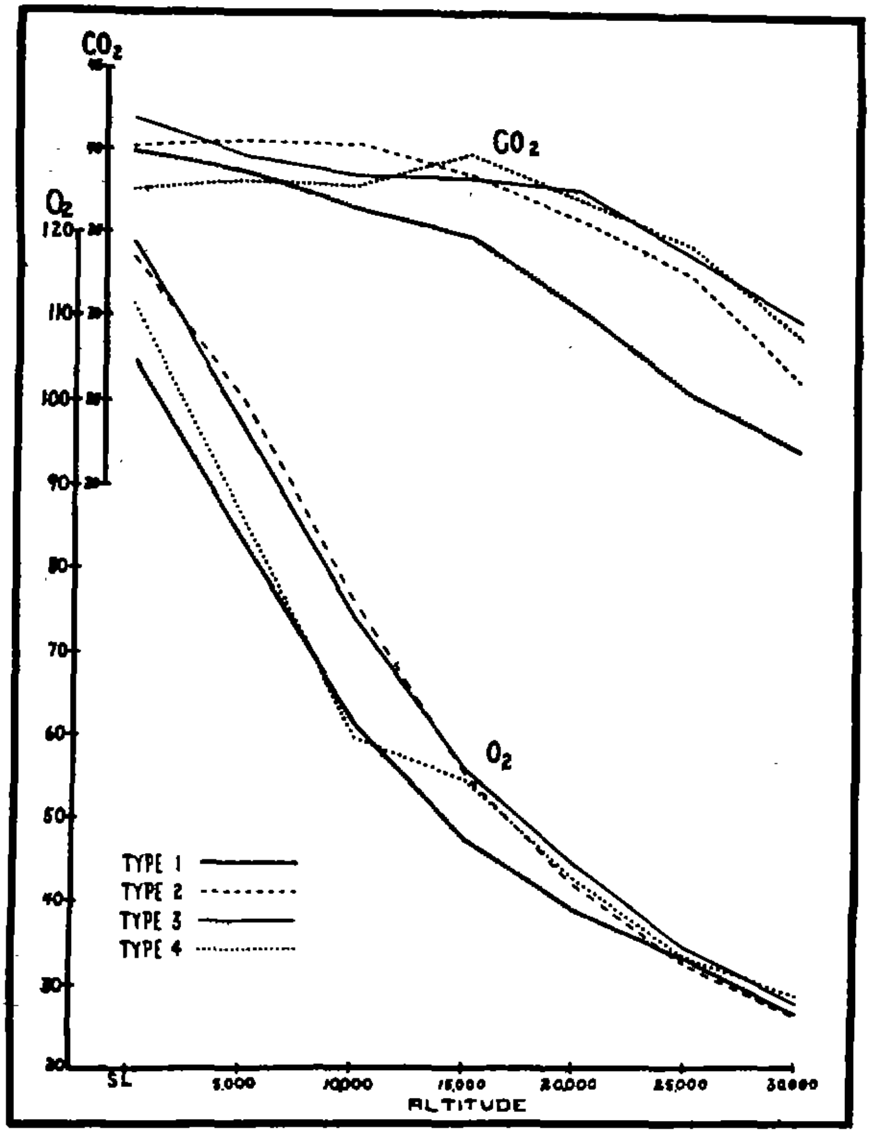


FIG. 10. (HALDANE)



Average alveolar CO_2 and O_2 tensions at simulated altitudes.

Type 1. Unmodified anoxemia.

Type 2. Effect of breathing 4 per cent CO_2.

Type 3. Effect of 4 per cent CO_2 up to a simulated altitude of 12,000 feet and of 8 per cent CO_2 thereafter.

Type 4. Unmodified anoxemia up to simulated altitude of 12,000 feet, 8 per cent CO_2 thereafter.

FIG. 11. (SCHNEIDER, TRUESDALE AND CLARK)

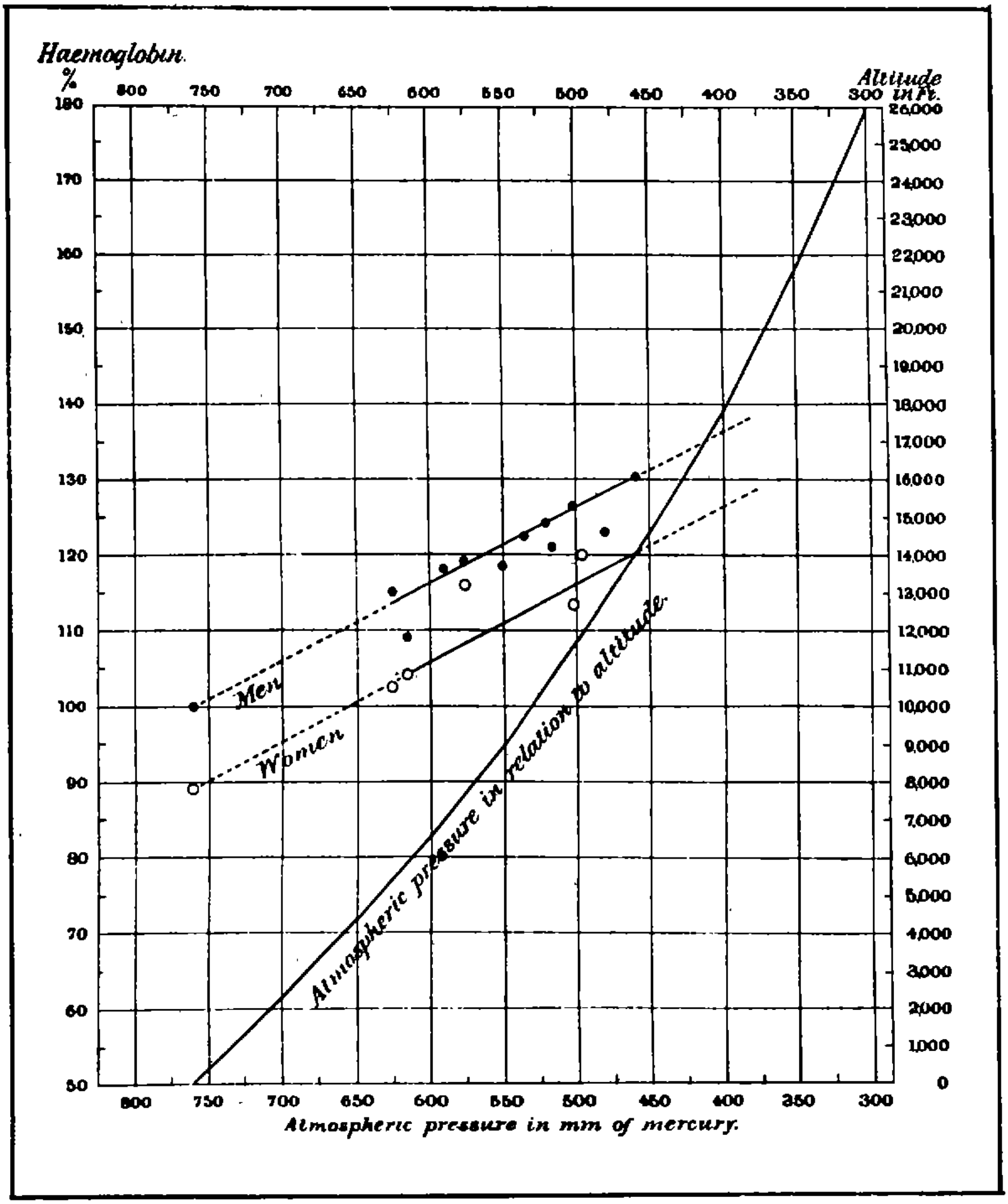


FIG. 12. (FITZGERALD)

central nervous system. The psychological impairment is insidious and often completely unobserved subjectively. When the barometric pressure is reduced one-third, i.e., to 480 mm. Hg, at approximately 12,500 feet, the psychological changes are objectively measurable by tests (45). A review of the literature indicates that the average unacclimatized subject during short exposures manifests only slight impairment at 12,000 feet and deteriorates rapidly at 15,000 to 16,000 feet. In a recent high altitude expedition to the Andes, significant psychological changes in acclimatized subjects were not observed until 15,500 and 17,500 feet altitude (44), where the oxygen saturation of the arterial blood in ten subjects averaged 80 per cent and 76 per cent respectively (cf. Figure 9). (17)

Previous studies dealing with the effects of high altitude while in flight have been chiefly concerned with the physiological changes during rapid ascents, i.e., within fifteen to twenty minutes, to critical altitudes varying from 15,000 to 25,000 feet. Schneider and Clarke (56) made observations on the changes in the alveolar oxygen and carbon dioxide during rapid ascents to 15,000 feet. Schnell (57), Beyne (7), Fronius (21), and Schubert (60) have carried out experiments dealing primarily with the circulation, respiration, alveolar air, and metabolism during aeroplane ascents within one-half an hour to 18,000 to 20,000 feet. On trans-Andean flights of approximately one-half hour's duration to 14,000 and 16,500 feet, McFarland (44) made observations of the sensory and mental functions as well as the alveolar air and circulation. These authors all emphasize the psychic nervous involvement and the impairment of sensory functions above 14,000 to 16,000 feet. In rapid ascents as high as 26,500 feet with pilots, Baertschi (5) observed that feelings of euphoria were noticeable up to 16,500 feet. Beyond that height weakness and apathy were noticeable, and in addition, there were disturbances of attention, of volition, and of the special senses, accompanied by marked sleepiness and fatigability. (49)

A number of experiments on airmen have indicated that repeated flights to high altitude facilitate acclimatization as manifested by a greater acceleration in the pulmonary ventilation (20), and increase in the red cells and hemoblogin (37), and a higher alveolar oxygen partial pressure. Fronius (21) found that daily flights have the same effect as a prolonged stay in the mountains and that progressively higher altitudes could be tolerated. In comparing a group of pilots who could tolerate very high altitudes with those who could not, Christensen and Krogh (15) found that the good ones showed a greater pulmonary ventilation, a distinctly lower partial pressure of carbon dioxide, and a higher partial pressure of oxygen. Thus there is some evidence that pilots become partially acclimatized through repeated flights to high altitude, particularly those who show an initial favorable response. No extensive studies have been made of the effects of high altitude on large numbers of passengers at comparable altitudes to those attained in commercial air transportation (49).

PART II. EXPERIMENTAL STUDIES

I. Statement of Problem

As indicated previously, this report attempts to analyze the effects of flying at high altitude on the average unacclimatized passenger under present flight conditions on commercial air transport planes. Interest has centered in studying large groups of subjects, varying in physical fitness and in age (from 18 to 72 years) at different rates of ascent and lengths of exposure to altitudes of 10,000 to 18,000 feet. An attempt has been made, therefore, to determine the altitudes where the physiological effects are extensive enough to bring about an impairment in the average passenger's psychological reactions and general comfort or feeling of well being, as well as the altitudes which appear to be definitely dangerous. In addition, an attempt has been made to determine the importance of rate of ascent relative to the specific altitudes studied. For example, is the average person significantly impaired at 10,000 or 12,000 feet, and if he is affected psychologically or in terms of discomfort by a rapid ascent to 12,000 feet in 15 minutes, will he be able to make a better adjustment, i.e., remain mentally alert and comfortable, if that altitude is attained during 1 hour and 15 minutes; also, are 2 or 3 hours at 12,000 to 14,000 feet positively dangerous to the average passenger's general physical well being after that altitude has been once attained?

II. <u>General Outline of the Investigation.</u>

The entire research program may be divided into six parts and the various experiments will be discussed in the following order. Parts I to IV, inclusive, were sponsored by the Bureau of Air Commerce:

<u>Part I</u>. This experiment was carried out in the Applied Laboratory of the Department of Psychology at Columbia University. Over 200 subjects were studied at various simulated altitudes and at two rates of ascent as shown in Table 7 in a low oxygen chamber. The tests included continuous records of pulse and blood pressure; alveolar oxygen and carbon dioxide; and a series of six psychological tests involving motor, sensory, and mental functions.

Part II. The second part of the investigation was concerned with the problem of age in relation to ability to tolerate oxygen deprivation or altitude. There were three groups of subjects divided into the following age groups: 18-30 years, 30-45 years, and 45-72 years. In this study the tests mentioned in Part I above were given following a rapid ascent to a simulated altitude of 14,000 feet in the low oxygen chamber at Columbia University.

Part III. The third aspect of the study was concerned with the question of physical fitness in relation to ability to tolerate high altitude. In this part of the investigation a group of Columbia college students in good physical condition were compared with those in poor health but without definite organic illness. The testing procedure was similar to the one described above. In addition, 30 control or "normal" subjects and 35 psychoneurotic patients from Vanderbilt Clinic without organic illness but with objective signs of "chronic exhaustion and fatigue" were tested twice, once under control conditions, i.e., normal air, and once following a rapid ascent to a simulated altitude of 18,000 feet in the low oxygen chamber at Columbia University. In this part of the investigation samples of blood were taken at the beginning and at the end of each session in addition to the Schneider Index and psychological tests.

Part IV. In cooperation with the late H. T. Edwards of the Harvard Fatigue Laboratory, a series of tests were made on four subjects in the low oxygen chamber at Columbia University, with and without 3.0% carbon dioxide in the inspired air. A series of physiological and psychological tests, as well as analyses of the blood gases, were made on each subject in an attempt to determine the value of excess carbon dioxide to counteract the effects of the oxygen want encountered at high altitude.

Part V. In cooperation with Dr. D. B. Dill and Mr. H. T. Edwards a number of experiments were carried out during the past year in the low oxygen room at the Harvard Fatigue Laboratory, Boston, and in the low pressure chamber at Wright Field, Dayton, Ohio. The results of these studies, especially the psychological data, will be reviewed briefly so as to compare the data obtained at similar altitudes under different experimental procedures of reducing the oxygen pressure. These studies will be reported separately by Dr. D. B. Dill et al, since they were sponsored by the Fatigue Laboratory independent of the grant from the Bureau of Air Commerce. The purpose of these experiments was to test the effects of more prolonged exposures to simulated altitudes of 14,000 and 17,000 feet over a six hour period with a normal amount of carbon dioxide and with the addition of 3 per cent carbon dioxide in the inspired air.

Part VI. During the summer months an opportunity was afforded through the cooperation of United Air Lines and Pan American Airways to carry out a number of studies during transcontinental flights, as well as, during the more prolonged flights of the trans-Pacific operations. These investigations have been reported separately but will be briefly referred to here so as to compare the data obtained under actual flight conditions with those collected under simulated altitudes in low oxygen and low pressure chambers at sea level. The essential information relating to these various parts of the investigation, such as number of subjects, altitude, rates of ascent, etc., has been summarized in Table 7.

III. Experimental Procedure.

In the major experiment (Part I) a large number of subjects were studied at six different altitudes from 10,000 to 18,000 feet at two rates of ascent--rapid (15 to 30 minutes) and slow (45 minutes to 1 hour and 30 minutes). The rapid ascents averaged between 600 and 700 feet per minute, and the slow ascents less than one-half as fast. The altitudes and the time required to simulate these ascents are shown in Tables 6 and 7 and also graphically in Figure 13. Once the simulated altitude was reached the various tests were given twice during the two hours at the altitudes indicated. The length of each experiment varied from 3 and one-half to 4 and one-half hours, depending on the rate of ascent. Over 250 experiments were carried out in the main part of the study. In a number of cases two subjects were studied at the same time; however, for the most part the subjects were tested in the chamber individually. Two experimenters inside the chamber gave the tests and one outside the chamber made frequent analyses on the Haldane apparatus of the percentages of oxygen and carbon dioxide in the chamber.

The subjects came to the laboratory at least 1 and one-half to 2 hours following a meal both in the mornings and afternoons. In the series where blood samples were collected, the subjects came to the laboratory in the mornings under basal conditions. Each subject was given the various tests a day or so previous to the experimental series so as to become acquainted with the procedures and also to attempt to overcome the effects of practice in the psychological tests. After the subject entered the chamber, a complete series of tests was taken before the ascent. Then the various tests were repeated twice, as indicated in Figure 13.

The tests were given in a Barach portable oxygen chamber (7 x 8 x 8 feet); where the gases, temperature, ventilation, and humidity could be regulated (4). The concentration of oxygen was maintained at the desired

Table 6

TIME REQUIRED FOR RAPID AND SLOW ASCENTS AT

ALTITUDES INDICATED

Altitude	Time in Minutes
10,000 Rapid	15
10,000 Slow	40
12,000 Rapid	20
12,000 Slow	45
14,000 Rapid	20
14,000 Slow	45
16,000 Rapid	30
16,000 Slow	75
18,000 Rapid	30
18,000 Slow	90
21,000 Rapid	35

Length of stay--two hours. Data taken as of control, first and second hour.

Table 7

NUMBER OF SUBJECTS IN THE VARIOUS EXPERIMENTS

AT THE ALTITUDES AND RATES OF ASCENT INDICATED

Experiment	Altitude	% Oxygen	Number of Subjects: Rapid Ascent	Number of Subjects: Slow Ascent
Part I. Major Experiment on Effects of Altitude	(1) 10,000 feet	14.25	18	14
	(2) 12,000 feet	13.20	14	12
	(3) 14,000 feet	12.20	50	13
	(4) 16,000 feet	11.25	27	19
	(5) 18,000 feet	10.35	30	13
	(6) 21,000 feet	9.15	12	
Part II. Age in Relation to Altitude	(1) 14,000 feet	12.20		
	(a) 17 to 30 years		50*	13
	(b) 30 to 45 years		15	
	(c) 45 to 72 years		16	
Part III.				
A. Rate of Ascent and Altitude in Relation to Physical Fitness	(1) 16,000 feet	11.25	10	
	(2) 16,000 feet			10
	(3) 12,000 feet	13.20	10	
B. Psychoneurotic Group	(1) 18,000 feet		35	
C. Control Group (same as Part I)	(1) 18,000 feet		30*	
Part IV and Part V. Low Oxygen (11% O_2) Experiments with and without Excess Carbon Dioxide (3.0% CO_2)	(1) 18,000 feet			
(a) Columbia Experiment	17-22,000 feet		4	
(b) Harvard Experiment	17,000 feet		4	
(c) Wright Field (Low Pressure Chamber) Experiment	17-22,000 feet		4	
Part VI. Experiments while in Flight on Commercial Air Transports				
(a) Transcontinental Flights	6-12,000 feet		6	
(b) Trans-Pacific Flights	8-12,000 feet			14
Total number of subjects			**255**	**108**

*Same group of subjects as in Part I; not included in total.

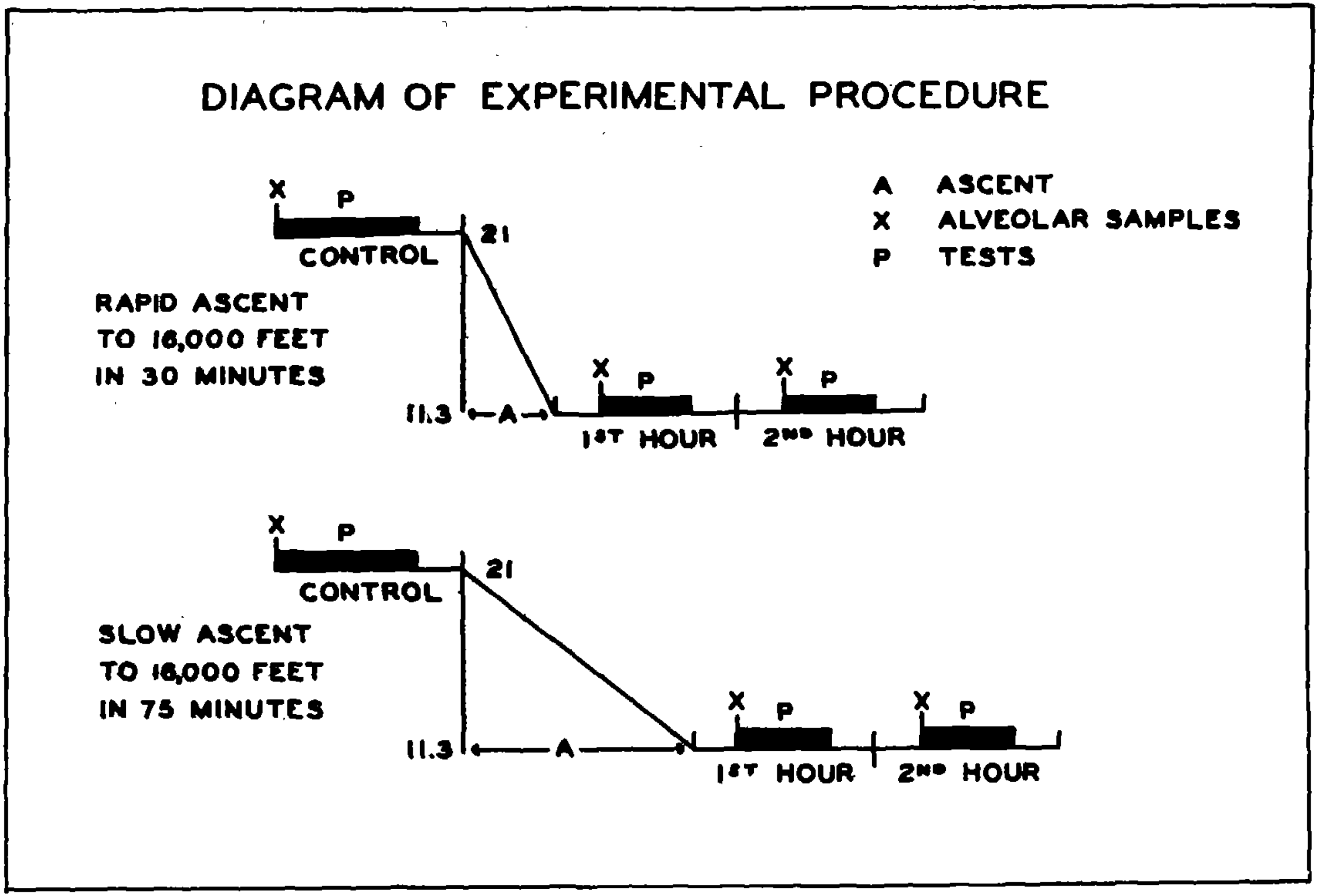


DIAGRAM OF EXPERIMENTAL PROCEDURE
A ASCENT
X ALVEOLAR SAMPLES
P TESTS
X
P
CONTROL
21
RAPID ASCENT
TO 16,000 FEET
IN 30 MINUTES
11.3
A
X
P
X
P
1ST HOUR
2ND HOUR
X
P
CONTROL
21
SLOW ASCENT
TO 16,000 FEET
IN 75 MINUTES
11.3
A
X
P
X
P
1ST HOUR
2ND HOUR

FIG. 13

percentage by running in nitrogen.* The carbon dioxide never exceeded 0.7 per cent. Samples of the gas mixtures were taken inside the chamber at the time the alveolar air was taken; also, a sample was taken by an assistant from the outside of the chamber. The analyses were made with a Haldane gas analysis apparatus. These determinations were made at the beginning and end of each period when the percentage of oxygen was altered. The ventilation was provided by a motor blower unit. The air current was passed through a tank which contained ice to cool and dry the air. The temperature was maintained between 68-74° F., and the humidity between 40-50 per cent. The chamber was in a part of the laboratory free from distractions and other outside influences. The experimenter was protected against the effects of anoxia by breathing additional amounts of oxygen through a nasal catheter. The small change in percentage of oxygen was compensated for by a small amount of nitrogen from a cylinder outside the chamber.

<u>The subjects</u>. An attempt was made to get subjects to serve in the experiments who were of the same socio-economic status as the average flying population. In the main experiment many of the younger subjects were undergraduate and graduate students in Columbia University. Those who were more advanced in age were for the most part professional men in New York City engaged in the practice of law, teaching, or business. The total age range was from 17 to 72 years. The subjects varied in physical fitness from

---

*The altitudes corresponding to the oxygen mixtures in the chamber were determined by data compiled by the U. S. Bureau of Standards (cf. Table 2) which relate altitude, barometric pressure and the percentage of oxygen available for the organism at each level. The calculations are based upon a constant temperature of 15° C. with allowance for the day-to-day variations in the barometric pressure.

college athletes to those who led sedentary lives with a very limited amount of exercise. There was also a fairly average distribution as to height and weight. Those with known organic illness were eliminated from the experiments. As a result of the tests, however, a number of the individuals were shown to be in very poor health and were sent to the University Medical Office. One of the subjects, for example, collapsed at 9,000 feet after approximately 10 minutes during the ascent. About half of the subjects volunteered to serve because of their general interest in aviation. The others were paid by the hour for each experiment. All of the subjects were males.

The physiological and psychological tests. During each experimental session a series of physiological and psychological tests was given to each subject, as follows:

Physiological tests:

1. Pulse rate recorded practically continuously during the ascent and at frequent intervals thereafter.
2. Systolic and diastolic blood pressure. Tycos recording sphygmomanometer.
3. Alveolar oxygen and carbon dioxide. The analyses were run in duplicate on the standard Haldane gas analysis apparatus.

Psychological tests:

1. Handwriting. The subject was asked to copy 8 lines of the Swedish language.
2. Heterophoria test for ocular muscle balance (1).

3. <u>Choice reaction times</u> (Sillitoe apparatus) (61). 50 reactions on a portable reaction time apparatus with five colored lights. Time recorded in hundredths of a second.

4. <u>Color naming</u>. Both time and errors were recorded during the naming of colors (68).

5. <u>Code test</u>. Cf. Johnson and Paschal (34). Recording of the time and errors involved in transliterating 50 letters from a code.

6. <u>Memory</u> (66). Immediate recall for series of ten four-letter words after exposure for 15 seconds each.

7. <u>Record of physiological and psychological complaints</u>. Each subject kept a running account of his chief symptoms in his own handwriting. Also at the end of each experiment the subjects indicated their chief ailments on a standardized test form (cf. Table 16).

<u>Biochemical tests</u> (Parts III, IV, and V):

1. Lactic acid (Friedemann, Cotonio and Shaffer).
2. Blood sugar (Folin-Wu).
3. Inorganic phosphorus (Youngberg).
4. Calcium (Clark Collip).
5. Creatinine (Folin-Wu).
6. Hemoglobin (Newcomer).
7. Blood gases, Van Slyke apparatus. (Arterial oxygen and carbon dioxide.) (52)

<u>Statistical treatment of data</u>. The pulse and blood pressure records were taken practically continuously during the ascent and well into the first part of the first experimental hour so as to follow the acclimatization made by the subject. Thereafter pulse and blood pressure records were made every 10 to 15 minutes. In the final data the pulse and blood pressure records were averaged for successive 5-minute intervals during the ascent and for every 20-minute period during the remaining 2 hours.

The alveolar air samples were taken 3 times during each experiment, first under control conditions and again at 15 to 25 minutes of the first and second hours at each altitude. A sample of the air in the chamber was also taken at the time the alveolar air was collected. Each sample was analyzed in duplicate on the Haldane apparatus.

The scores for each subject in the various tests were obtained first under control conditions (air) previous to the ascent and again during each of the two hours following the ascent. In the tables these three scores, Control, I and II, represent the averages for the number of forms or trials on each test for the respective periods.

All of the scores for the physiological and psychological tests are grouped according to altitude and rate of ascent. Separate groupings have been made for age and physical fitness. The final results are recorded in terms of means, variability (standard deviations) and critical ratios (determination of the significance of a difference between means in terms of probability).

These data have been treated by the usual statistical procedures. In determining the critical ratios, use was made of Fisher's method for small samples (cf. Guilford, J. P ., Psychometric Methods, McGraw-Hill, 1936). The critical ratios are important, since they are measures of the probability that the differences between the sea level and the altitude means are significant, i.e., due to the effects of the diminished oxygen pressure rather than resulting from sampling errors and variability. These measures are shown in the tables in terms of chances in 100 that the difference could have arisen by chance. It is generally accepted that 5 chances in 100 or less indicates a significant difference, and is so used in the results of this study. (cf. Fisher (18A).

Since the control scores in the various experiments were not identical due to different subjects being used, the changes in the mean scores in the physiological and psychological tests (with the exception of the heterophoria test) are also shown as per cent change, with the control score being taken as 100. The use of per cent change from the control makes direct comparison of results easier and at the same time made it simpler for charting the data.

The essential comparisons have been made between the results obtained in the physiological and the psychological tests at sea level and at the respective altitudes after a rapid ascent, using first hour data only. A comparison has also been made for the differential effects of rapid and slow ascents to a particular altitude, and finally the differential effect of age and physical fitness at a single altitude following a rapid ascent.

IV. Results of the Experiments on Large Groups of Subjects (Part I).

The pulse rate. The alterations in pulse rate per minute for each group (throughout the experimental session) under the various conditions of rate of ascent and altitude attained have been summarized in Table 8. In addition to the means, the standard deviation (index of variability within the group), the significance of the observed differences (whether the difference is due to chance or not), and the index of change (control = 100) are shown for the various groups under the conditions as indicated. The average increase in pulse rate during rapid ascents appeared to be significant statistically during the first 20 minutes at 12,000 feet; however, the mean pulse rate dropped to the control level by the end of the first hour. At 14,000 feet and above the mean pulse rate remained significantly higher throughout each experimental period. The first significant increase during slow ascents was at 16,000 feet.

The extent of the variations in pulse rate during rapid ascents varying from 10,000 to 18,000 feet are shown graphically in Figure 14 in terms of the index of change (control = 100). There appears to be a close relationship between increase in pulse rate and height attained. A well controlled rise in pulse rate is apparently a favorable response to lowered oxygen pressure in the average person in good health. Many of the subjects in poor physical condition responded with extreme variations in pulse rate, i.e., either an unusually large increase in rate, a sudden decrease in rate, or no change at all. There is a general tendency for the pulse rate to return to more normal levels at the lower altitudes (10-12,000 feet) provided the subject acclimatizes fairly well and remains at rest. At the higher altitudes, however, this does not occur (cf. Figure 14).

In comparing the alterations in pulse rate during rapid and slow ascents, ie., attaining the simulated altitudes within 15 to 30 minutes as contrasted with

Table 8

SUMMARY TABLE

PULSE

		Control	I 1-20	I 21-40	I 41-60	II 1-20	II 21-40	II 41-60
10,000 Rapid	Mean	74.33	77.00	75.06	73.86	76.00	74.80	74.71
	S.D.	10.03	11.23	12.11	11.79	13.05	10.07	7.56
	Significance*	---	5-10	60-70	50-60	100	60-70	70-80
	Index of change	100.0	103.6	101.0	99.4	102.2	100.6	100.5
10,000 Slow	Mean	80.33	77.83	74.00	74.67			
	S.D.	8.17	6.22	5.66	5.69			
	Significance	---	20-30	1-2	5-10			
	Index of change	100.0	96.9	92.1	92.9			
12,000 Rapid	Mean	78.36	83.69	81.62	79.46	78.55	77.36	78.05
	S.D.	9.42	9.90	10.80	9.67	14.27	12.81	15.55
	Significance	---	0-1	30-40	50-60	90-100	70-80	80-90
	Index of change	100.0	106.8	104.2	102.0	100.2	98.7	99.6
12,000 Slow	Mean	76.38	77.88	81.57	76.17			
	S.D.	8.60	6.99	10.58	7.16			
	Significance	---	50-60	10-20	70-80			
	Index of change	100.0	102.0	105.5	99.7			
14,000 Rapid 17-30 yrs.	Mean	77.27	86.21	83.96	83.36	83.49	82.34	83.91
	S.D.	9.50	8.85	9.38	10.40	9.29	9.70	9.62
	Significance	---	0-1	0-1	0-1	0-1	1-2	0-1
	Index of change	100.0	111.6	108.7	107.9	108.0	106.6	108.6
14,000 Slow	Mean	74.17	75.67	74.50	75.00			
	S.D.	14.11	11.47	12.54	---			
	Significance	---	70-80	90-100	70-80			
	Index of change	100.0	102.0	100.4	101.1			
16,000 Rapid	Mean	75.5	86.0	84.9	83.8	83.3	81.8	82.9
	S.D.	9.22	13.23	12.98	12.80	11.83	11.13	12.41
	Significance	---	0-1	0-1	0-1	0-1	0-1	1-2
	Index of change	100.0	113.9	112.5	111.0	110.3	108.4	109.8
16,000 Slow	Mean	78.50	85.05	83.17	83.67	84.61	84.67	84.40
	S.D.	10.78	10.77	14.29	10.85	12.47	12.92	12.10
	Significance	---	1-2	10-20	2-5	2-5	5-10	10-20
	Index of change	100.0	108.4	105.9	106.6	107.8	107.9	107.5
18,000 Rapid	Mean	70.30	84.80	---	81.20	---	79.96	---
	S.D.	6.62	9.65	---	8.48	---	8.92	---
	Significance	---	0-1	---	0-1	---	0-1	---
	Index of change	100.0	120.8	---	115.6	---	113.8	---
21,000 Rapid	Mean	67.80	---	94.30	---	---	96.50	---
	S.D.	---	---	---	---	---	---	---
	Significance	---	---	0-1	---	---	0-1	---
	Index of change	100.0	---	139.1	---	---	142.3	---
14,000 Rapid 30-45 yrs.	Mean	81.50	85.00	84.00	79.89	78.00	79.00	80.00
	S.D.	8.56	13.00	10.52	9.77	---	---	---
	Significance	---	60-70	90-100	40-50	---	---	---
	Index of change	100.0	104.3	103.1	98.0	95.7	96.9	98.2
14,000 Rapid 45 and over	Mean	74.33	76.58	74.75	72.27	72.33	73.83	73.80
	S.D.	13.62	14.96	14.07	12.99	10.25	11.99	10.04
	Significance	---	70-80	80-90	80-90	80-90	90-100	90-100
	Index of change	100.0	103.0	100.6	97.2	97.3	99.3	99.3

*Chances in 100 that the difference from the control could have arisen by chance. Five chances in 100 or less are necessary before the significance of the difference is reasonably certain, or before chance can be reasonably ruled out.

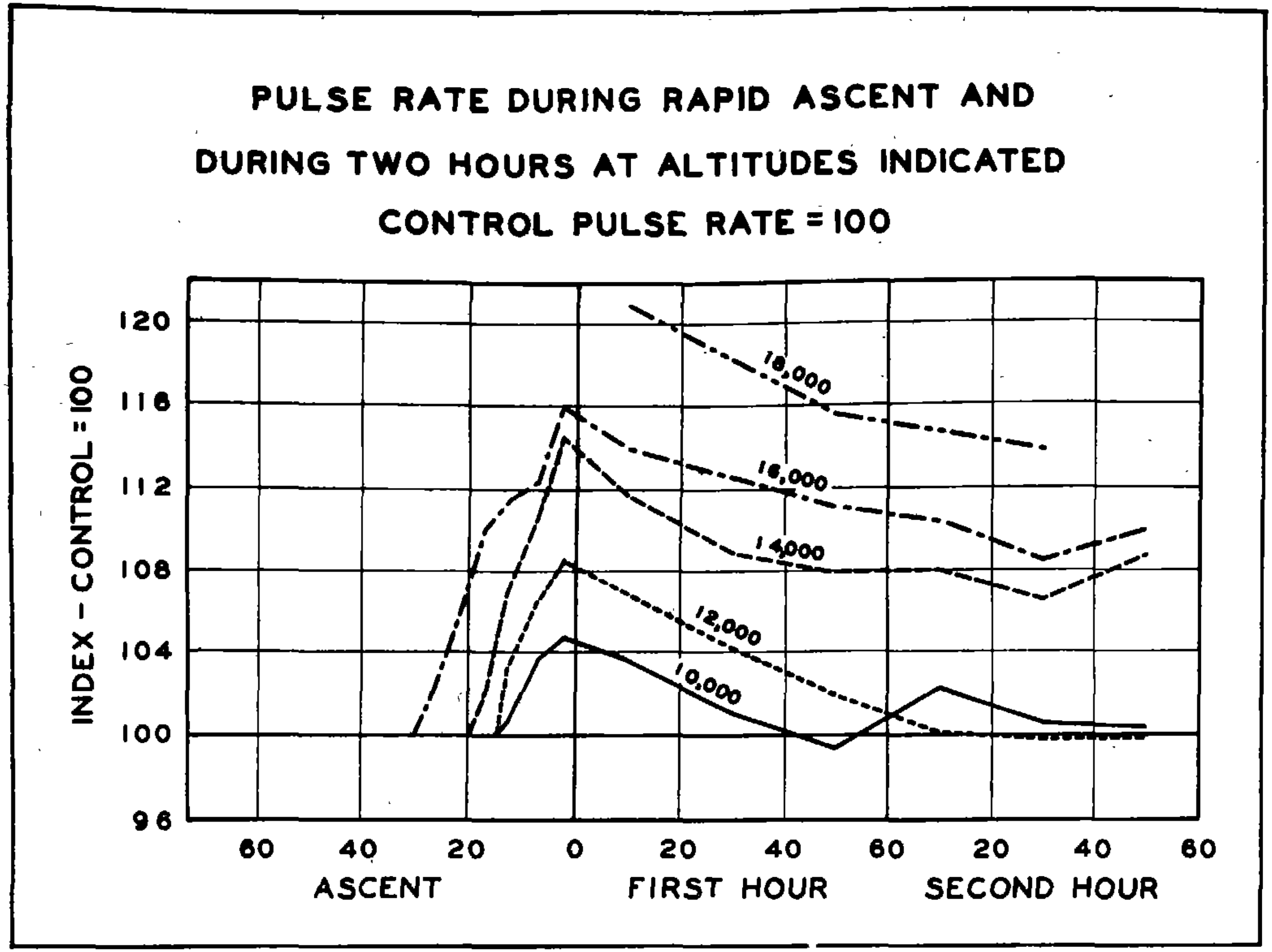

PULSE RATE DURING RAPID ASCENT AND
DURING TWO HOURS AT ALTITUDES INDICATED
CONTROL PULSE RATE = 100
INDEX - CONTROL = 100
120
116
112
108
104
100
96
60
40
20
0
20
40
60
20
40
60
ASCENT
FIRST HOUR
SECOND HOUR
18,000
16,000
14,000
12,000
10,000

FIG. 14

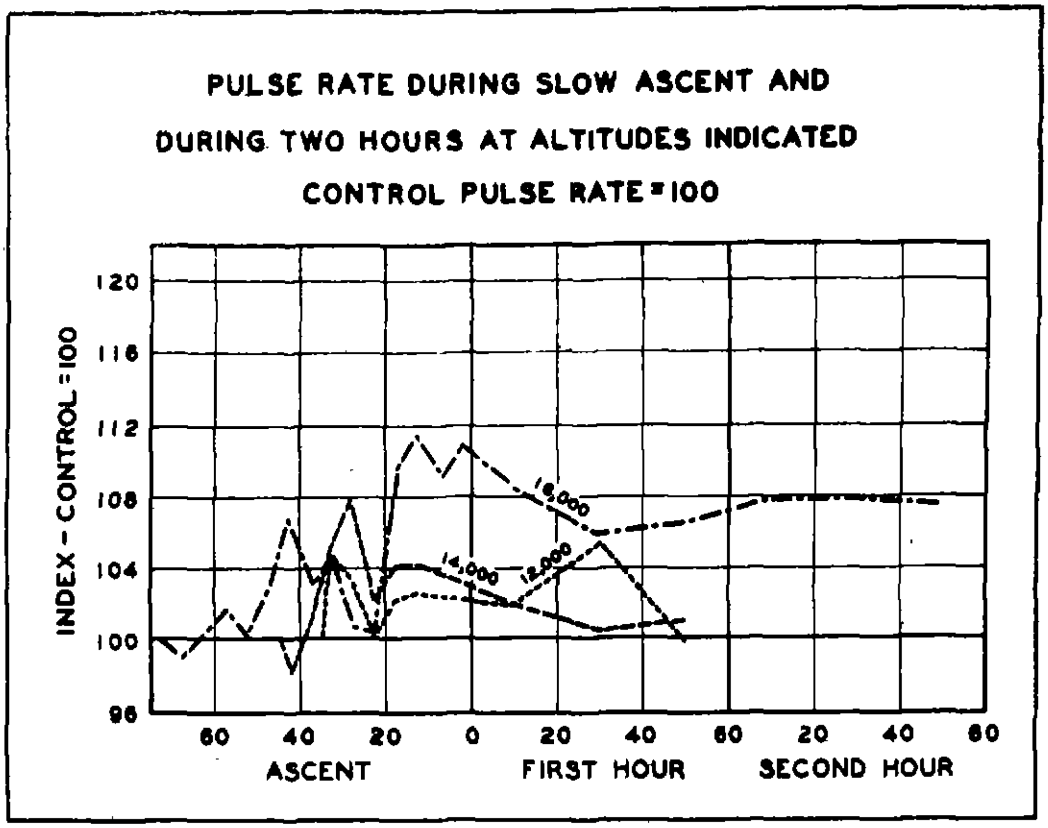

PULSE RATE DURING SLOW ASCENT AND
DURING TWO HOURS AT ALTITUDES INDICATED
CONTROL PULSE RATE = 100
INDEX - CONTROL = 100
120
116
112
108
104
100
96
16,000
14,000
12,000
60
40
20
0
20
40
60
20
40
60
ASCENT
FIRST HOUR
SECOND HOUR

FIG. 15

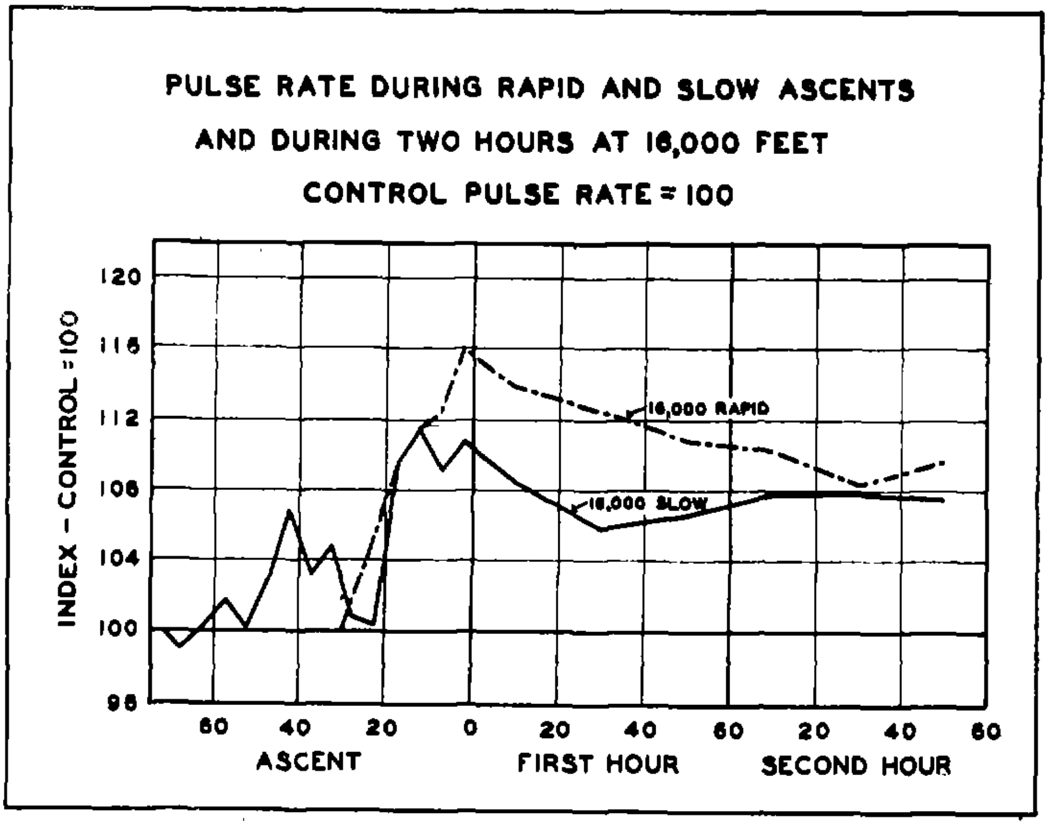

PULSE RATE DURING RAPID AND SLOW ASCENTS
AND DURING TWO HOURS AT 16,000 FEET
CONTROL PULSE RATE = 100
INDEX - CONTROL = 100
120
116
112
108
104
100
96
16,000 RAPID
16,000 SLOW
60
40
20
0
20
40
60
20
40
60
ASCENT
FIRST HOUR
SECOND HOUR

FIG. 16

1 hour and 15 minutes to 1 hour and 30 minutes, the variations appear to be less extreme if the organism has a longer time to become acclimatized. This tendency is shown graphically in Figure 16 for 16,000 feet altitude. In fact a number of the subjects who were able to become acclimatized to 16,000 feet following a slow ascent collapsed upon reaching similar altitudes after a rapid ascent. On the average the group differences in pulse rate were not significant; however, at 10,000, 12,000 and 14,000 feet, when the rapid and slow ascents were contrasted as shown in Figure 15.

<u>The systolic and diastolic blood pressure</u>. The mean variations in systolic and diastolic blood pressure under the different conditions of reduced oxygen pressure are shown in Tables 9 and 10. These results are partially shown in graphic form in Figures 17 and 18 in terms of the per cent change from the control.

On the average, the blood pressure records do not show very definite trends. This is primarily due to the fact that the increases and decreases tend to cancel out, thereby indicating only small changes in the group means. During the rapid ascents the variations both in systolic and diastolic pressure were less extreme than during the slow ascents. (Cf. Figures 17 and 18.) Most subjects react with an initial increase in both systolic and diastolic blood pressure, followed by a well controlled fall to normal values.

In contrasting the rapid and slow ascents to 16,000 feet, both the initial increase and prolonged effects in the systolic and diastolic pressures were higher during and following the rapid ascents.

<u>The alveolar oxygen and carbon dioxide</u>. The average partial pressure of oxygen and carbon dioxide in the alveolar air in relation to the percentage of oxygen and carbon dioxide in the chamber is shown in Table 11 and Figure 19

Table 9

SUMMARY TABLE

SYSTOLIC BLOOD PRESSURE

		Control	First Hour 1-20	First Hour 21-40	First Hour 41-60	Second Hour 1-20	Second Hour 21-40	Second Hour 41-60
10,000 Rapid	Mean	113.17	109.83	109.83	112.69	108.60	109.90	111.00
	S.D.	9.20	10.10	9.77	9.60	9.02	8.02	7.13
	Significance*	---	2-5	10-20	30-40	5-10	20-30	30-40
	Index of change	100.0	96.9	96.9	99.4	95.8	97.0	97.9
10,000 Slow	Mean	114.83	109.67	109.83	111.00			
	S.D.	7.72	9.18	9.03	6.06			
	Significance	---	20-30	10-20	10-20			
	Index of change	100.0	95.5	95.6	96.6			
12,000 Rapid	Mean	110.29	111.62	110.69	111.92	110.64	109.55	107.30
	S.D.	6.83	9.49	9.80	9.97	7.23	12.63	5.80
	Significance	---	50-60	80-90	60-70	40-50	70-80	60-70
	Index of change	100.0	101.2	100.3	101.5	100.3	99.3	97.3
12,000 Slow	Mean	107.13	107.86	102.71	103.86			
	S.D.	4.43	4.28	7.82	8.89			
	Significance	---	70-80	40-50	40-50			
	Index of change	100.0	100.7	95.9	97.0			
14,000 Rapid 15-30	Mean	112.77	112.13	109.05	109.74	109.51	111.41	109.65
	S.D.	12.73	14.01	11.23	14.28	14.84	14.09	15.65
	Significance	---	60-70	1-2	5-10	2-5	2-5	5-10
	Index of change	100.0	99.4	96.7	97.3	97.1	98.4	97.2
14,000 Rapid 30-45	Mean	120.00	123.38	112.71	115.67	115.67	117.67	119.00
	S.D.	13.17	16.84	11.55	12.40	---	---	---
	Significance	---	60-70	10-20	10-20	---	---	---
	Index of change	100.0	102.8	93.9	96.4	96.4	98.1	99.2
14,000 Rapid 45 and over	Mean	130.08	126.27	127.58	128.00	128.67	132.33	134.67
	S.D.	22.80	24.22	27.15	25.69	23.47	29.08	25.37
	Significance	---	60-70	40-50	20-30	20-30	70-80	90-100
	Index of change	100.0	97.1	98.1	98.4	98.9	101.7	103.6
14,000 Slow	Mean	113.83	111.33	114.33	111.00			
	S.D.	3.63	7.14	7.60	---			
	Significance	---	30-40	90-100	40-50			
	Index of change	100.0	99.5	100.4	97.5			
16,000 Rapid	Mean	110.4	109.4	109.4	110.8	109.4	109.8	108.6
	S.D.	10.19	7.74	11.40	11.75	12.41	12.04	18.36
	Significance	---	40-50	50-60	80-90	50-60	90-100	70-80
	Index of change	100.0	99.1	99.1	100.3	99.1	99.5	98.4
16,000 Slow	Mean	115.17	109.33	108.12	106.06	113.28	106.72	109.31
	S.D.	12.51	11.66	10.25	8.41	11.25	13.52	12.46
	Significance	---	0-1	1-2	0-1	5-10	1-2	5-10
	Index of change	100.0	94.9	93.8	92.1	98.5	92.6	94.9
18,000 Rapid	Mean	108.90	109.12	---	108.76	---	109.40	---
	S.D.	5.83	11.37	---	10.50	---	11.92	---
	Significance	---	90-100	---	80-90	---	90-100	---
	Index of change	100.0	100.2	---	100.1	---	100.5	---
21,000 Rapid	Mean	109.5	---	125.5	---	---	127.3	---
	S.D.	---	---	---	---	---	---	---
	Significance	---	---	---	---	---	---	---
	Index of change	100.0	---	114.7	---	---	116.3	---

*Chances in 100 that the difference from the control could have arisen by chance. Five chances in 100 or less are necessary before the significance of the difference is reasonably certain, or before chance can be reasonably ruled out.

Table 10

SUMMARY TABLE

DIASTOLIC BLOOD PRESSURE

		Control	First Hour 1-20	First Hour 21-40	First Hour 41-60	Second Hour 1-20	Second Hour 21-40	Second Hour 41-60
10,000 Rapid	Mean	65.72	66.17	66.44	69.50	66.30	66.50	67.57
	S.D.	7.66	6.72	8.90	9.14	6.83	7.86	6.22
	Significance*	---	80-90	70-80	30-40	80-90	80-90	60-70
	Index of change	100.0	100.7	101.1	105.7	100.9	101.2	102.8
10,000 Slow	Mean	61.67	63.67	66.17	63.00			
	S.D.	5.20	5.18	5.03	3.05			
	Significance	---	30-40	20-30	50-60			
	Index of change	100.0	103.2	107.3	102.2			
12,000 Rapid	Mean	66.71	66.69	66.18	66.36	67.27	66.91	67.40
	S.D.	6.97	6.94	5.19	6.73	5.67	7.64	3.67
	Significance	---	70-80	100	60-70	70-80	90-100	90-100
	Index of change	100.0	100.0	99.3	99.5	100.8	100.3	101.0
12,000 Slow	Mean	64.00	62.00	64.00	62.71			
	S.D.	6.47	4.58	5.10	5.04			
	Significance	---	40-50	80-90	30-40			
	Index of change	100.0	96.9	100.0	98.0			
14,000 Rapid 15-30	Mean	63.68	66.62	65.84	65.70	66.35	67.45	67.35
	S.D.	7.89	8.78	8.48	9.06	9.59	10.30	9.73
	Significance	---	2-5	2-5	10-20	5-10	1-2	0-1
	Index of change	100.0	104.6	103.4	103.2	104.2	105.9	105.8
14,000 Rapid 30-45	Mean	73.80	71.50	69.43	73.56	75.33	71.00	73.67
	S.D.	10.40	11.86	8.67	10.83	---	---	---
	Significance	---	20-30	20-30	50-60	---	---	---
	Index of change	100.0	96.4	94.1	99.7	102.1	96.2	99.8
14,000 Rapid 45 and over	Mean	80.00	77.83	78.67	83.00	84.33	87.20	97.20
	S.D.	17.84	17.80	18.50	23.19	26.66	34.49	31.01
	Significance	---	50-60	60-70	60-70	60-70	50-60	30-40
	Index of change	100.0	97.3	98.3	103.7	105.4	109.0	121.5
14,000 Slow	Mean	63.67	66.67	68.00	66.00			
	S.D.	5.64	7.80	8.69	---			
	Significance	---	20-30	10-20	5-10			
	Index of change	100.0	104.7	106.8	103.6			
16,000 Rapid	Mean	64.6	64.8	66.6	65.2	65.2	63.5	65.9
	S.D.	7.28	9.48	8.36	7.41	9.59	7.93	10.77
	Significance	---	80-90	10-20	70-80	60-70	80-90	50-60
	Index of change	100.0	100.3	103.1	100.9	100.9	98.3	102.0
16,000 Slow	Mean	67.06	66.82	67.20	65.71	67.17	66.88	69.21
	S.D.	9.59	9.00	7.82	10.10	6.45	10.36	12.09
	Significance	---	50-60	40-50	60-70	80-90	60-70	80-90
	Index of change	100.0	99.6	100.2	98.0	100.2	99.7	103.2
18,000 Rapid	Mean	70.30	63.12	---	67.12	---	67.40	---
	S.D.	6.70	11.65	---	10.01	---	9.00	---
	Significance	---	0-1	---	5-10	---	5-10	---
	Index of change	100.0	89.8	---	95.5	---	95.9	---
21,000 Rapid	Mean	70.0	---	48.50	---	---	47.50	---
	S.D.	---	---	---	---	---	---	---
	Significance	---	---	---	---	---	---	---
	Index of change	100.0	---	69.3	---	---	67.9	---

*Chances in 100 that the difference from the control could have arisen by chance. Five chances in 100 or less are necessary before the significance of the difference is reasonably certain, or before chance can be reasonably ruled out.

Table 11

MEANS OF ALVEOLAR pCO_2 AND pO_2 AND CHAMBER CONCENTRATIONS

FOR ALTITUDES INDICATED

	Control		I				II			
					Chamber				Chamber	
	pCO_2	pO_2	pCO_2	pO_2	$\%CO_2$	$\%O_2$	pCO_2	pO_2	$\%CO_2$	$\%O_2$
10,000 Rapid	40.4	99.0	38.1	54.3	.36	13.95	44.2	54.8	.65	14.16
10,000 Slow	39.2	103.0	37.6	59.3	.43	14.06	--	--	--	--
12,000 Rapid	38.2	105.5	36.1	56.8	.36	13.13	34.5	56.5	.51	12.94
12,000 Slow	40.5	100.1	37.7	53.7	.49	13.25	40.3	50.5	.72	13.36
14,000 Rapid 15-30	39.9	98.5	39.4	43.58	.38	12.06	37.0	44.4	.69	12.20
14,000 Rapid 30-45	37.5	101.9	35.5	43.2	.39	12.04	34.3	45.0	.90	12.14
14,000 Rapid 45 and over	38.03	100.3	36.2	47.6	.45	12.42	35.5	54.6	.63	12.19
14,000 Slow	38.8	100.9	38.8	43.9	.46	12.16	38.5*	38.5*	.55*	12.02*
16,000 Rapid	38.5	101.1	35.3	38.6	.37	11.16	34.9	38.4	.63	11.18
16,000 Slow	38.5	101.3	34.6	43.2	.47	11.10	34.3	39.4	.66	11.30

*One subject.

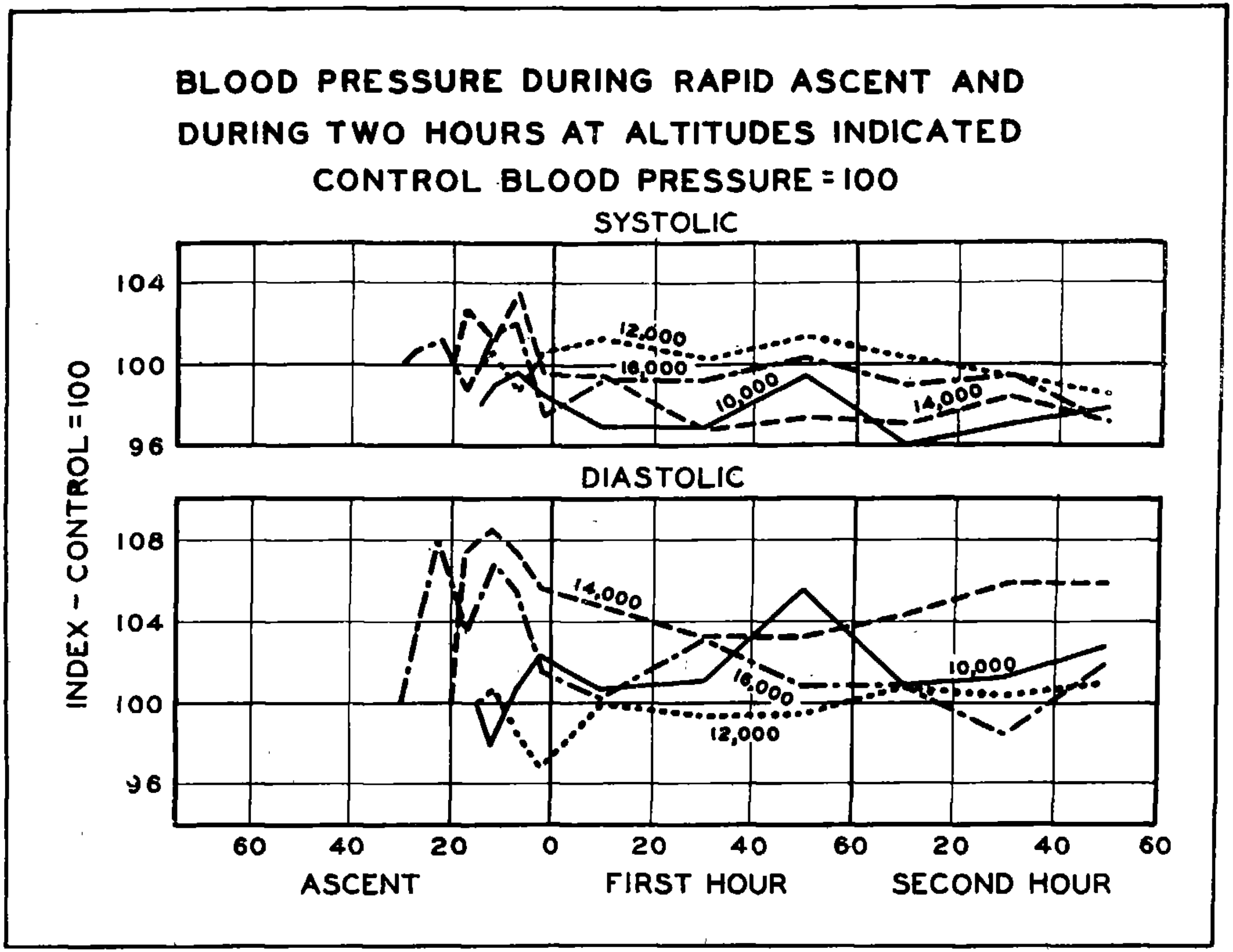
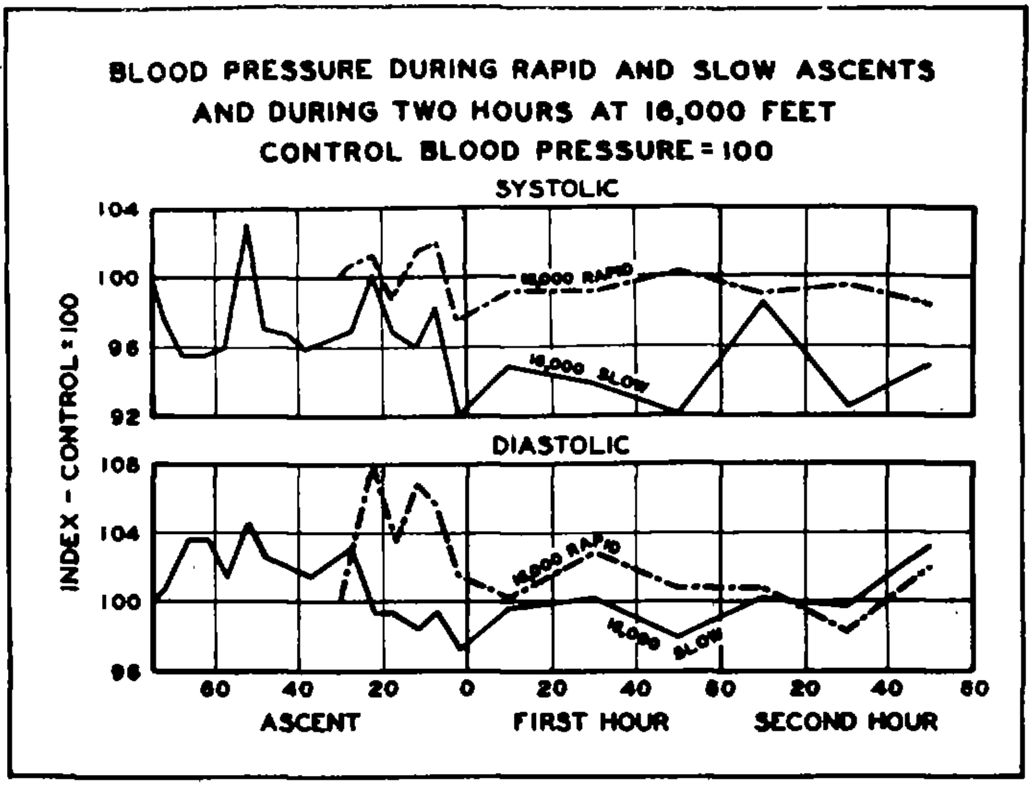

BLOOD PRESSURE DURING RAPID ASCENT AND
DURING TWO HOURS AT ALTITUDES INDICATED
CONTROL BLOOD PRESSURE = 100
SYSTOLIC
DIASTOLIC
INDEX - CONTROL = 100
104
100
96
108
104
100
96
12,000
16,000
10,000
14,000
14,000
16,000
12,000
10,000
60
40
20
0
20
40
60
20
40
60
ASCENT
FIRST HOUR
SECOND HOUR

FIG. 17


BLOOD PRESSURE DURING RAPID AND SLOW ASCENTS
AND DURING TWO HOURS AT 16,000 FEET
CONTROL BLOOD PRESSURE = 100
SYSTOLIC
DIASTOLIC
16,000 RAPID
16,000 SLOW
INDEX - CONTROL = 100
104
100
96
92
108
104
100
96
60
40
20
0
20
40
60
20
40
60
ASCENT
FIRST HOUR
SECOND HOUR

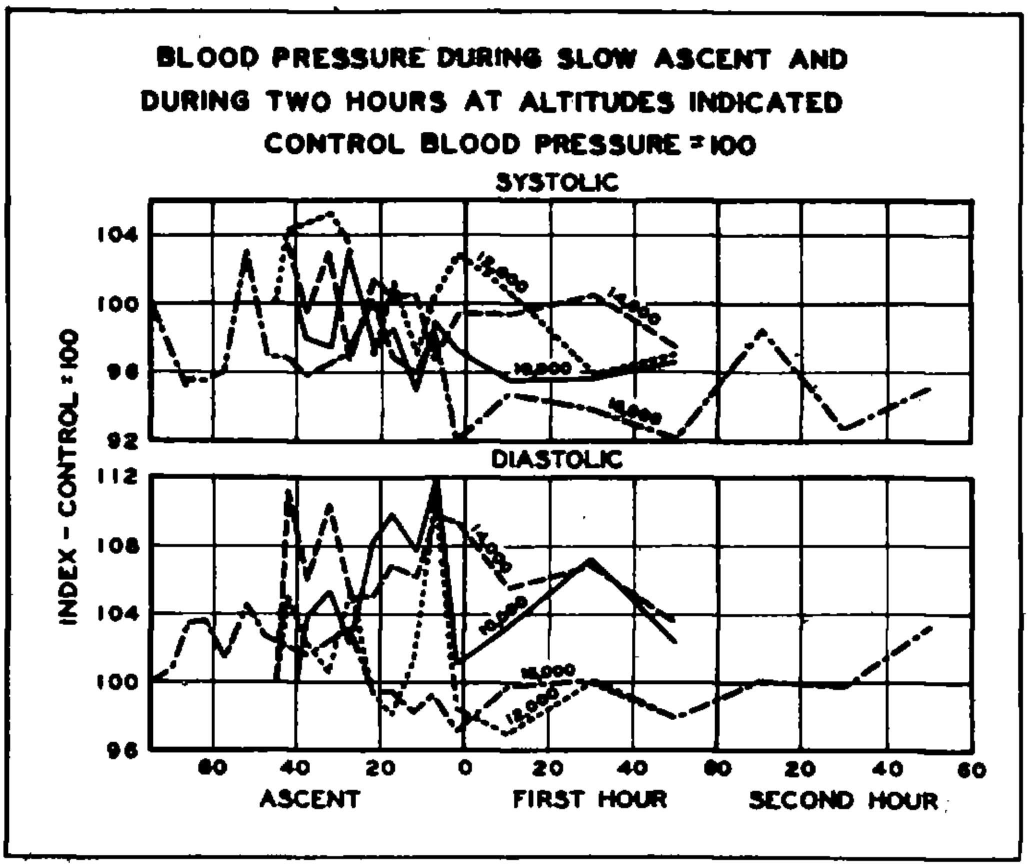

BLOOD PRESSURE DURING SLOW ASCENT AND
DURING TWO HOURS AT ALTITUDES INDICATED
CONTROL BLOOD PRESSURE = 100
SYSTOLIC
DIASTOLIC
INDEX - CONTROL = 100
104
100
96
92
112
108
104
100
96
60
40
20
0
20
40
60
20
40
60
ASCENT
FIRST HOUR
SECOND HOUR

FIG. 18

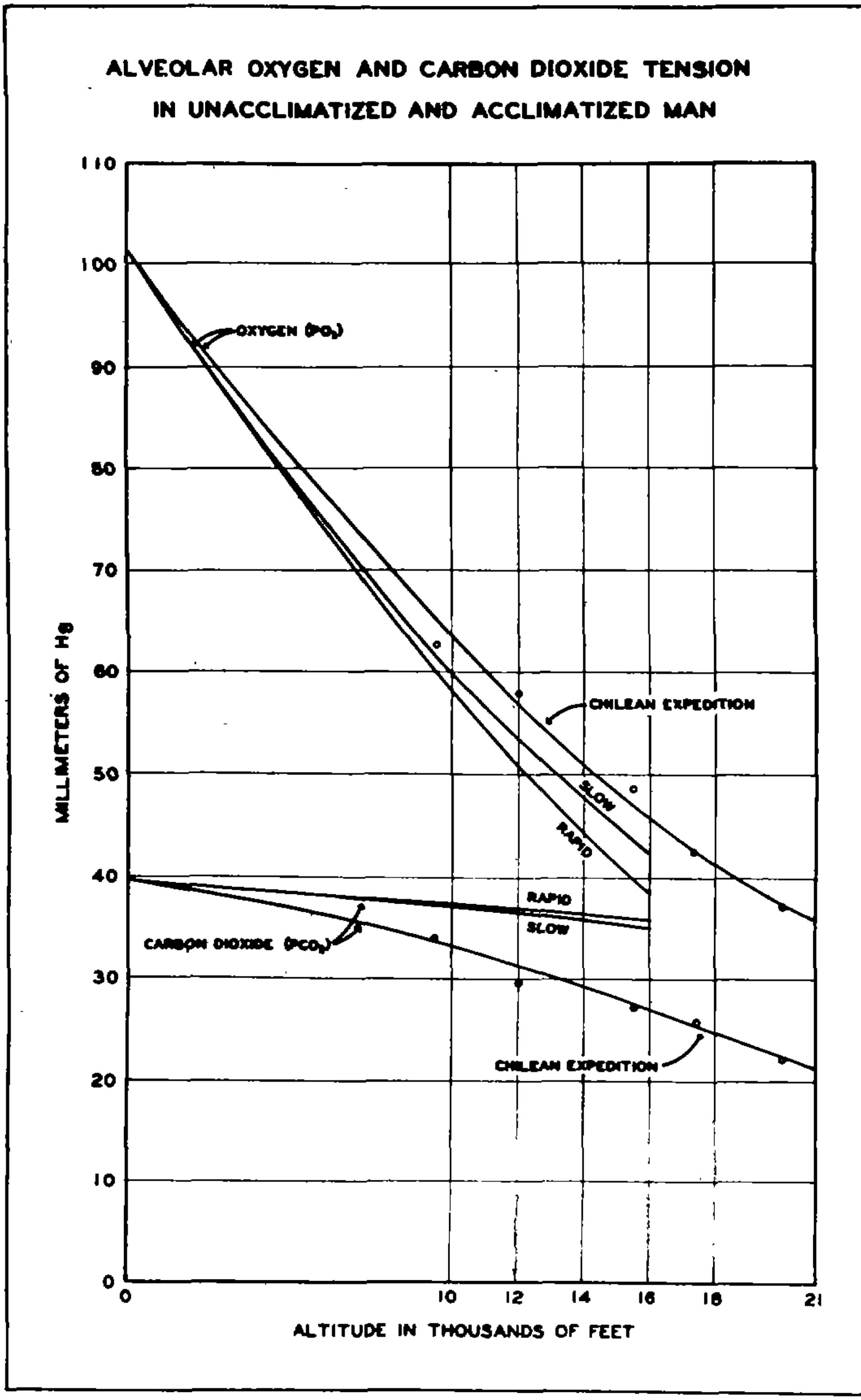

ALVEOLAR OXYGEN AND CARBON DIOXIDE TENSION
IN UNACCLIMATIZED AND ACCLIMATIZED MAN
MILLIMETERS OF Hg
ALTITUDE IN THOUSANDS OF FEET
OXYGEN (PO_2)
CHILEAN EXPEDITION
SLOW
RAPID
RAPID
SLOW
CARBON DIOXIDE (PCO_2)
CHILEAN EXPEDITION
0
10
20
30
40
50
60
70
80
90
100
110
0
10
12
14
16
18
21

FIG. 19

for the various groups under the conditions of diminished oxygen tension as indicated.

The results indicate that, on the average, the partial pressure of oxygen is significantly higher and the carbon dioxide lower in acclimatized subjects compared to unacclimatized ones. (Cf. Figure 19 for results from the Chilean Expedition (10 men) after several months at the various stations as indicated.) In contrasting the two rates of ascents in this experiment the partial pressure of oxygen was significantly higher following the slow ascents compared to the rapid ones.

Results of the Psychological Tests.

Handwriting test. In an attempt to observe the effects of diminished oxygen pressure on motor control in a highly practiced reaction like handwriting, two different tests were used, the first involving the copying of a paragraph of eight lines of Swedish language, and the second a handwritten commentary on the physiological and psychological changes observed during each experiment. The samples of handwriting were scored on the basis of changes from the normal handwriting, using the following criteria: (1) irregularities in distance and height, i.e., size; (2) slant of the letters; (3) changes in the slopes of the lines; (4) tremors; (5) omissions of letters and punctuation. The scores on these various items were then added into a total score and calculated in terms of the per cent change from the control.

The results are shown in Table 12 and Figure 20. On the average, there was a significant impairment in this test at 14,000 feet and above, the deterioration in motor control being fairly great at 16,000 and 18,000 feet following a rapid ascent.

A number of typical specimens of handwriting under control (air)

Table 12

PER CENT DEVIATION IN HANDWRITING FROM THE CONTROL (100)

FOR THE ALTITUDES AND RATES OF ASCENT INDICATED

	Control	First Hour	Second Hour
10,000 feet			
Rapid	100	98.0	96.3
Slow	100	99.2	--
12,000 feet			
Rapid	100	96.7	93.8
Slow	100	93.4	--
14,000 feet			
Rapid	100	93.8	92.2
Slow	100	95.0	--
16,000 feet			
Rapid	100	92.0	86.2
Slow	100	92.8	91.0
18,000 feet			
Rapid	100	76.2	--

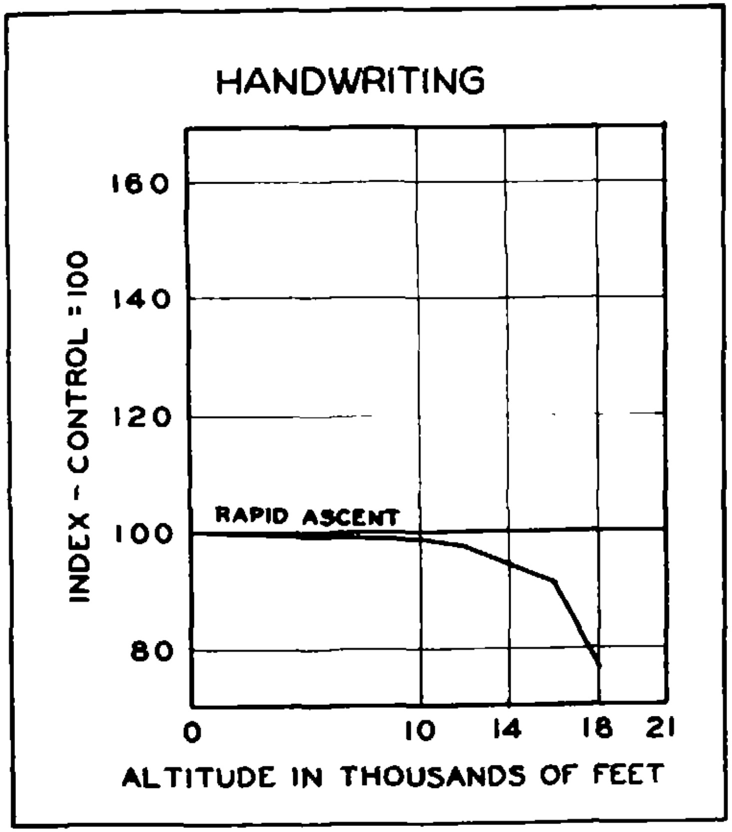

HANDWRITING
160
140
120
100
80
INDEX - CONTROL = 100
RAPID ASCENT
0
10
14
18
21
ALTITUDE IN THOUSANDS OF FEET

FIG. 20

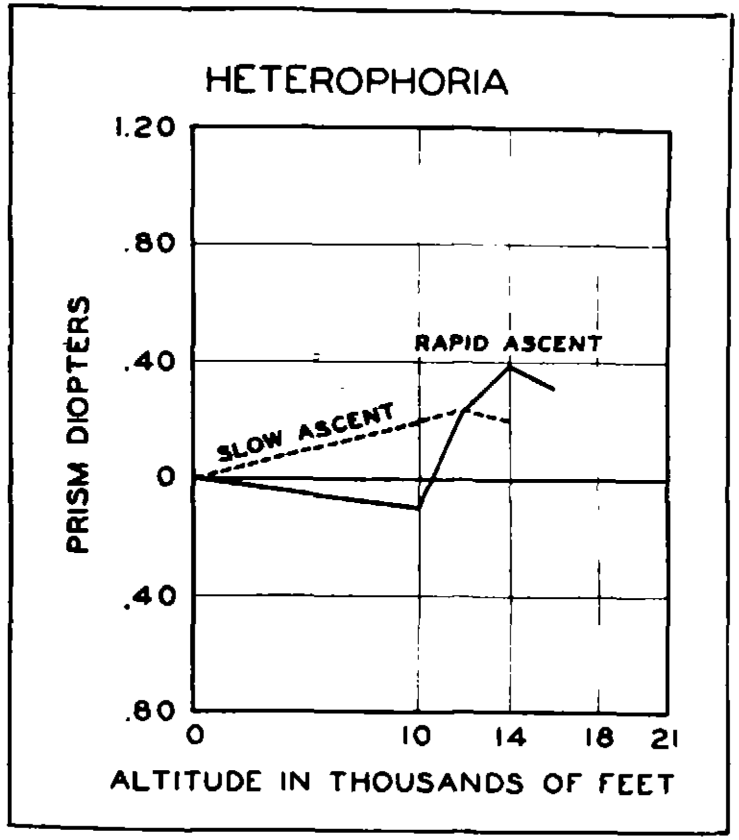

HETEROPHORIA
1.20
.80
.40
0
.40
.80
PRISM DIOPTERS
RAPID ASCENT
SLOW ASCENT
0
10
14
18
21
ALTITUDE IN THOUSANDS OF FEET

FIG. 21

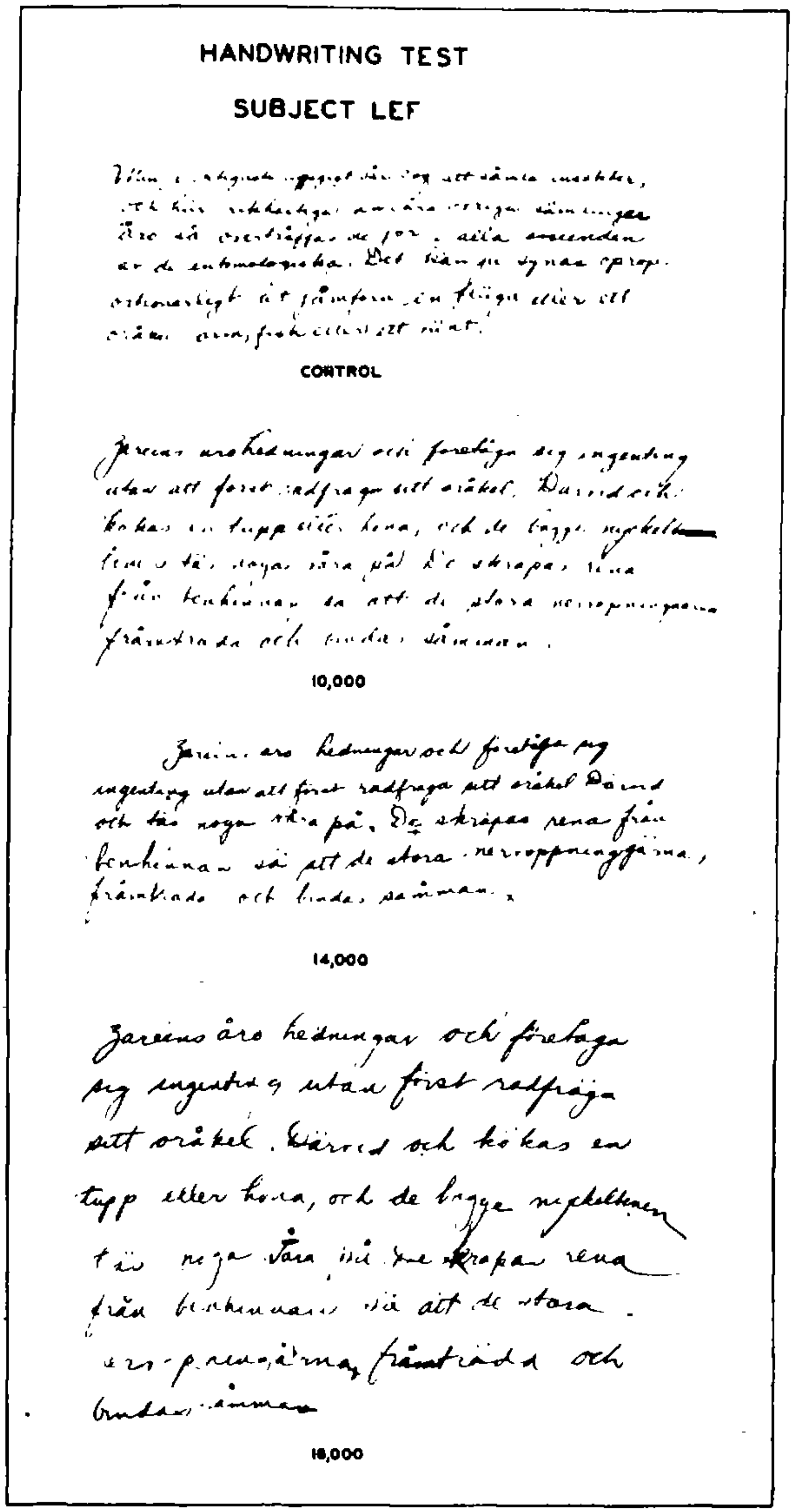


FIG. 22

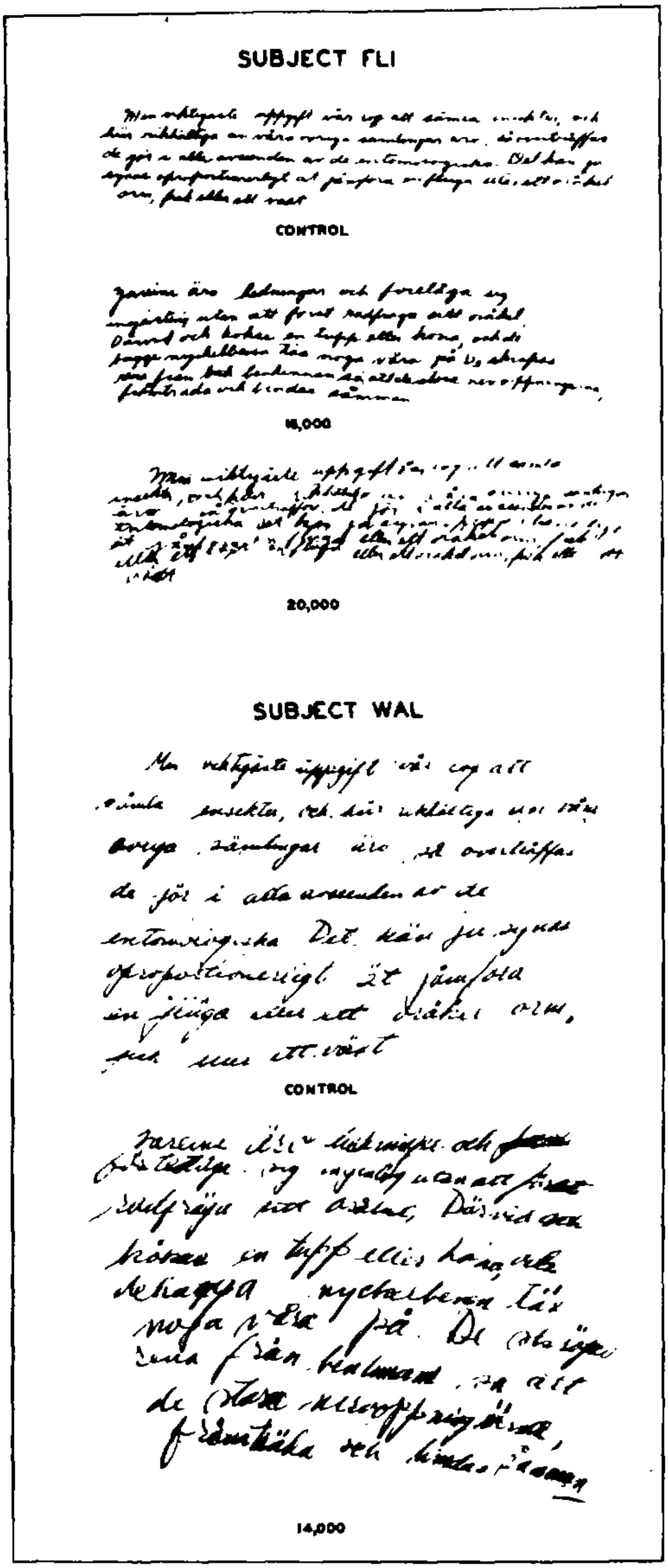


FIG. 23

Name Tatham, David Date 14R Feb. 11

Time	Subjective
A	
I 1	Pressure in region of brain & above eyes
	sleepy (slightly)
5	No pressure now
6	dulled senses somewhat of eyes & ears
11	all pressure gone—senses clear
26	hearing slightly dulled
II 4	slight headache over eyes.
	chilly + cold — Temp 74°
22	palms moist in spite of cold feeling
35	slight headache ✓
45	cold — fingertips rather cold
	breezy.
	hearing slightly dulled
50	slightly dizzy or nauseous

FIG. 24

18R

Name *William Tyrrell* Date *July 13 1932*

	Time	Remarks
A	15	Respiration faster & deeper
	20	Restless
	25	Slight dizziness upon blowing
I	1	Breathing still deep
	7	~~A slight feeling of fright~~
	11	Felt slightly chilly
	16	Code test more difficult.

FIG. 25

conditions and reduced oxygen tension are shown in Figures 22 to 25. Figures 22 and 23 show reproductions of the Swedish passages which were to be copied, and Figures 24 and 25 the voluntary comments of two of the subjects as to their general acclimatization to the lowered oxygen pressure.

Heterophoria test. In this test the amount of ocular muscle unbalance was measured under constant lighting conditions with a pair of 5-diopter prisms at 40 cms. distance. The results, as shown in Table 15 and Figure 21, indicate the mean deviation in prism diopters from the control value (not orthophoria) under the various conditions of diminished oxygen pressure. The significance of the observed differences was not reliable statistically until the oxygen partial pressure was reduced corresponding to altitudes of 14,000 feet and above.

Choice reaction times. The results of this test under the various conditions of oxygen deprivation are shown graphically in Figure 26 in terms of per cent change from normal -- 100. The reaction times, as measured in hundredths of a second with the portable choice reaction time box (61) were not significantly lowered until the partial pressure of oxygen was reduced so as to simulate an altitude of 14,000 feet and above. This particular test was not complex enough to bring out the more subtle mental changes associated with oxygen deprivation, and hence it was not used throughout the entire series of experiments.

Color naming test. In this test the subjects were required to name as rapidly as possible 100 colored squares (1/2 inch squares, red, blue, green, black, and yellow) arranged in random order. The score is given in seconds and errors. Individuals vary greatly in the rapidity and the number of errors with which this test can be taken, but few can escape the tendency toward "blocking" or naming the wrong color, especially those subjects who are emotionally unstable. Previous experiments have shown that following the ingestion of alcohol or acute

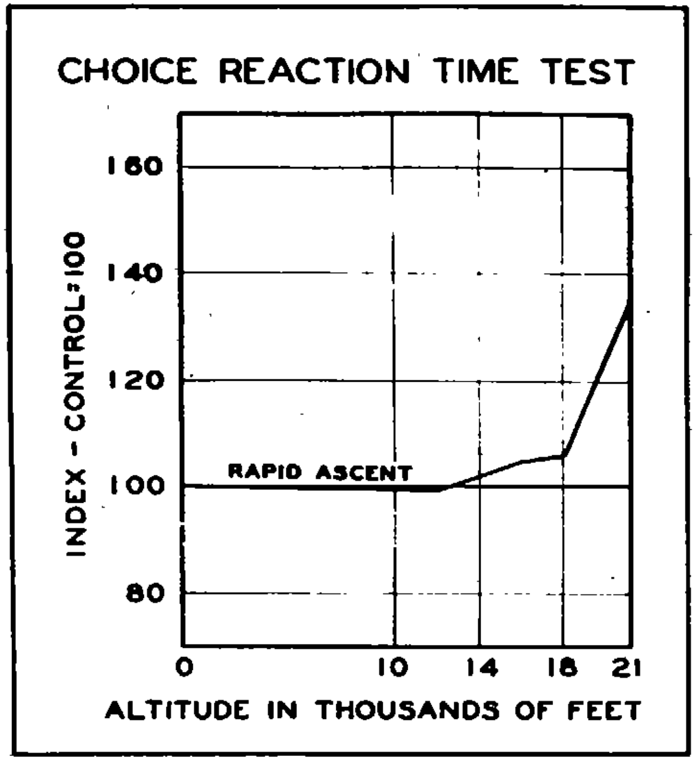

CHOICE REACTION TIME TEST
INDEX - CONTROL = 100
160
140
120
100
80
RAPID ASCENT
0
10
14
18
21
ALTITUDE IN THOUSANDS OF FEET

FIG. 26

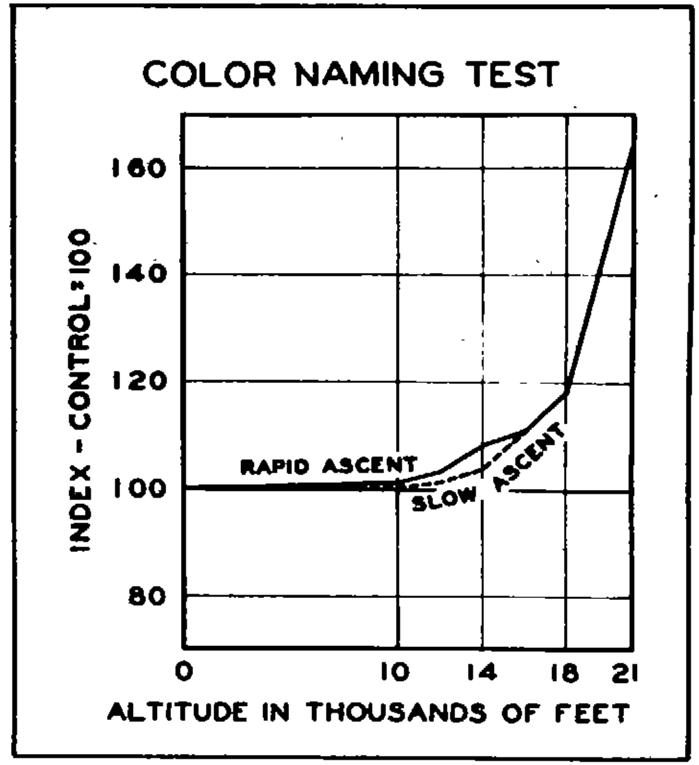

COLOR NAMING TEST
INDEX - CONTROL = 100
160
140
120
100
80
RAPID ASCENT
SLOW ASCENT
0
10
14
18
21
ALTITUDE IN THOUSANDS OF FEET

FIG. 27

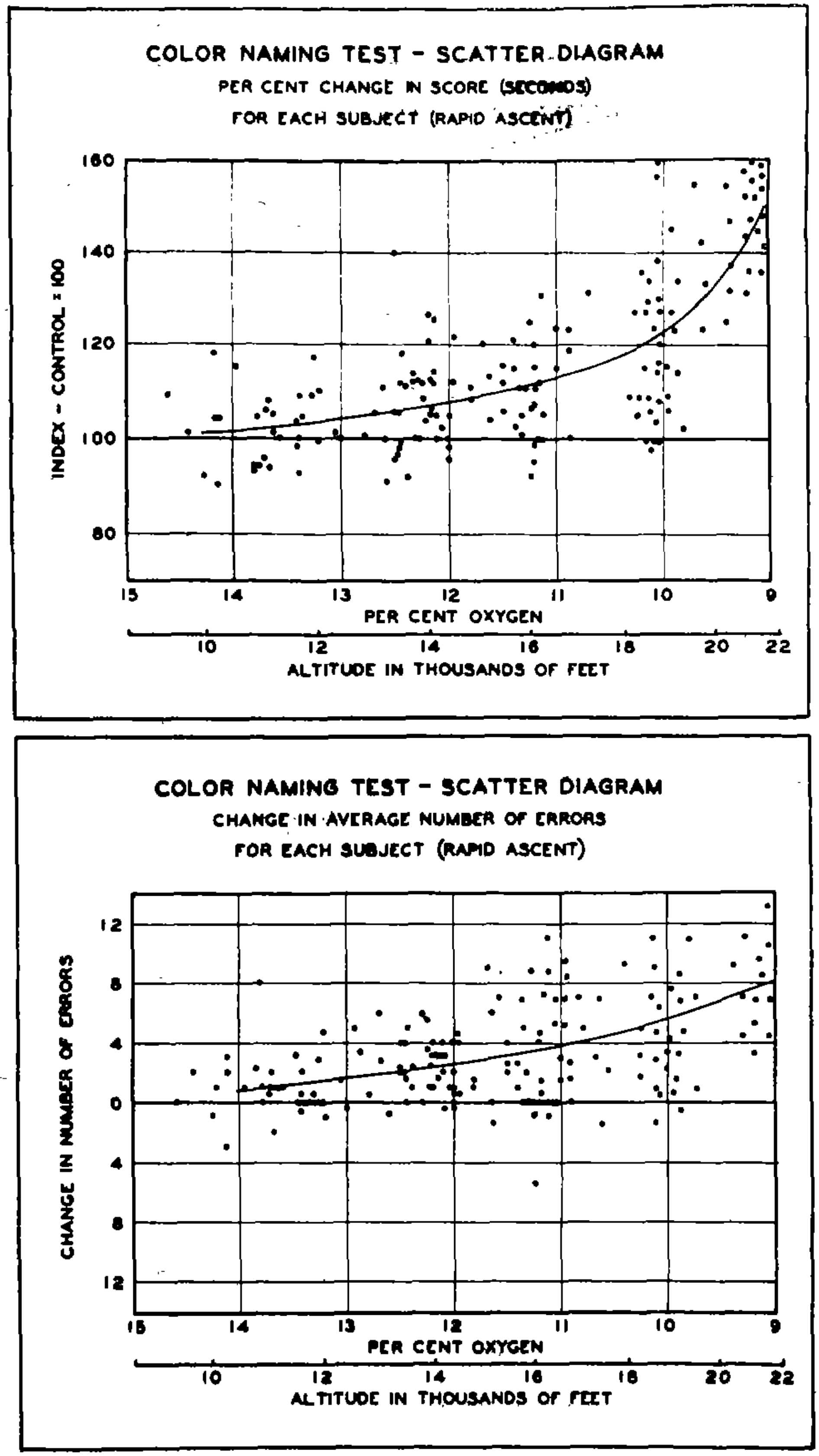

COLOR NAMING TEST - SCATTER DIAGRAM
PER CENT CHANGE IN SCORE (SECONDS)
FOR EACH SUBJECT (RAPID ASCENT)
INDEX - CONTROL = 100
160
140
120
100
80
15
14
13
12
11
10
9
PER CENT OXYGEN
10
12
14
16
18
20
22
ALTITUDE IN THOUSANDS OF FEET
COLOR NAMING TEST - SCATTER DIAGRAM
CHANGE IN AVERAGE NUMBER OF ERRORS
FOR EACH SUBJECT (RAPID ASCENT)
CHANGE IN NUMBER OF ERRORS
12
8
4
0
4
8
12
15
14
13
12
11
10
9
PER CENT OXYGEN
10
12
14
16
18
20
22
ALTITUDE IN THOUSANDS OF FEET

FIG. 28

Table 13

SUMMARY TABLE

COLOR NAMING

		Time in Seconds			Errors**		
		Control	First Hour	Second Hour	Control	First Hour	Second Hour
10,000	Mean	54.44	55.28	54.81	1.22	2.25	2.31
Rapid	S.D.	8.83	8.89	8.95	.97	2.09	2.07
	Significance*	---	40-50	70-80	---	2-5	5-10
	Index of change	100.0	101.5	100.7	100.0	102.1	102.2
10,000	Mean	49.16	49.25	---	.50	.67	---
Slow	S.D.	3.43	8.11	---	.50	.79	---
	Significance	---	90-100	---	---	70-80	---
	Index of change	100.0	100.2	---	100.0	100.4	---
12,000	Mean	51.50	53.31	53.59	.43	.77	.79
Rapid	S.D.	6.94	8.63	8.32	.62	1.55	1.04
	Significance	---	0-1	2-5	---	40-50	10-20
	Index of change	100.0	103.5	104.0	100.0	100.7	100.7
12,000	Mean	50.25	51.37	---	1.06	2.50	---
Slow	S.D.	6.14	8.28	---	.73	1.46	---
	Significance	---	50-60	---	---	5-10	---
	Index of change	100.0	102.2	---	100.0	103.1	---
14,000	Mean	55.19	59.81	60.04	1.65	3.90	3.76
Rapid	S.L.	9.72	14.41	14.43	1.40	2.47	2.74
15-30	Significance	---	0-1	0-1	---	0-1	0-1
	Index of change	100.0	108.4	108.8	100.0	104.9	104.5
14,000	Mean	62.6	69.22	73.67	1.60	2.86	3.33
Rapid	S.D.	16.30	16.97	---	.80	2.17	---
30-45	Significance	---	10-20	---	---	10-20	---
	Index of change	100.0	110.6	117.7	100.0	102.6	103.7
14,000	Mean	67.00	68.20	71.50	1.27	2.48	2.00
Rapid	S.D.	9.71	10.89	14.96	.97	1.51	.96
45 or	Significance	---	30-40	30-40	---	2-5	30-40
over	Index of change	100.0	101.8	106.7	100.0	102.5	101.7
14,000	Mean	51.83	53.92	---	.68	1.25	---
Slow	S.D.	4.30	5.83	---	.47	1.11	---
	Significance	---	10-20	---	---	20-30	---
	Index of change	100.0	104.0	---	100.0	101.2	---
16,000	Mean	54.00	60.01	62.07	1.48	2.89	2.52
Rapid	S.D.	9.15	12.44	15.43	1.82	3.25	2.61
	Significance	---	0-1	0-1	---	1-2	2-5
	Index of change	100.0	111.1	116.1	100.0	103.0	102.1
16,000	Mean	50.22	56.00	58.58	1.22	2.22	2.17
Slow	S.D.	9.21	13.67	13.26	1.75	2.59	2.71
	Significance	---	0-1	0-1	---	10-20	10-20
	Index of change	100.0	111.5	116.6	100.0	102.1	102.0
18,000	Mean	59.24	70.09	---	---	---	---
Rapid	S.D.	8.94	12.29	---	---	---	---
	Significance	---	0-1	---	---	---	---
	Index of change	100.0	118.3	---	---	---	---

*Chances in 100 that the difference from the control could have arisen by chance. Five chances in 100 or less are necessary before the significance of the difference is reasonably certain, or before chance can be reasonably ruled out.

**Total possible number of errors is 100.

"fatigue" this tendency toward "mental lag" or blocking is greatly accentuated. A careful record was kept by the experimenter of the number of errors, i.e., the number of times the subject called the color by the wrong name or was blocked in saying the words. Both the time score and the error score should be considered in interpreting these data. The results are shown in Table 13 and also in Figure 27 in terms of the per cent change from the control data.

The results show that, on the average, the mean impairment in time due to the oxygen deprivation was statistically significant following the rapid ascents to 12,000 feet and above and at 14,000 feet following the slow ascents. The variability of response also increased with increasing altitude as indicated in the larger standard deviations. The increase in errors in this test was statistically significant at 10,000 feet following the rapid ascent. This was not true following the slow ascents until a simulated altitude of 14,000 feet was attained.

In order to show the mean variability of response at the various simulated altitudes in the color naming test, the individual responses (in terms of per cent change from the control) for the score (time) and average increase in number of errors have been tabulated on scatter diagrams in Figure 28. These scatter diagrams indicate that there is a fairly wide range in individual differences, but that on the average there is a considerable degree of impairment with increasing depletion of the oxygen in the inspired air.

<u>The code test</u>. This test measures the speed and accuracy of transliterating 50 letters of a code. There are 40 forms and since each one is different the increased performance due to practice is not significant. The test measures a fairly wide range of psychological functions, including close

Table 14
SUMMARY TABLE

JOHNSON CODE TEST

		Time in Seconds			Errors**		
		Control	First Hour	Second Hour	Control	First Hour	Second Hour
10,000 Rapid	Mean	127.16	132.22	130.22	.28	.69	.58
	S.D.	26.85	31.17	29.73	.56	.93	.79
	Significance*	---	5-10	30-40	---	5-10	20-30
	Index of change	100.0	104.0	102.4	100.0	100.8	100.6
10,000 Slow	Mean	133.00	129.91	---	.67	1.33	---
	S.D.	35.54	31.42	---	.74	1.14	---
	Significance	---	40-50	---	---	30-40	---
	Index of change	100.0	97.7	---	100.0	101.3	---
12,000 Rapid	Mean	123.14	131.14	135.14	.71	.75	1.00
	S.D.	28.36	29.83	31.61	.89	.80	1.37
	Significance	---	1-2	0-1	---	90-100	40-50
	Index of change	100.0	106.5	109.7	100.0	100.1	100.6
12,000 Slow	Mean	122.25	128.31	---	.13	1.06	---
	S.D.	33.23	33.91	---	.33	.59	---
	Significance	---	2-5	---	---	0-1	---
	Index of change	100.0	104.7	---	100.0	101.8	---
14,000 Rapid 15-30	Mean	122.04	131.72	130.31	.27	.86	.96
	S.D.	21.24	23.60	25.05	.53	.84	1.06
	Significance	---	0-1	0-1	---	0-1	0-1
	Index of change	100.0	107.9	106.8	100.0	101.2	101.4
14,000 Rapid 30-45	Mean	159.70	170.06	167.50	.70	1.50	1.67
	S.D.	37.46	44.55	---	.78	1.03	---
	Significance	---	70-80	---	---	10-20	---
	Index of change	100.0	106.8	104.5	100.0	101.6	101.9
14,000 Rapid 45 and over	Mean	176.92	188.75	162.42	.42	.75	.83
	S.D.	45.92	52.37	27.31	.86	.72	.63
	Significance	---	10-20	1-2	---	50-60	10-20
	Index of change	100.0	106.6	91.8	100.0	100.7	100.8
14,000 Slow	Mean	119.50	130.42	---	.17	1.00	---
	S.D.	39.16	58.78	---	.36	.65	---
	Significance	---	20-30	---	---	0-1	---
	Index of change	100.0	109.1	---	100.0	101.7	---
16,000 Rapid	Mean	121.26	135.14	133.55	.37	1.20	1.21
	S.D.	16.85	18.36	21.87	.61	1.02	1.50
	Significance	---	0-1	0-1	---	0-1	0-1
	Index of change	100.0	111.5	110.2	100.0	101.7	101.7
16,000 Slow	Mean	111.72	124.78	127.36	.20	1.37	1.61
	S.D.	13.31	20.80	25.80	.42	1.77	1.40
	Significance	---	0-1	0-1	---	2-5	0-1
	Index of change	100.0	111.7	114.0	100.0	102.3	102.8
18,000 Rapid	Mean	126.03	147.83	156.66	2.61	3.64	2.45
	S.D.	24.33	36.87	53.76	3.11	3.34	2.49
	Significance	---	0-1	0-1	---	0-1	1-2
	Index of change	100.0	117.3	124.3	100.0	102.2	99.7
21,000 Rapid	Mean	128.79	215.33	---	1.0	21.67	---
	S.D.	---	---	---	---	---	---
	Significance	---	0-1	---	---	0-1	---
	Index of change	100.0	166.8	---	100.0	173.0	---

*Chances in 100 that the difference from the control could have arisen by chance. Five chances in 100 or less are necessary before the significance of the difference is reasonably certain, or before chance can be reasonably ruled out.

** Total possible number of errors is 50.

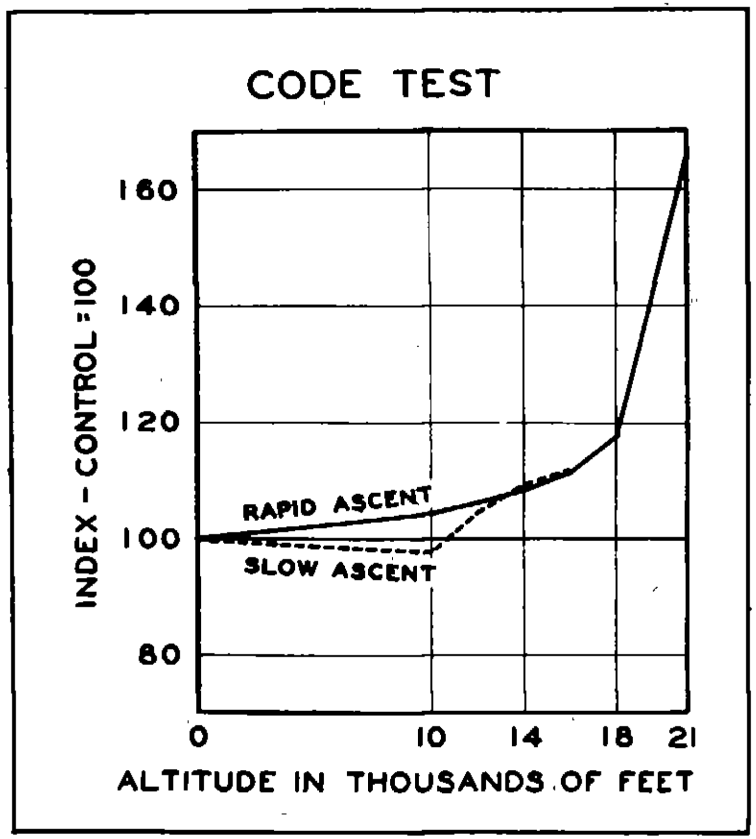

CODE TEST
160
140
120
100
80
INDEX - CONTROL = 100
RAPID ASCENT
SLOW ASCENT
0
10
14
18
21
ALTITUDE IN THOUSANDS OF FEET

FIG. 29

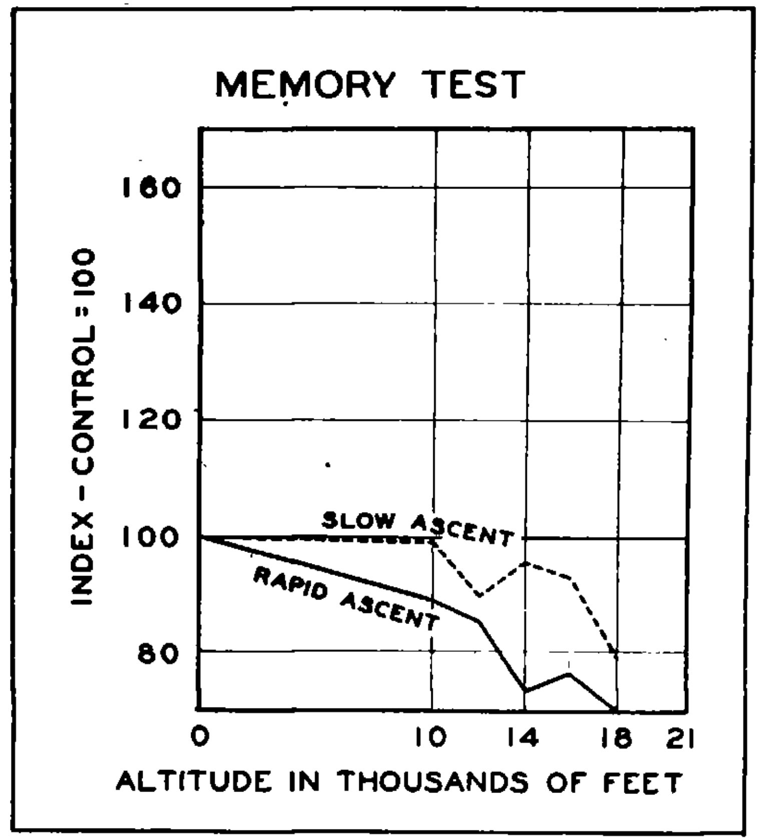

MEMORY TEST
160
140
120
100
80
INDEX - CONTROL = 100
SLOW ASCENT
RAPID ASCENT
0
10
14
18
21
ALTITUDE IN THOUSANDS OF FEET

FIG. 30

attention, accuracy, adjustments of accommodation and convergence and handwriting.

The results of this test, both the mean scores for time and errors, under the various degrees of oxygen deprivation are shown in Table 14 and graphically in Figure 29. Following the rapid ascent to 10,000 feet, there was a significant impairment during the first hour but not during the second hour. These mean decreases in time and errors became statistically reliable at simulated altitudes of 12,000 feet and above. At the highest altitudes the decrease in efficiency in this test became very marked, not only as manifested in the mean variability of the group, but also in the per cent decrease in time and increase in errors. The scatter diagram in Figure 31, showing the individual scores in the code test, illustrates quite clearly the wide range of individual differences, as well as the decrease in scores with an increase in oxygen deprivation.

<u>The memory test</u>. This test (memory for paired associates) measures the capacity for close concentration and immediate memory. Ten pairs of four-letter words (with no obvious associations in terms of meaning) were exposed for 15 seconds each. The cards were then turned over so that only the first of the pair of words was shown. The subject was supposed to remember the second or associated word within 5 to 10 seconds.

The results of this test are shown in Table 15 and Figure 30. There was a significant decrease in the average number of words recalled at 10,000 feet following the rapid ascent. The mean decrease was not statistically reliable, however, at 12,000 feet following both the rapid and slow ascents. At 14,000 feet and above the impairment in immediate memory was, on the average, significant statistically. At the higher altitudes (18,000

Table 15

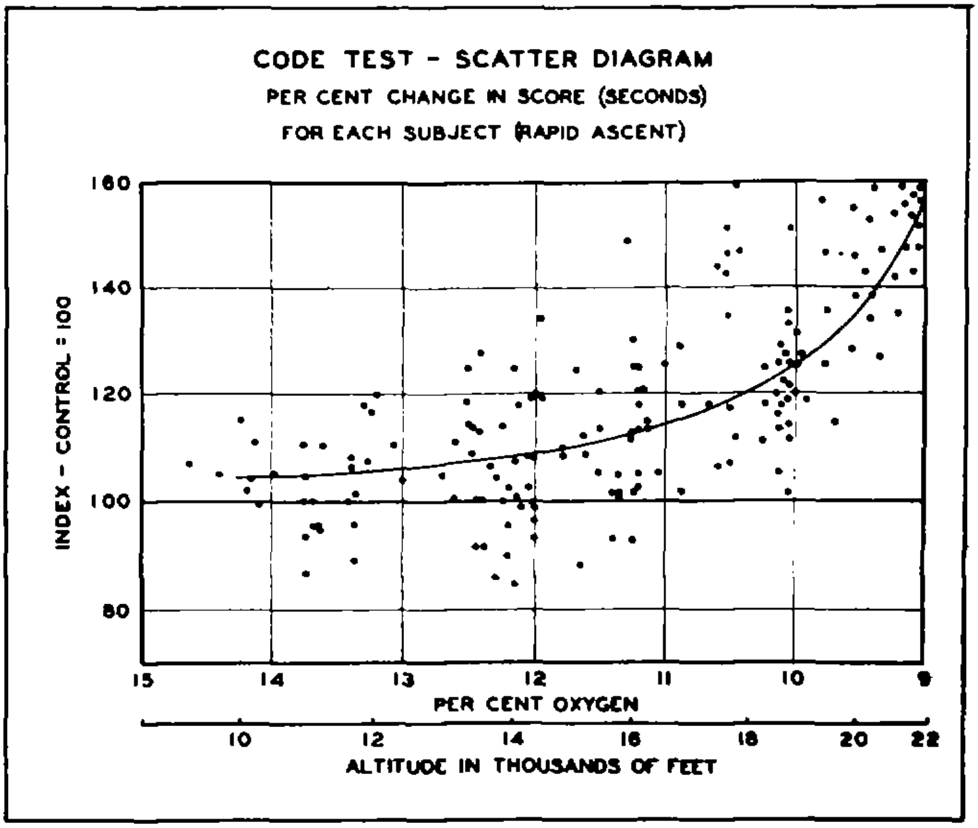
SUMMARY TABLE

MEMORY AND HETEROPHORIA TEST

		Paired Associates			Heterophoria		
		Control	First Hour	Second Hour	Control	First Hour	Second Hour
10,000 Rapid	Mean	8.94	7.88	7.41	1.90	1.80	1.80
	S.D.	1.12	1.48	1.83	3.27	2.99	2.99
	Significance*	---	0-1	0-1	---	100	100
	Index of change**	100.0	88.2	82.9	---	-.10	-.10
10,000 Slow	Mean	8.50	8.41	---	.60	.80	---
	S.D.	.96	1.63	---	.49	.60	---
	Significance	---	10-20	---	---	60-70	---
	Index of change	100.0	98.9	---	---	.20	---
12,000 Rapid	Mean	9.33	7.92	9.08	1.58	1.83	2.25
	S.D.	.53	2.38	1.04	2.50	2.49	2.74
	Significance	---	20-30	50-60	---	40-50	10-20
	Index of change	100.0	84.9	97.3	---	.25	.67
12,000 Slow	Mean	8.75	7.87	---	.87	1.12	---
	S.D.	.83	1.48	---	1.46	1.62	---
	Significance	---	20-30	---	---	90-100	---
	Index of change	100.0	89.9	---	---	.25	---
14,000 Rapid 15-30	Mean	8.11	5.91	6.50	2.47	2.86	2.88
	S.D.	1.99	2.64	3.18	4.19	4.46	3.91
	Significance	---	0-1	0-1	---	10-20	2-5
	Index of change	100.0	72.9	80.8	---	.39	.41
14,000 Rapid 30-45	Mean	8.13	6.79	8.5	1.63	2.86	1.33
	S.D.	1.24	2.33	---	2.39	2.78	---
	Significance	---	30-40	---	---	20-30	---
	Index of change	100.0	83.5	104.5	---	1.23	-.30
14,000 Rapid 45 and over	Mean	---	---	---	3.35	2.70	3.75
	S.D.	---	---	---	3.90	3.55	2.05
	Significance	---	---	---	---	40-50	---
	Index of change	---	-+-	---	---	-.65	.40
14,000 Slow	Mean	9.00	8.63	---	0	.20	---
	S.D.	---	---	---	.63	.90	---
	Significance	---	20-30	---	---	60-70	---
	Index of change	100.0	95.9	---	---	.20	---
16,000 Rapid	Mean	7.75	5.91	7.06	2.38	2.69	2.77
	S.D.	1.79	2.27	2.18	4.05	3.87	4.12
	Significance	---	1-2	10-20	---	40-50	30-40
	Index of change	100.0	76.3	91.1	---	.31	.39
16,000 Slow	Mean	7.33	6.83	7.22	2.56	2.22	3.06
	S.D.	1.71	1.67	2.40	3.59	3.21	3.44
	Significance	---	30-40	80-90	---	40-50	10-20
	Index of change	100.0	93.2	98.5	---	-.32	.50

*Chances in 100 that the difference from the control could have arisen by chance. Five chances in 100 or less are necessary before the significance of the difference is reasonably certain, or before chance can be reasonably ruled out.

**Index of change for heterophoria is amount of change in prism diopters.


CODE TEST - SCATTER DIAGRAM
PER CENT CHANGE IN SCORE (SECONDS)
FOR EACH SUBJECT (RAPID ASCENT)
INDEX - CONTROL = 100
160
140
120
100
80
15
14
13
12
11
10
9
PER CENT OXYGEN
10
12
14
16
18
20
22
ALTITUDE IN THOUSANDS OF FEET

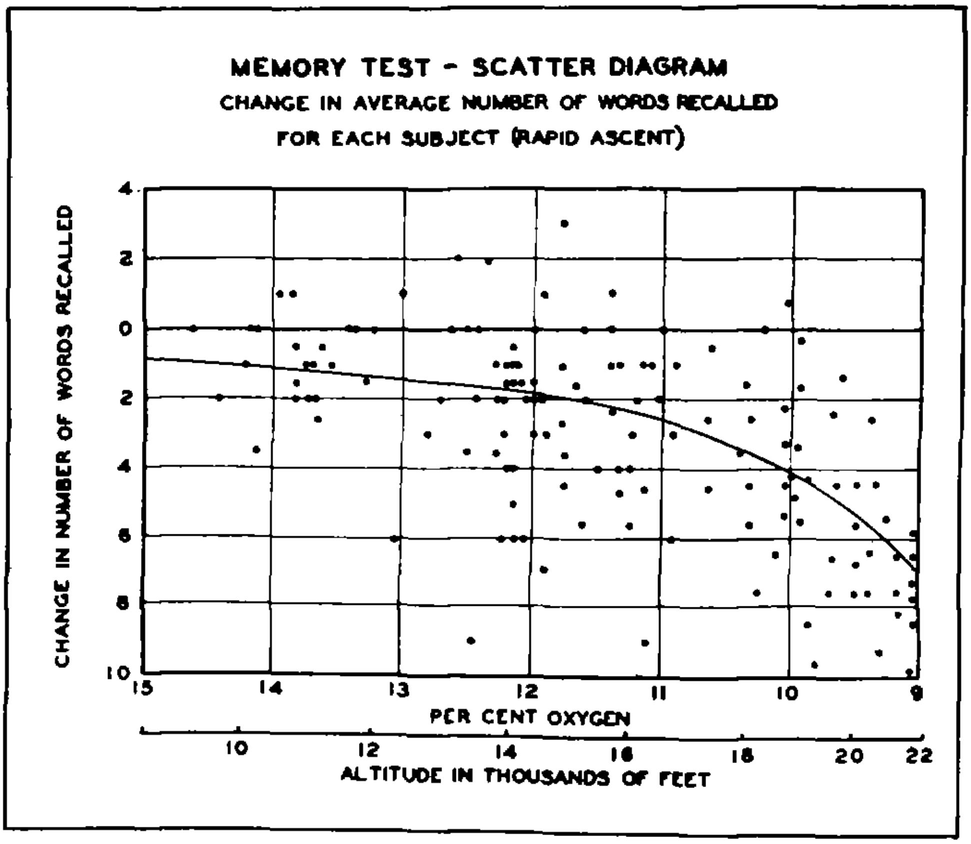

MEMORY TEST - SCATTER DIAGRAM
CHANGE IN AVERAGE NUMBER OF WORDS RECALLED
FOR EACH SUBJECT (RAPID ASCENT)
CHANGE IN NUMBER OF WORDS RECALLED
4
2
0
2
4
6
8
10
15
14
13
12
11
10
9
PER CENT OXYGEN
10
12
14
16
18
20
22
ALTITUDE IN THOUSANDS OF FEET

FIG. 31

and 21,000 feet) (data not shown in Table 15--only in Figure 30) the impairment was very marked.

A scatter diagram which indicates the range of individual variability is shown in Figure 31. The scattering in individual scores is greater than in other tests because it is such a difficult one. The general tendency for the average subject to be less efficient with increasing oxygen deprivation is very striking.

Physiological and psychological complaints. In an attempt to follow the relative amount of impairment in each subject, from the point of view of general discomfort or subjective complaints, two different tests were used. First, each subject was asked to write a running account of his physiological and psychological subjective feelings or impairment, and second, a standardized test of complaints (cf. Table 16) was arranged on the basis of the most frequent reactions observed in previous experiments in reduced oxygen pressure both in chambers at sea level and while in flight at high altitude.

The most frequent complaints recorded voluntarily by each subject at simulated altitudes of from 10,000 feet to 16,000 feet (rapid ascents) are shown in rank order as to frequency in Table 17. At 10,000 feet, for example, 10.3 per cent of the subjects reported headaches; at 12,000 feet, 33.3 per cent; at 14,000 feet, 62.4 per cent; and at 16,000 feet, 66.7 per cent. The results in this test are also shown graphically in Figure 32. The curves were charted so as to show the time when the various complaints were first observed (cumulative) and also what per cent of each group developed the symptoms during each experimental period. For example, during the rapid ascents to 16,000 feet, 10 minutes after the altitude had been simulated, 40 per cent of the group experienced headaches. By the end of the first hour, however, approximately 70 per cent of the subjects had a headache which persisted, on the average, until the end of the experiment.

Table 16

PHYSIOLOGICAL AND PSYCHOLOGICAL COMPLAINTS

1.	Headache. Where? ____________	YES	NO	?
2.	Visual or auditory impairment	YES	NO	?
3.	Ringing or buzzing in ears	YES	NO	?
4.	Vertigo or dizziness	YES	NO	?
5.	Easily fatigued on exertion	YES	NO	?
6.	Nausea or indigestion	YES	NO	?
7.	Gas on stomach or in intestines	YES	NO	?
8.	Cold extremities	YES	NO	?
9.	Feeling of heat and sweating	YES	NO	?
10.	Muscular stiffness and cramps	YES	NO	?
11.	Tremors - fingers, hands, etc.	YES	NO	?
12.	Impaired coordination or clumsiness	YES	NO	?
13.	Shortness of breath	YES	NO	?
14.	Periodic or irregular breathing	YES	NO	?
15.	Sighing or long deep breaths	YES	NO	?
16.	Excessive sleepiness	YES	NO	?
17.	Palpitations or cardiac distress	YES	NO	?
18.	Feel talkative and excited	YES	NO	?
19.	Stuttering or blocking of speech	YES	NO	?
20.	Difficulty in concentrating (distractable)	YES	NO	?
21.	Slowness in reasoning	YES	NO	?
22.	Greater effort to carry out tasks	YES	NO	?
23.	Mentally lazy	YES	NO	?
24.	Feel depressed and grouchy	YES	NO	?
25.	Feel exhilirated and gay	YES	NO	?
26.	Nervous, high strung, inward tension	YES	NO	?
27.	Sudden changes in mood	YES	NO	?
28.	Fidgety or restless	YES	NO	?
29.	Worry excessively about health	YES	NO	?
30.	Feel indifferent and exhausted	YES	NO	?

Table 17

MOST FREQUENT COMPLAINTS NOTED VOLUNTARILY BY SUBJECTS

AT THE ALTITUDES SHOWN FOLLOWING RAPID ASCENTS

Complaints	10,000 feet %	12,000 feet %	14,000 feet %	16,000 feet %
Headache	10.5	33.3	62.4	66.7
Respiratory changes or difficulties	26.3	16.7	42.5	60.0
Excessive sleepiness	21.1	50.0	37.5	30.0
Vertigo or dizziness	5.3	0.0	32.5	53.3
Difficulty in concentrating	21.1	16.7	5.0	46.7
Sensory impairment	5.3	16.7	30.0	33.3
Lassitude, indifference	21.1	16.7	25.0	13.3
Fatigue	5.3	0.0	27.5	33.3

Table 18

FREQUENCY OF THE VARIOUS PHYSIOLOGICAL AND PSYCHOLOGICAL COMPLAINTS

	10,000 Rapid			10,000 Slow			12,000 Rapid			12,000 Slow			14,000 Rapid			14,000 Slow			16,000 Rapid			16,000 Slow		
	Yes	No	?	Yes	No	?	Yes	No	?	Yes	No	?	Yes	No	?	Yes	No	?	Yes	No	?	Yes	No	?
Circulatory	0	94.5	5.5	0	100.0	0	14.4	85.6	0	0	87.5	12.5	4.2	87.3	8.5	0	100.0	0	26.3	68.4	5.3	11.8	88.2	0
Palpitations or cardiac distress	0	94.5	5.5	0	100.0	0	14.4	85.6	0	0	87.5	12.5	4.2	87.3	8.5	0	100.0	0	26.3	68.4	5.3	11.8	88.2	0
Respiratory	18.5	75.9	5.6	11.2	83.3	5.5	26.2	71.4	2.4	37.5	58.4	4.1	34.3	59.3	6.4	22.2	77.8	0	43.8	47.4	8.8	25.5	70.6	3.9
Shortness of breath	11.2	83.3	5.5	0	83.3	16.7	28.6	71.4	0	25.0	62.5	12.5	27.7	61.6	10.7	16.6	83.4	0	36.8	52.6	10.6	23.5	70.6	5.9
Periodic or irregular breathing	16.7	77.8	5.5	16.7	83.3	0	14.4	85.6	0	37.5	62.5	0	27.7	65.9	6.4	16.6	83.4	0	42.1	42.1	15.8	17.6	76.5	5.9
Sighing or long deep breaths	27.8	66.7	5.5	16.7	83.3	0	35.7	57.8	7.1	50.0	50.0	0	46.8	51.1	2.1	33.3	66.7	0	52.6	47.4	0	35.3	64.7	0
Digestion	8.2	89.0	2.8	8.4	91.6	0	10.7	82.1	7.2	6.2	81.3	12.5	13.8	83.0	3.2	0	100.0	0	21.0	76.4	2.6	14.7	79.5	5.8
Nausea or indigestion	0	100.0	0	0	100.0	0	0	92.9	7.1	0	87.5	12.5	6.4	89.4	4.2	0	100.0	0	10.5	84.2	5.3	5.9	82.4	11.7
Gas on stomach or in intestines	16.7	77.8	5.5	16.7	83.3	0	21.4	71.5	7.[illegible]	12.5	75.0	12.5	21.3	76.6	2.1	0	100.0	0	31.6	68.4	0	23.5	76.5	0
Exertion (Muscle)	11.9	86.5	1.6	9.5	88.1	2.4	10.3	72.4	11.[illegible]	12.5	76.8	10.7	25.8	67.4	7.4	7.1	90.5	2.4	36.1	57.1	6.8	27.7	68.1	4.2
Impaired coordination or clumsiness	16.7	83.3	0	16.7	83.3	0	21.4	64.2	14.4	25.0	62.5	12.5	25.5	70.2	4.3	16.6	83.4	0	31.6	52.6	15.8	29.4	70.6	0
Easily fatigued on exertion	11.2	83.3	5.5	16.7	83.3	0	21.4	78.6	0	12.5	75.0	12.5	27.7	57.4	14.9	16.6	83.4	0	36.8	52.6	10.6	23.5	64.8	11.7
Muscular stiffness and cramps	11.2	88.8	0	0	83.3	16.7	0	85.6	14.4	0	100.0	0	6.4	91.5	2.1	0	100.0	0	21.0	73.7	5.3	17.6	76.5	5.9
Tremors - fingers, hands, etc.	11.2	88.8	0	16.7	83.3	0	21.4	71.5	7.1	12.5	75.0	12.5	17.0	78.6	4.4	0	100.0	0	47.4	42.1	10.5	29.4	64.7	5.9
Excessive sleepiness	16.7	83.3	0	0	100.0	0	28.6	64.3	7.1	37.5	62.5	0	42.6	44.6	12.8	0	100.0	0	47.4	52.6	0	41.2	52.9	5.9
Stuttering or blocking of speech	0	94.5	5.5	0	100.0	0	7.1	85.8	7.1	0	87.5	12.5	6.4	87.2	6.4	0	100.0	0	15.8	78.9	5.3	5.9	94.1	0
Greater effort to carry out tasks	16.7	83.3	0	16.7	83.3	0	14.3	57.1	28.6	0	75.0	25.0	51.0	42.5	6.5	16.6	66.8	16.6	52.6	47.4	0	47.1	52.9	0
Sensory	6.5	93.5	0	8.4	91.6	0	19.0	77.4	3.6	12.5	85.4	2.1	25.5	70.2	4.3	11.1	88.9	0	36.0	57.9	6.1	29.4	65.7	4.9
Headache	11.2	88.8	0	16.7	83.3	0	42.8	42.8	14.4	25.0	75.0	0	61.7	36.2	2.1	0	100.0	0	78.9	15.8	5.3	52.9	47.1	0
Visual or auditory impairment	11.2	88.8	0	16.7	83.3	0	7.1	92.9	0	12.5	87.5	0	19.1	80.9	0	0	100.0	0	36.8	47.4	15.8	23.5	64.7	11.8
Ringing or buzzing in ears	0	100.0	0	0	100.0	0	0	100.0	0	0	100.0	0	6.4	91.5	2.1	0	100.0	0	10.5	89.5	0	5.9	94.1	0
Cold extremities	5.5	94.5	0	16.7	83.3	0	57.2	42.8	0	12.5	75.0	12.5	27.7	61.6	10.7	50.0	50.0	0	52.6	42.1	5.3	47.0	41.2	11.8
Feeling of heat and sweating	5.5	94.5	0	0	100.0	0	7.1	92.9	0	12.5	87.5	0	17.0	78.8	4.2	0	100.0	0	5.3	89.4	5.3	11.8	82.3	5.9
Vertigo or dizziness	5.5	94.5	0	0	100.0	0	0	92.9	7.1	12.5	87.5	0	21.2	72.4	6.4	16.6	83.4	0	31.6	63.1	5.3	35.3	64.7	0
Psychological	9.6	86.3	4.1	12.1	84.8	3.1	16.[illegible]	78.6	4.5	4.5	81.8	13.7	19.5	75.8	4.7	12.1	86.4	1.5	21.1	71.3	7.6	21.4	77.0	1.6
Feel talkative and excited	11.2	83.3	5.5	16.7	83.3	0	7.1	85.8	7.1	0	87.5	12.5	21.2	70.3	8.5	16.6	83.4	0	31.6	63.1	5.3	11.8	88.2	0
Difficulty in concentrating (distractable)	5.6	88.8	5.6	0	100.0	0	35.7	64.3	0	12.5	62.5	25.0	36.2	61.7	2.1	16.6	66.8	16.6	42.1	57.9	0	35.3	64.7	0
Slowness in reasoning	5.6	88.8	5.6	16.7	66.6	16.7	7.1	85.8	7.1	0	87.5	12.5	21.3	63.8	14.9	16.6	83.4	0	21.1	68.4	10.5	29.4	64.7	5.9
Mentally lazy	22.2	61.1	16.7	16.7	83.3	0	35.7	64.3	0	12.5	75.0	12.5	42.5	51.1	6.4	33.2	66.8	0	31.6	52.6	15.8	35.3	64.7	0
Feel depressed and grouchy	0	100.0	0	16.7	83.3	0	14.4	85.6	0	0	87.5	12.5	10.6	83.0	6.4	0	100.0	0	10.5	79.0	10.5	11.8	88.2	0
Feel exhilarated and gay	11.2	88.8	0	0	83.3	16.7	14.4	85.6	0	0	87.5	12.5	27.6	70.3	2.1	16.6	83.4	0	15.8	79.0	5.2	17.6	82.4	0
Nervous, high strung, inward tension	5.6	88.8	5.6	16.7	83.3	0	0	92.9	7.1	0	87.5	12.5	12.8	85.1	2.1	0	100.0	0	10.5	79.0	10.5	11.8	88.2	0
Sudden changes in mood	0	100.0	0	0	100.0	0	14.4	78.5	7.1	0	87.5	12.5	6.4	91.5	2.1	0	100.0	0	15.8	79.0	5.2	17.6	76.5	5.9
Fidgety or restless	22.2	72.3	5.5	16.7	83.3	0	28.6	64.3	7.1	12.5	75.0	12.5	25.5	72.4	2.1	33.2	66.8	0	31.6	63.1	5.3	35.3	58.8	5.9
Worry excessively about health	0	100.0	0	16.7	83.3	0	0	92.9	7.1	0	87.5	12.5	0	97.9	2.1	0	100.0	0	0	94.7	5.3	5.9	94.1	0
Feel indifferent and exhausted	22.2	77.8	0	16.7	83.3	0	28.6	64.3	7.1	12.5	75.0	12.5	10.6	87.3	2.1	0	100.0	0	21.1	68.4	10.5	23.5	76.5	0
Total	10.1	87.1	2.8	10.0	87.8	2.2	17.4	76.9	5.7	11.3	79.2	9.5	22.6	72.0	5.4	10.6	88.3	1.1	30.0	63.1	6.9	24.1	72.5	3.4

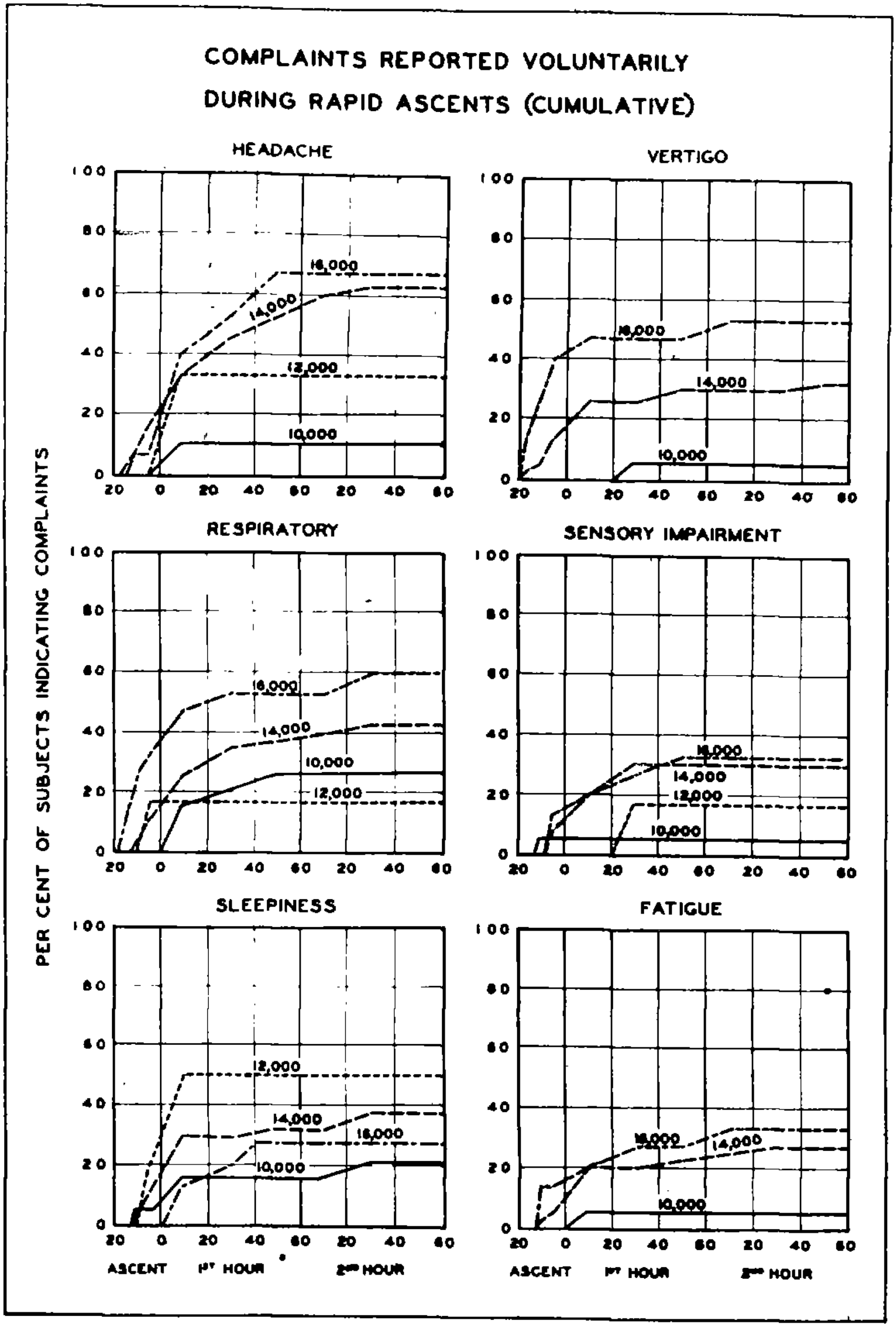

COMPLAINTS REPORTED VOLUNTARILY
DURING RAPID ASCENTS (CUMULATIVE)
PER CENT OF SUBJECTS INDICATING COMPLAINTS
HEADACHE
VERTIGO
RESPIRATORY
SENSORY IMPAIRMENT
SLEEPINESS
FATIGUE
16,000
14,000
12,000
10,000
ASCENT
1ST HOUR
2ND HOUR

FIG. 32

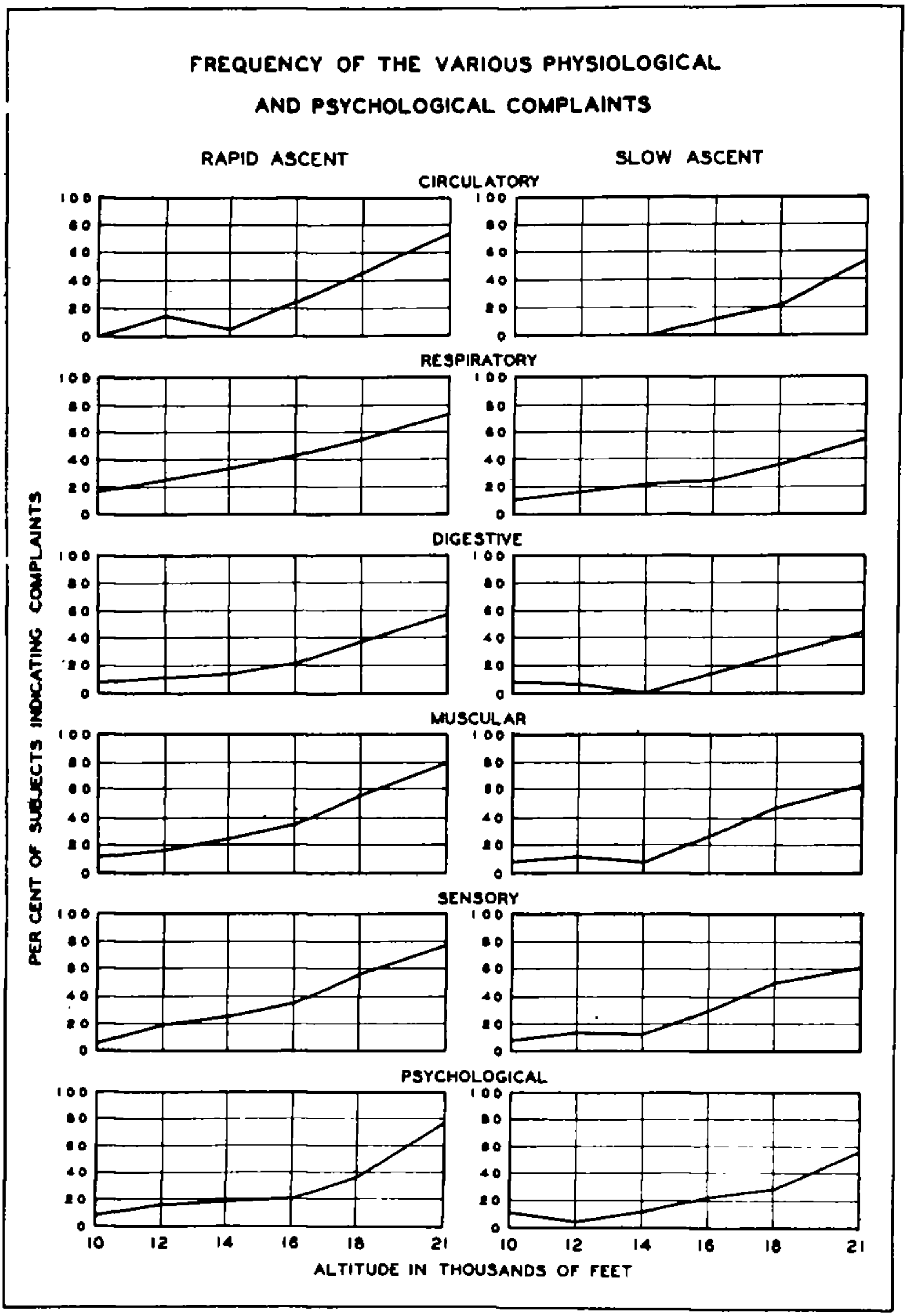

FREQUENCY OF THE VARIOUS PHYSIOLOGICAL
AND PSYCHOLOGICAL COMPLAINTS
RAPID ASCENT
SLOW ASCENT
CIRCULATORY
RESPIRATORY
DIGESTIVE
MUSCULAR
SENSORY
PSYCHOLOGICAL
PER CENT OF SUBJECTS INDICATING COMPLAINTS
0
20
40
60
80
100
10
12
14
16
18
21
ALTITUDE IN THOUSANDS OF FEET

FIG. 33

The results obtained from the questionnaire (cf. Table 16) are shown in Table 18 and Figure 33 for the various altitudes following both rapid and slow ascents in terms of frequency. The various questions have been classified into circulative, respirative, digestive, muscular (exertion), sensory, and psychological complaints in order to show the percentage of the subjects who experienced these different complaints at the various altitudes.

The results of these two tests correspond closely, which indicates that this procedure in recording the various complaints was quite reliable. These data also show that with increasing altitude the average subject is consistently impaired by the lowered partial pressure of oxygen. Comparing the rapid and slow ascents in Figure 33, it also appears that, on the average, a smaller percentage of each group is affected by the oxygen deprivation following the slow ascents in comparison with the rapid ones.

V. Results of the Experiment dealing with Age in Relation to Acclimatization to High Altitude (Part II).

Since a large number of the passengers who fly on the commercial air transport planes are fairly advanced in years, an attempt has been made to find out whether older persons are impaired by oxygen deprivation to a relatively greater extent than younger persons.

At the Harvard Fatigue Laboratory during the past two years an extensive investigation has been made of the physiological responses of persons (total number 79) varying in age from 6 to 75 years to several standard grades of work on the treadmill. The subjects came to the laboratory in a basal state and were asked to respond to 3 metabolic rates:
(1) rest; (2) walking (moderate work); and (3) running (maximal work). On the average, the pre and post adolescents were more variable in their physiological responses than the older subjects. One of the most striking results of the investigation was the gradual decrease in maximal heart rate with increasing age under conditions of maximal work. Through the kindness of S. Robinson and D. B. Dill,* the results obtained in the studies of the heart rate are shown in Figures 34 and 35 in the form of scatter diagrams. When the highest heart rate attained in maximal work was plotted against age, the range was from 210 beats per minute for the younger subjects to 155 beats per minute at the opposite extreme, i.e., for the older subjects (cf. Figure 34). The mean pulse rates in Figure 34 show the same general tendency. It is of special interest to observe in Figure 35 that this tendency was manifested in the younger subjects even while waiting to get on the treadmill before the experiment began. On the average, therefore, it appears that the younger subjects tend to manifest more flexible or less stabilized cardiovascular systems in responding to a

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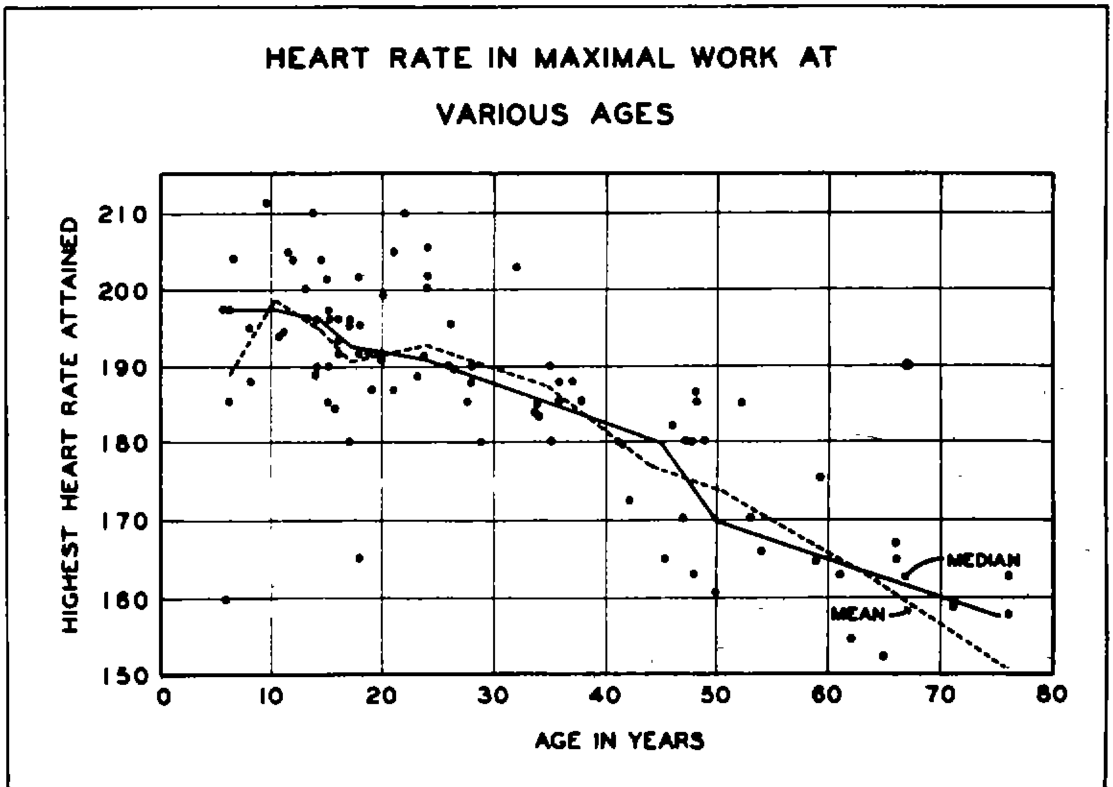
*Unpublished data from the Fatigue Laboratory, Harvard University, Boston, Massachusetts.



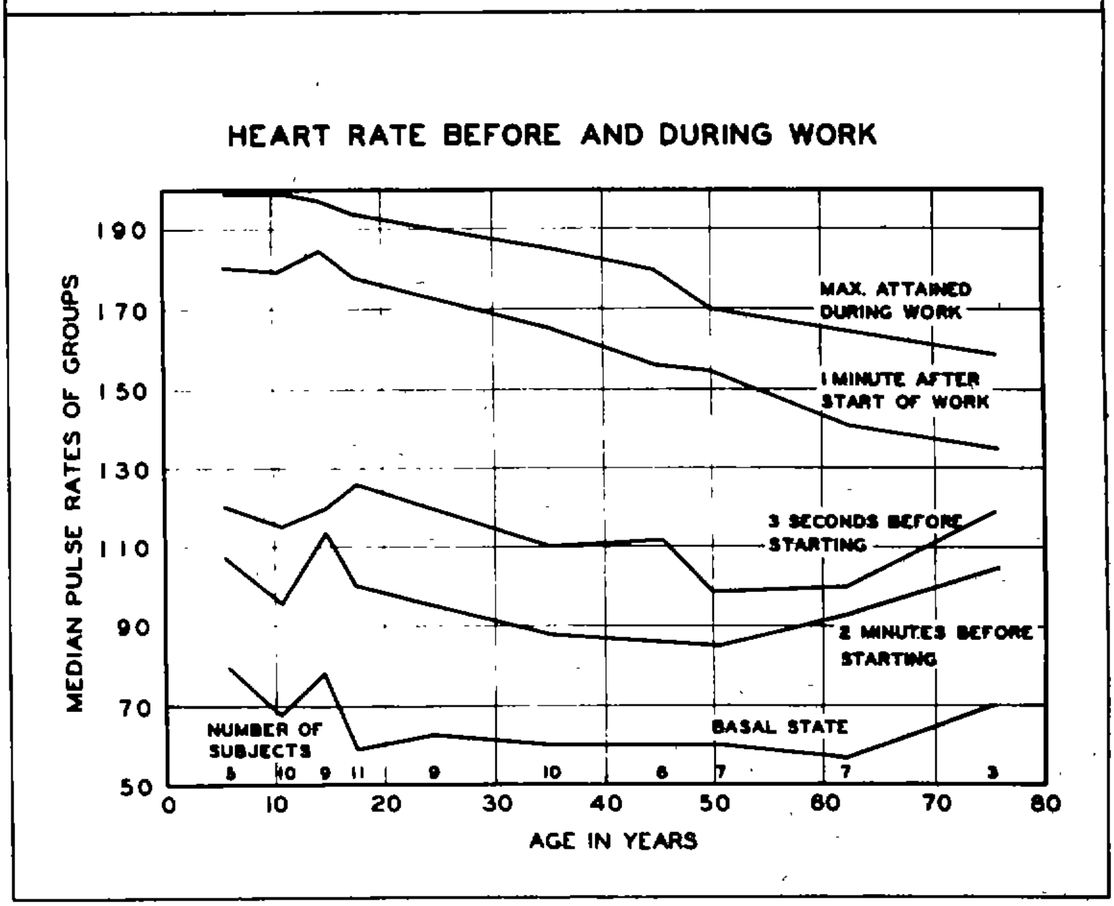


FIG. 34 & 35. (ROBINSON & DILL)

fixed stress such as running on the treadmill.

It is interesting and certainly quite relevant to compare the results obtained in the above experiment with the response of older subjects to the stress of oxygen deprivation encountered during flights to high altitudes. Three groups of subjects were compared during a rapid ascent to 14,000 feet. This altitude was selected since it seemed to be high enough to accentuate differences in physiological and psychological make-up and adaptability. The groups varied in age as follows: (1) 50 subjects, 17 to 30 years; (2) 15 subjects, 30 to 45 years; and (3) 16 subjects, 45 to 72 years. As indicated previously, the younger men were all college students or graduates from the University, and the others were business and professional men from New York City.

The results of the tests for pulse rate, systolic and diastolic blood pressure, and alveolar air are shown in Tables 8,9,10&11, respectively. The average increase in pulse rate for each group is plotted in relation to time in Figure 36. The results indicate that the older subjects show less extreme circulatory responses to oxygen deprivation as manifested in pulse rate per minute than the younger subjects. This observation is in agreement with the findings of Robinson and Dill in regard to increases in pulse rate under conditions of maximal work. We also observed that the younger subjects were more susceptible to fainting under low oxygen than the older subjects.

The group differences in systolic blood pressure were not very striking, as shown in Figure 37. There was a general tendency, however, for the diastolic blood pressure to increase toward the end of each experiment in the 45 to 72 age group. In the age group under 30 years, the diastolic pressure showed a higher initial increase than was the case with the two

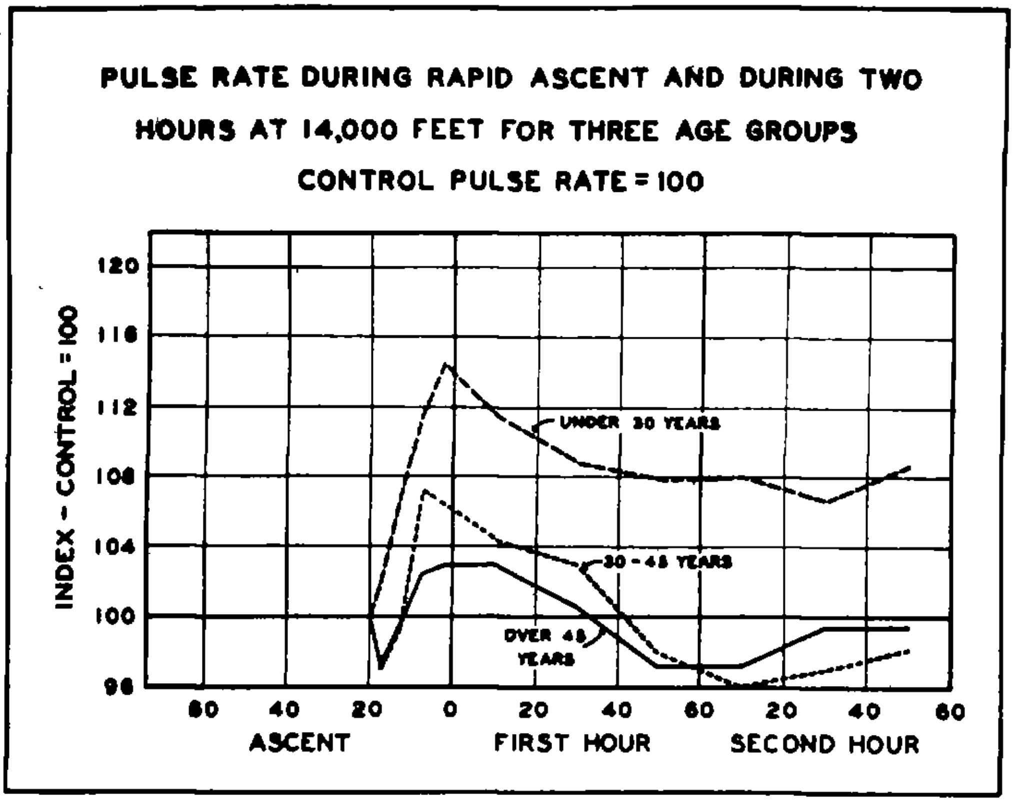

PULSE RATE DURING RAPID ASCENT AND DURING TWO HOURS AT 14,000 FEET FOR THREE AGE GROUPS
CONTROL PULSE RATE = 100
INDEX - CONTROL = 100
120
116
112
108
104
100
96
UNDER 30 YEARS
30 - 45 YEARS
OVER 45 YEARS
60
40
20
0
20
40
60
20
40
60
ASCENT
FIRST HOUR
SECOND HOUR

FIG. 36

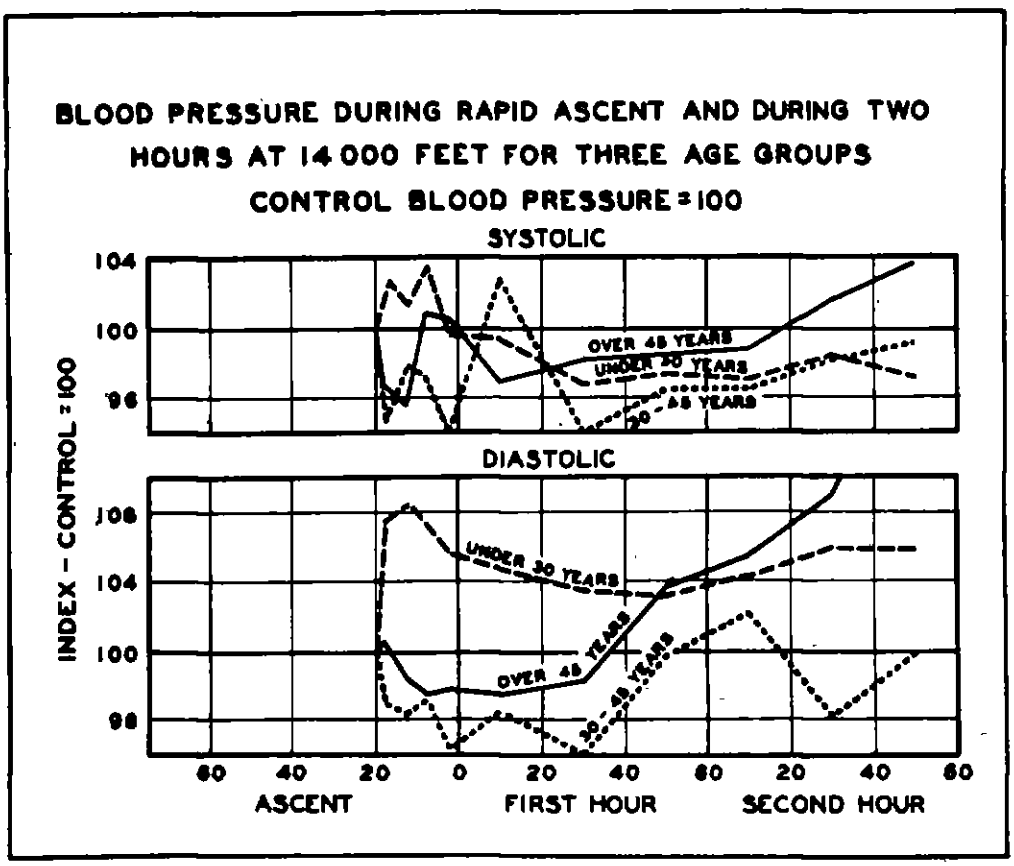

BLOOD PRESSURE DURING RAPID ASCENT AND DURING TWO HOURS AT 14 000 FEET FOR THREE AGE GROUPS
CONTROL BLOOD PRESSURE = 100
SYSTOLIC
104
100
96
OVER 45 YEARS
UNDER 30 YEARS
30 - 45 YEARS
DIASTOLIC
108
104
100
96
UNDER 30 YEARS
OVER 45 YEARS
30 - 45 YEARS
INDEX - CONTROL = 100
60
40
20
0
20
40
60
20
40
60
ASCENT
FIRST HOUR
SECOND HOUR

FIG. 37

other groups. The partial pressure of oxygen in the alveolar air was, on the average, higher in the 45 to 72 age group than in the two younger groups throughout each experimental period (cf. Table 11). The difference was 4.4 mm. Hg during the second hour. Since the respiratory and cardiovascular responses were less extreme in the older subjects, it is not surprising that the partial pressure in the alveolar air was significantly higher.

In comparing the results of the three age groups in the psychological tests (cf. Tables 13, 14, and 15) the average impairment in the color naming, code, and phoria tests was no greater for the 45 to 72 age group than for the two younger groups. The older subjects, on the average, made poorer control scores than the younger ones; however, if one takes the percentage of change of the low oxygen series compared with the control index of 100, then the impairment shown by the different age groups was of the same magnitude.

VI. Results of the Experiments dealing with Physical Fitness in Relation to Acclimatization to High Altitudes (Part III).

A. Rate of ascent and altitude in relation to physical fitness. In this part of the experiment an attempt was made to contrast the effects of rapid and slow ascents to high altitudes in the same group of individuals. An attempt was made to secure subjects varying in physical fitness so that the ones in training could be contrasted with those in poor physical condition. Such an experiment seemed relevant to some of the practical problems encountered in commercial aviation since many passengers acclimatize fairly easily to high altitudes during slow ascents but are quite severely influenced by the reduction in oxygen pressure during rapid ascents. The partial pressure of oxygen was varied so as to simulate altitudes of 16,000 feet within 30 minutes (rapid ascent) and 1 hour and 15 minutes (slow ascent). The group was also studied during a rapid ascent to 12,000 feet within 15 minutes. Previous experiments had indicated that very slow ascents to 12,000 feet would probably cause only minor variations in the tests.

The subjects ranged in age from 19 to 25 years. They were selected at random from a group of students in Columbia College and the College of Physicians and Surgeons. None of them were suffering from any known organic ailments. As far as could be judged from the physiological tests of "fitness" like the Schneider Index, basal metabolism, and vital capacity, they were quite representative of the "average run" of young college men, the group containing several subjects in rather poor physical condition and a number in unusually good physical condition. (For example, Houston, subject No. 10 (cf. Table 23), an experienced mountaineer who climbed to an altitude of 25,000 feet last summer on a Himalayan Expedition.) Each subject came to the laboratory three times, following the initial practice sessions, at intervals of approximately one week. The subjects were very cooperative throughout the series. They were not informed as to the purpose of the experiment until the end.

The general reactions to the three different rates of ascent may be briefly summarized as follows:

Rapid ascent, 16,000 feet. Five of the ten subjects collapsed and one approached collapse. In three of the poorest subjects collapse occurred at the end of the first hour and the other two toward the end of the second hour. One subject, No. 6, developed very marked tonic-clonic cramps from his lower extremities upward and had to be removed from the chamber. Upon being removed to the air and breathing a mixture of oxygen and carbon dioxide, these reactions became markedly intensified. Collapse in the other cases was accompanied by sudden and extreme changes in either pulse or blood pressure.

Slow ascent, 16,000 feet. This rate of ascent seemed to allow more time for acclimatization, and in general the responses of most of the subjects were less severe. Only two of the subjects actually collapsed during this series. Four of them, however, were impaired sufficiently to do rather poorly in the tests.

Rapid ascent, 12,000 feet. None of the subjects collapsed in this series of tests. Subject No. 6, however, the one who developed the severe cramps during the rapid ascent to 16,000 feet, had to be removed from the chamber because of a similar kind of response. The alterations in pulse and in blood pressure were only slight and usually returned to more normal values toward the end of each experiment. There were only very slight changes in the psychological tests in this series.

In the treatment of the data the subjects have been divided into two groups, i.e., the "fit" subjects or those who adapted easily, and the "unfit" group or those who reacted badly. In this way it is possible to contrast the extremes in physical fitness.

In Table 19 the effects of a rapid and a slow ascent to 16,000 feet in the various physiological functions are contrasted. The average differences in pulse and blood pressure are not great largely because the extremes tend to cancel each other and give somewhat similar means. In individual cases the differences were very great. During the rapid ascent all of the subjects were affected, the "fit" ones considerably less than the others largely because they became acclimatized during the second hour of each session.

The relative impairment in the psychological tests in the slow and rapid ascents is shown in Table 20. The Code test, one of the most reliable, since it involves very sustained and accurate attention, showed a significant difference as well as the Color Naming test. The differences in the Choice Reaction and Dotting tests were only slight, since the subject could frequently conceal the effects of the oxygen lack by exerting greater effort.

In Tables 21 and 22 the effects of the various rates of ascent on the physiological and psychological tests for the "fit" and "unfit" subjects are contrasted. The differences in the pulse and blood pressure were less extreme in the group that adjusted most easily; the same tendency was noticeable in the phoria test of ocular muscle balance.

The differences in the psychological tests between the various rates of ascent and height attained are quite significant. In the Code test, for example, the mean score was 128 for the "fit" group and 162 for those who adapted less easily.

At the end of each experimental session the subjects rated their physiological and psychological changes in accord with the questions in Table 16. The frequency with which each subject was affected in various ways

Table 19

COMPARISON OF RELATIVE EFFECTS OF RAPID AND SLOW ASCENTS

ON PHYSIOLOGICAL FUNCTIONS - 16,000 FEET

	Pulse (per minute)		Systolic Blood Pressure (mm. Hg)		Alveolar pO_2 (mm. Hg)		Alveolar pCO_2 (mm. Hg)		Phoria*	
	Rapid	Slow	Rapid	Slow	Rapid	Slow	Rapid	Slow	Rapid	Slow
Control	77	80	108	113	104.5	104.5	36.4	36.4	2.7	2.7
First hour	87	84	110	108	42.8	47.6	33.1	34.1	1.6	0.7
Second hour	84	85	113	109	39.6	41.9	33.9	33.7	1.9	1.5
End	72	78	107	108						

*Deviation from control in prism diopters.

Table 20

COMPARISON OF RELATIVE EFFECTS OF RAPID AND SLOW ASCENTS.

ON PSYCHOLOGICAL FUNCTIONS - 16,000 FEET

	Code Test (time in seconds)		Color Naming Test (time in seconds)		Reaction Time (1/100 seconds)		Dotting Test (number hits)	
	Rapid	Slow	Rapid	Slow	Rapid	Slow	Rapid	Slow
Control	109.0	109.0	48.5	48.5	40.9	40.9	287.0	287.0
First hour	139.5	122.0	61.0	53.5	45.3	44.1	251.0	278.0
Second hour	145.0	133.0	60.0	57.5	47.3	44.5	262.0	264.0

Table 21

COMPARISON OF THE DIFFERENTIAL EFFECT OF THREE RUNS ON PHYSIOLOGICAL FUNCTION OF A "FIT" GROUP (A) AND AN "UNFIT" GROUP (B)

	Pulse (per minute)		Systolic Blood Pressure (mm. Hg)		Alveolar pO2 (mm. Hg)		Alveolar pCO_2 (mm. Hg)		Phoria*	
	A	B	A	B	A	B	A	B	A	B
16,000 feet Rapid										
Control	77	77	110	105	105.7	103.2	36.6	36.2		
First hour	83	90	115	105	41.3	44.2	33.5	33.1	1.3	2.0
Second hour	81	87	111	115	39.6	39.6	33.4	34.5	1.3	2.6
End	79	66	106	107						
16,000 feet Slow										
Control	80	80	111	115	105.7	103.2	36.6	36.2		
First hour	81	87	109	107	45.6	49.8	34.2	34.0	0.0	1.4
Second hour	78	93	110	107	43.7	40.0	33.9	33.5	1.3	0.7
End	77	79	109	106						
12,000 feet Rapid										
Control	78	76	115	103	105.7	103.2	36.6	36.2		
First hour	81	79	114	110	55.1	57.9	35.5	35.3	0.7	0.7
Second hour	76	77	110	112	57.5	56.1	33.4	33.4	1.3	1.0
End	77	77	110	115						

*Deviation from control in prism diopters.

Table 22

COMPARISON OF THE DIFFERENTIAL EFFECT OF THREE RUNS ON PSYCHOLOGICAL FUNCTIONS OF A "FIT" GROUP (A) AND AN "UNFIT" GROUP (B)

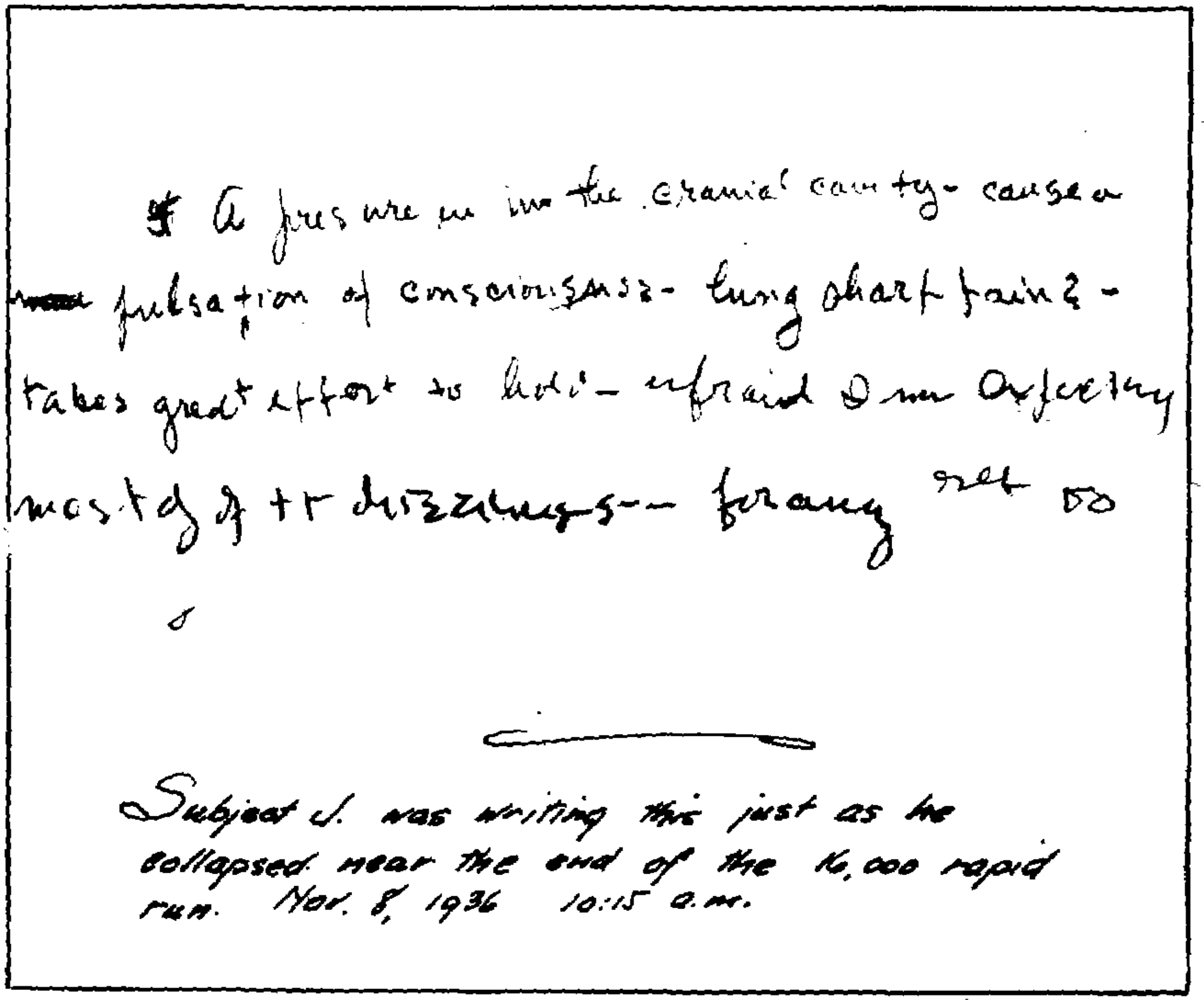
	Code (time in seconds)		Color Naming (time in seconds)		Reaction Time (1/100 seconds)	
	A	B	A	B	A	B
16,000 feet Rapid						
Control	106	111	47	50	39.8	42.1
First hour	131	148	60	62	43.6	47.0
Second hour	128	162	56	64	45.9	48.7
16,000 feet Slow						
Control	106	111	47	50	39.8	42.1
First hour	119	125	51	56	42.3	45.9
Second hour	126	140	55	60	42.3	46.6
12,000 feet Rapid						
Control	106	111	47	50	39.8	42.1
First hour	117	130	54	55	42.6	45.1
Second hour	128	139	53	51	42.0	47.4

Table 23

PHYSIOLOGICAL AND PSYCHOLOGICAL COMPLAINTS

Complaints as checked by the ten subjects after each of the three runs. An x represents a complaint; ?, not sure; a blank means no complaint.

	16,000 feet Rapid											16,000 feet Slow											12,000 feet Rapid										
Complaint	1	2	3	4	5	6	7	8	9	10	Total	1	2	3	4	5	6	7	8	9	10	Total	1	2	3	4	5	6	7	8	9	10	Total
1		?	x	x	x	x	x	x	x		7	?		x	x	x		x		x		5		?	x	?		x	x				3
2					x	x	x	x			4							?	x	?		1							x				1
3										x	1											0											0
4		x	x	x	x	x	x			x	7		x		x			x				3							?				0
5	?	x		x	x		x		x		5	?						x		?		1				x			x				2
6				x							1						N					0					N		?			N	0
7			x	x			x		x		4			x	x	x	O	x				4					O	x	x			O	2
8	?	x	x	x	x	x	x	x	x	x	9	?	x		x		T	x	x	x	x	6	x		x	x	T	x	x	x		T	6
9											0											0											0
10						x					1											0											0
11	x		x		?	x	x	x	x	x	7	?				x		x			?	2						x	?		x		2
12	?	x		x	x		x		x	x	6		x					x		x		3							x				1
13			x			x			x	x	4						R	x		x		2		x		x	R		x			R	3
14						x	?				1						U	x				1					U		x			U	1
15		x	x			x	x	x			5		x	x			N	x				3		x		x	N		?			N	2
16		x		x	x		x		x		5			x		x		x		x	?	4		x					?		x		2
17						x	?			x	2							x				1							x				1
18		x				x			x	x	4		x									1	?	x									1
19							?	x			1											0							?				0
20		x	x		x		x		x		5							x		x		2							x		x		2
21		x	x		?		?		x		3							x		x	x	3							x		?		1
22		x	x	x	x		x	x	x	x	8		x			x				x	x	4		?					?		?		0
23		x			?		x	?	x	x	4									x	x	2		x					x		x		3
24	?								x		1									X		1									x		1
25		x				x					2		x		x							2		x									1
26						x	?				1											0											0
27			x				x		x		3		x		x							2				x							1
28		x	x						?		2	?	x	x					x		x	4			x				?				1
29											0								x			1											0
30				x	?		x				2								x			1				?			x				1
Total	1	13	12	10	9	13	15	7	15	10	105	0	9	5	6	5		14	5	10	5	59	1	6	3	5		4	13	1	5		38



A pres ure in the cranial cavity - cause a
pulsation of consciousness - lung sharp pains -
takes great effort to hold - afraid I am [illegible]
most of it dizziness - for any [illegible]

Subject J. was writing this just as he collapsed near the end of the 16,000 rapid run. Nov. 8, 1936 10:15 a.m.

FIG. 38

Edward A. Jerome — 1st hr. 5 min —
12000 ft rapid

Pain below temples which disappears in 3 or 5 mins -

Constriction in center of throat shooting down toward center of lungs -

Periods of pulsating attention -

15 Slight feelings of nausea, without actual regurgitation - a rather burning feeling in stomach - progressing toward throat -

23 Seem to feel better after sample is taken -

35 - Find it hard to remember to write report; on last b.p. test meant to remark on extreme numbness of rt. hand

50 - Code translation - first; working automatically came too on the third line fully convinced that I had skipped a line or two -

Subjective symptoms - 12,000 rapid run
Nov 12, 1936

FIG. 39

by the oxygen deprivation is indicated in Table 23. It is obvious that the rapid ascent to 16,000 feet caused a greater amount of discomfort than the slow ascent. The total number of complaints in the rapid ascent to 16,000 feet was 105; in the slow ascent to 16,000 feet, 59, and in the rapid ascent to 12,000 feet, 38. Figure 38 shows the handwriting of subject J at the time he collapsed following the rapid ascent to 16,000 feet. Figure 39 shows the running account of the same subject's subjective symptoms during the experiment at 12,000 feet (rapid run).

A careful record was kept by each subject of the after-effects of the oxygen deprivation. In the subjects who collapsed, the headaches, nausea, palpitations, pain in the chest, and muscular twitchings lasted from one to ten hours. Even in several of the subjects who reacted easily, some of the after-effects mentioned above were noticeable for one to two hours later.

In Figures 40 and 41 the results of experiments carried out by McFarland (44) on trans-Andean aeroplanes and trains are contrasted relative to rate of ascent. Figure 40 shows that the relative increase in pulse rate and systolic blood pressure was greater in the plane when an altitude of approximately 16,000 feet was reached in 20 minutes compared with the more gradual ascent by train to similar altitudes. The same tendency is observed in Figure 41, where three rates of ascent to similar altitudes are contrasted, i.e., by plane in 20 minutes, by train in 6 to 8 hours, and during gradual acclimatization over two months (cf. McFarland (44), International High Altitude Expedition, 1935).

B. The response of the psychoneurotic group to low oxygen. This experiment deals with the responses of 30 normal subjects and 35 psychoneurotic patients to variations in oxygen tension in a low oxygen chamber at sea level. Each subject was tested under control conditions or in normal air (21% O_2)

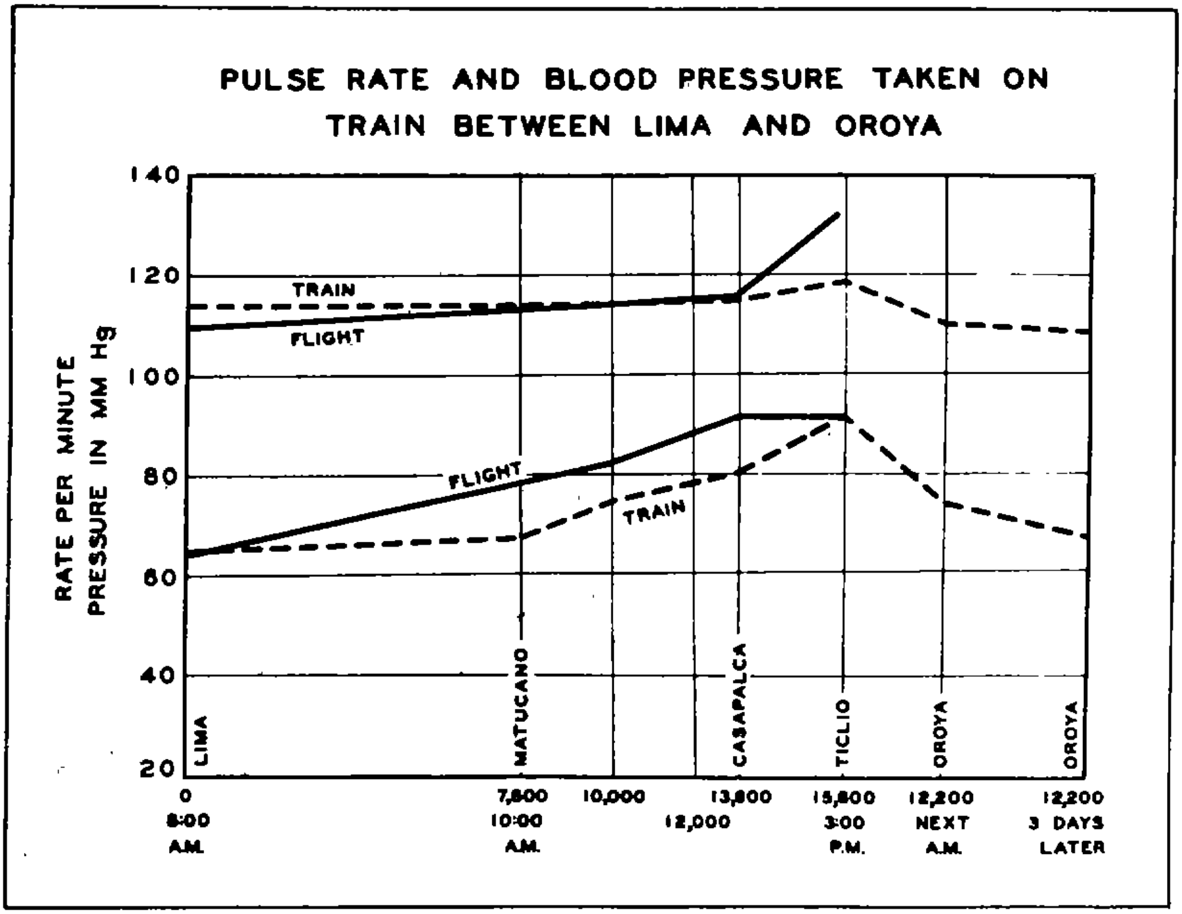

PULSE RATE AND BLOOD PRESSURE TAKEN ON
TRAIN BETWEEN LIMA AND OROYA
RATE PER MINUTE
PRESSURE IN MM Hg
140
120
100
80
60
40
20
TRAIN
FLIGHT
FLIGHT
TRAIN
LIMA
MATUCANO
CASAPALCA
TICLIO
OROYA
OROYA
0
8:00
A.M.
7,800
10:00
A.M.
10,000
12,000
13,800
15,800
3:00
P.M.
12,200
NEXT
A.M.
12,200
3 DAYS
LATER

FIG. 40

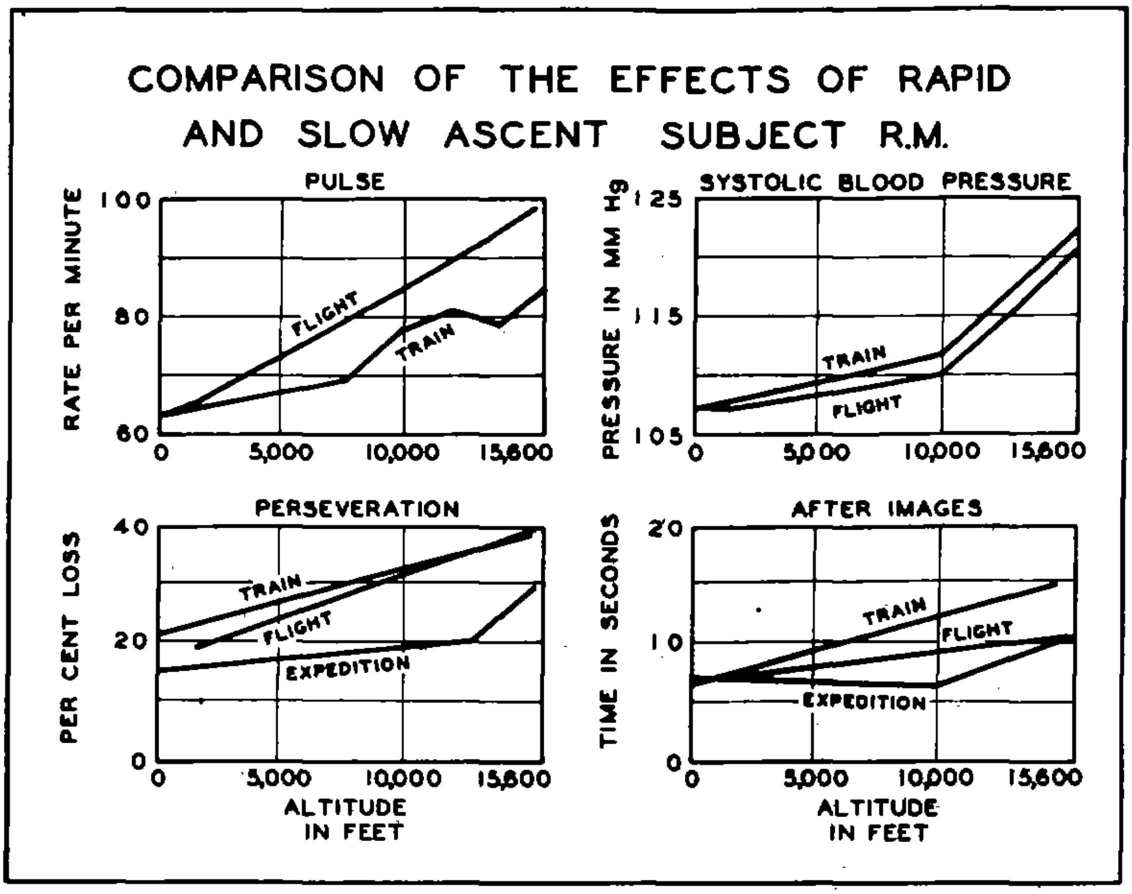

COMPARISON OF THE EFFECTS OF RAPID AND SLOW ASCENT SUBJECT R.M.
PULSE
RATE PER MINUTE
100
80
60
FLIGHT
TRAIN
0
5,000
10,000
15,600
SYSTOLIC BLOOD PRESSURE
PRESSURE IN MM Hg
125
115
105
TRAIN
FLIGHT
0
5,000
10,000
15,600
PERSEVERATION
PER CENT LOSS
40
20
0
TRAIN
FLIGHT
EXPEDITION
0
5,000
10,000
15,600
ALTITUDE IN FEET
AFTER IMAGES
TIME IN SECONDS
20
10
0
TRAIN
FLIGHT
EXPEDITION
0
5,000
10,000
15,600
ALTITUDE IN FEET

FIG. 41

and in 10.3% oxygen, corresponding roughly to 18,000 feet. In addition, each subject was given a series of physical fitness tests as a basis for classification. The results of these tests are shown in Table 24. (47)

The subjects. The control or normal subjects ranged in age from 19 to 30 years and the neurotics from 18 to 35 years. The controls were undergraduate and graduate students in Columbia University or instructors and technicians. For the most part, they were in good or average health, with normal habits of sleeping, eating, and exercise, and without known organic defects.

The patients were psychoneurotics selected from the Vanderbilt Clinic on the basis of chronic "fatigue and exhaustion"; this syndrome being characteristic of all of the patients. They were diagnosed (within the more general psychoneurotic classification) for the most part as: (1) neurasthenia; (2) anxiety state; or (3) anxiety hysteria. They were all ambulatory, cooperative, and of a fairly high level of intelligence, most of them being students or of the so-called "white collar" class. They were, on the average, in poor physical condition, but manifested no organic ailments following repeated examinations by the clinicans.

The experimental procedure. The subjects came to the laboratory under basal conditions. Following a half-hour rest, a sample of blood was taken. Then the subject entered the chamber and was suddenly exposed to the variations in the partial pressure of oxygen. The Schneider Index of neurocirculatory fitness was given first, followed by a series of six psychological tests. At the end of the experiment a second sample of blood was taken in the chamber and the subject was sent home. In case the subject's response was severe, i.e., either collapsing or approaching collapse, a small amount of oxygen was administered to facilitate the adaptation. The average experimental run lasted two hours.

Table 24

TESTS OF PSYCHOLOGICAL AND PHYSIOLOGICAL FITNESS

	Normal Subjects			Psychoneurotic Patients		
	Mean	S.D.	Range	Mean	S.D.	Range
Age	24		20 to 34	27		19 to 35
Otis Mental Ability Test (I.Q.)	125	6.2	117 to 133	106	9.8	80 to 131
Bernreuter Personality Inventory (BI-N)	41			88*		
Basal Metabolic Rate	-8(12)** +4(18)		-1 to -19 +2 to +14	-12(21) +9(14)		-3 to -22 +1 to +21
Vital Capacity (cc.)	4800		3800 to 6200	4100		2800 to 4700
Holding Breath (in seconds)	74	7.2	50 to 192	45	11.1	38 to 102
Schneider Index	+12.1	1.9	+9 to +17	+7.0	3.9	-3 to +13

*High score indicates greater degree of emotional instability.
**Figures in parentheses indicate number of subjects.

None of the subjects were informed as to the nature of the experiment. The control subjects were simply asked to volunteer for an experiment being given in an air conditioned room. The patients were asked to take a series of diagnostic treatments in attempting to determine more precisely the nature of their illness.

In an attempt to judge the reaction of each individual to the diminution in the partial pressure of oxygen, each subject was rated as to the degree of impairment based on the following criteria:

1. Adjusted easily, a high degree of adaptation, characterized by well controlled increases in pulse and blood pressure gradually returning to fairly normal reactions, and quite normal reactions in the psychological tests.
2. Serious impairment, but able to continue the tests. Marked variations in pulse and blood pressure, and poor response to psychological tests. Physical complaints of headache and dizziness, cold extremities, flushing of face, pupilary dilation, etc. Slight impairment in psychological tests with increased variability.
3. Impending collapse, followed by removal or oxygen inhalation. Extreme variations in pulse and blood pressure, vertigo, severe headache and drowsiness, and sensory and motor impairment.
4. Collapse, necessitating oxygen inhalation or removal from chamber. The cardiovascular reactions were characterized by either a sudden fall in pulse or blood pressure, the one usually closely accompanying the other. In these patients the failure of the respiratory center to respond to the oxygen lack appeared to be a very important factor.

In Table 25 the percentage of each group reacting according to the above criteria is tabulated.

Table 25

DEGREE OF ADAPTATION

	Normal Subjects Percentage	Psychoneurotics Percentage
Adjusted easily	40	15
Serious impairment	28	20
Impending collapse	18	21
Collapse	14	44

Table 25 shows that the psychoneurotics were more acutely impaired by the oxygen deprivation than the control subjects. Over 44 per cent of the patients collapsed within the first 20 minutes and only 14 per cent of the normal subjects. The effects were sufficiently accentuated, however, in both groups to indicate the danger of sudden exposure to a partial pressure of oxygen corresponding to 18,000 feet.

The most common alterations in behavior observed or complained of were sleepiness, yawning, tremors of the facial muscles or fingers, vertigo, headache, periods of sweating or coldness (especially in extremities), apathy and indifference, loss of capacity for close attention, impairment of sensory functions, unrestricted talking or laughing and loss of memory, judgment and self-criticism.

The cardiovascular reactions--pulse and blood pressure. The Schneider Index of cardiovascular fitness was given to each subject as soon as the partial pressure of oxygen in the chamber was adjusted (within 10 to

15 minutes). In Tables 26 and 27 the mean score on the Schneider Index and the standard deviation for each part of the Index is summarized for the normal and psychoneurotic groups respectively.

Upon examination of the tables, one finds that the mean Schneider Index for the normal group was 12.0 in air, and 8.7 in 10.3 per cent oxygen. The mean Index for the psychoneurotic group was 7.0 in air; +4.8 for approximately 40 per cent of the subjects in 10 per cent oxygen, and -4.2 for the other 60 per cent. According to Schneider's observations on aviators, 7.0 or below indicated "unfitness" and the pilots were "grounded" or given a vacation. The effect of the oxygen deprivation was more severe on the "nervous" subjects as compared to the normal ones. These results indicate that the psychoneurotics manifested a definite unfitness in their cardiovascular reactions compared with unselected normal subjects.

In analyzing the individual parts of the Index, the resting pulse in the control group averaged 61 in air and 76 in 10 per cent oxygen, while the resting pulse in the patients was 70 in air and 82 in 10.3 per cent oxygen. The change in the pulse on standing and after exercise was more extreme in the case of patients compared with the controls. We observed a considerable number of pulse rates in the patients which decreased on standing and after exercise. This seems to indicate inefficiency and a definite failure of the circulatory system to respond to the extra physical effort. This was especially noticeable just previous to collapse in the 10.3 per cent oxygen series. Extreme vertigo and dizziness on standing or after exercise was also accompanied by a sudden fall in pulse rate.

The systolic blood pressure in the patients was slightly higher than in the normal subjects. The extremely high and low blood pressures in the patients tended to cancel out each other and give a more normal mean than

TABLE 26

CARDIO-VASCULAR REACTIONS OF THE PSYCHONEUROTIC GROUP

MEASURED IN TERMS OF THE SCHNEIDER INDEX

	Control		18,000 feet	
	Mean	S.D.	Mean	S.D.
Schneider Index	6.9	3.8	4.8 -4.2	2.3 1.7
Pulse Reclining	69.8	11.5	81.8	17.4
Pulse Standing	87.2	11.5	93.5	16.5
Pulse Increase on Standing	19.2	8.4 (92%)*	13.8	23.3 (63%)*
Pulse Decrease on Standing	4.4	(10%)*	9.1	14.7 (29%)*
Pulse No Change on Standing				(8%)*
Pulse after Exercise	103.6	14.4	102.6	22.8
Pulse Increase after Exercise	17.9	9.1 (92%)*	19.5	14.1 (11%)*
Pulse Decrease	3.8	(8%)*	18.0	12.8 (77%)*
Pulse No Change				(2%)*
Pulse Time to Return to Normal (secs.)	58.8		66.0	
Systolic B.P. Reclining	113.7	12.7	107.4	14.7
Systolic B.P. Standing	110.7	14.1	98.7	14.9
B.P. Increase	5.0	3.6 (25%)*	9.8	4.7 (28%)*
B.P. Decrease	6.0	3.7 (65%)*	15.5	16.7 (62%)*
B.P. No Change		(10%)*		(10%)*
Diastolic Reclining	77.7	16.8	64.0	15.2
Diastolic Standing	83.7	11.2	70.1	14.0
Pulse Pressure Reclining	34.4	8.9	41.8	11.3
Pulse Pressure Standing	26.8	8.3	28.3	8.6
Pulse Pressure Increase	5.2	2.4 (13%)*	7.7	3.9 (11%)*
Pulse Pressure Decrease	10.0	6.4 (83%)*	13.4	16.0 (87%)*
Pulse Pressure No Change		(4%)*		(2%)*

*Per cent of the group showing an increase, decrease, or no change.

TABLE 27

CARDIO-VASCULAR REACTIONS OF THE CONTROL GROUP

MEASURED IN TERMS OF THE SCHNEIDER INDEX

	Control		18,000 feet		
	Mean	S.D.	Mean	S.D.	
Schneider Index	12.7	1.7	8.7	2.4	
Pulse Reclining	61.9	6.9	76.5	6.4	
Pulse Standing	75.6	8.5	88.2	9.5	
Pulse Increase on Standing	13.3	4.7	11.2	7.2	
Pulse after Exercise	91.5	9.1	104.0	12.6	
Pulse Increase after Exercise	15.3	4.7	18.3	7.9	(95%)*
Pulse Decrease after Exercise			12.0		(5%)*
Pulse Time to Return to Normal (secs.)	116.8		178.9		
Systolic B.P. Reclining	110.5	9.8	113.7	10.2	
Systolic B.P. Standing	111.8	8.4	107.0	10.7	
B.P. Increase on Standing	4.1	2.0 (79%)*	3.7	2.7	(19%)*
B.P. Decrease on Standing	3.9	2.4 (11%)*	10.1	6.1	(68%)*
B.P. No Change on Standing					(13%)*
Diastolic B.P. Reclining	76.6	8.4	69.7	10.3	
Diastolic B.P. Standing	81.0	9.2	69.4	12.2	
Pulse Pressure Reclining	33.8	7.0	43.3	13.4	
Pulse Pressure Standing	30.9	7.4	38.3	15.1	
Pulse Pressure Increase	4.2	2.5 (21%)*	12.3	6.9	(21%)*
Pulse Pressure Decrease	5.2	1.9 (52%)*	10.4	8.2	(71%)*
Pulse Pressure No Change		(27%)*			(8%)*

*Per cent of the group showing an increase, decrease, or no change in blood pressure.

was actually the case. This variability is reflected in the greater standard deviations in the scores for the patients.

The most striking difference between the two groups in systolic blood pressure was the tendency on the part of so many of the patients to show a decrease on standing rather than an increase. This occurred in over 50 per cent of the patients in air (20 per cent of the normal subjects) and 62 per cent of the patients in 10.3 per cent oxygen (45 per cent of the normal subjects).

In analyzing the records of 1,050 altitude classification examinations from the rebreather tests given during the World War, Schneider and Truesdell (55) reported two kinds of subjects, the fainting and the nonfainting types. In the fainting type (46.7 per cent falling into this classification), there was frequently a sudden fall in the pulse or blood pressure just previous to collapse, while in the other group (53.3 per cent) there was a well controlled reaction until the very end of the rebreathing test. The altitudes at which members of the two groups became wholly inefficient are indicated in the following table (from Schneider and Truesdell). (65)

Table 28

Lowest Oxygen Tolerated in Per Cent	Corresponding Altitude in Feet (000 omitted)	Per Cent of Nonfainting Group that Became Inefficient	Per Cent of Fainting Group that Became Inefficient
11-12	15 -17		0.7
10-11	17 -19.5	0.6	0.7
10- 9	19.5-22	1.2	13.0
9- 8	22 -25	13.0	30.9
8- 7	25 -28	40.1	41.7
Below 7	Above 28	45.2	13.0

In the experiment reported here, many of the psychoneurotic patients apparently belong to the fainting type in that we frequently observed either an uncontrolled rise or fall in pulse or blood pressure upon standing or after exercise.

The Schneider Index appears to be of value in detecting unfitness, but it should be used with additional measures with borderline subjects or those who fall in the middle range of a series. The test should be revised so that the following objections will be taken into account: (1) it gives an undue advantage to subjects with a slow pulse rate; (2) it does not penalize the subject who shows a significant fall in pulse rate on standing or after exercise; and (3) still more important, it fails to take into account body height and weight, the work involved in standing on a chair being much more difficult for a short person than for a tall one.

The blood chemical determinations. At the beginning of each experimental session a sample of venous blood was taken after a half-hour rest period (fasting state) in air and again at the end of each period (approximately two hours). In this way it was possible to compare not only the variability of each individual following repeated blood sampling, but also the variability of the groups, as well as any changes due to the anoxemia in the 10 per cent oxygen series.

The results of the biochemical tests are summarized in Table 29. On the whole, the differences in the means between the two groups in air compared to 10.3 oxygen do not show striking differences. In a number of the patients there were more extreme changes in the lactic acid in low oxygen and wider fluctuations in sugar, possibly associated with the impairment of the sympathetic nervous system or the more extreme discharges of the sympathetic system (adrenalin and consequent mobilization of sugar). The lactic acid

Table 29

BIOCHEMICAL DETERMINATIONS OF THE CONTROL AND PSYCHONEUROTIC GROUPS

	Control		18,000 feet	
	Before	End	Before	End
Lactic Acid in Blood				
Control				
Mean	16.32	16.56	16.84	20.96
Standard Deviation	2.34	2.55	2.94	4.04
Neurotics				
Mean	17.20	17.91	18.41	24.15
Standard Deviation	2.46	2.63	2.57	4.56
Sugar in Blood				
Control				
Mean	96.15	96.58	96.35	100.59
Standard Deviation	5.68	6.94	5.32	6.50
Neurotics				
Mean	92.49	90.95	91.59	95.57
Standard Deviation	7.24	6.60	7.23	8.72
Inorganic Phosphorus in Serum				
Control				
Mean	4.28	4.36	4.16	4.12
Standard Deviation	0.63	0.61	0.60	0.50
Neurotics				
Mean	4.24	4.26	4.46	4.17
Standard Deviation	0.74	0.77	0.84	0.91
Creatinine in Blood				
Control				
Mean	1.63	1.67	1.62	1.71
Standard Deviation	0.20	0.21	0.20	0.24
Neurotics				
Mean	1.47	1.47	1.51	1.53
Standard Deviation	0.14	0.15	0.18	0.21
Calcium in Serum				
Control				
Mean	10.40	10.35	10.81	11.05
Standard Deviation	1.14	1.30	1.00	1.38
Neurotics				
Mean	9.94	10.40	10.45	9.46
Standard Deviation	1.97	1.73	1.72	2.60

determinations in the control group were, on the average, lower, and variability less, than in the patients. Many of the patients tended toward the lower range of normal variation in sugar (normal 80 to 120 mg. per cent). The relative increase in sugar was greater for the patients in the low oxygen series. This was also noticeable in the calcium determinations, especially in the low oxygen series. The determinations for hemoglobin (results not shown in Table 29) were only made in the low oxygen series. There was an average increase of between 4 and 8 per cent in both groups, indicating that the percentage of increase in hemoglobin is only of minor importance in facilitating adaptation in flights of short duration.

The most striking difference between the two groups was in the greater individual and group variability of the patients, reflecting an organic instability as well as greater difficulty in meeting "emergency" situations or reactions involving stress and flexibility of adjustment. In the "nervous" patients the reaction to high altitude is probably accentuated because the sympathetic nervous system, which is usually impaired, is the one most actively involved in bringing about changes in circulation and respiration to adjust to the diminished oxygen.

Psychological tests. In an attempt to get a more objective record of each subject's adjustment to the variations in oxygen tensions, psychological tests were given involving quickness and accuracy of motor coordination, judgment, perseveration, and attention, or capacity to carry out standardized mental tasks. In addition to the objective tests, a record was kept by the experimenter of any obvious changes in mood or emotional reactions, as well as alterations in motor coordination, tremors, indifference or lethargy, etc.

The results of the psychological tests are shown in Table 30. On the average, the patients were more severely affected by the oxygen deprivation

Table 30

PSYCHOLOGICAL TESTS

A = Normal Subjects -- B = Psychoneurotics

	Control		18,000 feet	
	Mean	Standard Deviation	Mean	Standard Deviation
Color naming				
A	59.4	3.9	70.4	5.2
B	69.9	4.1	82.5	5.6
Perseveration				
A First hour	71.0		64.1	
Second hour	76.3		79.7	
B First hour	69.1		71.6	
Second hour	90.4		90.1	
Choice Reaction				
A	41.22	4.17	45.59	4.67
B	55.85	8.13	65.35	8.90
Pursuit Meter				
A First hour	56.74	5.24	89.16	7.95
Second hour	53.12	4.83	60.73	5.27
B First hour	78.46	8.57	90.67	14.89
Second hour	66.98	5.40	74.07	6.38
Dotting Test				
A	12.87	2.91	12.62	3.11
B	11.44	3.43	9.77	3.39
Code Test				
A	128.92	6.84	143.38	8.45
B	176.96	9.45	203.98	9.84

than the normal subjects. The mean scores are not only lower, but there is also a considerable increase in the variability (standard deviations) and the errors. Both groups, however, were severely impaired in the psychological tests by the anoxemia, indicating a general loss of sensory, motor, and mental alertness. The psychological tests reflected the impairment of the circulatory and respiratory mechanisms and the consequent lack of oxygen being delivered to the central nervous system.

VII. Results of the Experiments with Excess Carbon Dioxide (3.0%) in the Low Oxygen and Low Pressure Chambers. Parts IV and V.

In this part of the investigation an attempt has been made to study the effects of high concentrations of carbon dioxide in the presence of a deficiency of oxygen in the inspired air. As described in the introduction, one of the initial respiratory responses of the organism to low oxygen is a marked increase in the rate and depth of breathing which tends to upset the equilibrium of the gases in the alveolar air, particularly the carbon dioxide. Y. Henderson (31) and others have stressed the importance of the excess of carbon dioxide under conditions of anoxemia, and the possibility of counteracting the effects of oxygen want by excess carbon dioxide. The value of using mixtures of 7 per cent carbon dioxide and 93 per cent oxygen in carbon monoxide poisoning and in various clinical disorders where failure of respiration is an important syndrome has been fairly well established. No thorough studies have been made of the blood gases and psychological changes, however, of normal and excess amounts of carbon dioxide in the presence of a deficiency of oxygen. This problem seemed to be of particular relevance in high altitude flying in aviation and in the use of sealed cabins in commercial air transportation.

Three different experiments have been carried out relative to the hypothesis that the presence of two to three per cent carbon dioxide may stimulate the breathing so as to aid the uptake of oxygen. There was the possibility that 3 per cent carbon dioxide for 3 to 6 hours might be very uncomfortable and have certain harmful effects. Even if there were no advantage in the uptake of oxygen, there was the possibility that the excess carbon dioxide would increase the pulmonary ventilation so that sealed aeroplane cabins could be more easily equipped for operations at high altitude.

A. In the experiment at Columbia four subjects, somewhat below average in general physical condition, were tested under the following conditions in the low oxygen chamber: first, in approximately 11 per cent oxygen (17,000 feet) with 0.5 to 0.8 per cent carbon dioxide; and second, in 9 to 10 per cent oxygen (19,000 to 22,000 feet) with 3.0 per cent carbon dioxide. During each period a series of psychological tests was administered to each subject. Mr. H. T. Edwards collected samples of arterial blood and alveolar air. The results of the psychological tests are shown in Tables 31 and 32, and the physiological tests and biochemical determinations in Tables 33 to 36, inclusive.

In the psychological tests all of the subjects were significantly impaired in the presence of oxygen lack with a fairly normal concentration of carbon dioxide. The mean arterial oxygen saturation dropped to approximately 80 per cent, and the partial pressure of oxygen in the alveolar air to 40-45.mm. Two of the four subjects had to be removed from the chamber toward the end of the two-hour experimental session and a third developed severe tonic-clonic muscular twitches. When the experiments were repeated with 3.0 per cent carbon dioxide, even though the oxygen percentages were approximately 2 per cent lower, i.e., 5,000 feet higher, the arterial oxygen saturation remained elevated to approximately 80-85 per cent and the partial pressure of oxygen in the alveolar air to 45-50 mm. All of the subjects did better in the psychological tests in spite of being approximately 5,000 feet higher (cf. Table 31). The subjects were also more comfortable and complained of fewer unpleasant symptoms (cf. Table 32).

B. The Harvard Experiment was carried out in the low oxygen room

Table 31

PSYCHOLOGICAL TESTS - EXPERIMENT IN LOW OXYGEN AND WITH

3.0% CO_2 IN CHAMBER

Condition	Color Naming Time Sec.	Color Naming Errors	Code	Paired Associate Test
Berman				
Control	62	1	104	8
11% O_2* - 0.6% CO_2				
I Hour	70	7	141	4
II Hour	72	5	125	5
10% O_2/ + 3.0% CO_2				
I Hour	64	3	107	6
II Hour	66	2	126	6
Friedman				
Control	50	2	109	7
11% O_2 + 0.6% CO_2				
I Hour	47	13	118	4
II Hour	59	7	130	3
10% O_2 + 3.0% CO_2				
I Hour	49	4	108	6
II Hour	52	3	112	5
Jerome				
Control	51	2	139	6
11% O_2 + 0.6% CO_2				
I Hour	56	7	175	2
II Hour	60	5	172	2
9% O_2# + 3.0% CO_2				
I Hour	56	2	145	3
II Hour	59	3	141	4
Reichline				
Control	35	2	110	7
11% O_2 + 0.6% CO_2				
I Hour	42	10	150	3
II Hour	48	7	158	2
9% O_2 + 3.0% CO_2				
I Hour	39	7	118	5
II Hour	40	3	120	5

*11% oxygen corresponds to approximately 17,000 feet.
/10% " " " " 19,000 feet.
9% " " " " 22,000 feet.

Table 32

PHYSIOLOGICAL AND PSYCHOLOGICAL COMPLAINTS

	12% O_2 Oct. 15		12% O_2 + 3% CO_2 Oct. 22		11% O_2 + 3% CO_2 Nov. 5		11% O_2 Dec. 3	
	Yes	No	Yes	No	Yes	No	Yes	No
Circulatory								
Palpitations or cardiac distress	1	3	0	4	1	3	1	3
Respiratory								
Shortness of breath	4	0	4	0	4	0	3	1
Periodic or irregular breathing	2	2	2	2	1	3	3	1
Sighing or long deep breaths	2	2	1	3	3	1	4	0
Digestion								
Nausea or indigestion	3	1	0	4	0	4	3	1
Gas on stomach or in intestines	3	1	1	3	0	4	4	0
Exertion (muscles)								
Impaired coordination or clumsiness	0	4	0	4	2	2	3	1
Easily fatigued on exertion	4	0	3	1	4	0	3	1
Muscular stiffness and cramps	0	4	0	4	0	4	0	4
Tremors - fingers, hands, etc.	2	2	1	3	1	3	0	4
Excessive sleepiness	4	0	3	1	4	0	4	0
Stuttering or blocking of speech	0	4	0	4	1	3	0	4
Greater effort to carry out tasks	3	1	1	3	4	0	3	1
Sensory								
Headache	3	1	0	4	1	3	4	0
Visual or auditory impairment	3	1	1	3	0	4	4	0
Ringing or buzzing in ears	0	4	0	4	0	4	0	4
Cold extremities	1	3	0	4	0	4	0	4
Feeling of heat and sweating	0	4	0	4	0	4	1	3
Vertigo or dizziness	2	2	0	4	2	2	4	0
Psychological								
Feel talkative and excited	1	3	0	4	0	4	2	2
Difficulty in concentrating (distractable)	3	1	0	4	2	2	3	1
Slowness in reasoning	2	2	0	4	1	3	4	0
Mentally lazy	4	0	1	3	3	1	3	1
Feel depressed and grouchy	0	4	0	4	0	4	0	4
Feel exhilirated and gay	1	3	0	4	0	4	0	4
Nervous, high strung, inward tension	0	4	0	4	0	4	0	4
Sudden changes in mood	0	4	0	4	0	4	0	4
Fidgety or restless	0	4	0	4	0	4	0	4
Worry excessively about health	0	4	0	4	0	4	0	4
Feel indifferent and exhausted	2	2	0	4	1	3	2	2
TOTAL	50	70	18	102	35	85	58	62

Table 33

RESULTS OF THE PHYSIOLOGICAL TESTS AND BIOCHEMICAL DETERMINATIONS

Subject: Berman

Berman	Chamber O_2	Chamber CO_2	Pulse	Blood Pressure Sys.	Blood Pressure Dias.	Alveolar Air O_2	Alveolar Air CO_2	Arterial Blood % O_2	Arterial Blood % Saturation	Arterial Blood Lactic Acid	Arterial Blood Sugar
Control	20.96	0.04	60	101	53	102.7	36.8	19.7	96	12.6	100
Ascent											
10 minutes			57	106	54						
20 minutes			62	114	68						
30 minutes			64	108	61						
First hour											
10 minutes	11.2	0.3	61	103	60						
20 minutes			60	101	63	44.8	29.4				
30 minutes	11.1	0.4	58	105	66						
40 minutes			62	105	60			17.6	80	12.6	104
50 minutes			64	108	55						
60 minutes	11.0	0.6	64	115	66						
Second hour											
10 minutes	11.3	0.6	66	108	60						
20 minutes			64	108	60	40.6	37.1				
30 minutes	11.2	0.7	62	118	61			15.2	71	9.7	106
40 minutes			82	140							
50 minutes			(tremors)								
60 minutes	11.0	0.7	(tremors)								
Control	20.96	0.04		125	69	102.7	36.8	19.7	96	10.4	106
Ascent											
10 minutes	13.7	1.2	53	132	68						
20 minutes	10.8	4.4	60	135	68						
30 minutes	8.7	3.5	64	125	67						
First hour											
10 minutes			80	115	64						
20 minutes	9.8	3.0	68	113		54.0	43.4				
30 minutes	9.9	3.2	60	108	65						
40 minutes			60	105	65						
50 minutes	10.5	3.5	62	115	70				93	11.2	103
60 minutes			62	115	70						
Second hour											
10 minutes	10.2	3.2	58	113							
20 minutes	10.3	2.4	64	112	70	52.3	40.2				
30 minutes	10.5	3.1	64	105	68						
40 minutes			74	108	68			17.7	85	8.9	109
50 minutes			74	110	75						
60 minutes			76	115	80						

Table 34

RESULTS OF THE PHYSIOLOGICAL TESTS AND BIOCHEMICAL DETERMINATIONS

Subject: Friedman

Friedman	Chamber O_2	Chamber CO_2	Pulse	Blood Pressure Sys.	Blood Pressure Dias.	Alveolar Air O_2	Alveolar Air CO_2	Arterial Blood % O_2	Arterial Blood % Saturation	Arterial Blood Lactic Acid	Arterial Blood Sugar
Control	20.96	0.04	72	105	62	103.7	40.4	21.0	100	10.4	99
Ascent											
10 minutes			72	93	50						
20 minutes			72	95	51						
30 minutes			73	95	58						
First hour											
10 minutes	11.2	0.3	82	98	58						
20 minutes			68	100	48						
30 minutes	11.1	0.4	81	96	60						
40 minutes			80	96	60						
50 minutes			74	95				15.9	85	15.6	109
60 minutes	11.0	0.6	70	91							
Second hour											
10 minutes	11.3	0.6	90	88	48						
20 minutes			92/54			41.9	38.8				
30 minutes	11.2	0.7						17.0	83	14.1	108
40 minutes											
50 minutes											
60 minutes	11.0	0.7									
Control	20.96	0.04	76	125	82	103.7	40.4	21.0		11.9	110
Ascent											
10 minutes	13.7	1.2	81	128	76						
20 minutes	10.8	4.4	86	127	78						
30 minutes	8.7	3.5	100	127	78						
First hour											
10 minutes			100	120							
20 minutes	9.8	3.0	90	120		53.9	44.3				
30 minutes	9.9	3.2	84	115							
40 minutes			84	115	60						
50 minutes	10.5	3.5	80	115							
60 minutes			80	115				18.5	85	12.0	115
Second hour											
10 minutes	10.2	3.2	96	115	66						
20 minutes	10.3	2.4	96	115	65	50.6	39.9				
30 minutes	10.5	3.1	94	118	65						
40 minutes			84	115	66						
50 minutes			82					17.8	82	12.6	111
60 minutes			80								

Table 35

RESULTS OF THE PHYSIOLOGICAL TESTS AND BIOCHEMICAL DETERMINATIONS

Subject: Jerome

Jerome	Chamber		Pulse	Blood Pressure		Alveolar Air		Arterial Blood			
	O_2	CO_2		Sys.	Dias.	O_2	CO_2	% O_2	% Saturation	Lactic Acid	Sugar
Control	20.96	0.04	105	108	64	105.2	38.1	19.1	92	14.1	99
Ascent											
10 minutes			126	114	80						
20 minutes			138	120	78						
30 minutes			114	124	74						
First hour											
10 minutes	11.0	0.3	130	120	80						
20 minutes			111	122	84	45.2	34.1				
30 minutes	11.3	0.4	120	120	84						
40 minutes			128	120	84			14.6	71	10.4	109
50 minutes			118	121	83						
60 minutes	11.1	0.5	120	130	82						
Second hour											
10 minutes	11.2	0.6	80	118	75						
20 minutes			122	125	72	42.2	31.0				
30 minutes	11.1	0.7	90	115	76						
40 minutes			77	115	62			14.1	68	14.1	120
50 minutes			119/66	110	65						
60 minutes	11.0	0.7		100	68						
Control	20.96	0.04	90	115	70	105.2	38.1	19.1	92	11.9	113
Ascent											
10 minutes		3.1	88	120	69						
20 minutes		4.2	112	119	71						
30 minutes	8.0	3.3	108	110	70						
First hour											
10 minutes	8.7	3.2	104	118	66						
20 minutes	8.7	3.2	100	120	65	44.8	38.7				
30 minutes	8.7	3.1	112	120	65						
40 minutes			106	121	70			15.0	72	12.6	112
50 minutes			106	112	70						
60 minutes	9.6	3.3	106	112	66						
Second hour											
10 minutes	9.2	2.9	90	112	65						
20 minutes			99	100	70	44.9	38.1				
30 minutes			99	110	70						
40 minutes			118	115	70			15.5	67	12.6	102
50 minutes			108	105	70						
60 minutes			124								

Table 36

RESULTS OF THE PHYSIOLOGICAL TESTS AND BIOCHEMICAL DETERMINATIONS

Subject: Reichline

Reichline	Chamber		Pulse	Blood Pressure		Alveolar Air		Arterial Blood			
	O_2	CO_2		Sys.	Dias.	O_2	CO_2	% O_2	% Saturation	Lactic Acid	Sugar
Control	20.96	0.04	80	101	52	107.2	38.9	20.0	98	10.4	102
Ascent											
10 minutes			87	101	60						
20 minutes			91	101	61						
30 minutes			98	96	60						
First hour											
10 minutes	11.0	0.3	90	94	60						
20 minutes			90	94	58	45.8	32.1				
30 minutes	11.3	0.4	96	101	60			17.2	81	15.4	110
40 minutes			90	98	58						
50 minutes			90	92							
60 minutes	11.1	0.5	94	95	60						
Second hour											
10 minutes	11.2	0.6	100	90	60						
20 minutes			56			44.0	29.6				
30 minutes	11.1	0.7						17.4	82	11.9	109
40 minutes											
50 minutes											
60 minutes	11.0	0.7									
Control	20.96	0.04	72	110	74	107.2	38.9	20.0	98	11.2	105
Ascent											
10 minutes		3.1	72	108	75						
20 minutes		4.2	72	108	78						
30 minutes	8.0	3.3	72	111	78						
First hour											
10 minutes	8.7	3.2	80	105							
20 minutes	8.7	3.2	80	110		41.9	37.6				
30 minutes	8.7	3.1	76	108				17.2	82	13.4	108
40 minutes			82	105							
50 minutes			82	105							
60 minutes	9.6	3.3	78	112	75						
Second hour											
10 minutes	9.2	2.9	74	105	71						
20 minutes			82	115	70	46.1	33.8				
30 minutes			104	115	68			17.6	80	11.9	125
40 minutes			96	108	68						
50 minutes			90								
60 minutes			90								

at the Fatigue Laboratory. More extensive studies were made of the changes in respiration and the blood. The experiments also continued over a longer period of time (6 hours) and the concentrations of oxygen and carbon dioxide were more carefully controlled. The results of the psychological tests are shown in Tables 37 and 38, and the alveolar oxygen and per cent saturation of the arterial blood with oxygen in Table 39. The author is indebted to Dr. D. B. Dill for permission to use the data of Table 39 and for the interpretation of the physiological findings discussed below.

The first experiment was a control. The four subjects, who were also the four observers (Dill, Edwards, McFarland and Robinson), ate the same breakfast and were ready to begin observations at 8:30. The room was closed, an absorbing unit for carbon dioxide was started, and a simple cooling device was available. The temperature was kept between 20° and 26° C. and the humidity between 50 and 70 per cent. The carbon dioxide absorber provided a comfortable air circulation. The carbon dioxide was kept at about 0.6 per cent and the oxygen between 20.8 and 21.1 per cent. The day was divided into four periods of about two hours each. In each period a complete set of physiological and psychological studies was made on each individual. Four samples of arterial blood were drawn from each man during the day for study of the oxygen uptake, carbon dioxide content, alkaline reserve and pH. Between the second and third periods a lunch of soup and crackers was taken.

In subsequent experiments the same subjects were used and the same routine followed. In the second experiment the first two-hour period was carried out as before and then carbon dioxide was admitted and maintained for 6 hours at 2.8 to 3.1 per cent. In other respects conditions were the same as before. We found that this concentration of carbon dioxide increased the

Table 37

PSYCHOLOGICAL TESTS

	Audiometer		Heterophoria (Exo)		Choice Reaction Time			
	11% O_2 + 3% CO_2	11% O_2 + 0.5% CO_2	11% O_2 + 3% CO_2	11% O_2 + 0.5% CO_2	11% O_2 + 3% CO_2	Errors	11% O_2 + 0.5% CO_2	Errors
Dill								
Control	14	15	4	4	39	0	41	0
2nd hour	17	17	6	7	39	1	46	3
3rd hour	16	18	5	5	41	2	47	4
4th hour	17	--	5	-	37	1	--	-
Edwards								
Control	17	15	2	2	40	1	41	0
2nd hour	16	19	2	4	38	1	44	3
3rd hour	16	16	2	6	39	0	47	5
4th hour	17	--	3	-	42	0	--	-
McFarland								
Control	15	15	3	3	41	0	41	0
2nd hour	16	17	6	6	42	1	43	2
3rd hour	16	17	5	7	42	0	46	3
4th hour	17	--	6	-	43	0	--	-
Robinson								
Control	18	17	5	5	52	0	52	2
2nd hour	19	18	7	7	53	0	55	3
3rd hour	18	20	6	6	57	0	59	4
4th hour	18	--	6	-	52	1	--	-
Average								
Control	16	15.5	3.5	3.5	43.0	.3	43.8	.5
2nd hour	17	17.8	5.3	6.0	43.0	.8	47.0	2.8
3rd hour	16.5	17.8	4.5	6.0	44.8	.5	49.8	4.0
4th hour	17.3	--	5.0	-	43.5	.5	--	-

Table 38

PSYCHOLOGICAL TESTS

	Memory (% correct)		Code (in seconds)			
	11% O_2 + 3% CO_2	11% O_2 + 0.5% CO_2	11% O_2 + 3% CO_2		11% O_2 + 0.5% CO_2	
	Mean		Mean	Errors	Mean	Errors
Dill						
Control	90	90	117	0	118	1
2nd hour	70	50	121	1	124	6
3rd hour	60	40	123	0	135	2
4th hour	70	—	125	0	—	-
Edwards						
Control	80	80	121	0	121	1
2nd hour	60	60	122	1	126	5
3rd hour	50	50	127	2	134	2
4th hour	50	—	120	0	—	-
McFarland						
Control	90	80	143	1	127	1
2nd hour	70	50	153	1	147	3
3rd hour	70	50	151	2	156	2
4th hour	60	—	143	0	--	-
Robinson						
Control	100	90	151	0	150	1
2nd hour	70	60	150	1	165	4
3rd hour	60	60	154	1	173	-
4th hour	70	—	150	1	—	-
Average						
Control	90	85	133	.25	129	1.0
2nd hour	67.5	55	136.5	1.00	140.5	4.5
3rd hour	60	45	138.8	1.25	149.5	1.5
4th hour	62.5	---	134.5	.25	--	-

Table 39

ALVEOLAR OXYGEN AND PERCENTAGE SATURATION OF THE ARTERIAL BLOOD WITH OXYGEN

Fatigue Laboratory - Low Oxygen Room

Alveolar Oxygen in mm.Hg.				
	November 5, 1936 3% CO_2 11% O_2			
	Initial	After 1 hr.	After 2 hrs.	After 4 hrs.
Dill	105.5	60.7	57.9	61.0
McFarland	111.5	66.1	—	58.3
Robinson	104.5	57.2	63.9	63.7
Edwards	103.1	57.1	61.4	66.6
Mean	106.1	60.3	61.1	62.4
	December 3, 1936 0.5% CO_2 11% O_2			
Dill	103.2	37.8	41.2	
McFarland	106.1	34.3	38.3	
Robinson	109.7	43.5	—	
Edwards	113.2	40.6	—	
Mean	108.0	39.0	39.8	

Percentage Saturation of Arterial Blood with Oxygen				
	November 5, 1936 3% CO_2 11% O_2			
	Initial	After 1 hr.	After 2 hrs.	After 4 hrs.
Dill	95.1	—	—	86.4
McFarland	95.2	90.8	88.4	90.6
Robinson	96.7	87.6	89.8	89.4
Edwards	96.7	—	86.6	—
Mean	95.9	89.4	88.7	90.0
	December 3, 1936 0.5% CO_2 11% O_2			
Dill	—	61.4	70.4	
McFarland	—	73.8	67.8	
Robinson	—	73.5	*	
Edwards	—	73.4	—	
Mean	95.9	70.3	69.1	

*Experiment discontinued; observer fainted.

volume of air breathed per minute about 120 per cent. However, it did not modify significantly the oxygen uptake under the conditions of this experiment. This does not imply that increased breathing will not modify oxygen uptake under other conditions; this will be discussed below. The increased volume of air used kept the ratio of bicarbonate to free carbonic acid nearly constant; actually the ratio decreased from 20 to 18. This was associated with a decrease in pH from 7.40 to 7.36. These changes comprised the only physiological effects worth mentioning. The observations were carried on with no discomfort and without well defined awareness that the atmosphere was abnormal. There were no after-effects discernible. The results of the psychological tests were within the normal range of variability.

In the third experiment the room was closed after the preliminary observations, nitrogen admitted and enough oxygen was displaced to leave an atmosphere containing about 11.0 per cent oxygen. This is roughly equivalent to 17,000 feet and the ascent was made in step-wise fashion over one hour. Carbon dioxide was absorbed and after a short period of adjustment during which 11.0 oxygen was reached, that oxygen percentage was maintained for six hours. As will be seen in Table 39, this reduced the oxygen saturation to 70 per cent. Expressed in another fashion, the arterial blood contained nearly five times as much unoxygenated hemoglobin as is normally the case. The breathing increased about 20 per cent above normal and this had the effect of raising the ratio of bicarbonate to free carbonic acid in the blood from 20 to 22. This is about equal in magnitude, though opposite in sign to the effect of 3 per cent carbon dioxide. All of the subjects were definitely handicapped during the six hours of this experiment. The digestion was retarded, there was some nausea and dizziness, and three had moderate headaches which persisted for an hour or longer after leaving the room. All of the subjects were poorer in the psychological tests (cf. Tables 37 and 38).

The fourth experiment was devised to test the combined effects of 3% carbon dioxide and 11.0 per cent oxygen. The breathing was greatly increased.. The oxygen saturation was notably modified by the increased ventilation of the lungs. The mean saturation was 90 per cent instead of 70 (table 39). In other words, the unoxygenated hemoglobin in arterial blood was only twice normal instead of 5 times normal. In the one case the oxygen supply was seriously interfered with; in the other case it was slightly reduced.

It is notable in this fourth experiment that the ratio of carbonic acid to bicarbonate remains very nearly constant; in other words, the reaction of the blood remains at its normal value. In view of this and also the fact that the oxygen saturation was as high as 90 per cent, it is not surprising that none of us felt particularly uncomfortable in this experiment. Only one had a headache; it was slight and disappeared as soon as the experiment was over. There was reduced appetite and some indigestion in two cases, but all agreed that the experience was less arduous than with low oxygen alone. It was our impression that the presence of 3 per cent carbon dioxide lowered the altitude from 17,000 to approximately 12,000 feet.

C. Through the cooperation of Captain H. G. Armstrong and Dr. J. W. Heim, these experiments were repeated in the low pressure chamber at Wright Field, Dayton, Ohio. The same experimental procedure was used as in the low oxygen room at the Fatigue Laboratory and the same individuals (Dill, Edwards, McFarland and Robinson) served as their own experimental subjects. The results of the psychological tests are shown in Table 40 and the findings relating to the alveolar oxygen and per cent saturation of the arterial blood with oxygen

Table 40

PSYCHOLOGICAL TESTS

Wright Field - Low Pressure Chamber

May 11, 1937 - 20,000 feet (9.6% O_2 - 2.1% CO_2)

		Choice Reaction Time		Code		Memory
		Mean	Errors	Mean	Errors	Mean
Dill	Control	42.0	1	120	2	90
	Second hour	46.7	2	131	2	--
	Third hour	44.6	1	132	1	60
	Fourth hour	45.8	3	129	1	50
Edwards	Control	40.1	1	121	0	80
	Second hour	43.2	1	127	5	70
	Third hour	44.0	2	158	3	60
	Fourth hour	39.9	1	158	1	40
McFarland	Control	44.0	0	143	1	80
	Second hour	49.2	2	153	2	70
	Third hour	--	-	150	0	--
	Fourth hour	50.4	1	155	2	50
Robinson	Control	47.0	0	151	1	70
	Second hour	46.8	2	160	1	70
	Third hour	49.0	2	-	-	40
	Fourth hour	45.2	4	145	0	50
May 13, 1937 - 17,000 feet (11.0% O_2 - 0.3% CO_2)						
Dill	Second hour	43.7	4	124	1	--
	Third hour	45.2	1	118	1	50
	Fourth hour	44.3	2	122	1	50
Edwards	Second hour	40.5	4	107	2	40
	Third hour	42.0	2	105	1	50
	Fourth hour	45.5	4	130	2	50
McFarland	Second hour	45.7	2	143	2	60
	Third hour	44.1	1	145	0	70
	Fourth hour	45.9	1	143	1	50
Robinson	Second hour	48.2	2	150	0	50
	Third hour	--	-	157	1	60
	Fourth hour	48.3	0	153	3	50

Average	9.6% O_2		11.0% O_2		9.6% O_2		11.0% O_2		9.6% O_2	11% O_2
Control	43.3	.8	43.3	.8	133.8	1	133.8	1	80	80
Second hour	46.5	1.8	44.5	3.0	142.8	2.5	131	1.3	70	50
Third hour	45.9	1.3	43.8	1.3	146.7	1	131.3	.8	53	57.5
Fourth hour	45.3	2.3	46.0	1.8	146.8	1	137	1.8	47.5	50

Table 41

ALVEOLAR OXYGEN AND PERCENTAGE SATURATION OF THE ARTERIAL BLOOD WITH OXYGEN

Wright Field - Low Pressure Chamber

Alveolar Oxygen in mm. Hg			
May 11, 1937*		$2.1\% CO_2 - 9.6\% O_2$	
	Sea Level Boston	During Second Hour	During Fourth Hour
Dill	105.5		40.0
McFarland	111.5		39.4
Robinson	104.5		53.3
Edwards	103.1		48.0
Mean	106.1		45.2
May 13, 1937**		$0.3\% CO_2 - 11.0\% O_2$	
Dill		48.7	
McFarland			
Robinson		53.3	
Edwards		43.0	
Mean		48.3	

Percentage Saturation of Arterial Blood with Oxygen			
May 11, 1937*		$2.1\% CO_2 - 9.6\% O_2$	
	Sea Level Boston	During Second Hour	During Fourth Hour
Dill	95.1	65.0	62.2
McFarland	95.2	72.0	70.0
Robinson	96.7	73.3	77.4
Edwards	96.7	69.2	69.6
Mean	95.9	69.9	69.8
May 13, 1937**		$0.3\% CO_2 - 11.0\% O_2$	
Dill			64.4
McFarland		87.4	84.4
Robinson		74.0	76.8
Edwards		72.2	71.2
Mean		77.9	74.2

*During this experiment the carbon dioxide was being increased at the same time the barometric or total pressure was being lowered, so that the percentage of oxygen was equivalent to 20,000 feet altitude (9.6% oxygen) and the percentage of carbon dioxide was 2.1%.

**The barometric pressure was altered so that the percentage of oxygen available corresponded to 17,000 feet altitude (11.0% oxygen). The carbon dioxide was held constant at approximately 0.3%.

in Table 41.

It was our intention to reduce the total pressure to a value equivalent to 17,000 feet. On the whole, our subjective experiences and the psychological tests were not unlike those in the low oxygen chamber at the Fatigue Laboratory. Arterial blood samples were drawn and passed through the air lock for analysis. Samples of air from the pressure chamber were drawn at intervals during the day, but these were not analyzed until the following day. We were astonished to find that the carbon dioxide had been rising and the oxygen falling during the day due to a defect in the ventilating system. We had actually been working at 22,000 feet with carbon dioxide equivalent to 2.5 per cent. It is safe to say that with that reduction in oxygen taking place without carbon dioxide all of us would have been sick or collapsed. Two days later when the ventilation was working properly we observed that, aside from the effects on the eardrum of increasing and decreasing pressures, the physiological and psychological consequences of a given oxygen pressure were the same whether produced by adding nitrogen to the air at atmospheric pressure or by decreasing the total pressure in a low pressure chamber.

VIII. Results of the Experiments Carried out during Flights at High Altitude on Commercial Air Transport Planes (Part VI).

During the past summer (1937) an opportunity was afforded through the generosity of the United Air Lines and the Pan American Airways (both companies provided free transportation) to check some of the data reported above under actual flight conditions on their trans-Pacific and transcontinental operations.

A. Results of experiments on transcontinental flights. On June 3 D. B. Dill of Harvard University and F. G. Hall of Duke University made the flight between Newark and Salt Lake City. The average altitude was between 8,000 and 10,000 feet. The flying conditions were fairly good; however, rough air was encountered previous to reaching Denver and Salt Lake City. Both subjects felt quite nauseated on the flight between Denver and Salt Lake City, and just before reaching Salt Lake Dill vomited, and Hall would have vomited had he not rested quietly.

On June 21 R. A. McFarland of Columbia University made the flight between Newark and Chicago, and on June 22 from Chicago to Salt Lake City. J. W. McC., World War pilot of Portland, Oregon, and an interested passenger, served as subject between Chicago and Salt Lake City. The flying conditions were quite bad between Cleveland and Chicago on June 21 on account of rough air and thunderstorms.. Similar conditions were encountered between Denver and Salt Lake City on June 22.

On August 11 and 12 R. A. McFarland and H. T. Edwards made the flight between Oakland and New York. The flying conditions were, on the average, good. An attempt was made to get accurate determinations of the alveolar air. Samples of expired air were obtained in sampling tubes and analyzed in the standard Haldane gas analysis apparatus at the Fatigue Laboratory at Harvard. The results are shown in Table 44. The summary at the bottom of the table gives a comparison with similar tests made on the trans-Pacific flights at the same altitudes, i.e., 11,000 feet.

Results - Physiological tests. The results of the tests for pulse rate and alveolar carbon dioxide made by Dill and Hall are shown in Table 42. There was a slight yet significant increase in pulse rate with increasing altitude, with a tendency toward normal values as each flight progressed. A comparison of the alveolar carbon dioxide data with that obtained on the Chilean Expedition (cf. Figure 9, Chuquicamata - 10,000 feet) indicates that there was a close correspondence in these findings.

The results of the pulse rate and blood pressure tests (Recording Tycos Sphygmomanometer) obtained by McFarland are shown in Table 43. The changes in both McFarland and the passenger, J. W. McC., were only slight and, on the average, quite insignificant.

The data obtained by McFarland and Edwards for the alveolar oxygen and carbon dioxide are shown in Table 44. The results are in close agreement with those from the trans-Pacific flights. If one compares these results with those from the Chilean Expedition (Chuquicamata - 10,000 feet), (Figure 9) and from trans-Andean flights (Figures 40 and 41) (refs. 44), the results also show a close correspondence. The mean pO_2 and pCO_2 at Chuquicamata for ten subjects were 62.4 and 33.9 respectively. On these flights (at 11,000 feet) the mean pO_2 and pCO_2 were 62.1 and 34.5 respectively.

Results - Psychological tests. The psychological tests included: (1) heterophoria, or ocular muscle imbalance; (2) light sense for visual intensity - Reeves wedge; (3) color naming - naming 100 colors as rapidly as possible - score in seconds; (4) transliterating 50 code letters against time (in seconds); and (5) memory for paired words. In this test the ten pairs of words were exposed for 15 seconds each. Immediately following the initial presentation, the first word of each pair is shown to the subject and he is asked to recall the second (score in per cent correct).

Table 42

FLIGHT ON UNITED AIR LINES PLANE - NEWARK TO SALT LAKE CITY - JUNE 3, 1937

Subjects: Dr. D. B. Dill (age 44) and Dr. F. G. Hall (age 41)

Time	Altitude	Pulse	Alveolar pCO_2 mm.Hg	Heterophoria (40 cms.)	Color Naming (In seconds)	Code Test (In seconds)	Code Test Errors	Memory (% Correct)	General Sensations
	Sea level	Dill 68		D. 2.0	D. 54	D. 114	0	D. 80	
		Hall 70		H. 5.0	H. 56	H. 130	1	H. 95	
Newark to Cleveland									
9:13 a.m.	2,800 ft.	Dill 72							
		Hall 72							
9:35 a.m.	8,000 ft.	Dill 71				D. 118	1	D. 80	Dill, slight belching.
	slightly rough	Hall 74				H. 135	3	H. 100	
10:00 a.m.	10,000 ft.	Dill 70		D. 3.0	D. 55				Above clouds. Smooth.
		Hall 72		H. 7.0	H. 57				
10:10 a.m.	10,000 ft.	Dill 72				D. 116	0	D. 70	Above clouds. Smooth.
		Hall 72				H. 133	6	H. 90	
10:30 a.m.	6,000 ft.	Dill 68						D. 70	Rough air.
		Hall 68						H. 90	
10:55 a.m.	6,000 ft.	Dill 71		D. 2.5		D. 111	0		Rough.
		Hall 68		H. 6.0		H. 137	4		
Cleveland to Chicago									
12:30 p.m.	8,000 ft.		Dill 36.2			D. 117	0	D. 80	
			Hall 37.2			H. 131	2	H. 80	
1:10 p.m.		Dill 68	Dill 43.4	D. 2.5	D. 55	D. 110	0	D. 100	Enjoyed lunch (both).
1:20 p.m.	8,000 ft.	Hall 72	Hall 40.4	H. 6.5	H. 59	H. 128	1	H. 90	
Chicago to Denver (Captain H. G, M. - Stewardess S.)									
1:30 p.m.	8,000 ft.	Dill 80	Dill 38.8	D. 3.0	D. 51				Smooth air.
	(1 hr. after lunch)	Hall 78	Hall 36.2	H. 6.0	H. 55				
2:00 p.m.	8,000 ft.		Dill 40.3						
			Hall 38.8						

Table 42 (continued)

Time	Altitude	Pulse	Alveolar pCO_2 mm.Hg	Hetero-phoria (40 cms.)	Color Naming (In seconds)	Code Test (In seconds)	Code Test Errors	Memory (% Correct)	General Sensations
3:07 p.m.	8,000 ft.	Dill Hall S. P.	42.4 42.4 38.3 41.9						
3:40 p.m.	11,000 ft.	Dill 73 Hall 76		D. 3.0 H. 7.0	D. 58 H. 56	D. 120 H. 135	0 1	D. 80 H. 100	3:40, 3:50 rough; Dill slight breathlessness.
3:50 p.m.	10,500 ft.	Dill 74 Hall 77	D. 37.2 H. 36.3						Smooth air.
4:20 p.m.	5,000 ft.	Dill 65 Hall 68							Smooth air.
4:40 p.m.	6,000 ft.	Dill 66 Hall 70							Smooth air.
5:10 p.m.	7,000 ft.	Dill 71 Hall 71	D. 38.6 H. 39.7	D. 2.5 H. 7.0	D. 55 H. 56	D. 116 H. 145	o 1	D. 100 H. 90	
Denver to Salt Lake City									
7:10 p.m.	10,000 ft.	Dill 70 Hall 70	D. 36.6 H. 36.0	D. 3.0 H. 7.5	D. 55 H. 59	D. 112 H. 134	0 1	D. 80 H. 70	Rough. Dill vomited. Hall nauseated.
Means - Sea Level		Dill / Hall	Dill / Hall	Dill / Hall	Dill / Hall	Dill / Hall	Dill / Hall	Dill / Hall	
Sea level		68.0 / 70.0		2.0 / 5.0	54.0 / 56.0	114.0 / 130.0	0 / 1	80.0 / 95.0	
6,000-8,000 ft.		70.7 / 71.6	39.7 / 39.2	2.6 / 6.4	53.6 / 56.6	114.5 / 135.2	.2 / 1.6	86.0 / 90.0	
10,000-11,000 ft.		71.8 / 72.4	36.9 / 37.2	3.0 / 7.2	54.3 / 57.3	116.0 / 134.0	0 / 1.6	76.6 / 86.6	

During the last half hour the air was very rough. Hall slept through this, but awoke with nausea as the Salt Lake Airport was approached. He did not vomit, but had nausea for another hour. Dill vomited just as the airport was reached. Within a few minutes after landing he felt well and had no further discomfort. Neither had headaches.

Table 43

FLIGHT ON UNITED AIR LINES PLANE - NEWARK TO SALT LAKE - JUNE 21 AND 22, 1937

Subjects: Dr. R. A. McFarland (age 35) and Passenger J.W.Mc. (age 49)

Time	Altitude	Pulse	Blood Pressure	Heterophoria (40 cms.)	Visual Intensity Reeves Wedge R.	L.	Color Naming (In Seconds)	Code (In Seconds)	Errors	Memory (% Correct)	General Sensations
	Sea level	64	116/76	-2.0*	8.0	8.3	64	134	1	80	
Newark to Cleveland, June 21											
9:30 a.m.	6,000 ft. Climbing higher	66					66	141	0		Smooth. Felt O.K.
10:10 a.m.	10,000 ft.	72	120/80	-3.0	7.4	7.5				80	
10:45 a.m.	10,000 ft.	70					65				
Cleveland to Chicago											
11:30 a.m.	3,000 ft.	80						140	0	60	Air very rough. Thunder storms. Felt nauseated. Felt much better at 12:05.
12:05 a.m.	10,000 ft.	72	110/78	-2.5	7.6	7.5		146	2		
Chicago to Denver, June 22 (Captain V. W. V.)											
1:10 p.m.	10,000 ft.	68	118/74 (125/76	-3.0			67			80	Felt fine.
2:00 p.m.	10,000 ft.	72			7.4	7.8		140	0		
3:10 p.m.	12,000 ft.	78	120/76	-4.0	6.6	6.8				70	Felt sleepy.
4:05 p.m.	10,000 ft.	J.W.Mc 80	130/70		6.5	6.2					Felt nauseated.
4:40 p.m.	8,000 ft.							144	1	70	Air very rough.
Denver to Salt Lake City (Captain E. D. W.)											Air very rough. Storms.
6:15 p.m.	10,000 ft.	74		-4.5			68				R.M. Nauseated. J.W.M. headache. Air rough.
7:10 p.m.	10,000 ft.	78	112/76					145	1	60	
		J.W.Mc. 84	140/82								ø J.W.M. intense headache
9:40 p.m.	Hotel Utah	68	124/76		8.0	8.2	65	140	2	80	R.M. slight headache
		J.W.Mc. 78	135/80		7.2	7.6					and quite fatigued.
Means - Sea Level											
R.M.	Sea level	66	120/78	2.0	8.0	8.25	64.5	138	1.5	80	
	10,000 **	73	117/77	3.4	7.25	7.4	66.6	142.5	.75	75	
J.W.Mc.	Sea level	78	135/80	---	7.2	7.6	--	--	--	--	
	10,000 **	82	135/76	---	6.5	6.2	--	--	--	--	

* Minus signs indicate esophoria.
**Average altitude.

øExcessive amount of alcohol on the night previous to the flight.

Table 44

ALVEOLAR AIR SAMPLES FROM TWO PASSENGERS

ON FLIGHT BETWEEN OAKLAND AND CLEVELAND

United Air Lines Planes

August 12-13, 1937

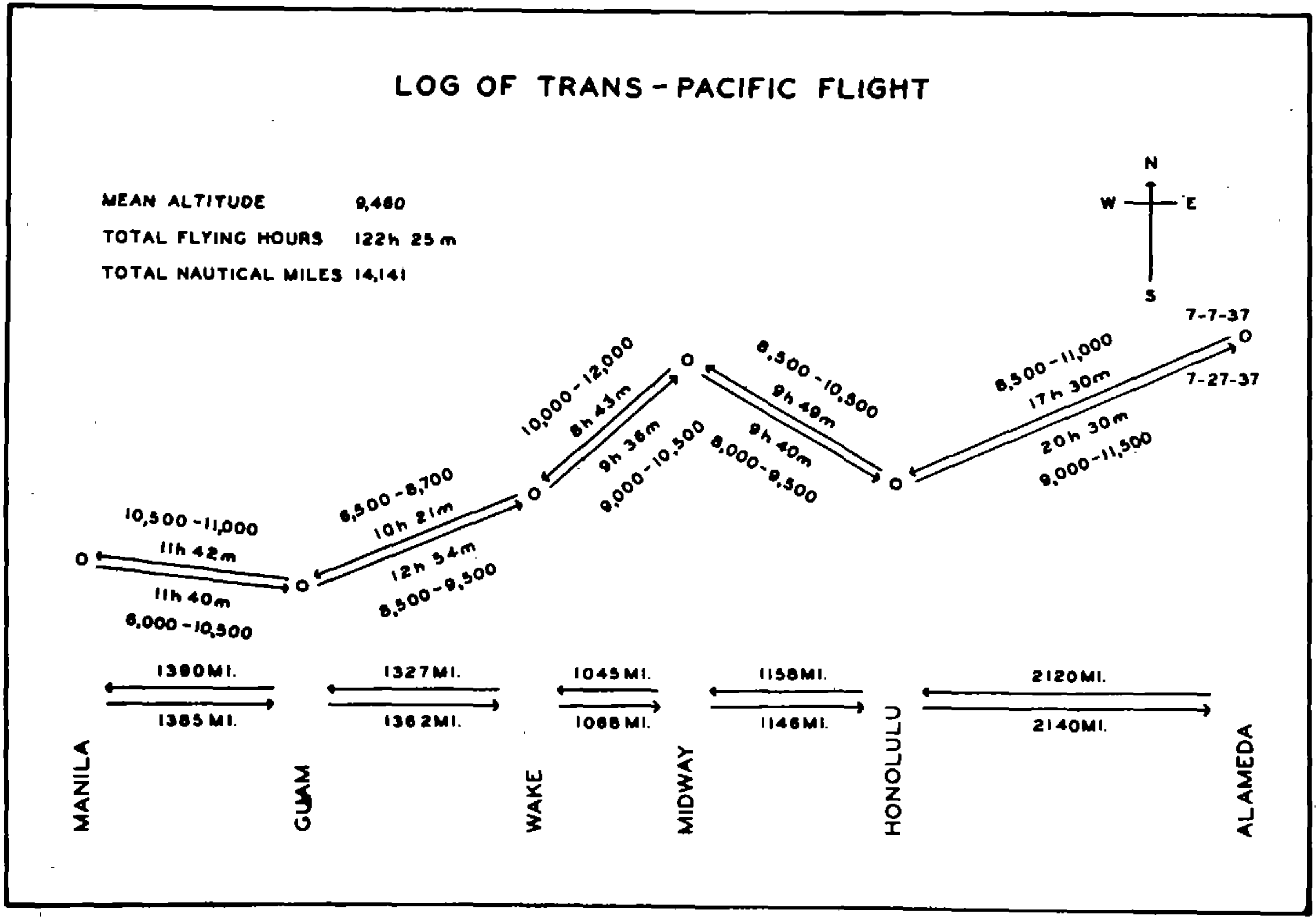
	9,000 feet Barometric Pressure 539		11,000 feet Barometric Pressure 509	
	pO_2	pCO_2	pO_2	pCO_2
Edwards				
Left Reno at 3 p.m. Sample taken at 5:05 p.m.			62.2	35.2
Left Cheyenne at 7:45 a.m. Reached 11,000 feet altitude at 8 a.m. Sample taken at 8:30 a.m.			60.4	30.3
Left Chicago at 8:30 a.m. Reached 9,000 feet at 9:15 a.m. Sample taken at 9:40 a.m.	66.7	34.3		
McFarland				
Left Cheyenne at 7:45 a.m. Reached 11,000 feet altitude at 8 a.m. First sample taken at 8:25 a.m.			62.7	36.6
Second sample taken at 9:15 a.m.			63.0	35.8
Left Chicago at 8:30 a.m. Reached 9,000 feet at 9:15 a.m. Sample taken at 9:35 a.m.	61.7	39.8		
Summary (Means)				
Edwards	66.7	34.3	61.3	32.8
McFarland	61.7	39.8	62.8	36.2
Average	64.2	37.0	62.1	34.5
Crew Average - Pacific Flights	--	--	66.9	35.3

The results, as shown in Tables 42 and 43, were consistently yet insignificantly lower at the high altitudes during the flights. The variations are only slightly greater than the experimental error and the possible effects due to the distractions while in flight. In the code test, for example, there was an average decrease in time for each test of 2 to 3 seconds at high altitude compared to sea level; in the memory test, from 4 per cent to 8 per cent.

The amount of unsaturation of the arterial blood with oxygen at 10,000 feet decreases from the normal sea level value of 96 per cent to approximately 90 per cent. At 12,000 feet the per cent saturation of the arterial blood would be approximately 86 per cent. From a wide number of observations at high altitude on mountain expeditions and in simulated high altitude in chambers at sea level, slight yet statistically insignificant changes in sensory or mental functions with this amount of arterial oxygen unsaturation have been observed.

It appears that healthy subjects between the ages of 18 and 60 years are only slightly affected at altitudes of 10,000 feet after two to four hours. At 12,000 feet to 14,000 feet the average passenger experiences sleepiness and lassitude, and if the air is smooth, tends to fall asleep. If rough air were encountered, however, any tendency toward nausea, headache, or cardiac distress tends to be accentuated. Passengers who have a tendency toward "nervousness" tend to be more susceptible to the ill effects of high altitude; also those who have had little sleep the night before, or excess alcohol.

B. <u>Results of experiments on trans-Pacific flights</u>. During the month of August, 1937, H. T. Edwards (biochemist at the Harvard Fatigue Laboratory) and R. A. McFarland carried out a series of studies on the crew and passengers during a routine flight of the Pan American Clipper Ships flying from Alameda, California, to Hong Kong, China. Between Alameda and Manila, P. I., the mean altitude was 9,500 feet; the total flying time, 122½ hours; and the total nautical miles, 14,141. A complete account of this study may be obtained in the original article (cf. reference 49). The log of the flight is shown in Figure 42.



LOG OF TRANS-PACIFIC FLIGHT
MEAN ALTITUDE 9,460
TOTAL FLYING HOURS 122h 25m
TOTAL NAUTICAL MILES 14,141
N
W
E
S
7-7-37
7-27-37
10,500-11,000
11h 42m
11h 40m
8,000-10,500
8,500-8,700
10h 21m
12h 54m
8,500-9,500
10,000-12,000
8h 43m
9h 36m
9,000-10,500
8,500-10,500
9h 49m
9h 40m
8,000-9,500
8,500-11,000
17h 30m
20h 30m
9,000-11,500
1390 MI.
1385 MI.
1327 MI.
1362 MI.
1045 MI.
1068 MI.
1158 MI.
1146 MI.
2120 MI.
2140 MI.
MANILA
GUAM
WAKE
MIDWAY
HONOLULU
ALAMEDA

FIG. 42

The investigation was concerned with the effects of gradual ascents (1 to 2 hours) to 8,000 to 12,000 feet altitude followed by long flights varying from 8 to 20 hours in length. It was made on airmen in good physical condition while carrying out the normal duties of operating an aeroplane on trans-Pacific operations, and on passengers. The air was relatively smooth throughout the entire flight. The investigation was undertaken from the practical point of view of aviation for the following reasons: (1) to determine the amount of fatigue involved in long transoceanic flights in terms of objective measurements; (2) to study the maintenance of health in the airmen in carrying out such operations; (3) to analyze the efficiency of the personnel while in flight; and (4) to recommend safety measures in relation to human limitations. The study was of general scientific interest from the viewpoint of measuring objectively the changes in the circulation, blood, the sense organs and the central nervous system due to long exposures at moderately high altitudes, as well as in analyzing the amount of acclimatization attained during 122½ hours in the air. It also afforded an excellent opportunity to compare the effects of oxygen want under actual flight conditions with studies made on mountain expeditions and in low oxygen and low pressure chambers at sea level.

The physiological tests included: (1) the Schneider Index, i.e., the pulse rate and blood pressure reclining, the changes on standing, the pulse rate after a standard exercise, and the time required for the pulse to return to normal; (2) the minute volume index of the circulation; and (3) the urine volume. The biochemical determinations were for oxygen and carbon dioxide in alveolar air and in blood, the concentration in blood of sugar and lactic acid, and the concentration in plasma of protein, cholesterol, chloride and nonprotein nitrogen. Also, counts were made of red cells and reticulocytes. The psychological tests included: (1) heterophoria; (2) near point of accommodation;

(3) brightness discrimination; (4) quickness of apprehending the meaning of words exposed for fractions of a second in a focal plane shutter apparatus; (5) code test for maintenance of attention and accuracy of transliterating letters; and (6) memory.

Results of the psychological tests. In selecting the psychological tests it was necessary to obtain those that could be repeated without marked practice effects, that were sensitive enough to measure slight alterations in functions, that included a fairly wide range of sensory and mental reactions, and that were portable and easy to administer. Visual tests were stressed because of the primary importance of that particular sense in flying. With the above considerations in mind, the following tests were administered in Alameda and at various intervals throughout the flight. The results are shown in Table 45. On the average, there was an impairment of 6 to 8 per cent in the psychological tests at 9,000 to 12,000 feet following slow ascents.

Results of biochemical tests. In an attempt to discover whether there was a significant alteration in the respiratory response of the airmen to the long flights at high altitudes, and consequently marked variations in the blood gases, an analysis was made of the alveolar air and the per cent saturation of the arterial blood. The following conclusions may be drawn from these tests:

Alveolar Air. The average partial pressures of oxygen and of carbon dioxide, expressed in mm. Hg, are normal for the 11,000 feet altitude (cf. Table 46). The mean partial pressure of oxygen in these airmen averaged 4.8 mm. higher than that of unacclimatized passengers after an ascent to the same altitude in 45 minutes and that of subjects transported by aeroplane to similar altitudes within one-half an hour by Schneider and Clark (56). The similarity of the averages for the crew and for acclimatized men at this altitude suggests that the airmen become adapted to the high altitude and maintain a higher oxygen

Table 45

PSYCHOLOGICAL TESTS - TRANS-PACIFIC FLIGHTS

Means and Standard Deviations of Sensory and Mental Tests for Six Airmen and Two Passengers after Five to Six Hours at the Altitudes Indicated

Test	Midway to Wake 11-12,000 ft. 7/10	Guam to Manila 11,000 ft. 7/13	Guam to Wake 9-10,000 ft. 7/18	Honolulu (Sea Level) End of Flight 7/19	Honolulu (Sea Level) End of Layover 7/26
Exophoria (Prism Diopters)					
Mean	1.56	1.94	1.82	.79	.75
S.D.	1.07	1.53	1.00	.52	.77
P.P. of Accommodation (c.m.)/					
(Right eye) - Mean	14.07	14.00	13.78	13.57	13.17
S.D.	3.81	3.59	3.96	3.25	3.10
Brightness Discrimination/					
(Right eye) - Mean	7.7*	7.6*	7.9*	8.8	8.8
S.D.	.31	.27	.27	.34	.60
Speed of Apprehension (1/90 sec.) One Word Series - Mean (% correct)	91.1	94.0	90.4	93.7	92.3
S.D.	8.44	3.46	5.95	8.45	8.12
Two Word Series--					
Mean (% correct)	60.8	65.0	60.0	68.6	68.3
S.D.	12.05	9.93	9.67	13.0	12.76
Johnson Code (Seconds)					
Mean	134.0	132.1	132.0	125.4	123.7
S.D.	8.53	12.06	8.18	6.71	9.25
Memory Test (% correct)					
Mean	75.71	74.29	73.57	85.00	88.33
S.D.	12.38	10.12	14.69	6.55	5.60

*These means represent statistically significant differences from the observed value at end of flight, i.e. less than 1 chance in 100 that chance variation could have accounted for this value. None of the other differences were reliable statistically.

/Results were similar for the left eye.

partial pressure than passengers. Thus, the added burden on the crew of flying the ship has no impairing effect on the respiratory mechanism.

Arterial blood. Five arterial bloods and one venous blood were obtained at approximately the time of obtaining the above alveolar air samples on the flight between Honolulu and Alameda (after 12 hours at 11,000 feet). (Cf. Table 46.) The average oxygen saturation of the arterial blood (90.1 per cent) is close to that found in closed chambers at sea level after several hours and on mountains after acclimatization at this altitude. Lactic acid values on these bloods were within the normal range, with the possible exception of Ralph (24.2 mgs. per cent).

Venous blood. Six venous bloods were drawn after flying for seven hours at 8,000 feet between Midway and Honolulu. The results of the various determinations relating to the blood morphology and blood chemistry are shown in Table 47. The increase in red cells was approximately 10 per cent. The normal reticulated count means that no unusual number of immature red cells had entered the blood stream and suggests that the increase is due to the addition of stored cells or to dehydration. The increase in serum protein and serum chloride is also suggestive of a certain amount of dehydration. The normal non-protein nitrogen, blood sugar and cholesterol values suggest that there was no serious upset of the protein, carbohydrate or fat metabolism. With accentuated emotional excitement or worry, the increased secretion of adrenalin may cause a rise in blood sugar. The normal values observed in these airmen suggest that no such excitement or worry was taking place.

In general, the 17 airmen studied during typical trans-Pacific operations became acclimatized to the high altitude and maintained a high degree of mental and physical efficiency throughout the flight. The 11 passengers of average age and fitness studied, although not manifesting the same degree of acclimatization as the airmen, showed no objective signs of fatigue or physical distress. It should be kept in mind, however, that the subjective feelings of fatigue were fairly acute in both the airmen and passengers at the end of the longer flights, although the results from the physiological and psychological tests were, on the average, negative. This study indicates that the stress of flying on these trans-Pacific operations is

Table 46

ALVEOLAR AIR AND BIOCHEMICAL DETERMINATIONS ON ARTERIAL BLOOD

Flight: Honolulu to Alameda
11,000 ft.--(509 mm. Hg) for twelve hours

Crew No. 2

	Alveolar Air		Arterial Blood			O_2 Capacity	% Sat.
	pO_2	pCO_2	Lactic Acid	Content O_2	Content CO_2		
	mm.	mm.	mgs.%	vols.%	vols.%	vols.%	
Radio (B)	78.9	28.7	14.0	18.14	39.8	20.42	88.8
Navigator (K)	74.0	33.9		—	41.5	23.35	90.2
Engineer (L)	65.8	40.5	9.7	18.44	44.3	19.91	92.6
Jr. Pilot (P)	67.4	33.0		21.44	36.4	23.01	91.2
Jr. Pilot (R)	59.9	38.4	24.2	—*	—	19.16	--
Passenger (M)	55.2	37.6	17.5	18.77	42.5	21.40	87.7
Average	66.9	35.3	16.3		41.1	21.2	90.1
Acclimatized man at this altitude	65.0	33.0	15.0		43.0	21	88-90

*Venous blood.

Table 47

BIOCHEMICAL AND MORPHOLOGICAL DETERMINATIONS ON VENOUS BLOOD

Flight: Midway to Honolulu: Alt.—8,000 feet for seven hours

	During Flight									After 6 days at Honolulu		
	Retic. Count	RBC Count	Cell Vol.	Size Vc/RBC	Plasma Protein	Non-Protein Nitrogen	Blood Sugar	Cholesterol Plasma	Chloride Plasma (not under oil)	RBC Count	Cell Vol.	Size Vc/RBC
	%	mill.	%		%	mg.%	mg.%	mg.%	mg.%	mill.	%	
Engineer (A)	1.0	5.55	46.2	0.83	7.56	30.6	90	206	108.7	5.06	46.5	0.92
Jr.Pilot (C)	0.3	6.00	51.2	0.85	7.68	29.4	118	217	110.2	5.05	49.9	0.99
Jr.Pilot (G)	0.4	5.75	48.0	0.83	7.24	29.7	108	207	107.1	left	-	-
Steward (H)	0.6	5.45	-	-	7.38	39.5	87	-	111.6	left	-	-
Navigator(L)	0.7	5.35	45.8	0.86	7.73	33.0	90	178	110.5	4.75	44.1	0.93
Jr.Pilot (O)	0.5	5.06	47.7	0.94	7.53	31.6	100	226	108.7	5.15	47.5	0.92
Average	0.6	5.53	47.8	0.86	7.52	32.3	99	217	109.4	5.00	47.0	0.94
Normal	0.5	5.00 ±0.5	45.0	0.90	7.00	25-35	90-110	200	105	5.00	45.0	0.90

not acute enough to deplete the fuel reserves of the body or give rise to the accumulation of fatigue substances in the blood.

IX. Summary: Before attempting to outline tentative conclusions, a general summary will be given of the entire investigation. First, the various problems relating to passenger comfort in modern air transportation were outlined. It was pointed out that one of the most important questions which has not been solved adequately by the aircraft engineers relates to the effects of the reduced oxygen pressure encountered at high altitudes.

Second, the physical factors of the environment at high altitude were discussed in relation to their reaction on the human organism and the amount of oxygen in the inspired air which would be required to maintain sea level conditions (159 mm. Hg).

Third, a description was given of the various experimental procedures used at sea level to simulate the essential conditions of high altitude, such as Douglas bags and rebreathing devices, low oxygen and low pressure chambers, in comparison with actual flights to high altitude.

Fourth, an analysis was made of the important variables of flying at high altitude, such as the height attained, the length of exposure, the rate of ascent, and the physical characteristics of the individual and of the air while in flight.

Fifth, the physiological mechanisms of acclimatization, with special regard for the importance of carbon dioxide, were analyzed briefly and the responses of the average unacclimatized passenger compared with the average acclimatized airman.

Sixth, a decription of the various experiments was then given, along with the presentation of the experimental data. More than 237 subjects were studied during rapid ascents and 84 during slow ascents in the parts of the investigation sponsored by the Bureau of Air Commerce. The experiments were divided into six parts, as follows:

Part I. In the major experiment there were two rates of ascent, approximately 20 minutes, and 1 hour and 20 minutes, to simulated altitudes of 10,000, 12,000, 14,000, 16,000, 18,000 and 21,000 feet. A series of physiological and psychological tests was given to each subject before and during each ascent. The data was treated by the usual statistical procedures to determine the reliability of the observed differences.

Part II. In this experiment the variable of age was partialed out for special study. Three age groups (17 to 30 years, 30 to 45 years, and 45 to 72 years) were given the various psychological and physiological tests during rapid and slow ascents to simulated altitudes of 14,000 feet.

Part III. The relationship between tolerance for altitude and physical fitness was analyzed in this part of the investigation. A group of physically "fit" and physically "unfit" college students was studied during rapid and slow ascents to simulated altitudes of 16,000 feet and during rapid ascents to 12,000 feet. Also, a group of patients diagnosed as psychoneurotic, with prominent symptoms of fatigue and exhaustion, was studied during rapid ascents to simulated altitudes of 18,000 feet.

Parts IV and V. (Sponsored independently of the Bureau of Air Commerce.) An attempt was made to analyze the effects of reduced oxygen pressure with and without an excess amount of carbon dioxide (3.0 per cent) in the inspired air. The experiments were made under three different experimental procedures: (1) low oxygen room at the Harvard Fatigue Laboratory; (2) low oxygen chamber at Columbia University; and (3) low pressure chamber at Wright Field, Dayton, Ohio.

Part VI. The final aspect of the investigation dealt with the attempt to check the data obtained at simulated altitudes in chambers at sea level under actual flight conditions at high altitude on commercial air transports. These studies were carried out during regular passenger flights on transcontinental (United Air Lines) and trans-Pacific (Pan American Airways) operations.

X. Conclusions: The following tentative conclusions may be stated concerning the effects of reduced oxygen pressure on man from these experiments, as well as from a review of the literature on the subject. These findings will be discussed under the following general headings: I. The specific altitudes where the organism is first affected and where there is a measurable degree of impairment. II. The effects of altitude in relation to rate of ascent. III. The cumulative effects of high altitude, that is, the length of exposure in relation to deterioration or, on the other hand, to acclimatization. IV. The way in which the physical characteristics of the individual may influence the response of the organism to high altitude, especially age, physical fitness, emotional excitement or psychoneurotic behavior, and alcohol. V. The role of carbon dioxide in facilitating adaptation, and VI. Interpretation of the possible ways in which a reduction in oxygen pressure may effect cellular activity and bring about an alteration in physiological and mental functioning.

I. The Specific Altitudes Where the Organism Is First Affected and Where There Is a Measurable Degree of Impairment.

The maintenance of an adequate oxygen supply in the blood is such an important factor for all cellular activity that changes in the organism apparently take place as soon as one leaves the ground in an aeroplane. If one examines the oxygen dissociation curve in relation to the partial pressure of oxygen in the alveolar air and the barometric pressure, it is obvious that alterations would naturally take place at very low altitudes (cf. Figure 9).

In a series of experiments on pilots during the World War Schneider (55) found that the pulse rate per minute was accelerated in a few men at

17.5 per cent oxygen (5,000 feet). In one group of 70 men the accelerations began as follows:

1% began to react between 7,000 and 8,000 ft. -- 16.0-15.5% O_2

12% began to react between 8,000 and 9,000 ft. -- 15.5-14.9% O_2

20% began to react between 9,000 and 10,000 ft.-- 14.9-14.2% O_2

14% began to react between 10,000 and 11,000 ft.--14.2-13.7% O_2

23% began to react between 11,000 and 12,000 ft.--13.7-13.2% O_2

20% began to react between 12,000 and 13,000 ft.--13.2-12.7% O_2

6% began to react between 13,000 and 14,000 ft.—12.7412.2% O_2

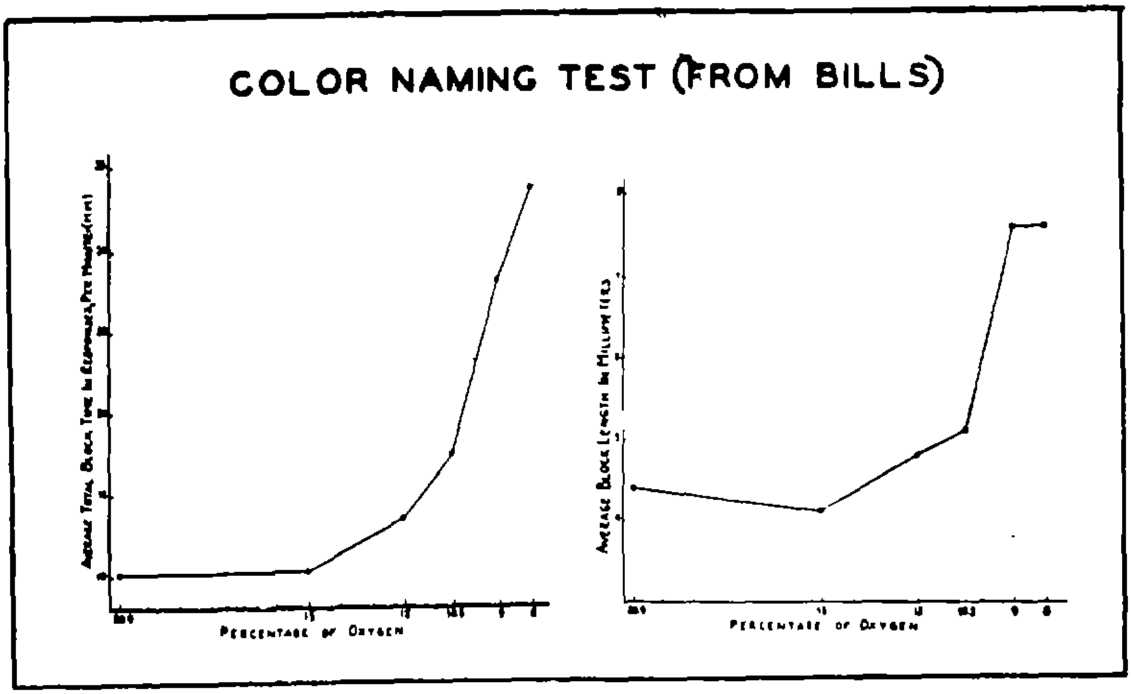
There is little evidence, however, that a slight reduction in oxygen pressure, giving rise to various compensatory mechanisms such as an initial increase in circulation, in hemoglobin, or in pulmonary ventilation, is necessarily harmful to the organism, especially if the person is not ill. It is also well known that frequent exercise of ones adaptive mechanisms may, on the other hand, be beneficial. The most important question, therefore, is not where the very first effects of altitude are manifested but where the alterations may be accentuated enough to actually impair ones sensory and mental functions or bring about physical symptoms of unpleasantness, such as, headaches, vertigo, excessive sleepiness, and fatigue or exhaustion.

In the series of studies reported above on large groups of unacclimatized subjects, corresponding to an average cross section of the flying public, the first impairment on psychological functions which proved to be statistically significant was, on the average, in the neighborhood of 12,000 feet. (The scattering of the means around the central tendency, however, was fairly large (cf. Figures 28 and 31)). This applies to the effects of a reduction in oxygen pressure (under simulated conditions of high altitudes) while the subject was comfortablely seated in the chamber and completely unaware of the extent of the alteration in oxygen supply. cf. Tables 12 to 15 inclusive. The only psychological test which showed statistical reliability at 10,000 feet compared with the control was the one for immediate memory following a rapid ascent. Since the means in this test were not significantly different from the control at 12,000 feet, both for the rapid and slow ascents, too much importance cannot be attached to the above finding. In general it may be concluded that the average impairment in the most sensitive and reliable psychological tests approximates 6-10 per cent at 12,000 feet whether the oxygen pressure is reduced within ½ hour or 4 hours, in a chamber at sea level or in flights at high altitude.

The physiological effects are also, on the average, significantly different from the control data in the neighborhood of 12,000 feet. cf. Tables 8 to 11 inclusive. The initial increase in pulse rate was significant at 12,000 feet following rapid ascents but not at 10,000 feet. The findings on the systolic and diastolic blood pressure are difficult to interprete since many subjects show an increase and others a decrease, the net result being that the changes in the means are only slight until the more acute stages of oxygen want are reached.

Considered from the point of view of feelings of bodily discomfort, or in terms of physiological and psychological complaints (cf. Table 16), the average unacclimatized passenger is significantly effected at 12,000 feet (cf. Tables 16 to 18 inclusive, also Table 23). A certain number of subjects are affected at 10,000 feet, but if one considers all of the variables, such as, the numbers who might have a headache from doing the tests in normal air, etc., 12,000 feet appears to be the more critical altitude. This applies to the complaints mentioned voluntarily, as well as, in answer to the questions in Table 16, for normal subjects whil seated in a chamber or in flight at high altitudes.

The results of other studies dealing with the psychological effects of lowered oxygen pressure are in general agreement with the findings of this investigation. In an experiment with a Douglas bag, for example, Bills (9) found that at 15 per cent (8,000 ft.) oxygen the number of "blocks" (indicating mental fatigue) was insignificant but that 12 per cent (or approximately 14,000 ft.) there was a significant degree of blocking. (cf. Figure 43). In experiments on handwriting with a modified rebreathing apparatus, Goralewski (26) found that the initial effects in a handwriting test were apparent in 44.5 per cent of his subjects at 18-14 per cent O_2, (cf. Part A, Figure 43) and significantly advanced in 52.9 per cent subjects at 14-10 per cent O_2 (13,000 to 22,000 ft.) (cf. Part B, Figure 43). In a series of psychological tests McFarland observed that the initial effects were apparent in the neighborhood of 12,000 feet (45, 48). As shown in Figure 44 the deterioration of motor control in handwriting is progressive with increasing altitude (45). Also Tanaka (64), as clearly illustrated in Figure 45, found that increasing and decreasing the oxygen pressure in Haldane's low pressure chamber at Oxford significantly altered the average subjects' responses on psychological tests in the neighborhood of simulated altitudes of 12,000 feet. Other psychological studies which tend to support this general conclusion of 12,000 feet as being the critical turning point are as follows: Lowson, low oxygen chamber (41), Jongbloed, low pressure chamber (35), Barach, McFarland, and Seitz, low oxygen chamber (3), Wespi, low pres-


COLOR NAMING TEST (FROM BILLS)
PERCENTAGE OF OXYGEN
PERCENTAGE OF OXYGEN

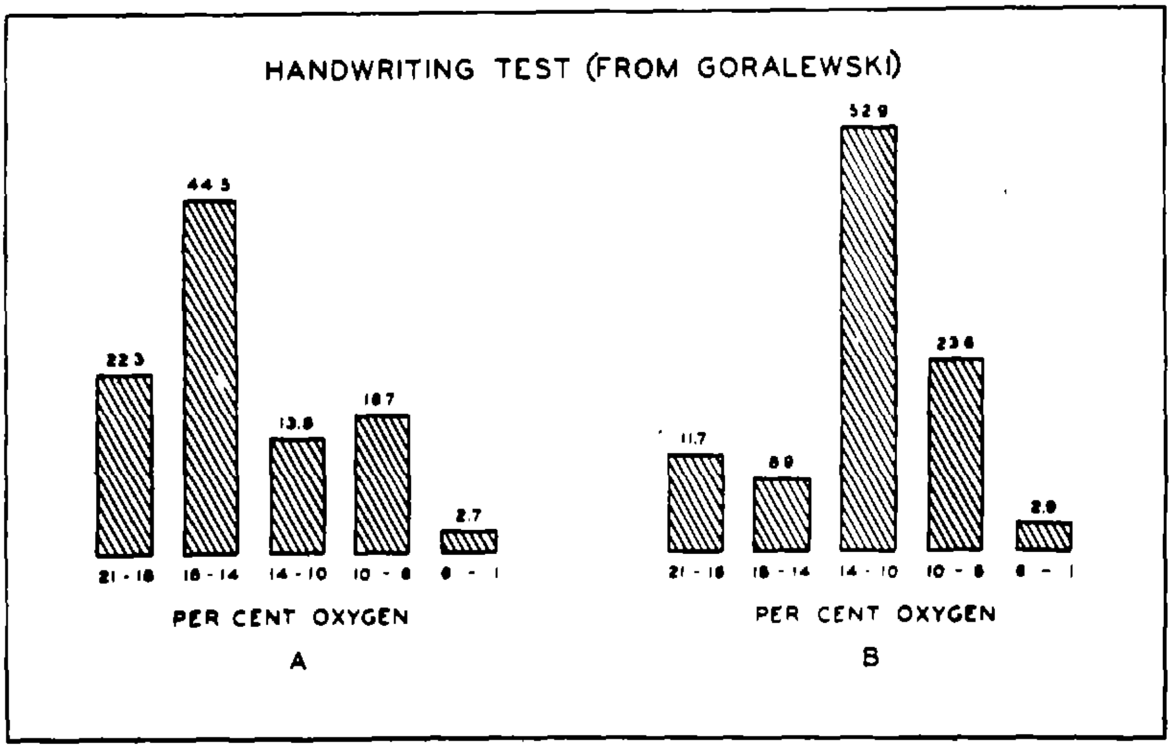

HANDWRITING TEST (FROM GORALEWSKI)
22.3
44.5
13.8
18.7
2.7
21 - 18
18 - 14
14 - 10
10 - 8
8 - 1
PER CENT OXYGEN
A
11.7
8.9
52.9
23.6
2.9
21 - 18
18 - 14
14 - 10
10 - 8
8 - 1
PER CENT OXYGEN
B

FIG. 43

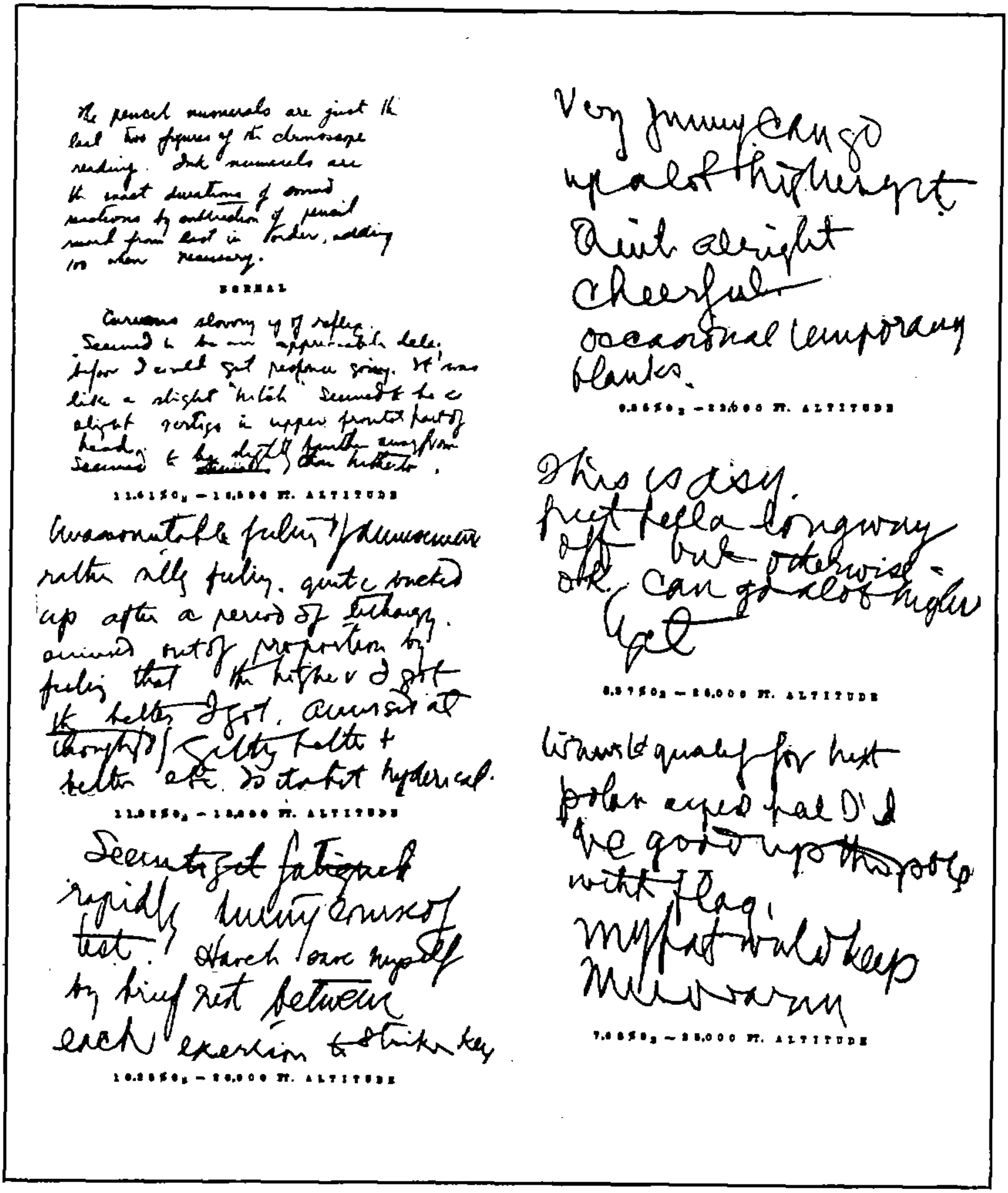
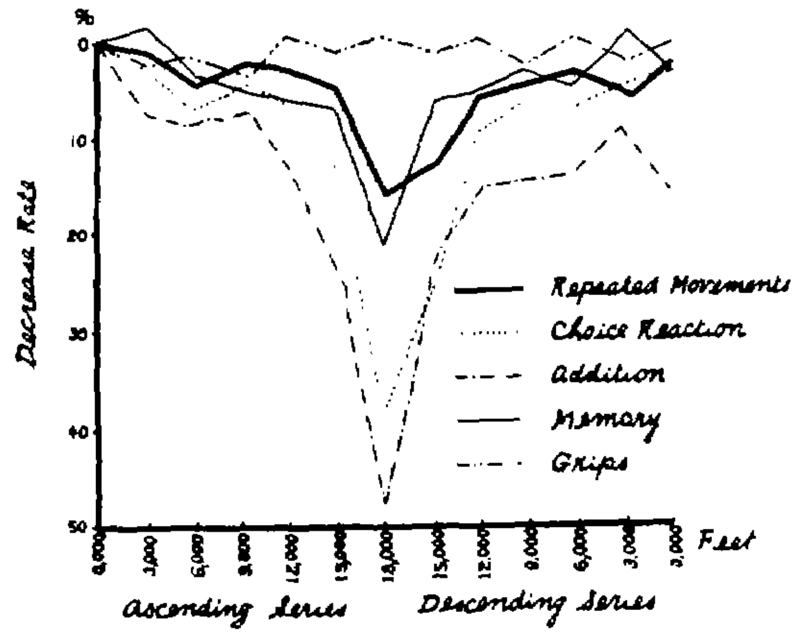

NORMAL
11.61% O_2 — 16,000 FT. ALTITUDE
Unaccountable feeling of amusement
rather silly feeling. quite bucked
up after a period of lethargy.
amused out of proportion by
feeling that the higher I got
the better I got. amused at
better etc.
11.03% O_2 — 18,000 FT. ALTITUDE
rapidly
test.
each exertion to strike key
10.28% O_2 — 20,000 FT. ALTITUDE
Very funny can go
up a lot higher yet
Quite alright
Cheerful
occasional temporary
blanks.
9.65% O_2 — 22,000 FT. ALTITUDE
This is easy.
ok. can go a lot higher
yet
8.37% O_2 — 24,000 FT. ALTITUDE
Would qualify for next
polar expedition
with flag.
7.68% O_2 — 25,000 FT. ALTITUDE

FIG. 44



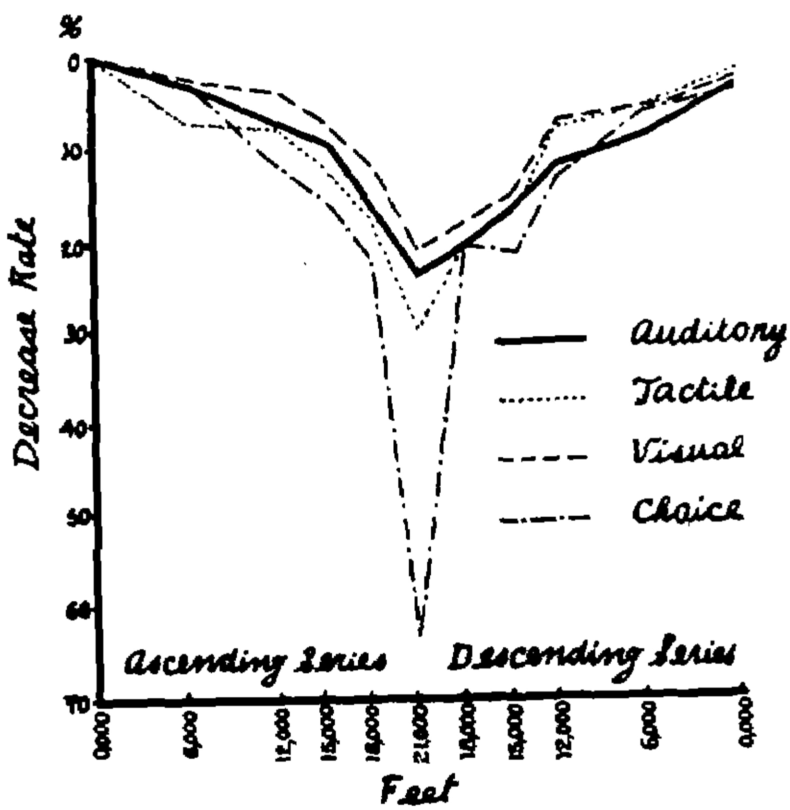


FIG. 45. (TANAKA)

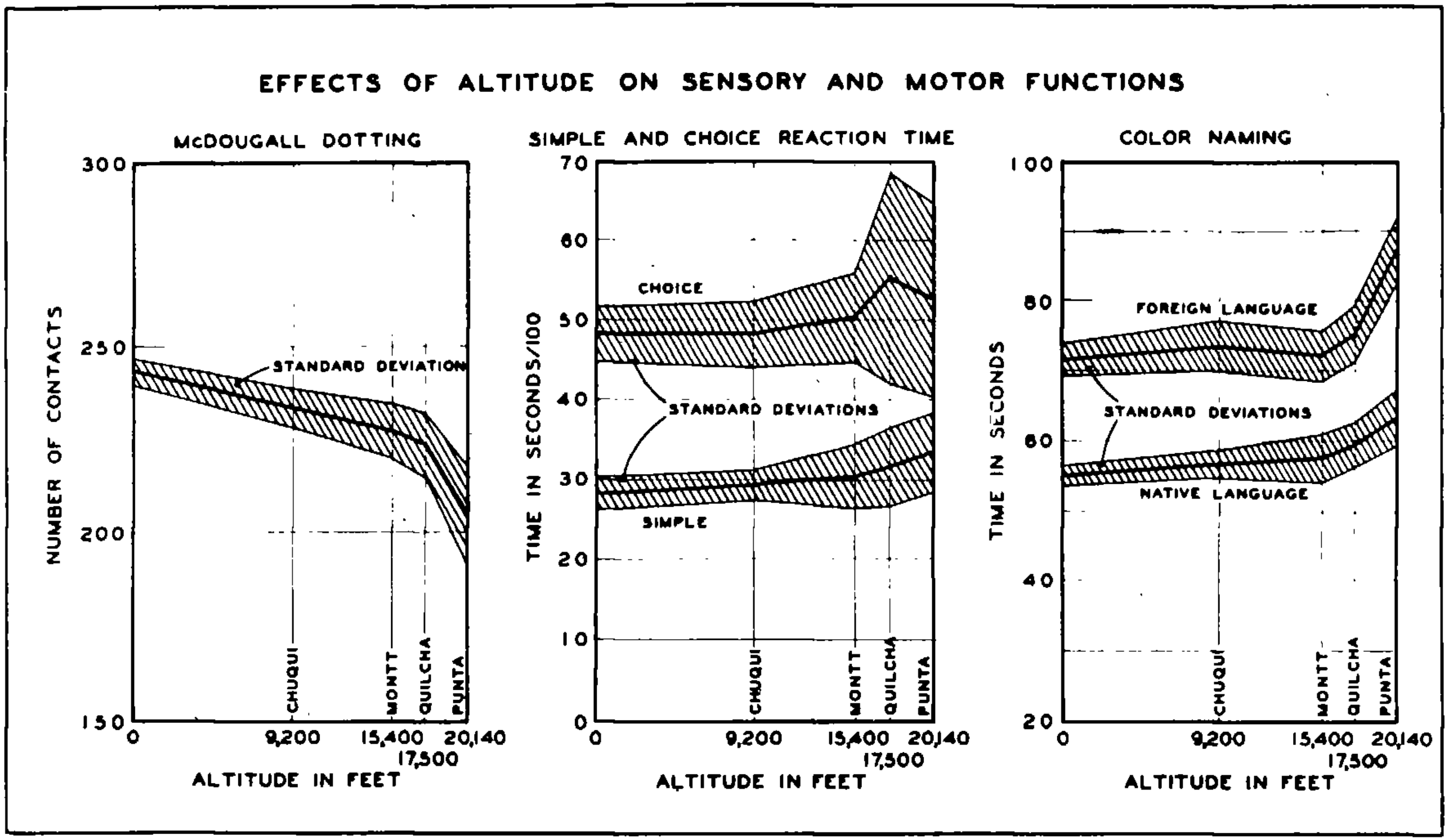

EFFECTS OF ALTITUDE ON SENSORY AND MOTOR FUNCTIONS
McDOUGALL DOTTING
NUMBER OF CONTACTS
300
250
200
150
STANDARD DEVIATION
CHUQUI
MONTT
QUILCHA
PUNTA
0
9,200
15,400
17,500
20,140
ALTITUDE IN FEET
SIMPLE AND CHOICE REACTION TIME
TIME IN SECONDS/100
70
60
50
40
30
20
10
0
CHOICE
STANDARD DEVIATIONS
SIMPLE
CHUQUI
MONTT
QUILCHA
PUNTA
0
9,200
15,400
17,500
20,140
ALTITUDE IN FEET
COLOR NAMING
TIME IN SECONDS
100
80
60
40
20
FOREIGN LANGUAGE
STANDARD DEVIATIONS
NATIVE LANGUAGE
CHUQUI
MONTT
QUILCHA
PUNTA
0
9,200
15,400
17,500
20,140
ALTITUDE IN FEET

FIG. 46

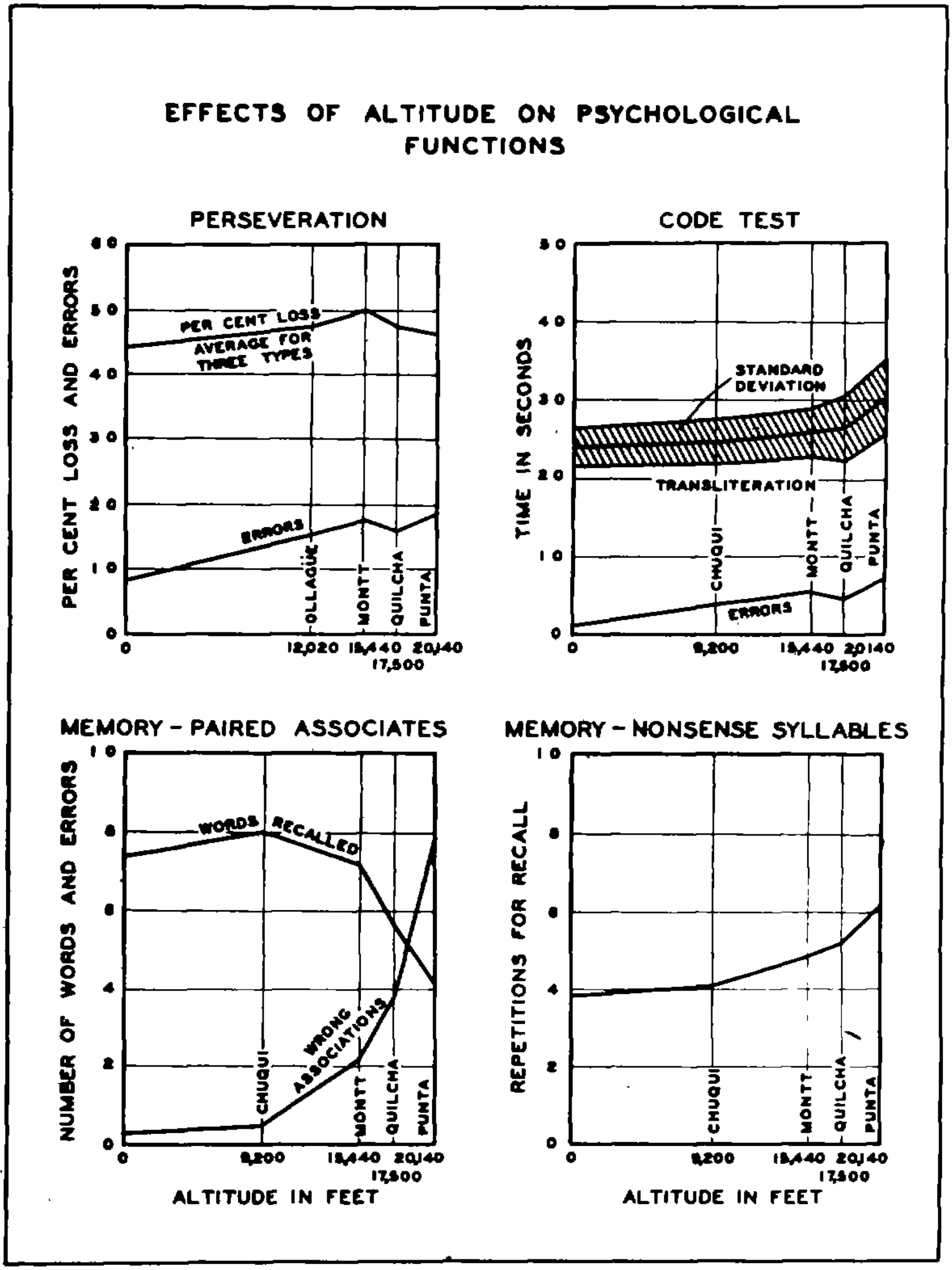

EFFECTS OF ALTITUDE ON PSYCHOLOGICAL FUNCTIONS
PERSEVERATION
PER CENT LOSS AND ERRORS
PER CENT LOSS AVERAGE FOR THREE TYPES
ERRORS
OLLAGUE
MONTT
QUILCHA
PUNTA
0
12,020
15,440
17,500
20,140
CODE TEST
TIME IN SECONDS
STANDARD DEVIATION
TRANSLITERATION
ERRORS
CHUQUI
MONTT
QUILCHA
PUNTA
0
9,200
15,440
17,500
20,140
MEMORY - PAIRED ASSOCIATES
NUMBER OF WORDS AND ERRORS
WORDS RECALLED
WRONG ASSOCIATIONS
CHUQUI
MONTT
QUILCHA
PUNTA
0
9,200
15,440
17,500
20,140
ALTITUDE IN FEET
MEMORY - NONSENSE SYLLABLES
REPETITIONS FOR RECALL
CHUQUI
MONTT
QUILCHA
PUNTA
0
9,200
15,440
17,500
20,140
ALTITUDE IN FEET

FIG. 47

sure chamber (67), Loewy, mountain expeditions (40), (Stern observed differences at 8,000 feet in the Alps (62, 63)), and McFarland, high altitude flights following rapid ascents (44) and McFarland and Edwards, high altitude flights following slow ascent (49). In air men who are well acclimatized to high altitude flying the psychological effects are hardly apparent at 12,000 feet (49). During the Chilean Expedition (1935) ten men, between the ages of 29 to 44 years, who became acclimatized to high altitudes over a period of three months were not significantly impaired in a series of sensory, motor, and mental tests until altitudes as high as 15,440 feet and 17,500 feet, indicated that acclimatization is an important variable. cf. Figures 46 and 47(ref. 44).

II. <u>The Effects of Altitude in Relation to Rate of Ascent.</u>

The results of this investigation indicate that rate of ascent is an important variable at 10,000 feet and above, i.e. if the average subject is transported to simulated altitudes of 10,000 feet and above within 15-30 minutes the effects of the altitude are, on the average, significantly greater than when similar altitudes are attained within one hour and thirty minutes. This appears to be true of the physiological responses as well as the psychological ones.

In regard to the physiological tests, the partial pressure of the alveolar oxygen was significantly higher and the carbon dioxide lower in the acclimatized members of the Chilean Expedition compared with the subjects of this experiment (cf. Figure 19); also the partial pressure of the alveolar oxygen in the alveolar air was higher in the air men contrasted with the passengers on the trans-Pacific flights (cf. Table 46 (49). Likewise in these experiments in simulated high altitudes the partial pressure of the alveolar oxygen was higher following slow ascents than following rapid ascents (Figure 19).

In general it may be said that the variations in pulse rates were less extreme particularly at 14,000 feet and above following slow ascents than following rapid ones. This may be verified by observing in the Tables that the significance of the observed differences were greater for each altitude following rapid ascents than following slow ones (cf. Figures 16 and 18). In physically unfit subjects these differences were quite marked. At 14,000 feet and 16,000 feet, for example, a number of subjects collapsed during rapid ascents, while they became fairly well acclimatized during slow ascents to similar altitudes. The physiological and psychological complaints were also less numerous during slow ascents as contrasted to rapid ones. The greater frequency of complaints during a rapid ascent to 16,000 feet contrasted with a slow one is clearly demonstrated in Table 23 and in Figure 33.

Rate of ascent appeared to be a significant factor in success with the various psychological tests at 12,000 feet and above. This general observation may be verified in the case of each test by referring to the relative degree of impairment in the rapid and slow ascents, particularly of the statistical significance of their differences (cf. Tables 12 to 15 inclusive). These differences are very striking in certain of the psychological tests at 16,000 feet (cf. Table 20) particularly in the "unfit" group contrasted to the physically "fit" group.

These findings relative to rate of ascent have been verified by Graff* in Germany in a study with animals (mice) at critical altitudes in a low pressure chamber. He found that the critical level of 12,000 meters at an ascent of 1,000 meters per minute was displaced upward if the pressure was lowered slowly.

*Graff, W. D. Altitude stability as dependent upon rate of ascent in animal experiments. Luftfahrtmed., 1:351-354, 1937.

Armstrong and Heim*, on the other hand, in similar experiments at critical altitudes (33,000 feet) observed that with rabbits the faster the rate of ascent the higher the altitude tolerance. These experiments with animals at critical altitudes between 30,000 to 38,000 feet, however, are not directly applicable to the responses of human subjects to moderate altitudes of 12,000 to 18,000 feet. In this investigation under simulated altitudes of 10,000 to 18,000 feet, as well as under actual flight conditions to moderate altitudes, both passengers and airmen appeared to acclimatize more successfully during slow ascents (49).

III. <u>The Cumulative Effects of High Altitude, i.e., the Length of Exposure in Relation to Deterioration, or, on the Other Hand, to Acclimatization.</u>

It is quite difficult to draw conclusions from the evidence which is available dealing with the cumulative effects of reduced oxygen pressure. The problem is complicated by the fact that at moderate altitudes of 8,000 to 12,000 feet one may continue to improve during exposures of 10 to 12 hours' duration due to the mechanisms of acclimatization; while at high altitudes of 15,000 to 18,000 feet, over similar periods of exposure, the mechanisms of acclimatization may be inadequate to compensate for the oxygen lack and consequently deterioration may set in after an hour or longer. From the experiments which are available thus far the evidence seems to indicate that the average person can become acclimatized to 8,000 to 12,000 feet while seated quietly in an aeroplane (or in a chamber at sea level) for 6 to 12 hours, while exactly the opposite is true at 16,000 to 18,000 feet. Several experiments may be mentioned to support this view.

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*Armstrong, H. G., and Heim, J. W. Factors influencing altitude tolerance during short exposures to decreased barometric pressures. Jr. Aviation Medicine, 9:45-56, 1938.

During the trans-Pacific flights the passengers and airmen maintained a high degree of mental and physical efficiency, i.e., there were no measurable signs of cumulative deterioration (49). On the other hand, two of the same subjects in both experiments manifested objective signs of deterioration rather than acclimatization after six hours at 17,000 feet in the low oxygen chamber at the Harvard Fatigue Laboratory and also after 4 hours in the low pressure chamber at Wright Field. Just as Barcroft was showing marked signs of deterioration following his six day sojourn in the low oxygen chamber at simulated altitudes of 18,000 feet, so were the subjects in the low oxygen room at the Fatigue Laboratory quite uncomfortable after six hours at 17,000 feet. As mentioned above, one physician collapsed after four hours and a second one was markedly affected after 6 hours at a similar altitude, not regaining complete rationality for some hours following the experiment. In the Andes and in other mountainous regions thousands of persons became acclimatized to altitudes of 8,000 to 14,000 feet and, as observed by the Chilean Expedition over 150 miners, many of them from the lowlands, were able to become acclimatized so as to live at 17,500 and work at 19,000 feet. These miners, however, were unable to live permanently at the mine at 19,000 feet since they were unable to sleep and soon showed marked signs of deterioration (38, 44). Likewise, on the Expeditions to the Himalayas the climbers have found that although they can live for a number of weeks or months above 20,000, definite signs of deterioration are manifested sooner or later and they are forced to return to lower altitudes.

A diagram showing the effects of altitude in relation to length of exposure has been drawn in Figure 48 based upon the limited amount of

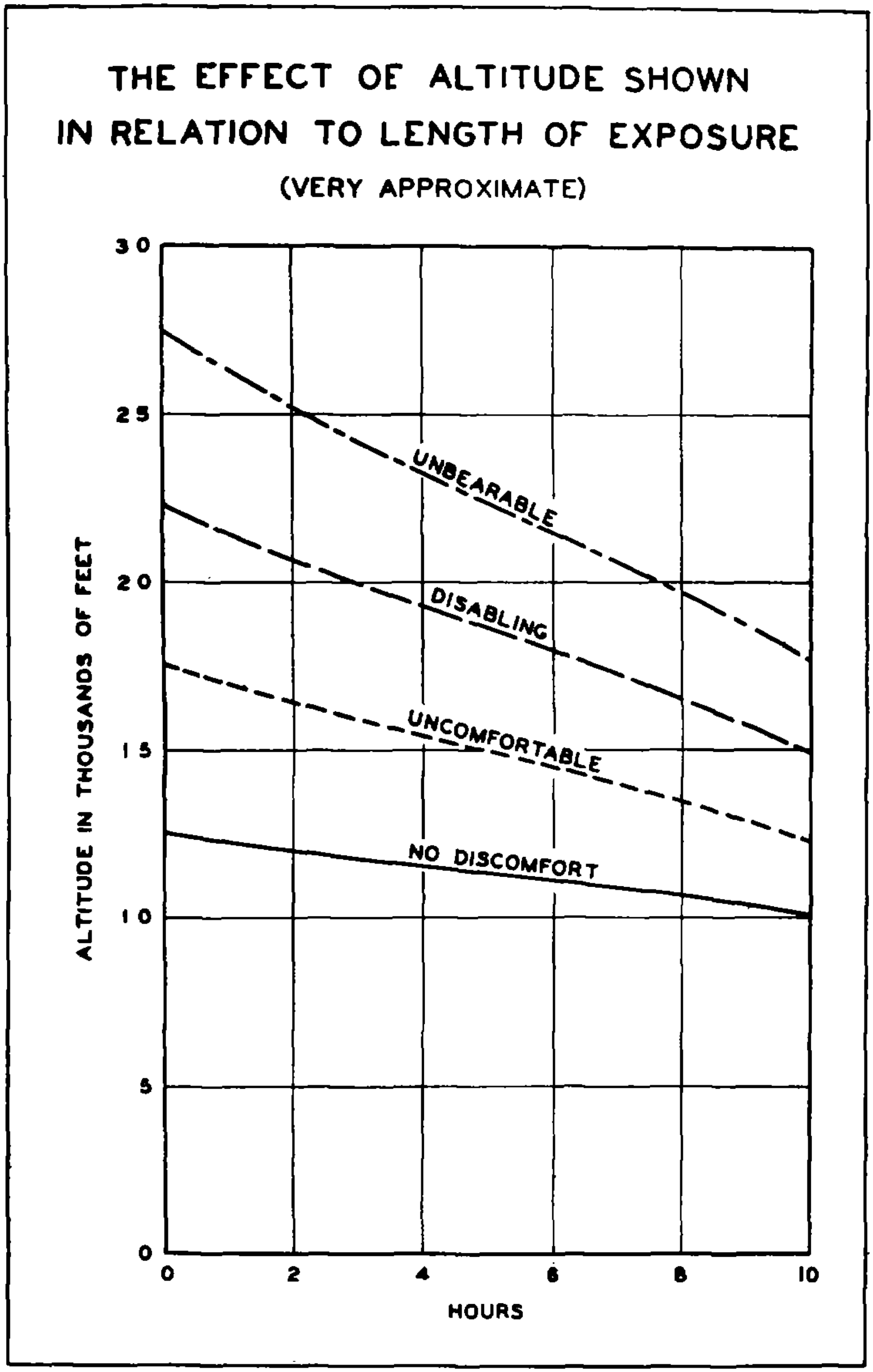
THE EFFECT OF ALTITUDE SHOWN
IN RELATION TO LENGTH OF EXPOSURE
(VERY APPROXIMATE)
30
25
20
15
10
5
0
ALTITUDE IN THOUSANDS OF FEET
UNBEARABLE
DISABLING
UNCOMFORTABLE
NO DISCOMFORT
0
2
4
6
8
10
HOURS

FIG. 48

experimental data available. It should be kept in mind that these curves are very approximate.

IV. <u>The Way in Which the Physical Characteristics of the Individual May Influence the Response of the Organism to High Altitude, Especially Age, Physical Fitness, Emotional Excitement, or Psychoneurotic Behavior and Alcohol.</u>

<u>Age</u>. The experiments reported above dealing with the response of a large group of subjects classified as to age indicate that there are significant differences in cardio-vascular responses. One of the most striking differences relates to the facts that there was a tendency for less extreme increases in pulse rate with increasing age. That is to say, just as Robinson and Dill observed that the older a subject becomes the less the pulse rate can be elevated in maximum work on the treadmill, so with oxygen deprivation the older the subject becomes the less the pulse rate is increased. This indicates that the circulatory mechanisms of adaptation become more stabilized or less flexible with increasing age. cf. Figure 36. Although it may be difficult to draw conclusions as to whether this is a good or poor sign of acclimatization, we observed that the older subjects were less susceptible to sudden collapse or fainting than the youngest subjects of 17-22 years of age. General observations on the air lines tend to verify these conclusions in that many subjects over 45 to 50 years of age fly with very few symptoms from the altitude alone.

The differences in blood pressure were not so striking as in the pulse rate. On the average, however, the age group 45 to 70 years showed an average tendency toward an elevated systolic and diastolic blood pressure during the second hour. cf. Figure 37. The differences between the various age groups in the partial pressure of alveolar oxygen and carbon dioxide were not significant.

The results from the psychological tests indicated that although the older subjects tended to be poorer, on the average, in the control experiments the relative impairment due to the reduced oxygen pressure was not significant based upon the relative change from a control index = 100. cf. Tables 12 to 15 inclusive.

An extensive investigation dealing with age as a variable in response to reduced oxygen pressure has recently been carried out in Germany by Schwartz.* The 237 subjects were studied in a low pressure chamber. The findings, in general, were similar to those from this investigation stated above, namely, that the older subjects showed more stable cardiovascular responses to oxygen deprivation or altitude than the younger ones and in general were less susceptible to collapse or fainting.

Physical fitness and psychoneurotic behavior. There are wide variations in ability to tolerate reduced oxygen pressure based upon the physical condition of the person being studied. On a number of occasions when the subjects came to the laboratory for the experiments following a night of limited or disturbed sleep or with definite illnesses, such as the grippe, headaches, or indigestion, the responses were perceptably poorer and more extreme. In contrasting the responses of two groups of students, i.e., a physically "fit" group and an "unfit" group there were significant differences in both the rapid and slow ascents in the psychological tests, cf. Table 22, as well as the physiological tests, cf. Table 21. Practically all

*Schwartz, W. Der Einfluss des Alters auf die Widenstandsfahigkeit gegen Sauerstoffmangel. Luftfahrtmed., 1:39-43, 1936.

of the subjects in poor physical condition collapsed or approached collapse during rapid ascents to 16,000 feet. Only two of these subjects, however, collapsed during slow ascents to similar altitudes. Only one of the poorer subjects collapsed following a rapid ascent to 12,000 feet.

Passengers with marked respiratory or cardiac defects should be discouraged from high altitude flying because of the possible harmful effects from the reduced oxygen pressure. A number of cases have been reported in the literature suggesting that clinical syndrones such as malaria and tubercular disorders may become more accentuated. Although it has been suggested that the average cardiac patient who can walk can also fly, the altitude should be restricted in patients with decompensated coronary disease so as to avoid any serious effects during or after the flight. The average cardiac patient is not apt to collapse during a flight, as witnessed by the fact that so few have actually died on the commercial air transports. It is known that under certain degrees of oxygen deprivation coronary vasodilatation occurs, in which case it may well offset, in part, at least, the unfavorable effects of high altitude.

The average passenger who becomes too emotionally excited or the one who is suffering from an impairment of the autonomic nervous system is apt to respond to a reduction in oxygen pressure very poorly indeed. We observed that psychoneurotic patients from the clinic who were under constant emotional stress and who complained constantly of fatigue and exhaustion were more susceptible to collapse when suddenly placed in simulated altitudes of 18,000 feet compared with control subjects. This is in line with a previous study by McFarland and Barach (47) in which they reported that 70 per cent of a group of psychoneurotic patients collapsed when suddenly placed in simulated altitudes of 20,000 feet compared with only 14 per cent of the control subjects. cf. Figure 49. In this investigation the biochemical changes in reduced oxygen pressure were insignificant in the psychoneurotic compared with the control group (cf. Table 29). The neuro-circulatory responses were significantly different, however, as manifested in more extreme reactions in pulse and blood pressure. cf. Tables 26 and 27. This observation is in line with the findings of Schneider (54) who found that pilots who tested below + 7 in the Schneider Index were unfit for altitude flying and of McFarland and Huddleson[46] who found that large groups of psychoneurotic patients made a mean score of + 7 or below in this index compared with + 12 for an unselected group and + 14.6 for college athletes. cf. Figure 50. It is quite possible that those individuals who are under temporary or chronic emotional stress are apt to acclimatize poorly to a reduction in oxygen pressure since the nervous mechanisms involved in adaptation to oxygen lack are reported to be somewhat similar to the ones involved in emotional experiences (sympathetic nervous system). The results of these investigations tend to substantiate the general observations of pilots that passengers who are especially "nervous" or emotionally excited are apt to be affected adversely by high altitude.

Alcohol. Although no special studies have been made in this investigation of the effects of alcohol on the average passenger under reduced oxygen pressure, some evidence is available which indicates that the action of alcohol is greatly accentuated at high altitude. On the Chilean Expedition (reference 7) it was observed that the blood alcohol rose more rapidly and reached a higher level at high altitude (17,500 ft. and 12,000 ft.) than at sea level. cf. Figure 51. If Peters and Van Slyke are correct in classifying

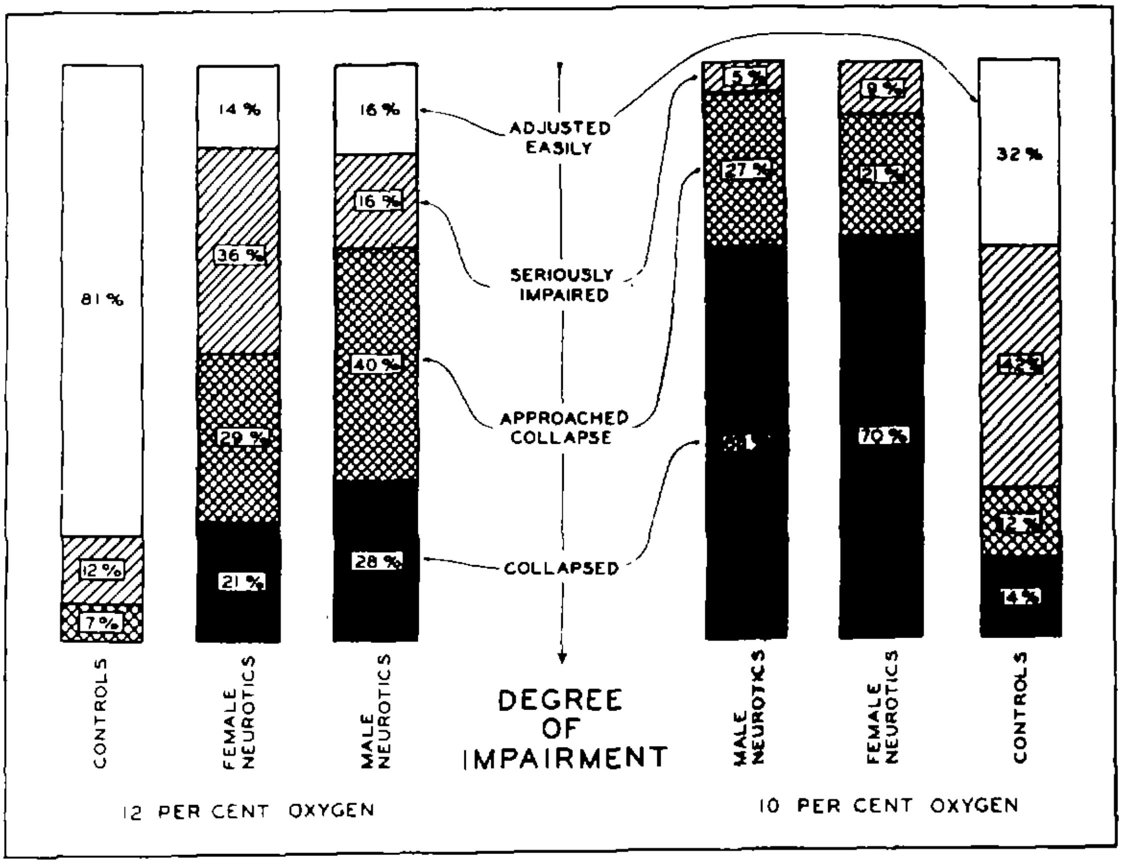
81 %
12 %
7 %
14 %
36 %
29 %
21 %
16 %
16 %
40 %
28 %
ADJUSTED EASILY
SERIOUSLY IMPAIRED
APPROACHED COLLAPSE
COLLAPSED
5 %
27 %
21 %
70 %
32 %
42 %
12 %
14 %
CONTROLS
FEMALE NEUROTICS
MALE NEUROTICS
DEGREE OF IMPAIRMENT
MALE NEUROTICS
FEMALE NEUROTICS
CONTROLS
12 PER CENT OXYGEN
10 PER CENT OXYGEN

FIG. 49

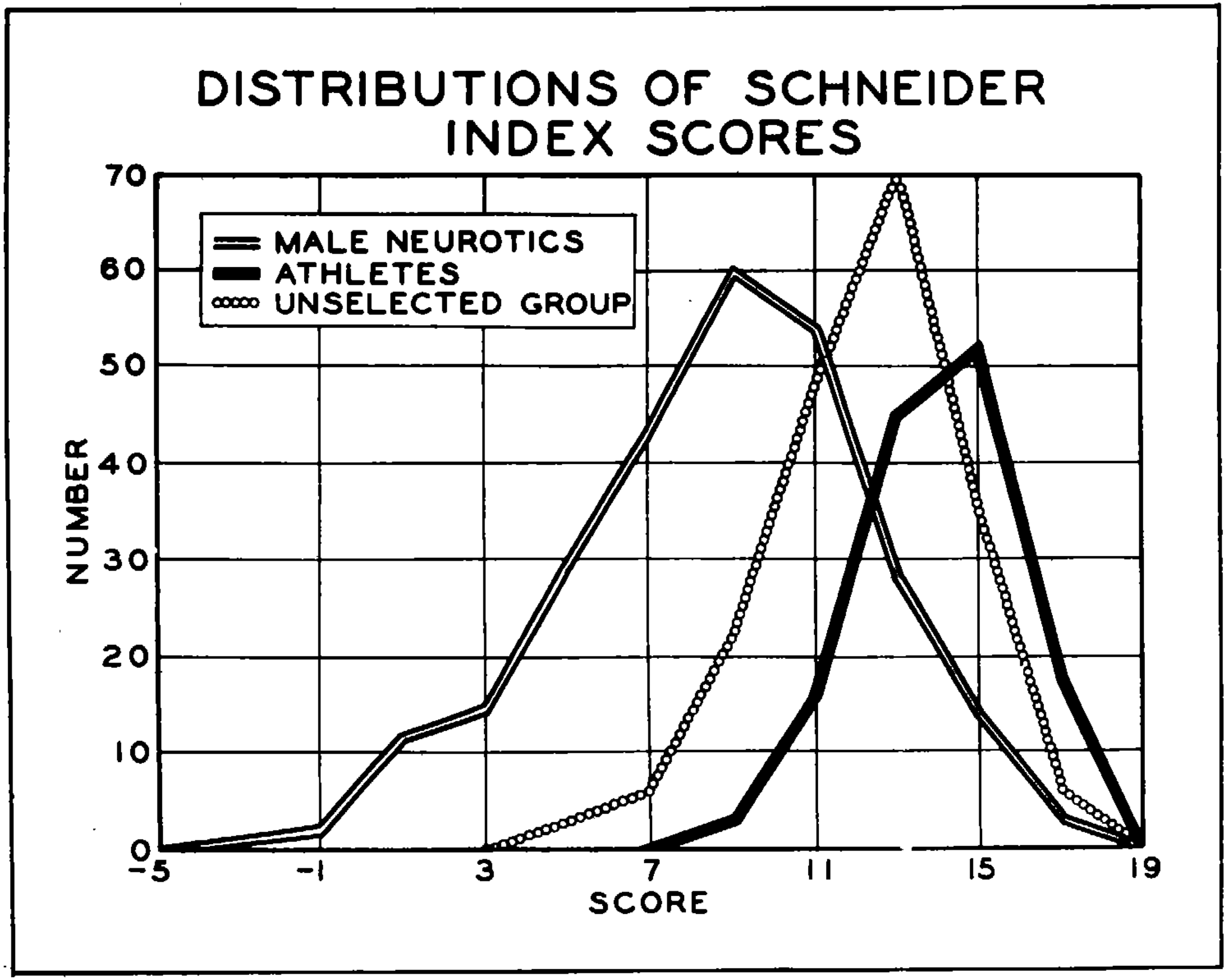
DISTRIBUTIONS OF SCHNEIDER INDEX SCORES
MALE NEUROTICS
ATHLETES
UNSELECTED GROUP
NUMBER
0
10
20
30
40
50
60
70
-5
-1
3
7
11
15
19
SCORE

FIG. 50

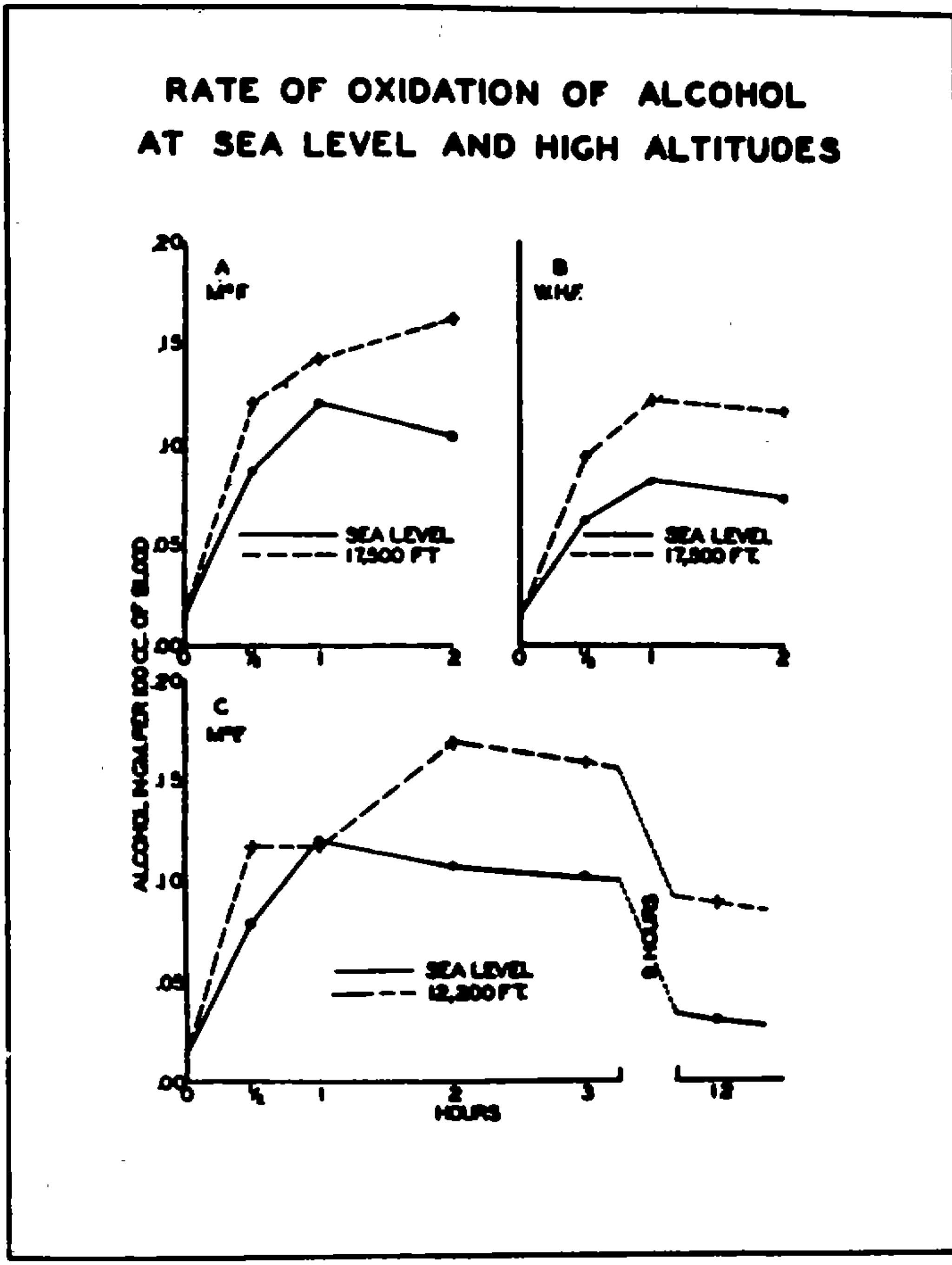

FIG. 51

Grams of alcohol per 100 cc. of blood following ingestion of alcohol; dose approximately 200 cc. of fluid containing 100 cc. of ethyl alcohol. Altitude 17,500 feet, and 12,200 feet.

alcohol as a histo- toxic anoxia, i.e., an oxygen lack due to the failure of the tissues to be able to utilize the oxygen once it is delivered to them, then at high altitude one would be subject to the effects of both a reduction in oxygen from the atmosphere and from the alcohol as well. This appears to be substantiated from the observations of stewardesses on the commercial air line planes that those who react to altitude most severely as manifested by excessive sleepiness, headaches, or nausea, have indulged in excessive amounts of alcohol previous to the flight. The average passenger should be discouraged from the use of alcohol previous to flying and the implications are obvious for the pilots who are in control of the aeroplane.

V. The Role of Carbon Dioxide in Facilitating Acclimatization to High Altitudes.

One of the most important effects of a reduction in oxygen pressure at high altitude is to bring about variations in breathing and an alteration in the delicate balances of the alveolar oxygen and carbon dioxide. Numerous experiments, notably those of Y. Henderson (30, 31) have shown the beneficial effects of excess amounts of carbon dioxide in clinical syndromes involving respiratory failure. In the experiments described above in the low oxygen and low pressure chambers with and without an excess amount of carbon dioxide (3.0 per cent) the beneficial effects were very striking. In three different experiments the partial pressure of the alveolar oxygen, the per cent of the alveolar oxygen, the per cent saturation of the arterial blood with oxygen were significantly increased and there was a distinct improvement in the psychological tests. cf. Tables 31 to 41. No unpleasant effects were experienced with 3.0 per cent carbon dioxide in the inspired air at sea level. The results indicate that this amount of carbon dioxide in the inspired air give rise to an increased pulmonary ventilation and a greater saturation of the arterial blood with oxygen which lowered the altitude by approximately 5,000 feet. These findings suggest that an accumulation of 2 to 3 per cent of carbon dioxide in the fuselage of an aeroplane might prove to be of practical significance in greatly increasing the pulmonary ventilation.

VI. <u>Interpretation of the Effects of High Altitude on the Human Organism.</u>

The important factor in high altitude which causes the abnormal symptoms is the diminished partial pressure (or concentration) of atmospheric oxygen and the consequent decrease of oxygen in the alveolar air and arterial blood. In general, the effects of reduced oxygen pressure are approximately the same whether they are brought about in a low oxygen or low pressure chamber or during flights to high altitude in an aeroplane, provided the rate of ascent, the length of exposure, and the physical characteristics of the individuals are comparable. On the average, there is a significant amount of impairment in behavior, both physiologically and psychologically when the partial pressure of oxygen in the alveolar air drops to approximately 50 mm. and the saturation of arterial blood is as low as (roughly) 85 per cent (approximately 12,000 feet altitude). It should be kept in mind, however, that oxygen lack has profound effects throughout the organism and that there is apparently no single mechanism of acclimatization of outstanding significance.

It may be tentatively concluded from these and other studies of the effects of reduced oxygen pressure that the impairment in psychological functions may be attributed to the alterations in both the oxygen and carbon dioxide; or more specifically, to the diminished partial pressure of oxygen in the arterial blood being delivered to the nervous tissue. This psychological change is probably cellular in origin, rather than due [illegible] alteration in ci[illegible] in [illegible] th[illegible] of unoxidized metabolic products. It is known from previous investigations that the alterations in the circulation (16,28) or in the body temperature (40) must be more extreme than those which occurred in these experiments to bring about an impairment in sensory or mental functions (22). Nor can the loss in efficiency be attributed to the accumulation of lactic acid or other unoxidized metabolic products in the blood (Chilean Expedition, refs. 11). The vasomotor reactions known to occur under diminished oxygen pressure produce vasodilatation and increased blood flow to various centers of the brain (23,39). But the increased blood supply cannot fully compensate for the reduced oxygen supply and as a result the amount of oxygen reaching the cerebral tissue is reduced and the carbon dioxide tension altered (58,59). The final result is a diminished amount of oxygen being delivered to the brain, the cortical elements (or more complex mental functions) being more sensitive to oxygen lack than any other part of the central nervous system (16,24). The most important abnormal symptoms of high altitude under 30,000 to 35,000 feet, therefore, can be alleviated by the maintenance of a normal partial pressure of oxygen (159 mm. Hg) in the inspired air.

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