959 INDEXED Henderson

Medical Studies in Aviation

YANDELL HENDERSON, Ph.D. (New Haven, Conn.)
E. G. SEIBERT (Washington, D. C.)
Lieutenant-Colonel, M. C., N. A.
EDWARD C. SCHNEIDER, Ph.D. (Colorado Springs)
Major, S. C., N. A.
JAMES L. WHITNEY, M.D. (San Francisco)
Major, M. R. C., U. S. Army
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Lieutenant-Colonel, M. C., N. A.
STEWART PATON, M.D. (Princeton, N. J.)
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NOTE.—This series of papers represents the results of investigations made at the Medical Research Laboratory, Air Service, Mineola, L. I. It concerns particularly the protection of aviators against the effects of high altitudes, low barometric pressure and deficiency of oxygen.

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CHICAGO

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MEDICAL ASPECTS OF AVIATION *

This reprint contains a series of papers[1] showing the work that is being done to protect aviators against the effects of altitude, low barometric pressure, and deficiency of oxygen. This is a matter that has steadily increased in importance from both the medical and the military standpoints. The rapid improvements in aeroplanes under the stimulus of military needs have made it possible to carry aerial fighting to greater and greater altitudes. Speed and its equivalent, the ability to climb above the opponent, is to air fighting very much what the windward position, or weather gage, was in naval warfare in the days of sailing ships. Accordingly, even the bombing and observation planes are now able to fly for hours at altitudes of 12,000 and 15,000 feet, as they must do in crossing the enemy line; while the pursuit or battle planes fly at the enormous altitudes of 18,000 and 20,000 feet and even more. Everything depends on these hawks of the battle field, and it is they that protect their own observation planes, or in a swift swoop drop down on and destroy the observation planes of the enemy.

With the increase in the altitudes at which flying is common, there has been a corresponding increase in the development of so-called air staleness among pilots. It is particularly the most experienced aviators who succumb to this disorder and become unable to fly longer at the necessary altitude. This is, of course, a matter of the utmost military importance, as it deprives the service of its best aviators. Air staleness is a condition in some respects like the irritable heart of the overstrained soldier, or like overtraining in the athlete. To what extent such conditions are functional or neu-

* From an editorial in THE JOURNAL A M. A., Oct. 26, 1918, p. 1408.

1. THE JOURNAL A. M. A., Oct. 26, 1918, pp. 1382-1400.

rotic or dependent on some abnormality of chemical balance is a problem that is now under active investigation both in America and in England in military hospitals for cardiac patients. Individual predisposition toward air staleness is subject to wide variations, and it is a matter of great importance, therefore, both for the avoidance of loss of life among the men in training for our air service, and for the development of the highest military efficiency among those selected, that the capacity of every candidate to withstand the effects of altitude and deficiency of oxygen should be determined.

The investigators at the Medical Research Laboratory at Mineola have found not only the theoretical but also a highly practical solution for this problem. By means of the rebreathing apparatus introduced by Henderson for this purpose, the subject breathes a closed volume of air and thus consumes the oxygen. The exhaled carbon dioxid is absorbed by alkali. By the reduction in the amount of oxygen, the subject is exposed to progressively lower tensions of oxygen, and thus to the physiologic equivalents of greater and greater altitudes until the limit of his endurance is reached.

During the low oxygen test, continuous observations are made on the arterial pressure, pulse and breathing, on the sounds and size of the heart, on alterations of vision, particularly stereoscopic and peripheral, and on the development of mental instability and muscular incoordination. The peculiar response of the cutaneous blood vessels known as the tache cérébrale (a concomitant of various nervous and cerebral diseases) likewise occurs in a considerable proportion of the men undergoing the test, and tends to indicate unsuitability.

The results obtained show that a considerable percentage of the men who pass even the exacting medical examination required by the Aviation Service are unable to withstand altitudes even as low as 10,000 feet without exhibiting such physical or mental depreciation as would seriously endanger a man piloting a plane. On the other hand, these tests reveal a small percentage of men who are naturally so resistant to low oxygen that they can withstand the equivalent of 20,000 feet or more for a half hour or longer without serious depreciation, either mental or physical. Evidently such men are specially fitted for work at high altitudes.

Nor is the usefulness of these tests ended by the enlistment and grading of the pilot. The Medical Corps is assigning to each aviation unit one or more flight surgeons, assisted by physical directors selected from among the men who were formerly trainers of college athletic teams. It is their duty to keep the aviators in as perfect physical condition as if they were so many football players. The flight surgeons are all given a special course of training at the Medical Research Laboratory of the Air Service in the physiology, or as it has now become, the medicine of altitude.

Previous investigations, such as those of the Pike's Peak Expedition,[2] have demonstrated that the acclimatization of persons living at various altitudes involves certain functional readjustments, especially an increased number of red corpuscles, a decreased alkali reserve in the blood, and a larger volume of breathing, that is, a lowered alveolar carbon dioxid. These readjustments, however, require days or even weeks to develop, and the study of the condition of aviators has demonstrated that unfortunately the brief periods during which they are exposed to low oxygen result in no appreciable degree of acclimatization. On the contrary, repeated flights at altitudes above those which the individual's unacclimatized (i. e., sea level) functional capacity can easily compensate act like repeated nervous and cardiac overstrains. If too often repeated, air staleness results, and the pilot is either incapaci-

2. Douglas, Haldane, Helies and Solander: Phil. Trans., 1913, B. 203, p. 185.

tated to fly at all or, if he persists, he is liable to lose consciousness in the air and fall.

The rebreathing test finds its use, therefore, as a means of diagnosis, for it now becomes possible, whenever the flight surgeon suspects that air staleness is developing in one of the men in his charge, to determine accurately the degree of overtraining. Furthermore, it appears[3] that the use of the low oxygen test administered by means of the rebreathing apparatus may have a broader application in internal medicine as a measure of the functional power of the heart and circulation.

The application of physiologic knowledge to this problem appears likely to prove one of the most valuable contributions to the efficiency of the American Air Service.

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3. Whitney, J. L.: Medical Studies in Aviation, III, Cardiovascular Observations, The Journal A. M. A., Nov. 26, 1918, p. 1389.

I. ORGANIZATION AND OBJECTS OF THE MEDICAL RESEARCH BOARD, AIR SERVICE, U. S. ARMY *

YANDELL HENDERSON, Ph.D. (New Haven, Conn.)

AND

E. G. SEIBERT, M.D. (Washington, D. C.)
Lieutenant-Colonel, M. C., N. A.

MINEOLA, L. I., N. Y.

The Medical Research Board was organized early in the autumn of 1917, "to investigate all conditions which affect the efficiency of pilots; to institute and carry out at flying schools or elsewhere such experiments and tests as will determine the ability of pilots to fly in high altitudes; to carry out experiments to provide suitable apparatus for the supply of oxygen to pilots in high altitudes; to act as a standing medical board for the consideration of all matters relating to the physical fitness of pilots." The equipment controlled by the board consists of a large and constantly expanding laboratory for research and teaching at one of the principal eastern flying fields, and of smaller branch laboratories for examining purposes already at work or being organized at twenty other flying fields and ground schools. In the main laboratory, departments have been organized in physiology, cardiovascular functions, psychology, ophthalmology, otology and psychiatry and neurology.

The general purpose of the organization is the study of the effects on the aviator of the peculiar conditions involved in flying. Among these the effect of altitude, that is, of altered barometric pressure, has presented itself as the one of most immediate importance. This

* From the Medical Research Laboratory, Air Service, Mineola, L. I.

series of papers will present a general oversight of the results on altitude thus far accomplished.

In this field four problems demand solution:

1. The cause and nature of the failure, physiologic or psychologic, or both, on the part of the pilot which frequently precedes a fall.

2. The development of a method for determining the maximum altitude to which each individual pilot can ascend without danger of such failure.

3. The development of forms of physical training for increasing the resistance of the pilot to the ill effects of altitude, and for maintaining him in a state, not of acclimatization to great altitude like the mountaineer, but rather in the perfect physical condition of the athlete.

4. A deeper knowledge of the nature of air staleness —a condition closely similar to athletic "overtraining," and to the so-called "irritable heart" or neurasthenia of the overstrained soldier.

We are now able to report an approximate solution of the first problem and a complete solution of the second. The third and fourth remain for further investigation from the starting point defined by these studies.

The results of previous investigations, from those of Paul Bert down to those of the Pike's Peak Expedition, had demonstrated clearly that the essential element in the effects of low barometric pressure, that is, great altitudes, on men consists in the reduced partial pressure of oxygen. Mountain sickness had been shown to be fundamentally due, not to the merely mechanical effects of decreased air pressure in the ears and on the blood vessels, but to oxygen deficiency. It was a fair presumption, therefore, from which to start investigation that the same thing would hold true in general of the functional disturbances of the aviator, although some modification of the symptoms might arise from the differences between mountaineering and vaiation. These differences evidently consist in the aviator's more rapid ascent and descent, in the greater altitudes reached, and in the briefer period for which he remains at the altitude.

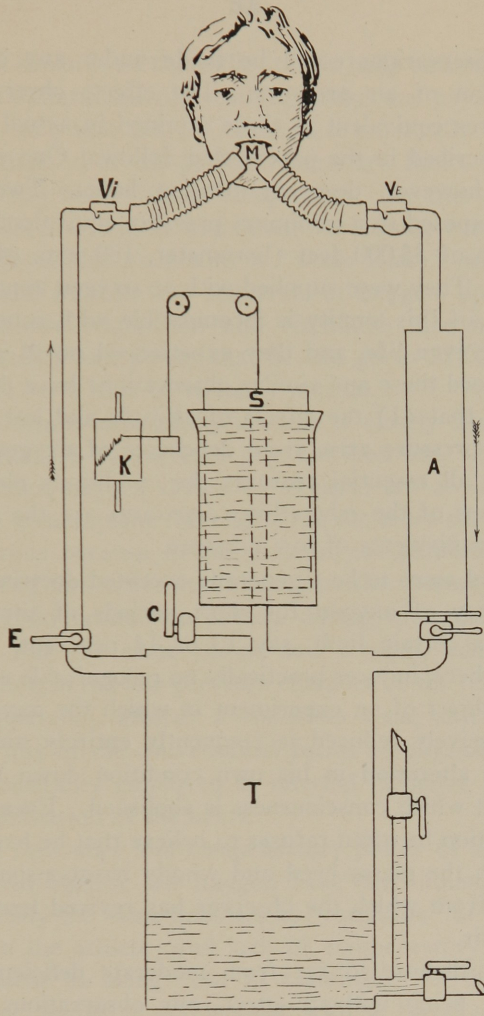
Previous investigations, notably those of the Pike's Peak Expedition, were directed largely to discovering the nature of acclimatization to altitudes. The length of time during which the aviator remains at altitudes is, however, too brief for any appreciable degree of acclimatization to be developed. On the contrary, day by day the brief but repeated strain of oxygen deficiency—a strain much like that of athletic overexertion—produces a cumulative ill effect on the aviator of the higher levels, until, if his condition is not recognized and his flying stopped, he one day loses consciousness at a great height, and falls. For the aviator is essentially an unacclimatized man, and must depend on the capacities of the healthy body adjusted only to the level of his hangar and his quarters. Our investigations have dealt, therefore, not with acclimatization, but with a hitherto largely neglected problem, namely, the organism's immediate compensatory reactions to oxygen deficiency.

In another class of accidents and near-accidents, the pilot's failure occurs near the end of a rapid descent. Often he has no recollection of how the crash occurred; he had lost consciousness, was asleep. This is highly significant; for this is a state which is induced by an ample supply of oxygen, or fresh air at full pressure, after a period of deprivation. As yet undescribed in the literature, so far as we are aware, and largely unexplained, this interval of unconsciousness, or collapse, or sometimes of excitement and loss of balance physical and mental of alcoholic type, is nevertheless a phenomenon often met by students of the low oxygen problem. It occurs in a wide variety of conditions: in miners escaping from "after-damp," in city firemen after coming out of smoke, in the older types of submarines on opening the hatches after submergence, in persons who are given oxygen after overexertion on a mountain, and after low oxygen experiments in the laboratory. But in none of these conditions are the consequences so serious as for the aviator, when, after remaining for a time at a height greater than he can safely withstand, he makes a rapid descent to denser air. Then, just as he is about to land and needs all his faculties at their best, he develops this oxygen intoxication as the rebound from oxygen deficiency.

Laboratory experience had shown that to produce the acute effects of oxygen deficiency it is not necessary to climb a mountain, or to go up in a plane, or even to be exposed to low barometric pressure. The result is easily accomplished at sea level by breathing into an apparatus consisting of a spirometer and a canister containing alkali. The exhaled carbon dioxid is absorbed by the alkali, while the oxygen is gradually reduced by the continual rebreathing. An apparatus of this sort, the so-called rebreathing apparatus, has been in use for some years past in the physiologic laboratory at the Yale Medical School as a simple and ready method of studying what are virtually the effects of altitude.

Accordingly, as a preliminary to our work, the first step taken by the physiologic division was to perfect the rebreathing apparatus for routine use. Then followed several months of investigation to determine which of the autonomic functions of the body, e. g., the pulse and the arterial pressure, are most affected by low oxygen. Simultaneously the psychologic and ophthalmologic divisions perfected the apparatus and technic for observation, measurement, and record of motor and sensory disturbances.

Later, a steel chamber large enough to hold six or eight men at once and an air pump were installed, so



The rebreathing apparatus employed in all routine tests of the aviators' ability to withstand low oxygen. It consists of a tank, *T*, of about 120 liters capacity. The volume of air is determined by the amount of water that is run into it. The man under examination continually rebreathes the air of the tank (a clip is placed on his nose) through the inspiratory and expiratory valves, *Vi* and *Ve*. The oxygen is thus consumed and reduced. The exhaled carbon dioxid is taken up by sodium hydroxid in the absorber, *A*. The movements of respiration are recorded by the spirometer, *S*, connected to a smoked drum, *K*. As the oxygen is consumed and the air volume is thus reduced, the spirometer falls and the graphic record on the smoked drum rises. At the end of the test a sample of air is drawn from the tank and analyzed as a confirmation of the oxygen consumption and of the oxygen percentages (that is, altitudes) indicated by the graphic record.

that observations could be made under any desired reduction of air pressure. The effects observed at pressures equivalent to those attained in actual flying are described in the papers that follow. One experiment, however, deserves mention here: Two men were exposed to a minimum pressure equivalent to an altitude of 35,000 feet (barometer, 180 mm. of mercury). They were supplied with an oxygen apparatus, for air of this tenuity is incompatible with consciousness or even life, and they experienced no ill effects. In a word these and similar observations have demonstrated that (1) the effects of altitude and low barometric pressure arise from deficiency of oxygen, and (2) in all essential features the conditions obtained by means of the rebreathing apparatus are the physiologic equivalents of low pressure.

It had come to be a generally accepted doctrine that deficiency of oxygen for short periods of time and above a certain limit, say 13 or 14 per cent. of an atmosphere, induces practically no recognizable effects. The subject of an experiment in which the oxygen is progressively reduced is frequently entirely unaware of any alteration in his own condition down to the point at which consciousness is abolished. Even after restoration he often refuses to believe that he has been through the glassy-eyed and wholly irresponsive condition from which the observer has revived him with fresh air.

Nevertheless, so far from moderate deficiency of oxygen being without effect, our observations have revealed the fact that in normal men characteristic alterations of function begin even with a slight lowering of the oxygen tension. Thus it appears that in flying the normal person begins to react almost from the moment that he leaves the ground. These reactions are found to be of a compensatory nature: the resistance of the healthy subject, the fact that up to a certain altitude he feels and shows no immediate ill effects, depends on the ability of his body automatically to effect alterations of breathing, pulse, and psychologic forces such that the net result is a practically normal individual. For all persons there are limits beyond which the body cannot compensate. In this respect there are the widest individual variations, forming a scale from the man with a "weak heart," who can withstand scarcely any reduction of oxygen, up to the man whose respiration and circulation are of such adaptability and power that he can go to 25,000 feet, and yet for a time be virtually normal.

The strain imposed by altitude is closely similar to that induced by extreme physical exertion. In both conditions, oxygen deficiency occurs; but at altitudes and in an aeroplane the effects are the more subtle and dangerous because of the lack of the stimulation to breathing and other functions that the increased carbon dioxid production affords during muscular exertion. For the same reason low oxygen, used with discretion in the low pressure chamber or the rebreathing apparatus, affords a condition clear and simple above any of the conventional forms of physical exercise sometimes employed in internal medicine as aids to examination of the heart.

The resistance and compensatory power of the normal man against low oxygen have been found to be practically the same qualities as "condition" or "training" in the athlete; and lack of compensatory power equivalent to being "out of training." In its more extreme forms it is identical with a "weak heart." From this it follows in theory, as the cardiovascular division in the Research Laboratory has in fact discovered, that the methods based on the rebreathing apparatus are not only applicable for measuring "fitness" and "staleness" in the aviator, but also offer hope for development into that long sought and greatly needed aid to cardiovascular diagnosis: a general test and measure of the "functional power of the heart."

It will be evident, however, that by the expression "functional power of the heart" we mean much more than merely the strength of that organ. We mean, rather, the totality of the processes of the body's gaseous exchanges with its atmospheric environment. These processes are the very essence of life. Low oxygen tests are thus fundamentally measurements of vitality.

In the following papers is contained a general description and a proximate analysis of the compensatory reactions and the forms of overstrain occurring under brief periods of partial oxygen deficiency in men who, having passed the ordinary medical examination, would generally be considered as normal. Among them our methods have revealed a considerable percentage unsuited to fly except at very moderate altitudes, and some unfit to fly at all. It is our hope that the institution of routine examinations by this technic will result in greatly reducing the number of pilots who may lose consciousness in the air and fall, whether because of inherent unfitness or because of otherwise unrecognized air staleness.

During the inception of our work and while our laboratory was being erected, we were allowed the privilege of laboratory space and facilities in the War Gas Experimental Laboratory, then under the U. S. Bureau of Mines. In this and in other matters this bureau has rendered us invaluable assistance. On behalf of the Medical Research Board it is a pleasant duty to express to Director Van H. Manning an acknowledgment of our debt.

II. PHYSIOLOGIC OBSERVATIONS AND METHODS *

EDWARD C. SCHNEIDER, Ph.D.
(Colorado Springs, Colo.)
Major, S. C., N. A.
MINEOLA, L. I., N. Y.

In the Medical Research Laboratory of the Air Service the ability of the aviator to respond to a decreasing oxygen supply is tested by an experiment of from twenty-five to thirty minutes' duration with the Henderson rebreathing apparatus. As the oxygen in the air inhaled from the apparatus is reduced, the man is thereby virtually elevated to a corresponding altitude.

During the test, the rate and volume per minute of respiration, the pulse frequency, and the systolic and diastolic arterial pressures are studied and have been found to give valuable evidence as to the altitude at which the man first responds to oxygen deficiency and as to the efficacy of his compensatory reactions. These reactions consist chiefly in an increased ventilation of the lungs and a more rapid blood flow. In a few men a concentration of the blood also occurs.

Some men compensate so easily and so well that they endure, at least for brief periods, as low as 6 per cent. of oxygen, corresponding to 31,000 feet: an altitude greater than any heavier than air machine has yet reached. Others fail to compensate, or compensate inadequately, and therefore cannot endure even the slight oxygen deficiency of moderate altitudes. From the data obtained in the test on the rebreathing apparatus, it becomes possible to determine approximately the maximum altitude to which the aviator may safely ascend.

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* From the Medical Research Laboratory, Air Service, Mineola, L. I.

If the man is even slightly below the best of physical condition, the altitude to which he is safe is distinctly reduced. A cold, indigestion, late hours, or worry may reduce his resistance temporarily by many thousand feet. More serious indisposition affects him to a corresponding extent.

THE BREATHING UNDER PROGRESSIVE DECREASE OF OXYGEN

The character of the breathing is important. In shallow breathing, only a comparatively small amount of the fresh air gets past the so-called dead space—the nose, pharynx, trachea and bronchi—to mingle with the air in contact with the blood vessels of the lungs. The deeper the breathing the greater will be the amount of fresh air that reaches the alveoli of the lungs, and hence the greater will be the supply of oxygen for the body tissues.

As the percentage of oxygen gradually decreases during a rebreathing test, there occurs a marked respiratory response. In a few men this increase in the lung ventilation begins with the first decrease in the oxygen percentage of the air breathed, and is a gradual proportional increase in inverse ration with the reduction in oxygen. More than 50 per cent. of the men examined, however, gave the first respiratory response between 16 and 14 per cent. of oxygen. Twenty-five per cent. responded first at a lower oxygen tension, while a small number gave no response. The increase in lung ventilation is for the higher percentages only slight, but it usually becomes more pronounced when the available oxygen has been decreased to between 12.5 and 9 per cent.

The rate of breathing for many men remains unchanged throughout the rebreathing test. The majority, however, show an increase of from two to four breaths per minute at between 8 and 6 per cent. of oxygen. A few of the men examined, showed by other tests to be physically somewhat stale, increased the frequency of breathing enormously.

The increase of volume per minute in the breathing during a rebreathing test differs with individuals. At percentages of oxygen between 8 and 6, the majority show an increase of 5.5 liters over the volume breathed at the beginning of the experiment, when on the average it is about 8.5 liters per minute. This increase gives for the average man a total volume of breathing per minute of approximately 14 liters at oxygen tensions corresponding to an altitude of 25,000 feet. The total per minute volume of air breathed has, in exceptional cases, been as great as 26 and 37 liters of air at oxygen tensions corresponding to from 25,000 to 28,000 feet.

It is the depth of breathing that ordinarily is increased by low oxygen. The vast majority of subjects show an increase in depth of breathing of from 20 to 128 per cent. when under from 8.5 to 6 per cent. of oxygen. The volume of each breath in these men is found to range between 600 and 1,250 c.c., while for the same subjects when breathing air of normal oxygen content is between 360 and 640 c.c.

A good respiratory reaction to the gradual decrease in the oxygen of a rebreathing test is manifest in a slight increase in the depth of breathing, which begins at 16 or 15 per cent. of oxygen and continues progressively to increase slightly and gradually until from 12.5 to 9 per cent. of oxygen is reached. From these percentages down to 8.5 and 6 per cent. of oxygen, the total volume per minute of breathing increases much more rapidly; and the frequency of breathing may also increase from two to five breaths per minute. A total per minute increase of at least 5.5 liters should occur at the lower percentages of oxygen.

When the volume per minute of the breathing fails to increase as the amount of oxygen inhaled decreases, or when it increases only slightly, 1 or 2 liters, the lung ventilation is insufficient, and the subject is found unable to tolerate as low a tension of oxygen as the man whose breathing gradually deepens as the available oxygen decreases. Only a few men have failed to show a respiratory response to low oxygen, and none of these have tolerated well even such oxygen tensions as from 10 to 9 per cent. An occasional subject has been examined whose breathing responded well at first, but who later, when the percentage of oxygen was low, suddenly began to breathe less. When this happened, fainting or unconsciousness quickly followed.

THE HEART RATE UNDER DECREASING OXYGEN SUPPLY

In the active tissues the oxygen tension is always low. The higher the oxygen pressure in the blood, the greater therefore will be the amount of oxygen passing from the blood of the capillaries into the tissues. The dissociation of oxygen from the hemoglobin occurs with great rapidity and is most rapid when the differences in pressure are greatest. (This is not dependent on blood pressure.) It follows, therefore, that when the blood flows more rapidly through the capillaries of a tissue, more oxygen will be made available than if it flows slowly. At high altitudes, or under low oxygen, the blood, at first at least, is less saturated with oxygen than at low altitudes Therefore, if the blood contains less oxygen, an increase in the rate of blood flow through the capillaries would be a means of providing the tissues with the oxygen demanded for their activity.

An increased rate of the blood flow has been demonstrated in men living at high altitudes and is, undoubtedly, one of the first of the adaptive or compensatory changes occurring in the rapid ascents made by the aviator.

Circulatory observations made on Pike's Peak (14,110 feet) indicate that the increase in the rate of blood flow is largely the result of a greater frequency of heart beat. A study of the pulse rate during expo-

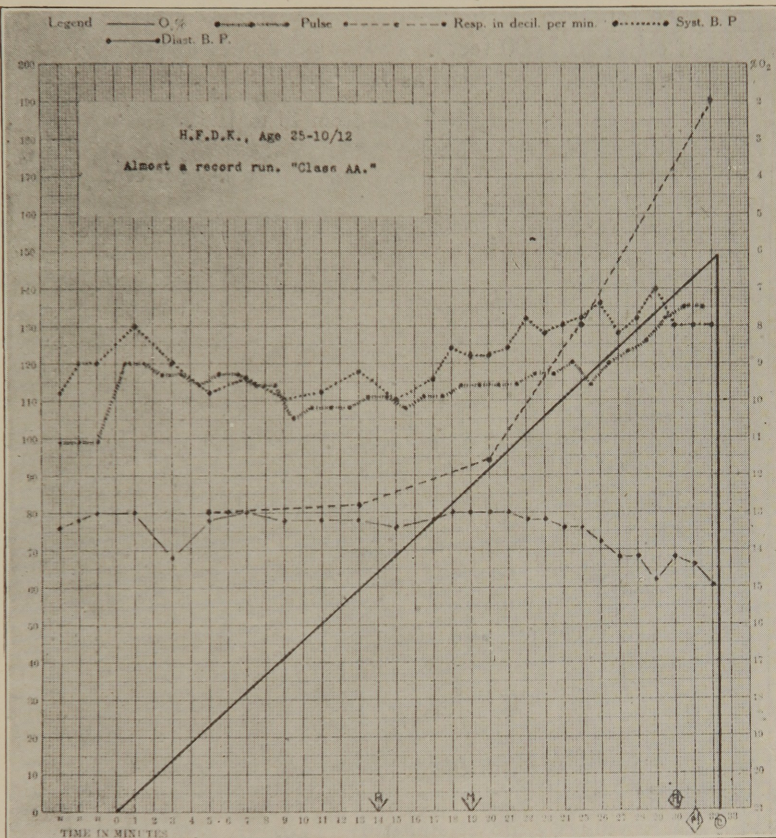

Chart 1.—Results obtained in the examination of an extra good man. The symbols at the bottom of the chart indicate his psychologic condition.

sure to low oxygen should, therefore, give a definite indication of the sensitiveness of the organism. We have found the pulse rate to be a trustworthy indicator of oxygen want, provided care is taken at the beginning of a rebreathing experiment to have the subject calm and quiet.

Throughout the rebreathing test the candidate's pulse rate is counted and the systolic and diastolic blood pressures are determined. The rate of heart beat has been found to accelerate in a few men at 17.5 per cent. of oxygen (5,000 feet). In one group of seventy men the accelerations began as follows:

Between 7,000 and 8,000 feet—from 16 to 15.5 per cent. of oxygen—1 per cent. began to react.

Between 8,000 and 9,000 feet—from 15.5 to 14.9 per cent. of oxygen—12 per cent.

Between 9,000 and 10,000 feet—from 14.9 to 14.2 per cent. of oxygen—20.

Between 10,000 and 11,000 feet—from 14.2 to 13.7 per cent. of oxygen—14.

Between 11,000 and 12,000 feet—from 13.7 to 13.2 per cent. of oxygen—23.

Between 12,000 and 13,000 feet—from 13.2 to 12.7 per cent. of oxygen—20.

Between 13,000 and 14,000 feet—from 12.7 to 12.2 per cent. of oxygen—6.

The increase in frequency of heart beat is at first slight, only from one to three beats; but as the oxygen percentage decreases, a greater increase in rate is likely to occur with each decrement in oxygen. A very marked acceleration usually occurs when the oxygen has fallen to between 13 and 9 per cent. Some men at first react with a good acceleration in rate, but soon reach a rate beyond which there is no further response, even though the oxygen percentage continues to be lowered. In such cases after holding at a fixed rate for a while the heart suddenly begins to slow: a sure indication that the limit of endurance has been reached.

A total increase of from fifteen to forty beats in the heart rate during a rebreathing test, in which the oxygen is lowered in half an hour to between 7.5 and 6.5 per cent., constitutes a good reaction to oxygen want. A failure to respond by an acceleration of the heart rate to lowered oxygen means either inability to react to a low oxygen of high altitudes and early failure, or that sufficient compensation is secured by increased breathing or blood concentration or both. Our experience indicates that the failure to respond is associated

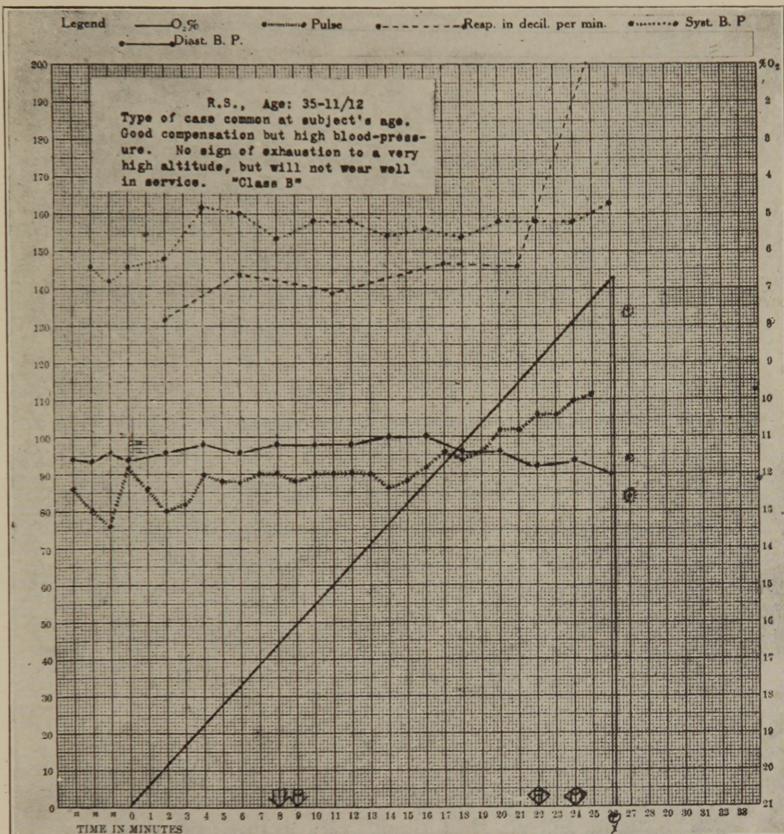

Chart 2.—Examination of a good man who is too old (note his arterial pressure) to be quite first class.

with poor toleration of low oxygen. An acceleration in heart rate of more than forty beats—from 50 to 70 have been observed—throws too great a burden on the circulatory mechanism, and occurs only in men who do not tolerate well low percentages of oxygen. In such men other compensatory reactions may fail to occur. So far as the response in pulse rate to decreasing oxygen is concerned it therefore becomes possible to rate the reactions poor, good and excessive. A poor or an excessive heart response should disqualify the candidate for very high altitudes; he should ascend to only moderate heights.

A delay in the first appearance of acceleration of the heart rate may be due to an insensitive cardiac brain center, while an early response may indicate a mechanism very sensitive and responsive to any decrease in available oxygen. It should be borne in mind, however, that while ordinarily there is an early acceleration in the heart rate, a delay may be due to the efficiency of other methods of compensating to the stimulus of oxygen want.

THE ARTERIAL PRESSURES UNDER DECREASING OXYGEN SUPPLY

The determinations of systolic and diastolic arterial blood pressures show whether the vasomotor mechanism responds to the stimulus of oxygen want in a manner adequate to maintain the increase in the rate of blood flow. At the same time they show whether the heart is compelled to work against an increased resistance. They also give an index, the pulse pressure, of the volume of ventricular output.

In the optimum type of response to the low oxygen of the rebreathing test the systolic pressure remains unchanged, that is, it holds on a level, until the oxygen has been lowered to between 14 and 9 per cent., after which as the oxygen is further lowered it gradually rises. Occasionally there may occur a gradual rise in the systolic pressure beginning with the first increase in heart rate. This rise in pressure is ordinarily from 15 to 20 mm. of mercury. Other subjects who appear to have tolerated low oxygen equally well, even down to 6.5 per cent., have had a systolic pressure which held at the normal.

A rise in the systolic pressure of more than 30 mm. of mercury—from 40 to 60 mm. have been observed—is very likely due to a vasomotor failure to respond with a dilatation of the arterioles. Such conditions overwork the heart and may result in early circulatory failure.

There are other conditions of systolic pressure that are occasionally found in men undergoing the rebreathing test. A small percentage have a fall in the systolic pressure which begins about the time the pulse rate starts to accelerate, and continues to decline throughout the test. Such men have not tolerated the extremely low percentages of oxygen that men of the optimum type of response have endured. A large number have shown a sharp and sudden fall in the systolic pressure at low percentages of oxygen. This fall, if allowed to continue, leads to fainting. The subject recovers his normal pressure at once if he is returned to atmospheric air.

The best condition in the response of the diastolic pressure to a decreasing oxygen supply consists in an unchanged or slightly increased pressure throughout the test. Many men show a gradual well controlled fall in the diastolic pressure during the terminal period when the systolic pressure is rising. Such a fall in the diastolic pressure, if it occurs slowly and is not great, constitutes a fairly good reaction to extreme oxygen want. It can be explained as a vasomotor dilatation which occurs in order to protect the heart against the rising systolic pressure. In the optimum type of response to low oxygen the terminal fall in the diastolic pressure may not occur. If present it is never very pronounced and comes only after the oxygen is reduced to 9.5 per cent or less.

About 66 per cent. of all men examined have had a fall in the diastolic pressure. In at least half of these the fall has been sudden and great. It is always associated with fainting and usually precedes a systolic fall. If the two occur together, in the order just indicated, the experiment must be terminated at once. The pronounced and sudden fall in diastolic pressure may occur at a high oxygen percentage. It has been found to occur as early as 14 and 13 per cent. of oxygen (10,400 and 12,200 feet). Such sudden falls in the diastolic pressure appear to be due to an overcoming of the vasomotor center by oxygen shortage. A decided fall in the diastolic pressure, even if more or less definitely controlled, is an indication that the subject will not tolerate well the altitude corresponding to the oxygen percentage at which it appears.

Three types of circulatory reaction to oxygen want have been observed: The first, the optimum, in which the pulse rate accelerates moderately as the oxygen decreases, the systolic pressure is unchanged or shows a terminal rise of not more than from 20 to 30 mm. of mercury, and the diastolic pressure remains unchanged or rises slightly. The second, the controlled diastolic fall, in which the pulse rate accelerates moderately and the systolic pressure rises as the diastolic pressure gradually falls. The third, the fainting type, in which after a period of fair, good or excessive response in the rate of heart beat to low oxygen, the diastolic pressure suddenly falls, and soon thereafter the systolic pressure, and the pulse rate slows. The optimum type may tolerate as low an oxygen as 6 per cent. (equivalent to an altitude of 29,000 feet) and may lose consciousness without fainting. He recovers quickly when restored to air, while the heart rate and blood pressures are soon back to their normals. The fainting type rarely endures as low an oxygen. If allowed to run his course he faints completely; and as he revives he requires a considerable time, sometimes an hour or two, to regain his normal pulse rate and blood pressures. There are, of course, gradations between the types here described.

The pulse pressure during a rebreathing test remains fairly constant in most men until the oxygen has fallen

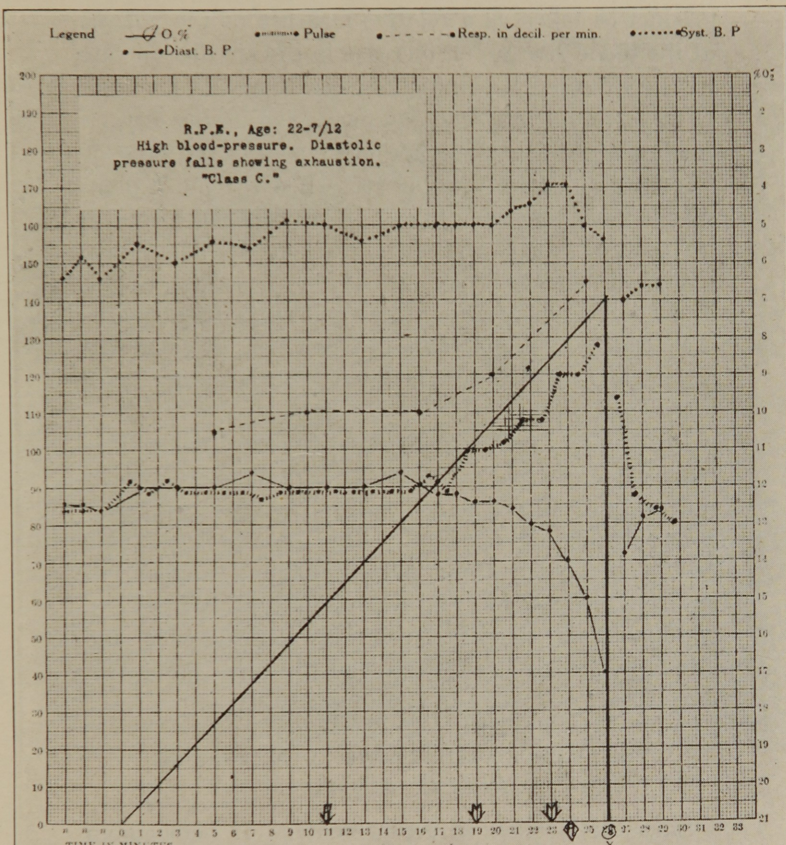

Chart 3.—Examination of a man unfit to ascend above moderate altitudes, unless supplied with oxygen apparatus.

to between 12 and 9 per cent. (from 14,500 to 22,000 feet), after which it increases in amount during the further reduction in oxygen. The rise in pulse pressure occurs when the systolic pressure is rising and the diastolic either remaining constant or slowly falling. This is also the period when the heart beat is accelerating most rapidly. The amplitude of the heart output, it is claimed, is shown by the pulse pressure. If the pulse pressure be multiplied by the pulse rate and the product be taken as a relative measure of the volume of the blood stream, an increase in the circulation rate will be indicated, beginning between 16 and 14 per cent. of oxygen and progressively increasing as the oxygen further decreases. The period of most rapid flow of blood would, therefore, be that when the pulse pressure is also increasing, that is, from between 12 and 9 per cent. of oxygen to the end of the test. Therefore, a marked increase in the rate of the circulation of the blood during exposure to a low and decreasing oxygen is indicated. This increase in blood flow is, as shown earlier, an important and necessary compensatory reaction to low oxygen.

Incidently a few venous blood pressure determinations made during exposure to a decreasing oxygen supply have shown a fall which becomes very pronounced when the oxygen is 10 per cent. or less. This fall in venous pressure calls to mind a similar fall reported by Schneider and Sisco in men on Pike's Peak and indicates that the reactions observed in the rebreathing tests are the result of the same cause, low oxygen.

THE HEMOGLOBIN UNDER A DECREASING OXYGEN SUPPLY

Since an increase in the percentage of hemoglobin in the blood is one of the most important of the low oxygen compensations found to occur in men and animals living at high altitudes, it is interesting to find that it may also occur during short exposures to low oxygen. The rebreathing test of not more than thirty minutes' duration is too short to permit a concentration of hemoglobin in the majority of men. In order to test the part that the blood changes may play as a compensatory factor for oxygen want in such a short period as the aviator spends in the air, a series of experiments are now being made in the pneumatic chamber and also under low oxygen. In these the subject is held at a chosen pressure or a given percentage of oxygen for from forty to ninety minutes,

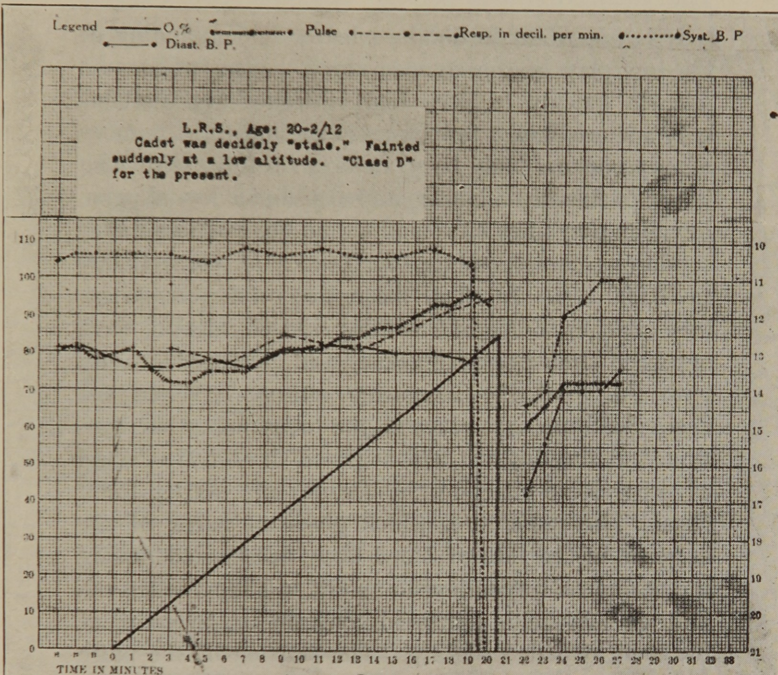

Chart 4.—Examination of a man unfit to fly at all until his physical condition improves.

the entire experiment lasting as much as two or two and a half hours. The hemoglobin has been determined with the Gower-Haldane hemoglobinometer on blood taken from a finger or an ear and also from a vein in the arm. At least 25 per cent. of all men examined have shown a well defined increase in the percentage of hemoglobin (from 4 to 9 per cent.) and the majority some evidence of concentration. It has been most clearly induced at pressures, and percentages of oxygen corresponding to between 18,000 and 20,000 feet. Almost all of the men have had to be held at the high altitudes twenty or more minutes before concentration began to be evident.

THE RELATIVE VALUE OF THE COMPENSATORY FACTORS

It is important to obtain a better understanding of the interplay of the compensatory factors when man ascends quickly to very high altitudes and remains only a short time, a few hours at the most. A number of experiments have been made, therefore, with men in the pneumatic chamber, and also under low oxygen, in which they have been held for an hour or two under conditions corresponding to altitudes of from 15,000 to 20,000 feet. In all of these, two of the compensatory changes, those in breathing and circulation, have appeared almost simultaneously and increased steadily with the gradually increasing altitude. When the desired altitude was reached, the breathing either continued at the depth it had acquired during the period of progressive change or it became still deeper for a time. The pulse rate, which gives an index of the increase in the rate of blood flow, accelerated during the period corresponding to ascent and then, when the altitude was held, remained constant or, in some of the men, retarded slightly. The slowing of the pulse rate, when an altitude was thus maintained for a time, was so frequently observed that we sought for an explanation of it. In a number of men it was found that the heart was being relieved by other compensatory factors. In such cases one or the other or both of two changes occurred. There occurred a further deepening of the breathing, or a concentration of the hemoglobin, or both of these changes took place together. Often the breathing, after increasing in amount during the ascent, held at a constant increased depth during the stay at a given altitude; but in such case the hemoglobin was found to be concentrating as the pulse rate slowed.

An unusual but interesting case was found in a man whose breathing failed to respond to the changes in altitude. He did not tolerate the low pressure well at first, but felt better after some time had been spent at the chosen pressure. In this man the heart accelerated decidedly, and later his hemoglobin concentrated about 8 per cent. His improvement occurred when the hemoglobin showed concentration.

Our studies show that during short exposures to high altitudes or low oxygen, such as the aviator experiences, the compensatory reactions of the body to a decreased oxygen are made almost entirely by the circulation and by the breathing. A considerable number of men may, after the lapse of about an hour, secure some benefit from a slowly developing concentration of the hemoglobin. The order of response by the adaptive mechanisms is not that of the good reaction seen among mountaineers, in whom the breathing first responds while the other compensatory changes take place more slowly. The reaction resembles more nearly that seen during an attack of mountain sickness among mountaineers. In such men the heart beat is greatly accelerated during the attack. The aviator, it appears, must depend largely on his heart and his breathing for compensation to the fall in oxygen that he encounters as he ascends.

III. CARDIOVASCULAR OBSERVATIONS *

JAMES L. WHITNEY, M.D. (San Francisco)
Major, M. R. C., U. S. Army
MINEOLA, L. I., N. Y.

It has long been known that persons with defective hearts tolerate very badly such altitudes as those of Denver, Phoenix and Mexico City. Many instances have been quoted of serious and even fatal attacks of cardiac dilatation, pulmonary edema, etc., occurring within a few days after arrival at these places. This popular view has, however, received up to the present very little confirmation from scientific work. Marked alterations in respiration have indeed been described; and the effects on the chemistry of the blood and tissues in reference to transport of oxygen have been studied in great detail. Beyond suggestions, however, that certain changes in blood flow might occur as the result of high altitudes, very little evidence has been at hand that the effect on the circulation is of great importance; and especially there has been entire lack of proof of marked circulatory strain, or of the possibility of such disasters to the heart as have been popularly described.

The explanation is that the best type of organism makes its circulatory adjustments so smoothly and with so little strain that there is almost no evidence of anything of great importance going on. It is only by study of less normal types that we appreciate both the serious effects that may be due to failure of circulatory reaction, and the nature of this reaction itself.

Perhaps the most striking single fact brought to light by the present research is that heart failure, fol-

* From the Medical Research Laboratory, Air Service, Mineola, L. I.

lowing marked dilatation is exceedingly common as the result of reduction of atmospheric pressure. Dilatations of from 3 to 5 cm. have been not infrequently found, always followed by collapse and fainting if oxygen is not immediately given. The commonness of this syndrome may be judged from the experience of ten medical officers taken into the low-pressure chamber on two occasions for demonstration purposes. These were men of average constitution, though not of athletic type. Five of them developed marked dilatation, one at 14,000, one at 16,000, two at 18,000 and one at 20,000 feet. It was interesting that in each case the dilatation was discovered by percussion before any subjective symptom was present; but in each case the individual began to feel very ill within a minute thereafter and would have fainted if oxygen had not been administered. It is our practice in using the low-pressure chamber for the observer to take oxygen even at the lower "altitudes."

COMPENSATION BY THE CIRCULATORY SYSTEM FOR LOW OXYGEN

The explanation of many physiologic events lies in the power of the organism to make readjustments to compensate for deleterious changes in the environment. In the compensation for low oxygen, the circulation appears to be the factor of first importance. Changes in respiration, in concentration or chemical constitution of the blood, or in the mechanism of gaseous exchange are important, but they are able to make good only partially for the deficiency. The factor of chief importance with a wide range of adaptability is the rate of blood flow, both in general and as regards special parts. If the blood carries less oxygen per unit, more blood must be sent to the organs that need it in order to furnish the sum total of what is required.

This, of course, means increase in pulse rate, often increase of blood pressure (especially of pulse pressure) and delicate readjustments of blood distribution. All of this calls for accurate control of the vasomotor system and increased strain on the heart. This strain must be carried at a time when the oxygen supply of the heart muscle itself is precarious.

Not only is the maintenance of perfect circulation vitally important for efficient existence at high altitudes, but the heart is itself particularly vulnerable to direct effects of oxygen deficiency. There is the possibility of a vicious circle of a most dangerous kind. For if the circulation falters for a moment, not only will the nerve centers run the risk of subjection to a paralyzing anoxemia, but the nutrition of the heart muscle is impaired. Further interference with circulatory efficiency ensues, and total collapse is inevitable.

Add the fact that this collapse comes practically always without premonitory symptoms of any kind, and the very great danger to the aviator becomes apparent. There is a total reversal of conditions from those of heart strain from vigorous exercise, in which the intense discomfort caused by overexertion gives ample warning that one is approaching the limit, and in which at worst partial failure of the heart would do no more than make further exertion impossible, and so automatically terminate the strain.

This vicious circle may satisfactorily explain many cases of sudden fainting at low altitudes. For if there were a momentary failure of coronary circulation due perhaps primarily to a wholly neurotic influence on the vasomotors, a condition of undernourishment of the heart would be started that would be rapidly cumulative.

The elements of strength in meeting the situation are a strong heart muscle, efficient and accurately adjustable coronary circulation, and the ability of the peripheral vasomotors to allow increase of blood flow to the parts that need it without undue strain on the heart by increased blood pressure. These arterial reactions demand in the first line perfect anatomic condition of the vascular walls and perfect vasomotor control. As a consequence, two classes of cases are found that are most likely to react badly to lowered oxygen tension: men who have any arterial change in the way of sclerosis, and those with poor vasomotor control.

The latter class includes numerous individuals who are either overvigorous in their reactions and run a

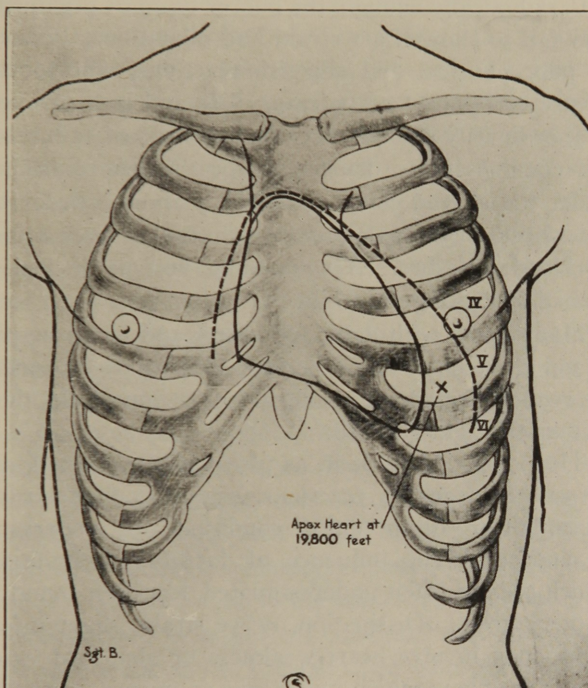

Fig. 1.—Dilatation of the heart under deficiency of oxygen beyond the individual's power of compensation: solid line, percussion outline of heart before and after experiment; broken line, outline at 19,800 feet elevation in low pressure chamber.

high blood pressure (often high strung, efficient people) or who have fluctuations of vasomotor tone which are manifested in a variety of ways but eventually lead to an identical result, namely, circulatory collapse and fainting, usually following marked dilatation of the heart.

The "optimum" type of individual will go to extreme heights with practically no signs of circulatory difficulty, and will at the end become unconscious from direct effect of oxygen want on the cortical centers, giving quite a different picture from that of circulatory collapse.

FAILURE TO COMPENSATE

Paradoxically enough, the poorer types of organisms also fail to show heart strain and dilatation. Persons of poor physical and sluggish reactions, whether by nature or because of sedentary life and lack of exercise, ordinarily show a more or less marked failure of the compensations demanded for efficient existence under the altered conditions. They show little or no quickening of the pulse, and no change, or even a fall, in blood pressure. They simply become inefficient instead of making the strain.

Many types with defective hearts and blood vessels do not show heart strain because, having tried to meet the requirements, and having found it impossible, they give up the fight and fail.

Those who do show it, as previously suggested, are persons of vigorous reactions, especially high strung types, but are often "out of condition" for one reason or another. The influence of factors of condition, which are too often underestimated, has been found to be very great. Dissipation, nerve strain, slight infections, may involve heart weakness or abnormal vasomotor reactions which overstrain or undernourish the heart, and thus cause the aviator's death.

CONDITION

The influence of "condition" is a point of the greatest practical importance, of course. One of our hardiest subjects illustrated this. He had been in the low-pressure chamber on one occasion at an elevation of 23,000 feet for some minutes and remained in practically perfect condition. The following day the experiment was repeated; but on the evening between he had dined late with friends, with the usual but not excessive accompaniments. When the altitude of 18,000 feet was reached on the second test he was found to be completely inefficient; he was markedly cyanotic; his heart was dilated 3 cm., and the heart sounds were of very poor quality. He would have collapsed in another minute if oxygen had not been administered.

The question of just what is involved in "good condition" has received much consideration. On the basis of our present knowledge, the most important element seems to be normal vasomotor control, that is, adequate nourishment of the tissues with a minimum of strain on the heart. In this the coronary circulation is of first importance. Other factors are, doubtless, the strength and condition of the heart muscle and probably certain matters of general metabolism, for example, the ability to generate energy rapidly without the accumulation of harmful waste products.

The practical result of this knowledge of the strain on the circulatory system involved in aviation, and the paramount importance of "condition," bear on both the selection and the maintenance of the flying personnel. Only those men should be allowed to fly who possess faultless circulatory systems; and once in the service, aviators deserve the most scrupulous oversight to keep them in as perfect condition as a well-trained football team, and to prevent them from going into the air when they are not in condition.

LOW OXYGEN AS A FUNCTIONAL HEART TEST

As far as the selection of men with perfect circulation is concerned, we possess fortunately a wonderful diagnostic agent in the low oxygen test, to which eventually all flyers will be subjected. We have come to regard the Henderson rebreathing apparatus as affording by far the most efficient test of the heart, from both anatomic and functional points of view, that we possess.

The strain of making good for low oxygen tension in the atmosphere is so great that any latent defect, fully compensated and not to be discovered by ordinary methods of examination, becomes glaringly apparent during a rebreathing test.

The question of anatomic condition of the valves, however, is not the only consideration with regard to a heart. Many a damaged heart will compensate so well, as the result of the quality of the heart muscle, that its functional power may even be above normal. Clinicians have long been searching for a functional heart test which would tell them, not what the heart was anatomically, but what it could do. In the low oxygen methods we have just such a test, and it should be of great value in ordinary clinical work.

In the case of well compensated valvular disease, murmurs develop under low oxygen or become much stronger, and accentuation of heart sounds takes place, indicating hypertrophy of the left ventricle or back pressure through the lungs; the blood pressure is high and the heart is evidently overworking seriously. Often in young men such a heart will be fully as successful as a normal one in meeting the demands made on it in ordinary life; in fact, overcompensation is the rule rather than a failure to compensate. But under the low oxygen test the underlying defect is revealed.

In the case of valvular lesions that are less well compensated, the heart is more readily reduced to incompetence; after the period of overwork there is marked cyanosis, excessive discomfort, and insufficiency of the peripheral circulation, most delicately shown by inability to perform well on the psychologic apparatus that forms part of the rebreathing test.

In subjects with arterial disease there is a more or less marked rise in blood pressure owing to inability of the peripheral vessels to make way for the increase of blood flow without throwing a much increased strain on the heart. At the same time there is doubtless insufficiency of the coronary circulation as well, so that between high blood pressure and poor nutrition the heart muscle soon becomes incompetent; the heart

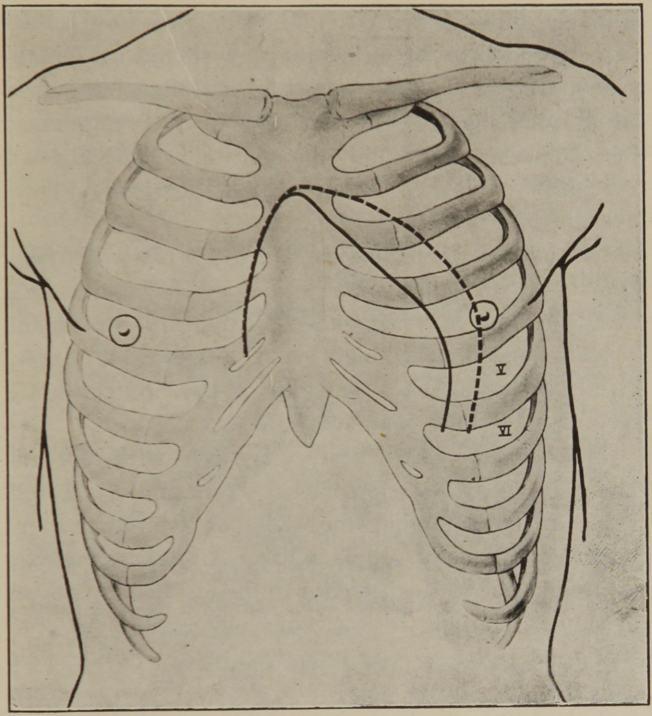

Fig. 2.—Dilatation of the heart at 18,000 feet when man was in poor condition; when feeling well, this man could go 5,000 feet higher without any ill effects: solid line, outline of heart before and after experiment; broken line, heart outline to percussion at elevation of 18,000 feet.

sounds deteriorate rapidly in quality, and the peripheral circulation becomes insufficient.

Tendencies to arrhythmia are brought out in a remarkable way by the rebreathing apparatus: several hearts that showed at the start only an occasional extrasystole have become arrhythmic to a degree that was positively alarming. We suspect that there is the possibility of danger in this method of examination for hearts showing difficulty of conduction or in which there is a possibility of the development of ventricular fibrillation.

One of the most gratifying features of this work has been the direct bearing of the observations on fundamental questions of circulatory physiology and pathology. In this way they go far beyond the narrow field of aviation medicine in their scope. It is impossible here to discuss thoroughly the many side-lights thrown on clinical medicine. A few of these points may, however, be briefly mentioned.

One is the supreme importance of normal vasomotor control in connection with circulatory efficiency, which means general efficiency as well. Abnormal vasomotor reactions mean either high blood pressure with excessive heart strain if the demands on the circulation are met, or inefficiency if the demands are not met.

The behavior in the test of subjects with more or less marked arteriosclerosis has been of the greatest value in understanding the effect of arterial change[1] under conditions of ordinary life. An interesting fact is brought out by the behavior in the test usually shown by subjects in their thirties, which suggests that arterial change at this age is commonly already considerable. This may account to a large degree for the well known fact that 20 is the best age for flyers, and that every year above this decreases the likelihood of their being able to stand the strain of hard service.

The relation of nerve tension to vasomotor control is a subject on which we have been able to throw some light, and our results fit in well with the demonstration by the British commissions of the intimate relation of the vasomotor system to shell shock, trench neuroses,

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1. See Chart 2 in the preceding paper of this series.

irritable heart and allied conditions that have contributed so largely to the disabilities of this war. The frequency with which slight cardiac lesions have been demonstrated among presumably healthy men has been striking. Even among a class of men as carefully picked as American aviators we have found more than 5 per cent. These were usually cases that could hardly have been demonstrated by ordinary means of examination, and would have passed the most rigid inspection as "functional heart murmurs" or at worst as borderline cases with a wide margin of safety. Every one who has worked on the Army cardiovascular boards knows how common and how troublesome such cases are; and the British experience shows that men who genuinely have slight organic lesions will not stand up under modern war conditions. For this kind of work the low oxygen test should be of the greatest value.

Similar to this class of cases are "athletic hearts," which we have very frequently encountered among aviators, who are to a large extent drawn from the ranks of college athletes. Such hearts behave very badly under low oxygen. They show high blood pressure, marked heart strain, with exhaustion and eventual collapse. Without entering into any discussion of the question, it may be said that our evidence points strongly to the belief that the so-called "athletic heart" represents not a faulty involution of a normally hypertrophied heart, but a heart that has either been definitely injured by strain, or one with an underlying vascular lesion too slight or too well compensated to be discovered. We have demonstrated slight old mitral insufficiency in several men whose names are familiar on the sporting page of the papers.

IV. PSYCHOLOGIC OBSERVATIONS AND METHODS *

KNIGHT DUNLAP (Baltimore)
Major, S. C., N. A.
MINEOLA, L. I., N. Y.

The psychologic tests now used in determining the ability of candidates for the aviation service to withstand altitude have been developed for use under the practical conditions of the Henderson rebreathing apparatus, in which the rate of oxygen decrease is rapid. The statements made here with regard to the course of the phenomena apply only to conditions of brief ascents, and do not necessarily hold in all particulars for cases in which the aviator is kept at corresponding altitudes for long periods of time.

The effects of oxygen insufficiency on the physiologic process were in the beginning of our work studied empirically, with the least possible hypothetic guidance. Our results square distinctly with the conception of psychologic processes as integrative, that is, as dependent on the working together of the central nervous system as a whole rather than on the action of any specific parts of the system.

The basic and important psychologic effects of oxygen deficiency are on voluntary sensorimotor coordination and attention. Until asphyxiation reaches the stage in which the integrative mechanism is rapidly approaching the condition of complete failure, no effects are demonstrable that are not clearly the failure of the one or the other, or both, of these two mental factors. In the prefinal stages perception is as efficient as the muscular control of the sense organs and organs

*From the Medical Research Laboratory, Air Service, Mineola, L. I.

of expression, and the power to attend to the stimuli, permit. Discriminative judgment, likewise, shows no falling off in rapidity or accuracy except as impaired motor control and attention produce it. Memory, both "immediate memory," as tested by the ability to reproduce what has been perceived or learned immediately before, and "true memory," as tested by the ability to reproduce something that has been "latent" for a certain interval after being learned, is apparently not affected, except as the inability to attend to the details in learning or in reproducing, or inability to control the muscular mechanism of expression, may enter. The efficiency of limited neuromuscular groups, as indicated by dynamometer tests, is not impaired in the prefinal stages of asphyxiation.

As instances of tests involving perception and discrimination, we may cite the copying of a list of words and the translation of words into code. In both of these cases, speed and accuracy are maintained up to the final stages of asphyxiation, provided the muscular mechanism of accommodation and convergence is not seriously affected; although the mechanism for handwriting may be so affected that the written results of the list are legible with difficulty.

In more complicated discrimination, in which rapid and accurate recognition and classification of material are required, the results are similar. Ability to locate correctly on a chart the positions of objects previously seen is unimpaired up to the point at which the individual's coordinations of movement become so much affected that the charting is defective on that account.

It is interesting to note that the sensitivity and acuity of the sense organs show no consistent impairment, and that apparently the speed of simple reactions (the simple reactions do not, in general, require a high degree of integration) is not intrinsically diminished. More work remains to be done on simple reactions, however, before definite statements can be made. The distinctive effect on the nervous system, in short, seems to be a change in its integrative action, and not a change in the efficiency of any particular part or unit. The whole picture of progressive asphyxiation, from a psychologic point of view, is strongly suggestive of the picture of progressive alcoholic intoxication.

Under the practical requirements of rating, tests must be single and brief, during progressive depletion of the oxygen supply. If many individuals are to be examined it is not practicable to spend even several hours on each one. Hence it is not possible to hold the subject at a moderately high altitude, such that asphyxiation effects will eventually appear. Nor is it possible to repeat a briefer test a number of times. Hence, the subject must be allowed to rebreath himself rapidly (during not much over a half hour, at most) to a low point of oxygen tension, reaching his maximal "altitude" for that rate of "ascent." It follows that the method used must be one which is not approved for psychologic work under other conditions, and which, for want of a better term, is called clinical. That is, since the reactor's condition is rapidly changing from minute to minute, we must be able to determine at any minute his psychologic condition, and cannot use the method (more exact under other conditions) of determining the average speed and accuracy of work done during a period of several minutes.

It was early discovered that under asphyxiation, as under alcoholic intoxication, it is possible for a reactor to "pull himself together" for a brief span of time (a minute or even several minutes), during which his efficiency on a set task may be as high as in his normal condition, or even higher, sinking at the termination of the task to a relatively low level of efficiency. If given a series of tasks, with brief resting intervals between, the reactor may therefore accomplish a performance that is practically normal, even up to a minute or two before the point at which complete lapse of integration occurs. In this way, his real psychologic deterioration may be concealed. It is necessary, therefore, to set a task which, although minimally fatiguing, is practically continuous, allowing the reactor no expected periods in which no work will be demanded of him, and thus preventing him from making use of attention peaks, as the phases of "pulling himself together" may justly be called. In determining the sensitivity or acuity of sense organs, on the other hand, the "attention peaks" are precisely in order, and pause should be taken to present the stimuli at the highest peaks.

It is probable that in earlier work on the action of alcohol and other drugs, and of fatigue, many failures to find psychophysical effects were due to the evoking of attention peaks by brief or periodic tests, thus masking the real condition of the patient tested.

Many tests that otherwise would be applicable impel the reactor to hold his breath during the crucial moments. The conventional steadiness test is one of this sort. If the reactor, already suffering from oxygen deficiency, holds his breath for twenty seconds, or largely reduces his breathing during that period, he makes a large change in his oxygen supply. Hence the purpose of the test is largely defeated. The steadiness test, and others in this class, although some show marked effects of low oxygen tension, cannot be used.

The apparatus used in administering the psychologic test we have called the "L V F" apparatus. The principal parts of the apparatus are assembled on a table with a top adjustable in height and slope, supported on a single heavy post from a cast iron base. This table (the so-called Dunlap table) is designed to give the necessary rigid but convenient mounting.

APPARATUS AND METHOD OF TESTING

The apparatus mounted on the table is designed to require attention and reaction on the part of the man undergoing the test analogous to the conditions of the pilot in the air. It allows the slightest deviation of reaction or lapse of attention to be noted. It consists of three separate units:

1. A series of fourteen stimulus lamps (2 candle power) arranged in two rows of seven each, with two similarly arranged rows of contact buttons, each button surrounded by a metal washer; a green check lamp and a red error lamp, and a stylus with a hard rubber handle and metal tip. These parts of the unit are so wired electrically that when a stimulus lamp is lighted the corresponding contact button is "alive," and if touched with the metal tip of the stylus causes the check lamp to light. If the washer surrounding any of the buttons is touched with the stylus at any time, the error lamp is lighted.

2. Two ammeters, mounted on a metal arm above the table top. These are connected in series with two rheostats, one on the upper side of the table top at the edge nearer the reactor, the other underneath, at the edge nearer the observer. One ammeter faces the reactor, the other the observer. A change in the resistance made by the observer at his rheostat, causing a change in the ammeter reading, may be compensated for by a change in the reactor's rheostat, by which the original ammeter reading may be restored.

3. A small electric motor, mounted on the upper side of the table top. This motor is connected in series with a third rheostat underneath the table. A two-way lever switch mounted underneath the table at the observer's edge and a rocking pedal two-way switch on the floor under the table, connected with the rheostat, can be cut out (thus increasing the speed of the motor) by either switch, and again cut in (thus restoring the lower motor speed) by either switch.

In order to control the fourteen stimulus lamps, lighting them at the proper time, an accessory piece of apparatus is mounted on a small table in any convenient position, and electrically connected with the apparatus on the Dunlap table. At first, this accessory apparatus consisted of a button board, having fourteen buttons corresponding to the fourteen lights; and from these buttons an enlisted man controlled the lighting of the stimulus lamps, timing his actions by a stop-watch.

For this button board an automatic distributor is now being substituted, which both times and selects the lights, being operated by a synchronous motor.

Before the rebreathing is commenced, the reactor is given carefully formulated instructions, and if necessary he is coached during the first three minutes of the work. His tasks are as follows: 1. As soon as a stimulus lamp lights he must touch with the stylus, held in the right hand (except in the case of left-handed subjects), the corresponding "button," touching it accurately and carefully. 2. Whenever the motor increases speed, as indicated by a change in its sound, he must bring the speed down to normal again by throwing his pedal switch. 3. When the hand of the ammeter is changed from its standard position, he must bring it back to standard by varying the position of the rheostat handle.

During the early part of the test, the psychologist notes the composure and attention of the reactor, and his comprehension of the instructions; also his motor tendencies, which are recorded in a fixed scale of types. Further, the psychologist watches for the beginning of the effects of oxygen deficiency on attention and coordination; for the moments at which these effects attain a certain standardized importance, and for the final moment of "complete inefficiency," which will be followed very quickly by a complete breakdown and unconsciousness unless the reactor is given air. Since the change in the reactor's condition is very rapid at this phase, and the effects on the nervous system lag behind the respiratory conditions somewhat, prompt relief is necessary, or the reactor may become unconscious after being given air: before the renewed air supply "catches up" with the nervous system, as it were.

RESULTS

The various ways in which the effects on coordination and attention are manifested in different reactors have been carefully analyzed and studied, and, as a result, very satisfactory results are obtained.

In addition to the practical application of the tests to the rating of aviators, we have obtained results that have considerable scientific value for future psychologic work. The application of our general method (that is, involving a group of continuous tasks) to the study of problems of drug and fatigue action is an obvious possibility. Our specific apparatus and routine are adapted to the oxygen rating problem alone, but modifications to suit the purposes of research may be readily made. One such modification has been made already by Captain Dockeray, for work on fatigue and "staleness," and is being given thorough trial. Carefully worked out series of experiments on discrimination and judgment, code translation, mathematical operations, memory, auditory functions, etc., have been made under the supervision of Captains Dockeray and Johnson and myself for the purpose of checking my earlier results, and tests on handwriting have been made by Major Watson in the low pressure tank. These, in addition to their bearing on the rating tests, have produced important scientific results.

In working on the psychologic factors in blood pressure changes, striking indications of the presence of which appeared in the rating tests, we have found strong evidence that apprehension is uniformly accompanied by a rise in systolic pressure, which tends shortly to return to normal, but that when actual fear is present the rise is much more sustained. The conditions under which the rise due to apprehension occurs are somewhat complicated; we should have reason to expect it under practical conditions, for example, when the flying cadet is notified that he is to make a flight, with possibly entire subsidence a short time later when he actually gets into the machine.

V. THE EFFECT OF ALTITUDE ON OCULAR FUNCTIONS*

WILLIAM H. WILMER, M.D. (WASHINGTON, D. C.)
Colonel, M. C., N. A.
AND
CONRAD BERENS, JR., M.D. (NEW YORK)
Captain, M. R. C., U. S. Army
MINEOLA, L. I., N. Y.

The examination of the aviators for the Air Service of the United States is much more strict than that of any other nation. In spite of the careful examination that eliminates men with manifestly imperfect eyes, fliers sometimes exhibit marked derangement of the ocular functions under the stress of flying and the conditions connected with it.

In all articles pertaining to the selection of aviators, from the Allies or from alien countries, normal vision is considered to be the chief requisite. Surgeon H. Graeme Anderson of the Royal Naval Service and adviser to the British Air Medical Service, in a discussion of the physical qualifications of fliers, says, "Practically every one of the physicians and officers taking part in the discussion agreed that the function of vision was of the greatest importance."

With this in mind, visual acuity under oxygen depletion, as compared with the behavior of this function under normal oxygen supply, has been studied with the aid of the Ives visual acuity test object, Snellen's type and Johnson's apparatus.

It was soon found that Snellen's type and similar test objects were unsatisfactory for use with the rebreathing apparatus and that the observations thus

*From the Medical Research Laboratory, Air Service, Mineola, L. I.

made were inconclusive. The accompanying tabulation gives the results of visual tests made on thirty-three subjects on the rebreathing apparatus and in the low-pressure chamber, with the aid of the Ives instrument.

The subjects are classified as normal and subnormal, that is, those who, so far as the eyes are concerned,

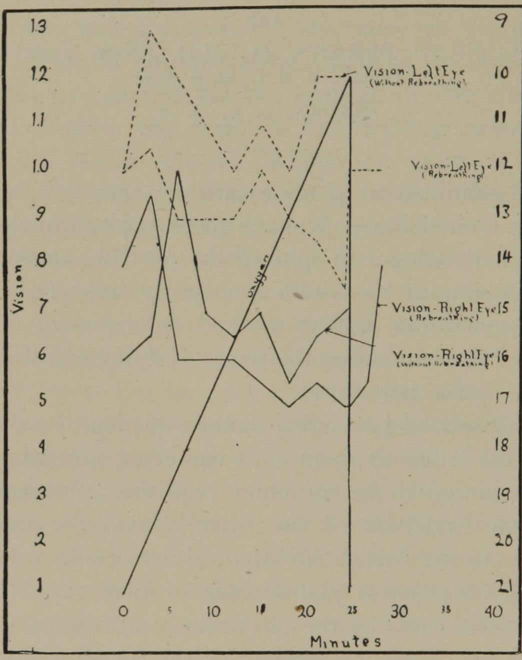

Fig. 1.—Effect of lack of oxygen on visual acuity, showing decrease during test on rebreathing apparatus.

would pass the examination for the flying corps and those who would be ocularly disqualified.

RESULTS OF VISUAL TESTS

	Normal		Subnormal.	
	No.	Per Cent.	No.	Per Cent.
Vision improved	3	12	..	....
Vision deteriorated	7	28	3	37.5
No change	15	60	5	62.5

The eight subnormal cases were so classed because of defective vision due to errors of refraction.

As Dr. Guilbert of the French Air Service says that, "at 2,000 meters, in general, the visual acuity increases by a third by reason of the congestion of all the organs of the head, and in particular of the choroid and retina," we have tested the visual acuity of twelve subjects while inhaling 2 minims of amyl nitrite, thus causing congestion of the vessels of the head. In all of the cases but one (a myope) there was impairment of the vision during the period of maximum nitrite effect.

JUDGMENT OF DISTANCE AND STEREOSCOPIC VISION

In the judgment of distances there are many factors involved, practice and training play a great part. The power to stereoscope accurately and quickly gives, according to our experience, most valuable aid in determining the flier's ability to judge distance.

The stereoscopic vision was tested, on the Henderson rebreathing apparatus and in the low-pressure chamber by the use of the ordinary stereoscope. The ability to maintain perfect stereoscopic vision at different altitudes was noted.

Six normal cases examined on the rebreathing apparatus showed change in only two. These manifested a confusion in this power at high altitudes.

One of the three subnormals examined in this way became confused at the time of his general break; the other two remained unchanged.

Three normals and three subnormals were taken in the low-pressure chamber. One out of each group showed a confusion at high altitudes. One of these manifesting confused stereoscopic vision was rapidly restored to normal by the administration of oxygen.

REACTION TIME

It is absolutely essential that the pilot think and act quickly and accurately, for the man with the quickest reaction usually lives to tell the tale. The French and Italians have placed great confidence in determining simple reaction time, that is, one possible reaction to one possible stimulus. This form of reaction is too apt to become a simple reflex and hence become independent of the higher processes. Therefore, this laboratory has chosen the Reeves visual discrimination reaction time experiment with four possible reactions and five possible stimuli. The subject sits facing a ground glass plate on which the stimuli appear, and he reacts to the various stimuli by pressing the key corresponding to the stimulus presented. The instant the stimulus appears, the Dunlap chronoscope begins recording time, and is stopped by the subject's reaction. All false reactions are recorded by means of a secondary circuit. The average discrimination reaction time for normal subjects has been found to be around half a second.

COLOR VISION

Normal color vision is considered a requisite for a good pilot by all Allied air services. The object of our tests has been to determine the effect of low oxygen tension on color vision.

Stilling's plates were used in these tests. Five subjects were examined in the low-pressure tank and carried to 20,000 feet or above. Five subjects were examined on the rebreathing apparatus and carried above 20,000 feet. This series of subjects, during the entire experiment, showed no change in color vision. Threshold color vision will be considered under retinal sensitivity.

FIELD OF BINOCULAR FIXATION

It is important that the aviator be able to carry the eyes as far as possible in the various directions without seeing double. If a man has a contracted field of fixation, it necessarily impairs his ability in flying. The field of binocular fixation has been taken by means of the Schweiger perimeter modified for binocular use or by means of a large tangent screen, the Wilmer wand and Wilmer glasses being used. Of 122 men acceptable for the Aviation Section, Signal Corps, who have been examined and sixteen who were not acceptable, 7.37 per cent. of the normals showed contraction of the field of binocular fixation, and 50 per

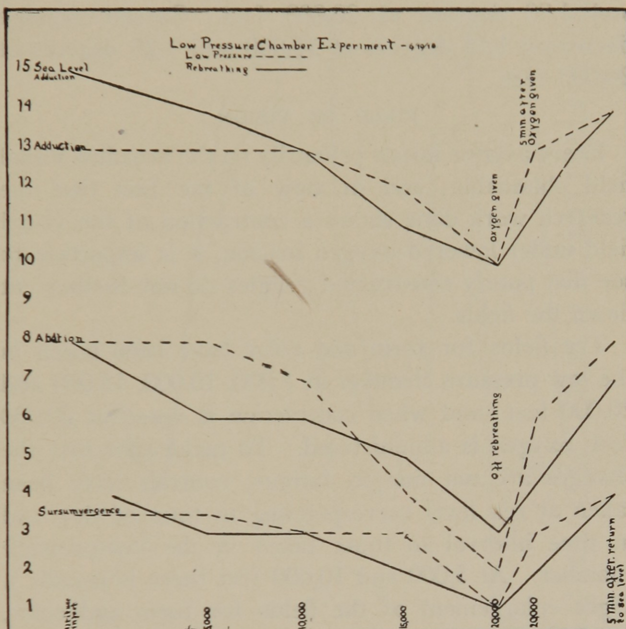

Fig. 2.—Effect of lack of oxygen on the strength of the ocular muscles. Rebreathing and low-pressure findings compared. Note return of strength on administration of oxygen, even when under low barometric pressure in the decompression chamber.

cent. of the subnormal men showed contraction. Narrowing of the field was most marked above.

MUSCLE BALANCE

Normal muscle balance should be insisted on, for even a small defect may be accentuated by the strain of flying and lack of oxygen, resulting in diplopia or at least a marked contraction of the field of binocular fixation at low altitudes. Exophoria and hyperphoria are more serious than esophoria. Twenty-five men, ocularly acceptable for the Aviation Section, Signal Corps, were examined in the low-pressure chamber and on the rebreathing apparatus. Abduction decreased 1.31 degrees at 15,000 feet and 1.55 degrees at 20,000 feet. Adduction decreased 1.75 degrees at 15,000 feet and 1.90 degrees at 20,000 feet. Sursumvergence decreased 1.15 degrees at 15,000 and 1.25 degrees at 20,000 feet.

FIELD OF VISION

Every aviator insists primarily on the broadest visual field obtainable; and in view of the fact that the research work done shows a contraction of the visual field under lowered oxygen tension, it is important to see that poorly constructed goggles do not further cut down the fields.

The fields for form and color have been taken in the low-pressure chamber at 5,000, 10,000, 15,000 and 20,000 feet; and when contraction is noted at 20,000 feet, oxygen is administered. To make sure that the changes are not due to fatigue, controls have been taken at sea level corresponding in time of day and in time interval to those taken in the low-pressure chamber. At 5,000 and 10,000 feet there is usually a slight enlargement of the fields for form and color, at 15,000 a slight contraction, and at 20,000 a marked contraction. Twenty men have been examined, and at 20,000 feet the fields for form have shown a contraction of 14 per cent. of their original size below, 3.5 per cent. in the temporal field, 4 per cent. above, and 8 per cent. in the nasal field. The red has lost 9 per cent. below, 6.5 per cent. temporally, 4 per cent. above, and 6 per cent. nasally. The green, 4.5 per cent. in the lower, 5 per cent. in the temporal, 5 per cent. above, and 25 per cent. in the nasal field. Five minutes after returning to sea level, fields are normal in size. Giving oxygen at 20,000 feet for four or five minutes causes a return of the field to normal. Several fields have been taken on the rebreathing apparatus, and the results are fairly comparable with those found in the low-pressure chamber.

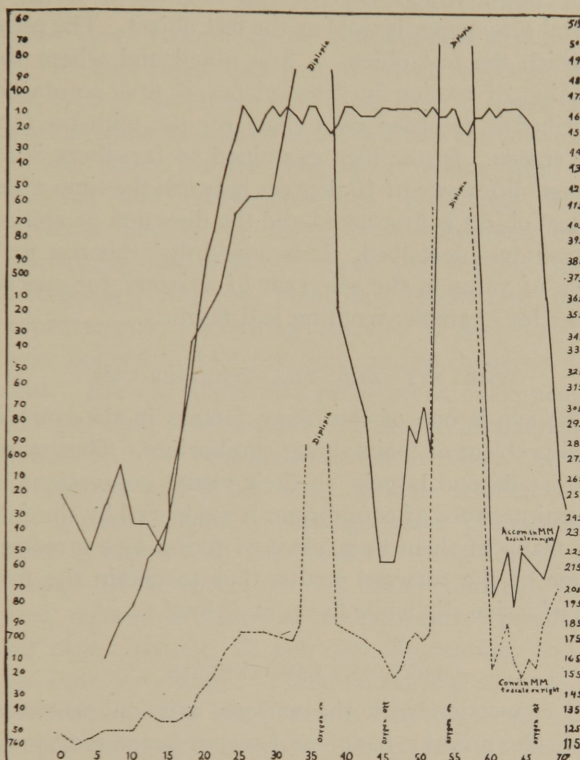

Fig. 3.—Falling off of accommodation and convergence in low-pressure chamber and return of strength on administration of oxygen.

PERCEPTION OF MOTION AND ITS DIRECTION BY THE RETINA

Perception of motion and its direction is of great importance to the aviator, and a test has been devised in this laboratory that will give some indication of the flier's power in this respect. The best pilots feel that by constant practice they may develop this important function to a marked degree. The test is performed with the subject seated 15 inches from a Bjerrum screen, fixing with both eyes a 3 mm. white pin placed in the screen on a level with the eye. A small light, which is visible through the cloth or neutral gray paper is used as the test object. The point at which the test object is first noted and where the direction of motion in three planes is first accurately described is recorded on a chart for use with the tangent screen. In the men examined so far, there is an average difference of 10 degrees between the time when the test object is first noted and the direction of motion is accurately described. It is hoped that this test may prove of value in the selection of aviators for special work; for example, scouting and fighting.

THE EYE AND THE EQUILIBRIUM

The eye is one of the many factors in the complicated problem of maintaining equilibrium. That many aviators depend largely on their visual impressions in the maintenance of equilibrium is evidenced by the fact that many of them tie a piece of string as a streamer to one of the forward struts, thus to obtain the first sign of a side slip while flying in a cloud.

INTRA-OCULAR TENSION

In connection with the various aviation problems, where there is the factor of lowered barometric pressure as well as lowered oxygen tension, the intra-ocular tension has been taken at different altitudes. Fourteen men have been examined in the low-pressure chamber. The examinations so far have not been numerous enough to draw very definite conclusions. We have found, however, no correlation between the intra-ocular tension and the blood pressure, lowered oxygen tension and various cardiovascular changes. Later on, a detailed report on this subject will be possible.

ACCOMMODATION IN FLYING

It is important that the flier maintain his ability to accommodate under all conditions to which he is subjected, for his life may depend on his ability to see clearly. The near point of accommodation has been taken every minute in the low-pressure chamber and on the rebreathing apparatus, a Prince rule with Jaeger test type or the Duane disk being used as a test object. Normal runs have been made without the low oxygen tension effect for the purpose of comparisôn. One hundred and forty-eight men, acceptable for the Aviation Service as fliers, were examined on the rebreathing apparatus. Of these, 44.6 per cent. showed a receding of the near point, and 18 per cent. showed improvement; fluctuating changes in accommodation were noticed in 14.4 per cent., and no change in 23 per cent. Eleven subnormal cases were examined, and 63.7 per cent. manifested a decrease in accommodative power, 18.3 per cent. an apparent increase, 9 per cent. no change, and 9 per cent. variable reactions. The low-pressure chamber findings were practically the same as those with the Henderson rebreathing apparatus. Of seventeen normal men examined, 47 per cent. showed decrease in accommodative power, 11.7 per cent. increase, 23 per cent. fluctuation, and 17.8 per cent. no change. Three subnormal subjects were examined in the low-pressure chamber; two showed a decrease in accommodative power, and the other gave a varying reaction. When the subject is brought to sea level, the accommodation comes back rapidly in some and slowly in others. The inhalation of oxygen invariably causes a return to normal, even though the subject may be kept at 20,000 feet in the low-pressure chamber.

That these changes do not follow the cardiovascular reactions is shown by the fact that fifty-seven men, exhibiting acceleration of pulse rate and maintenance of pulse pressure, showed in 42.1 per cent. decrease in the power of accommodation, and 15.8 per cent. increase in power of accommodation, 15.8 per cent. fluctuation in accommodation, and 36.3 per cent. no change in accommodation. Our researches would lead us to believe that hyperopes and subjects with a marked amount of hyperopic astigmatism show the most marked changes in accommodation.

Fatigue of accommodation has been studied with Howe's ophthalmic ergograph as modified by Captain Berens. Normal three-minute runs were made without the low oxygen tension effect as controls; then three-minute runs with the same time interval were made in the low-pressure chamber and on the rebreathing apparatus. The findings on the rebreathing apparatus and in the low-pressure chamber showed, at 15,000 feet, a more rapid onset of fatigue than was evidenced by the controls; and at 20,000 feet, the fatigue was marked. The administration of oxygen in the low-pressure chamber or rebreathing apparatus rapidly restored the normal tone of the ciliary muscle.

CONVERGENCE

The near point of convergence has been tested, because of the belief that the aviator should have binocular vision and that a weakness in convergence, which might lead to diplopia, would certainly impair his efficiency and could easily result in an accident. A U-shaped piece was cut out of the Prince rule to fit over the nose, and a 2 mm. black dot on a white background was used as a test object for making this determination. Readings were taken without low oxygen tension effect and with low oxygen tension effect, and the effect of the administration of oxygen was determined. Readings were taken every two minutes and charted. One hundred and forty-seven men with normal eyes were examined on the Henderson rebreathing apparatus, of whom 50.3 per cent. showed decrease in convergence power, 17.6 per cent. increase, 11.5 per cent. fluctuation, and 20.6 per cent. no change.

Of eleven subnormal men examined (six were disqualified for visual acuity and five for muscular imbalance), 45.7 per cent. showed decrease in power of convergence. Increased converging power, fluctuating changes and no change in the near point of convergence were each noted in 18.1 per cent. Of

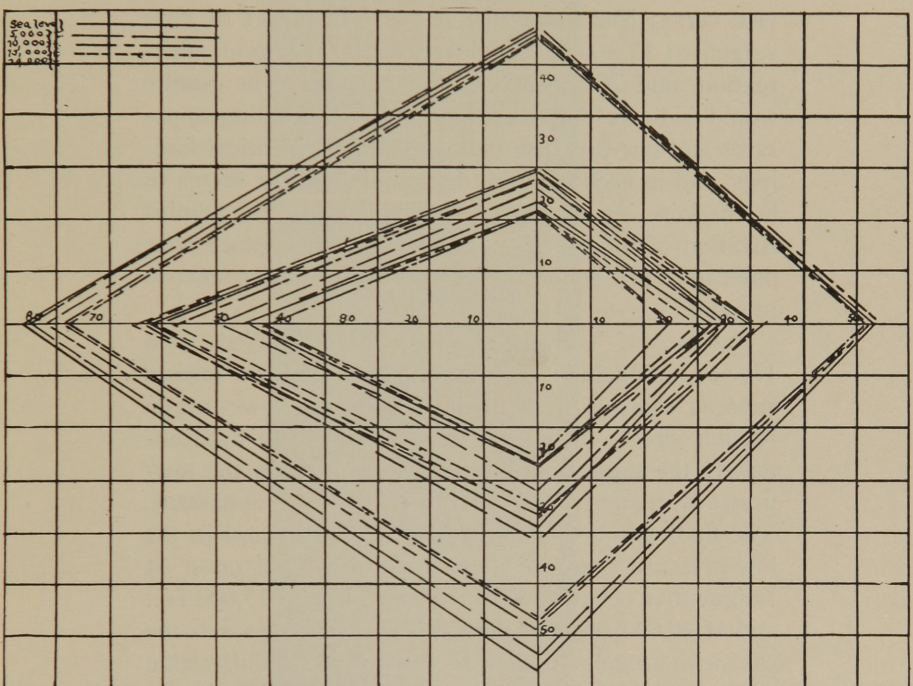

Fig. 4.—Contraction of field of vision in low-pressure chamber at pressures equivalent to 5,000, 10,000, 15,000 and 20,000 feet.

sixteen normal men examined in the low-pressure chamber, 50 per cent. showed falling off in power of convergence, none showed increase, fluctuating reactions were present in 12.5 per cent. and 37.5 per cent. remained unchanged. In the subnormal group the recession of the near point was very marked, sometimes resulting in diplopia.

It was attempted to show what relationship, if any, exists between the convergence and the cardiovascular reactions to low oxygen tension. Seventy-two subjects showing an increase in pulse rate and a maintenance in pulse pressure gave these convergence changes, which would seem to indicate the ocular changes cannot be predicted by the cardiovascular reaction and vice versa: 54.2 per cent., decrease in power of convergence; 15.3 per cent., increase; 9.7 per cent., fluctuation, and 20.8 per cent., no change. The results would indicate that the Henderson rebreathing apparatus and low-pressure tank give almost identical findings, and in each case the determining factor seems to be the lowering of oxygen tension, because the administration of oxygen soon causes the convergence near point to return to normal, irrespective of the barometric pressure.

Fatigue of convergence has been studied with Howe's ophthalmic ergograph. Normal three-minute runs as controls were made without the low oxygen tension effect; then three-minute runs with approximately the same time interval were made in the low-pressure chamber and on the rebreathing apparatus. The findings on the rebreathing apparatus and in the low-pressure chamber showed a more rapid onset of fatigue than occurred with the controls. At 15,000 feet and at 20,000 feet the fatigue was marked, as was the case with accommodation. Here also the administration of oxygen caused a rapid return of converging power.

RETINAL SENSITIVITY

It is important that the retina be normally sensitive to light impressions, especially for those men who must fly at night, notably bombers and fliers doing patrol duty. A test for the contrast sensitivity of the retina has proved most useful and practical for our work, and only men who have normal sensitivity in this respect will be selected for night flying.

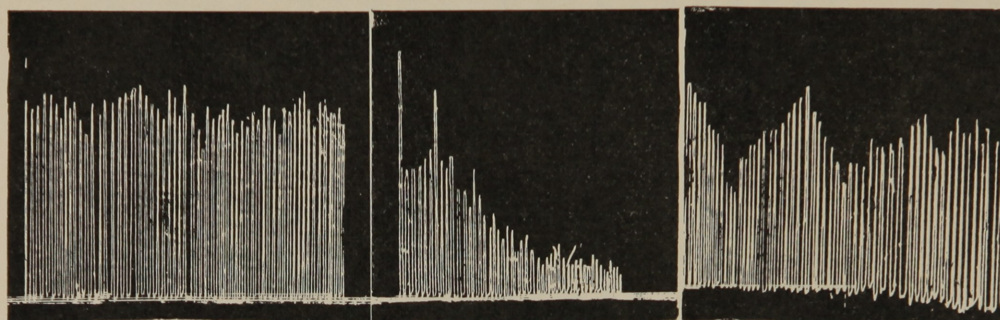

Fig. 5.—Fatigue of accommodation: Normal at sea level (left hand record); rapid fatigue at 22,000 feet in rebreathing test (middle record), and variations occurring 1.3 minutes later, subject breathing normal air (right hand record).

In this laboratory, tests to determine the threshold sensitivity of white and colored lights and for contrast are conducted in the following manner:

The Reeves wedge is made of two pieces of glass at a known angle, between which is run a solution of gelatin and neutral dye. The wedge is calibrated in millimeters, which is translatable into the percentage of light transmitted.

To test the threshold sensitivity to light, the subject is placed 20 feet from a spot of light, 3 mm. in diameter. Holding the wedge before the right eye, he slowly draws the slide from its cover, and as the light just disappears, a reading is taken. This reading is in millimeters and is then translated to percentage of transmission.

The threshold for color is taken the same as the foregoing, red and green lights, which are practically monochromatic, being employed.

The test of contrast sensitivitiy is made with a Reeves wedge and Reeves contrast square. The contrast square is made by placing a square of dark gray paper on a larger square of lighter gray, there being thirteen perceptible differences between the two papers. An illiterate "E" with the same perceptible differences is used as a check of the findings. This is lighted by a 75-watt nitrogen daylight lamp at a given angle and distance from the test object, and the subject is placed 20 feet in front of the object. The reading on the wedge is taken just as the contrast between the squares disappears. The average readings taken with the contrast sensitivity square gives 3.4 mm., and the illiterate "E" 3.2 mm. To date, the normal for the light threshold of thirty-five subjects is 6.5 mm. The threshold for colors is: red, 4.4 mm., green, 3.7 mm.

Under the rebreathing test the threshold for light has shown an improvement in 25.9 per cent.; 44.5 per cent. show neither improvement nor falling off, and 29.6 per cent. show a falling off in sensitivity.

In the study of the threshold for colors, the red and green both show a falling off in 71.4 per cent., and neither a gain nor a loss in 28.6 per cent.

In former tests with a blue light, which was not absolutely monochromatic, there was improvement in 66.6 per cent. and falling off in 33.4 per cent.

CONCLUSION

In spite of the fact that the tests made in the laboratory are influenced somewhat by the psychologic elements of excitement, concentration, etc., still, we have found very sensitive and definite ocular reactions under the conditions to which the airman is subjected. The changes in the eye (one of the most delicate of the peripheral sense organs) are due mainly to the want of oxygen, and not to the many other suggested conditions, such as lowered blood pressure, decreased atmospheric pressure, carbon monoxid, nervous strain, and vibration of the motor. In our experience, the administration of oxygen prevents the occurrence of the untoward symptoms; but when these symptoms have occurred through its want, oxygen quickly restores the functions to normal.

VI. INFLUENCE OF ALTITUDE ON THE HEARING AND THE MOTION-SENSING APPARATUS OF THE EAR *

E. R. LEWIS, M.D. (Dubuque, Iowa)
Lieutenant-Colonel, M. C., N. A.
MINEOLA, L. I., N. Y.

The middle ear mechanism is normally adjusted to transmit sound vibrations in either direction. Ordinarily this apparatus is largely occupied in transmitting sound vibrations from without inward. The membrana tympani is set into vibration by impact of vibrations transmitted by the air in the external auditory canal, and the ossicular chain carries the vibrations across the tympanic cavity to the footplate of the stapes, which, with its annular ligament, fills the oval window. The perilymph there receives the impact, and owing to the venting action of the internal drumhead of the round window, this incompressible fluid is enabled to take up the vibrations and distribute them by way of the saccule and cochlea in such a manner as to bring about interaction between the sensory cells of Corti and the tectorial membrane. This stimulation causes these cells to emit nerve impulses which are translated in the sensorium into hearing.

Whereas the conformation of the auditory canal, tympanic cavity, saccule, scala tympani, and scala vestibuli is such as to facilitate delivery of most of the incoming vibrations to the cells of Corti, the petrous bone conducts a certain amount of the incoming vibrations away from their ultimate cochlear distribution.

Any obstruction in the path of these vibrations determines an increase in the conduction of sound vibrations

*From the Medical Research Laboratory, Air Service, Mineola, L. I.

away from the Corti cells, and the volume of such afferrent vibrations is directly proportionate to the amount of obstruction.

Sound vibrations are also conducted to the tympanic cavity by way of the bony structures of the skull, and a certain amount of such vibrations are conducted away from Corti's cells by way of the ossicular chain, membrana tympani and thence the air in the external auditory canal.

By utilizing certain uniform sound stimuli applied in the form of standard tests and observing responses, it is possible to determine the normality of sound conduction and sound perception; also the general character of certain abnormalities of sound conduction and sound perception.

The motion-sensing mechanism of the internal ear is situated within an intricate physical instrument, the utricles and semicircular canals; one half of this physical instrument is housed in the right petrous bone, the other half in the left. Motion to which this instrument is subjected is immediately participated in by the fluid contained within it and brings about an interaction between the hairs of the sensory cells of the cristae and the cupula surmounting them, causing stimulation of these sensory cells and emission of nerve impulses, which are translated in the sensorium as sense of the body being in motion. A certain quotum of these impulses originating in the cells of the cristae are distributed as motor impulses to the extra-ocular muscles, causing involuntary movement of the eyes.

By utilizing certain uniform motion stimuli applied in the form of standard tests, and observing responses in a certain standard manner, it is possible to determine the normality of motion perception of this apparatus, and of eye movements resulting from stimulation of the cells of the cristae; also the general character of certain abnormalities of motion sensing and of eye movements.

Without going into the details of standard tests of the cochlear and vestibular (or motion-sensing) portions of the ear, which would entail a discussion too voluminous for presentation in this connection, it may be briefly stated that experiments have been conducted with a view to determining the effects of altitudes on each of these ear functions. In these experiments, both the Henderson rebreathing apparatus and the decompression tank types of artificial altitude have been utilized.

It has been determined that the hearing function shows no deterioration attributable to impairment of the perceptive element (stimulability of the Corti cells) prior to attaining a degree of altitude that causes acute general functional impairment of all the higher cerebral sensory and psychic centers. This condition is signalized by the onset of semiconsciousness or unconsciousness.

During ascent from a denser to a rarer atmosphere, the sound-conducting apparatus may show transitory interference with function attributable to expansion of air incarcerated within the eustachian tube, tympanic cavity or air spaces of the mastoid resulting in inequality of intratympanic and extratympanic air pressures. As adjustment of these air pressures occurs by venting through the eustachian tube, interference with function of the sound-conduction apparatus ceases.

Such disturbances are much more marked during rapid descent, when the discrepancy between intratympanic and extratympanic air pressure becomes very marked. Cases have been observed in which the extratympanic pressure was so great as to cause perforation of the drumhead. Practically all cases showed congestion of the drumhead following rapid descent. Occasionally the irritation and congestion resulting from rapid changes of altitude have been observed to cause acute otitis media.

Observations on the effects of altitude on the motion-sensing function of the ear have revealed nothing in the nature of obtunded ability to perceive motion or alterations in eye reactions to motion stimulus. Certain individuals showed greater inability to tolerate motion stimulus at 16,000 to 18,000 feet than they had shown at the accustomed altitude, as evidenced by the onset of nausea and vomiting. This, however, may be regarded as indicative of the onset of altitude sickness (ordinary "mountain sickness") rather than of altered vestibular function.

VII. EFFECTS OF LOW OXYGEN PRESSURE ON THE PERSONALITY OF THE AVIATOR *

STEWART PATON, M.D. (PRINCETON, N. J.)
Major, M. R. C., U. S. Army
MINEOLA, L. I., N. Y.

The effects of diminished oxygen supply on the personality cannot be explained until the results of the reduction on the functions of different organs have been made known. Until this information is gathered, our views on this subject are based to a great extent on a review of clinical data, illustrating some of the changes of temperament and character of the aviator taking place in the effort to adjust the organism to high altitudes.

Before reference is made to a few of the symptoms already noted, it is desirable to remind the reader of the fact that the problems involved in the study of any personality are not merely psychologic, but should include the biologic analysis of the reactions of the entire organism, considered as a living unit. It is extremely important that this point of view should be appreciated and accepted by the investigator. A personality study is a great deal more than a mere psychologic analysis, and often the correct interpretation of emotional and mental reactions is to be sought in the solution of the complex biologic problem.

Among the more frequent phenomena associated with reduced oxygen pressure is an increased irritability of the reflexes, particularly noticeable in very active knee-jerks. Sometimes there is a reduction of the knee-jerk, due to an apparent hypertension of the

* From the Medical Research Laboratory, Air Service, Mineola, L. I.

muscles and an inability to relax them. In these cases reinforcement is necessary in order to bring out the knee-jerk. This evidence of increased muscular tension in connection with the aviator is an interesting phenomenon, and deserves careful consideration. Probably impulses from the higher cortical centers are responsible for this interference with the tendon reflexes. In order to facilitate the study of these reactions it is desirable that the capacity of the aviator to relax his muscles should be tested before as well as after flying. The muscles to be tested should include those of the face, head and neck as well as the arms, legs, hands and feet. In some cases the increased tension seems to be localized. An aviator who is capable of relaxing his limb muscles may show a very tense condition of his facial muscles, or vice versa. The mental tension is reflected in many different ways. Those who suffer from the effects of reduced oxygen supply generally give some indication of this trouble in their facial expression. Varying degrees of anxiety may be represented, ranging all the way from the indefinite expression, accompanying the ill defined consciousness that some impossible task or unpleasant experience is impending, to a state of mind indicating that well formulated ideas play an important rôle in the disturbance, causing not merely apprehensiveness but also an anxiety in which intellectual processes have become active determining factors. In the indefinite states of apprehensiveness and ill defined anxiety the reactions correspond to the conditions described by the French as *angoisse,* a condition in marked contrast to the one described as *anxiété,* in which the disturbances of the higher mental responses are more strikingly in evidence than are the bulbar symptoms, marked by disorders of the circulatory, respiratory and other physiologic systems.

The occurrence of specific sensations of pain are indicative of local disorders, but the evidences of bodily and mental distress and the varying degrees of discomfort and unpleasantness evoke a variety of symptoms. Not infrequently these signs of imperfect adjustment to life in the air are intensified by conflicting trends: one a desire to continue in the Air Service and the other a consciousness of not being equal to the task. The failure of the aviator to face the dilemma squarely and settle the conflict definitely invariably leads to complications often ending in a serious loss of nerve and morale.

Mental disturbances of this character occurring as the result of lowered oxygen supply at times become sufficiently accentuated to suggest the beginning complex associated with an anxiety psychosis. In addition to the emotional disorders there is generally a very slight incoordination of the finer muscular movements, and often a marked fine tremor of the fingers and tongue.

It is interesting to note that from time to time clinicians have suspected the occurrence of some defect in the amount of oxygen supplied in connection with the various forms of anxiety neuroses. Using a form of treatment based on empiricism, attempts have been made to remedy this condition. The French clinicians for some time have recommended that oxygen be administered in these neuroses; and one or two different forms of apparatus for giving the oxygen by subcutaneous injections have been used with varying degrees of success.[1] The amount of pain accompanying the injections and the difficulty in perfecting the technic have been the chief objections to the use of this method of treatment. Heckel[1] says the method of administration that he has devised obviates these defects.

Unquestionably the administration of oxygen to a person who has been subjected to an experimental test

1. Heckel, F.: La neuroses d'angoisse, Paris, Masson & cie, 1917, p. 496.

or has ascended to a high altitude in a plane is followed by a number of interesting reactions, which have not received the attention they deserve.

We have noted that the character of the dermagraphia in a person who has been deprived of oxygen changes completely after oxygen has been inhaled for one or two minutes. The blotching character of the red line noticeable in states of fatigue, as well as following a period of reduced oxygen supply, disappears after the inhalation, and the puckering of the skin and clear edges of the line suggest that a decided improvement in the vascular tone has taken place.