Reports of the Air Medical Investigation Committee : The sense of stability and balance in the air / [by Henry Head].

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Reports of the Air Medical Investigation Committee

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OF THE

AIR MEDICAL INVESTIGATION COMMITTEE

THE SENSE OF STABILITY AND BALANCE IN THE AIR

Approved for Publication by the Medical Research Committee, November 14th, 1918.

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THE SENSE OF STABILITY AND BALANCE IN THE AIR

BY

HENRY HEAD, M.D., F.R.S.

CONTENTS.

Introduction.

The faculty in man, which has raised him to a dominant position in the animal kingdom, is his capacity to make use of tools. He projects his powers of appreciation to the extremity of some mechanical contrivance, manœuvred by hand or foot, and so enormously extends his power to influence objects at a distance from his body. When we probe a wound or use a stick to explore the ground, we 'feel' at the end of the rod, not in our fingers. From such comparatively simple acts we can rise to the most complicated adjustments of eye and hand. For example, when shooting, our eyes are fixed on the bird passing across the field of vision; the gun is then thrown up with a movement so exactly regulated in time and direction, that the shot will arrive at a certain spot at the precise moment when the flight of the bird brings it to that position in space. We do not 'aim' or calculate some hypothetical distance 'in front'; nor do we actually see the gun at all. We carry out a reaction exactly adapted to the information given by our eyes. The more automatic this response the more likely is it to succeed in bringing down the bird.

Man not only uses this power of projecting himself to the end of some mechanical appliance in his work, but games were invented to exercise this faculty. Flying a machine heavier than air is nothing more than an extended application of this power, demanding adapted movements of every part of the body and limbs. No new elements come into the mechanical problems of flying that are not evident in riding a motor-bicycle, game shooting, cricket, or golf.

The vast majority of young men can acquire any of these aptitudes. A small minority are so constituted that they cannot do so; they 'do not feel safe' on a bicycle, and 'cannot hit the ball'. Such persons are rare amongst the healthy members of the community; but they form a small group who are 'not fond of games'. At the other end of the scale stand a small number of super-men, who seem to have been born with a natural gift, which rapidly carries them to a position above the average of their fellows.

Amongst candidates for the R.A.F. our aim must be to exclude those who are congenitally incapable of flying. At the same time we cannot hope to pick out super-men. We are concerned with the average youth who is capable of adjusting himself to conditions in the air. Any healthy young man, who is able to ride a motor-bicycle and play cricket or lawn-tennis well, can be taught to fly.

Were this the whole problem it would not be difficult to select suitable candidates. But it must not be forgotten that the R.A.F. is a fighting force. A man must not only be a good chauffeur, but he must be able to fight. I examined a pilot,

who was acknowledged to be a remarkable aviator capable of flying any machine and apparently fearless in the air. But he was sent back from France because he could not fly over the lines. On the other hand, I have come across pilots with a fine fighting record, who were not good flyers in the technical sense, and neither knew nor cared anything about the details of their machine.

At first, candidates for the flying branches of the two services were admitted after a medical examination which varied greatly in strictness. But, with the coming of the Military Service Act, the rush of volunteers greatly increased. This enabled the authorities to raise the standard of the medical examination; but at the same time its aim was somewhat extended. An attempt was made, not only to exclude those who showed signs of pathological states, organic or functional, but to select men who would be able to fly well.

The various functions which come into play during aviation were analysed, and methods were devised to test the physiological activities on which they were supposed to depend.[1] At the same time the importance of the abnormal states induced by flying at high altitudes led to the invention of simple cardio-vascular and respiratory tests, which were found to be of value in appraising the general medical condition of a candidate or flying officer.

In its final form the medical examination of the Candidates Board was intended to fulfil a threefold object:

(1) To exclude all who suffered from pathological conditions. These included, not only gross defects of the heart, lungs and nervous system, but also such functional defects as 'nervous instability'.

(2) Some persons of normal constitution are liable to suffer in the air from certain grave disabilities, such as 'giddiness' and 'fainting'. These states are no more evidence of a pathological condition than is sea-sickness or inability to swing without discomfort. It was hoped that by applying tests which made a call on the activity of the semicircular canals, muscular sensibility and other fundamental sensory functions, it would be possible to exclude candidates who would suffer from these disabilities in the air.

(3) A certain proportion of pupils are rejected because they have difficulty in learning to fly; they are 'heavy on controls', 'make bad landings', or 'have no air feeling'. It was hoped that tests, founded on the sensations underlying balance, would exclude candidates who might show these defects.

On the protocol (Form C.B. 7) of the R.A.F. Commissions Board are three headings, 'Nervous Stability', 'Muscle Sense' and 'Vestibular Stability'; it is with these we are mainly concerned in the first part of this report.

Unfortunately these portions of the schedule have been filled up with the conclusions arrived at by the examiner, without any

[1] All the tests for balance were invented and carried out by Arthur H. Cheatle, F.R.C.S., who directed the Otological work of the Candidates Board.

definite record of the tests employed. In actual practice his opinion was based on the following methods of examination:

(1) The '*Nervous Stability*' of a candidate was judged from his past history, revealed by a few direct questions; by the evidence of nail-biting, tics or other signs of want of control, such as tremor of the hands and inability to balance a rod on a flat board with the eyes open.

(2) The condition of the '*Muscle Sense*' was estimated by the manner in which he balanced a rod on a flat board with his eyes closed and by his capacity to stand on one foot for 15 seconds under the same conditions.

(3) As tests of '*Vestibular Stability*' the candidate was asked to walk along a line heel to toe and to turn completely on one foot, so as to face in the opposite direction. The character of the entry under this heading was also determined by the manner in which he stood on one foot with his eyes closed.

Thus it is obvious that three mechanical tests were habitually relied on to give the information required. First, the candidate was made to extend his arms and hands to see if he was steady or tremulous. Then he was made to stand on one foot for 15 seconds and then on the other, both with the eyes open and shut; he was also made to walk along a line and turn at the word of command. Thirdly, he was made to balance a rod on a flat board by means of each hand in turn, with his eyes open and shut.

But, before any conclusion can be reached concerning the correlation of these tests with ability to fly, the results must be recorded in terms of the actual methods employed. No general opinion should be given such as 'Muscular Sense defective'; the actual facts of the examination must be recorded.

Unsteadiness, when standing on one foot with the eyes closed, was supposed to represent want of 'Muscle Sense'. I therefore examined a number of pilots and pupils, who were unable to carry out this test on either foot, for their power of recognizing passive movement at the various joints of the lower extremities. Now we know from other lines of research that this is the most delicate of all the measurable tests for what is usually called 'Muscle Sense' or 'Deep Sensibility'. So fine is the power of perceiving passive movement at all the joints from the great toe to the hip, that the normal individual can appreciate without difficulty a range of 1° or even less. This is scarcely perceptible to the eye and yet its direction can be accurately described by any intelligent person. Amongst the pilots and pupils who were unable to stand on one foot with the eyes closed, I did not find a single one who could not appreciate 1° of passive movement at all the joints of the lower extremity. It is obvious, therefore, that in the class of young men with whom we have to deal, inability to carry out this test has nothing to do with defective 'Muscle Sense', but is due to lack of motor control or want of resolution.

The condition of 'Muscle Sense' in the upper extremities is supposed to be revealed by the manner in which the rod is balanced on a board, when the eyes are closed. I have carefully

measured the power of recognizing passive movement in a series of pilots and pupils who were unable to carry out this test; records from the joints of fingers, wrist, elbow and shoulder, showed that they had no difficulty in appreciating a movement of 1°. Evidently, in the class of case from which our material is drawn, failure to carry out this test has nothing to do with defective 'Muscle Sense'.

'Vestibular Stability' is estimated by the power to walk along a line, to turn on one foot and to stand on one leg with the eyes closed. But there is no evidence to show that any of these acts bears a direct relation to the activity of the semicircular canals. Moreover, I have examined four pilots who were intensely giddy and vomited in the air, none of whom had the least difficulty in carrying out these tests perfectly.

Before any progress can be made in our knowledge of abnormal conditions of balance in the air, all such headings as 'Muscle Sense', 'Nervous Stability', and 'Vestibular Stability', must be abolished, and the records should show the results of the actual tests employed. Then only will it be possible to obtain statistical evidence of their relation to flying capacity.

Chapter I. The Tests and what they reveal.

Although success or failure in these tests does not reveal the state of the 'Muscle Sense' or extent of 'Vestibular Stability', they form a valuable guide to the patient's physical and mental condition. I shall therefore consider these different methods of examination one by one, pointing out under what circumstances they are capable of yielding useful information. The material at my disposal consisted of 30 cadets, in 22 of whom I was able to obtain the after history; 20 pupils who were rejected for some inability to fly of a non-medical nature; 30 cases where a pilot or observer came to me on account of some disability such as vomiting or fainting in the air. In addition I have gained much useful experience from the patients under my care who passed through the annexe to the R.A.F. Central Hospital (Oakhill House).

1. *Tremor.*

When a young man is made to hold his hands out in front of him, and at the same time to protrude his tongue, any considerable tremor is a sign of some definitely abnormal condition. A tremulous tongue may be indicative of chronic indigestion or of alcoholic excess; unsteadiness of the fingers, especially when they are abducted and brought together again, is a certain sign of lack of control. Tremor is not so much an indication of a neuropathic temperament as of a definite disturbance of function. It is not surprising therefore that Major Bowdler concluded that the group which contains 'tremor' showed a high correlation with want of aptitude to fly. He found that out of 54

candidates who were accepted in spite of 'marked tremor', 14 did not qualify, a ratio of success to failure of 2·8 to 1. Amongst 2,000 candidates who showed no abnormal signs 7·6 per cent. only were ultimately rejected.

The number of completely normal young men who show tremor of the hands must be extremely small. In every case of a pupil, pilot, or observer that has come under my notice, this sign has been associated with some obvious cause. In a certain number it was due to alcoholic excess, and it was particularly evident in those pilots who took alcohol in order to be able to carry on their work. But, apart from alcohol, it is one of the commonest signs of stress of war service and was particularly frequent in those candidates who had already served in the infantry at the front. It was almost universally present in those officers who were admitted to hospital for some functional psychosis ('Shell Shock').

Tremor of the hands is a not infrequent sequel to malarial infection; it is more evident in delicate and precise movements, such as shaving, and the handwriting may be affected. Such unsteadiness comes out particularly well when attempting to balance the rod on a flat board.

Excessive smoking, especially the perpetual misuse of cigarettes, is responsible for much tremor of the hands in members of the R.A.F.

Thus, tremor is evidence of some disordered functional state, and should be looked for definitely in the course of the routine medical examination of candidates or pilots. It will be found most commonly amongst those who have been sent back from the front on account of stress of service, exhaustion, or states of anxiety.

2. *The Knee-jerk.*

The condition of the knee-jerk is of little importance in the class from which the candidates for the R.A.F. are drawn. They are all young. None of them have reached the age at which syphilis is likely to have attacked the mechanism of this reflex, and 'exaggerated' knee-jerks are of little significance. Major Bowdler could find no evidence that any flying disability was associated with 'exaggerated reflexes'.

A condition not infrequently called 'exaggerated knee-jerks' is, however, an indication of loss of general control, but has in reality nothing to do with tendon reflexes. Sometimes on tapping the knee the whole body is thrown into agitation and the patient may even cry out. If the knee is carefully watched, the true knee-jerk is seen to precede the general commotion. This 'exaggerated knee-jerk' is in reality an uncontrolled reaction to a gentle blow and the same person will be found to start at a sudden noise. This 'general response' to tapping the knee is a valuable sign of loss of control, but is no indication of the condition of the deep reflexes. It is usually associated with a state of anxiety and is more likely to be found in unfit pilots than in candidates for the R.A.F.

3. *Walking a line heel to toe and turning on one foot.*

The result of this test is recorded by the Examining Board under the heading of 'Vestibular Stability'. But there is nothing to show that inability to walk a line and to turn on one foot is evidence of anything more than clumsiness in action or slowness of comprehension.

We examined a number of cadets, all of whom had been passed by the Candidates Board and had already begun to fly. We were able to obtain the ultimate history in 22 cases; 13 flew well and amongst them 9 could walk a line and turn on one foot well, but 4 carried out this test badly. Amongst the 9 pupils who failed to qualify, 3 walked and turned well, whilst 6 were bad at this test.

Such numbers are useless for any statistical comparison; but certain points came out on closer personal examination of those who failed. One pupil showed astonishing lack of comprehension of the task he was asked to perform; when told to turn on one foot only, he walked round in a circle and repeatedly turned in this way, although we demonstrated to him the manner in which we wished him to carry out the test. This man did 6 hours and 25 minutes dual flying; but when the time came to go up alone, he 'went sick' and did not fly again.

The same failure to comprehend what was required was apparent to a less degree in two other cases amongst the pupils who were finally rejected. It has nothing to do with want of stability, but is evidence of a slow response to unexpected verbal commands.

Another cadet, who had fought successfully in France, found considerable difficulty in walking heel to toe and turning on one foot. He ultimately became an excellent scout pilot, but confessed that he disliked dancing. In fact it seems to us that this test is more likely to show ability to dance than any capacity to fly.

But whatever relation it may bear to flying it is certainly not evidence of 'Vestibular Stability'. For, out of 8 pilots who suffered from profound giddiness associated with vomiting in the air, two only failed to pass this test; both of these men were tremulous and showed other neuropathic signs and symptoms.

4. *Standing on one foot for* 15 *seconds with the eyes closed.*

If a candidate is unable to carry out this test, his failure has been attributed to defective 'Muscle Sense'. But I carefully tested the power of recognizing passive movements at the various joints of the lower extremities in several R.A.F. pilots and pupils, who failed to stand on one foot with the eyes closed. I selected the grossest cases only; but in no single instance was the power of recognizing posture and passive movement affected. Moreover, these same persons, who were unable to stand on one foot, could do so with both feet on the ground even when the eyes were closed; Romberg's sign was completely absent, showing

that the impulses passing up the posterior columns of the spinal cord were not affected. There is no evidence, therefore, that inability to stand on one foot for 15 seconds with the eyes closed bears any relation to disturbed sensations from the muscles and joints, in the class of young men with whom we have to deal. Moreover, all the pilots and pupils who failed to carry out this test in spite of repeated attempts, showed considerable tremor of the hands and were evidently suffering from some neuropathic or psychopathic condition.

Amongst the cadets who ultimately proved to be successful pilots, two carried out this test poorly. Both showed some tremor of the hands, and one of them had come home after fighting in France to join the R.A.F. Of the nine unsuccessful cadets, three showed defective power of standing on one foot, and of these two had distinct tremor of the hands.

Amongst 20 healthy pilots who were rejected on account of inability to fly and not for any physical reason, 15 carried out this test perfectly. Of the five who could not stand on one foot for 15 seconds on the first attempt, three were able to do so on a second trial and two only failed three times on each foot.

But amongst 20 pilots who came under my care for some pathological condition, such as vomiting or fainting in the air, fatigue, or anxiety, 11 showed gross defects in carrying out this test. Thus if we place together in one group the unselected cadets and the officers who had been rejected for defective flying capacity, we obtain 42 healthy individuals; amongst them were 10 cases where this test could not be carried out perfectly. On the other hand, of 24 pilots and pupils who ceased to fly because of some morbid condition in the air, 15 showed considerable difficulty in balancing themselves on one foot.

Thus it is evident that amongst candidates, pupils, and pilots of the R.A.F., inability to stand on one foot with the eyes closed for 15 seconds is evidence of some want of control and is not due to defective 'Muscle Sense'.

Secondly, this test is more likely to be badly executed by those who show other signs and symptoms of fatigue or anxiety, whether temperamental or acquired. It is not directly a test for flying capacity; but a man who has difficulty in carrying it out successfully will probably be found to be suffering from mental or physical stress. This will ultimately affect his handling of machines heavier than air, although it may have no influence on his work as an airship pilot.

To stand on one foot with the eyes closed for 15 seconds requires not only perfect automatic control but some determination. One of the respiratory tests invented by Colonel Flack also calls for a certain amount of resolute effort, and it is interesting to notice the frequency with which the results of the two methods fall together. The pilot under examination is told to blow into a U-tube and to support a column of mercury 40 mm. in height for as long as possible. Forty seconds is taken to be normal, although a healthy young man usually greatly exceeds this period. But the result is gauged not only by the time but also by the effect on the patient; if he becomes suffused and dis-

tressed he is considered to have failed even if he slightly exceeds 40 seconds.

Amongst 20 pilots who suffered from some abnormal condition in the air, 9 failed to pass both the balancing and U-tube tests. One showed defective power of standing on one foot, but supported the mercury for 45 seconds; one other failed in the respiratory test, but succeeded in balancing himself on one foot.

This association between the results of the two methods of examination might have been anticipated. Both depend on sustained effort, and anything which diminishes the power of concentration will influence both tests. All the 9 pilots who failed were suffering from fatigue, anxiety, want of sleep, bad dreams, or other analogous symptoms; it is such states which above all others are associated with defective concentration and diminished control.

5. *Balancing a rod on a flat board with the eyes open or closed.*

This is an easy test to carry out and requires no apparatus that cannot be improvised out of the lid of a cigar-box and a small tuning-fork with a flat base. The board is placed on the table with the rod standing upright on that part further from the person to be examined. He is then asked to grasp the edge nearest to him with his fingers, to raise the board to the level of his shoulders and to replace it on the table without upsetting the rod. Should he fail at the first attempt with either hand, he is allowed to try three times in succession. He is then examined in the same way with the eyes closed.

Failure to balance the rod with the eyes open was assumed by the Examining Board to be evidence of want of 'Nervous Stability', a heading shared with Tremor, Tics, and other symptoms of want of control. But inability to pass this test, with the eyes closed, was classed as due to defective 'Muscle Sense'.

I therefore selected for closer investigation several of the worst cases, where the subject of examination failed entirely to balance the rod with either hand, when his eyes were closed. In no instance could I find any measurable defect in 'Muscle Sense'; 1° of passive movement could be accurately appreciated at all the joints of the upper extremity. It is evident, therefore, that, amongst pilots and candidates of the R.A.F., failure to balance the rod with the eyes closed is not dependent on lack of Muscular Sensibility. It is, in fact, simply another and more severe method of examining the same want of control and clumsiness of action, betrayed by balancing the rod with the eyes open.

Most normal persons find greater difficulty in balancing a rod on a flat board with the eyes closed than when they are open. Now, whenever some function of the nervous system is defective, the more complex and difficult task shows evidence of failure before one that is simpler and easier of execution. It is not surprising, therefore, to find that out of 20 cadets who had already begun flying, 4 showed some difficulty in balancing

the rod with the eyes open and 8 with the eyes closed ; but this difficulty bore no relation to their subsequent career as aviators. Moreover, amongst 20 pupils rejected solely because of inability to fly, 5 had some difficulty in balancing the rod with the eyes open, 10 with the eyes closed. Thus if we compare the normal cadets and rejected pupils there is nothing to show that there was any material difference in behaviour between those who could and those who could not fly, provided they were physically healthy.

But when we turn to the 25 pilots or pupils who suffered from abnormal symptoms in the air, the proportion of failures was nearly double as great; 13 had difficulty in balancing the rod with the eyes open, 19 with the eyes closed. Evidently this test reveals some condition common amongst those who have suffered from pathological states in the air. But provided the individual is otherwise healthy, it does not bear any direct relation to flying capacity.

On looking through the records of those who failed more or less grossly in this test, the high proportion of cases of tremor is at once evident. This might have been anticipated ; for any tremor makes it difficult to carry out an operation which requires a steady hand. Out of 28 pilots who had suffered from pathological states in the air, 14 were tremulous and all but one showed difficulty in balancing the rod on the board. In the same way, out of 50 cadets and rejected pupils 11 showed some tremor of the hands, and all of these failed to balance the rod satisfactorily.

But it must not be supposed that this test is only another means of discovering tremor. Amongst 28 pathological cases there were 7 persons who were not tremulous but could not balance the rod with normal certainty. In the same way, amongst 30 cadets and 20 rejected pupils, 9 could not carry out this test satisfactorily, though free from tremor. In almost every instance of this class I made a special note that the failure was due to erratic conduct, carelessness, want of resolution, or defective comprehension of the task and the best method of carrying it out. In other cases the movements were 'clumsy' and 'stiff', or the subject seemed 'utterly worn out' and 'tired'.

Thus we may conclude that provided the subject of examination is in perfect physical health, this test has no direct bearing on his capacity to fly a machine heavier than air. But, on the other hand, it is a useful method of detecting states of exhaustion, flying-stress, insomnia, and other neuropathic and psychopathic conditions, in an early stage of development. There is no difference in principle between the test carried out with the eyes open or shut. The latter is a more difficult task, and therefore tends in most cases to show defects sooner than when the balance is guided by sight.

6. *Conclusions.*

Some of the methods of examination discussed in this chapter are of sufficient value to form part of the routine medical

examination of candidates and pilots of the R.A.F. Tremor of the hands and tongue must always be carefully noted. The candidate should be asked to stand first on one leg and then on the other for 15 seconds with the eyes closed. He is also made to balance a rod or tuning-fork on a flat board with either hand in turn, first with the eyes open and then with them closed. He is allowed three attempts, and the character of his failure to carry out this test should be recorded, if possible.

In every case the actual method of examination must be recorded, and all such general categories as 'Muscle Sense', 'Vestibular Stability', and the like, must be avoided. The vast mass of material collected by the Candidates Board is rendered almost worthless from lack of this obvious precaution.

With such material as we meet with in the R.A.F., consisting as it does of young men in whom gross organic disease is almost absent, these tests reveal the condition of physiological or psychical control. Such control may be defective from innumerable causes; some of the most potent are fatigue, physical or mental stress, anxiety and fear. All of these conditions may appear in the course of the work of any aviator, but were enormously aggravated by flying under war conditions.

Chapter II. 'Giddiness', Vomiting, and 'Fainting' in the Air.

1. *Introduction.*

A pilot may lose control and become unconscious in the air from many various causes. Of these want of oxygen at high altitudes is perhaps the best known, and has formed the subject of several previous Reports. It is not my intention to deal with this condition, but to consider abnormal symptoms which may occur at any height and are not due to physical or chemical deficiencies in the atmosphere.

These are usually called by the sufferer 'giddiness', 'dizziness', and 'fainting in the air'. Unfortunately many medical men record them as 'vertigo' and 'syncope', without any qualification or explanatory statement of what actually happened. Nothing could be more fatal for the progress of knowledge than this widespread tendency to translate popular nomenclature into nosological language. To say that an aviator suffered from 'vertigo' inevitably suggests that the cause of his trouble was the semicircular canals, whilst 'syncope' attracts attention to the cardio-vascular system.

Throughout this chapter I shall allude repeatedly to the way in which the patient reacts when rotated in a chair. American workers have laid great stress on this response to rotation, and have carried out their observations in such a way that each group of semicircular canals is stimulated in turn. In fact, this method of examination formed, at one time, the determining test for admission to their Flying Service. A candidate was

obliged to react in a certain manner or he was not accepted. The Report of the American Surgeons states—

'It was decided to reject applicants whose vestibular apparatus gave evidence of motion-sensing acuity below a certain degree, albeit it was fully recognized in establishing this limit, that it in no way represented a line of demarkation between acuities of this perception compatible with and incompatible with flying.'

The extent of the response of the vestibular apparatus to disturbances of equilibrium was estimated in two ways. First, the candidate was rotated with his head in a strictly regulated position and the duration of the nystagmus was measured. Secondly, without rising from the chair and with his eyes still closed, he attempted to find the observer's finger, which was placed in a certain, previously familiar, position. If the deviation to this test did not reach a certain amount the candidate was assumed to be endowed with less than the normal vestibular acuity; if, on the other hand, it exceeded certain limits, arbitrarily fixed, he was rejected as over-sensitive. But this method of examination is purely empirical, and the data obtained have not so far been correlated with ability to fly.

I have not attempted to check these results; for throughout this work I have used the rotating chair, not as a method of measuring the response of the semicircular canals, but as a means of inducing an abnormal reaction. A healthy man responds in a certain way to rotation, although the degree of giddiness varies greatly. But in certain persons, who suffer from morbid phenomena in the air, the reaction is abnormal and excessive. It is frequently possible, by rotation, to induce physiological states and sensations analogous to those experienced in the air; the disability can be reproduced in a minor form. This is true, not only in cases of 'giddiness', but also in those where the pilot has 'fainted' in the air.

When we sit upright in a chair, the horizontal canals are not strictly in a plane parallel to the ground; they are slightly tilted and the head must be inclined to about 30° before they become strictly horizontal. But this is not the natural position; the head is usually carried so that the eyes look directly forwards and not on to the ground. This is the posture to which we are adapted in daily life, and the head can be turned rapidly to the right or left without giddiness or abnormal symptoms; for these movements occur more frequently than any others under natural conditions. And yet at no time, either during this static pose or on lateral deviation, are any of the semicircular canals in a position suitable for exclusive physiological stimulation. If we want to test the response of the horizontal canals specifically, the head must be suitably adjusted before rotation; but if, as is my intention, we wish to study the general functional reaction of the patient, he must be placed in the natural position seated upright in the chair.

It is important to understand the different aims of the two methods of carrying out this test. Those who carefully place the head in such a posture, that each set of canals is stimulated in

turn, look to the specific nature of the physiological response. On the other hand, I was anxious to determine, not the afferent results of such stimuli, but the way in which the patient could adapt himself to somewhat violent sensory impressions. My object was to examine his control in face of disturbances of equilibrium. Similarly, I not infrequently tested his reaction to a slight blow on the knee or to a sudden noise.

When a healthy man is rotated ten times in twenty seconds with his eyes closed, the results depend mainly on the position of the head. I have not attempted to modify its posture so as to stimulate any one set of semicircular canals alone; but the patient was directed to sit upright in the chair, as if he was gazing directly forwards. On opening his eyes the room seems to be going round in a direction opposed to that in which he was rotated. A normal man is not giddy, and suffers from no nausea, headache, or other discomfort.

If he is asked to rise and walk forwards he may tend to deviate, but rapidly recovers himself and reaches the table, five paces in front of him, without difficulty. When the chin has been held somewhat downwards, so as to bring the one set of canals strictly into the horizontal position, this deviation tends to take place in the direction of the rotation. But with the head in the erect position this is not the case in most instances; thus rotation clockwise is usually followed by more or less deviation to the left.

It is most important to record all rotation, actual or apparent, in terms of the long axis of the body and not as movements to the right or left. But deviation on rising from the chair is described as 'to the right' or 'to the left', because this is the only movement that can be actually observed, although the patient is often aware that it is the expression of a rotatory sensation.

In all my cases the patient was first turned 10 times in 20 seconds clockwise. Then, after a pause, varying in length according to the severity of the reaction, he was rotated in the opposite direction. Usually this second stimulation produced a somewhat greater effect than the first, particularly in subjects who showed other evidence of some abnormal condition.

2. *Giddiness associated with temporary abnormalities of the Auditory Apparatus.*

In order that we may be able to adapt ourselves to changes in position the auditory apparatus must be structurally sound. This is assured in most cases by the careful examination of candidates before they are accepted into the R.A.F.

But Sydney Scott[1] has pointed out that giddiness and other allied symptoms may occur in aviators who are unable to obtain a free and immediate passage of air through the Eustachian

[1] *Journ. of Laryngology, Rhinology, and Otology*, Feb. 1919, Vol. XXXIV, No. 2, p. 51. A fuller account of these researches is about to be published as a Report of the Air Medical Investigation Committee.

tubes. The ears may be normal, but the pilot suffers from a cold in the head. The air no longer passes freely through one or both Eustachian tubes and, when he rises to a considerable height or descends with great rapidity, an abnormal condition of tension is produced in one or both middle ears. This, acting on the vestibular apparatus, evokes intense giddiness and is accompanied by pain of more or less severity. Not infrequently effusion, or even haemorrhage, occurs into the middle ear.

Most experienced pilots are conscious of the salutary effect of swallowing during a rapid descent, and habitually chew gum for this purpose. But, in some cases, a temporary condition of the nose or throat may make it impossible to regulate the tension within the middle ear, with disastrous results to the pilot.

In the following instance the giddiness occurred whenever the patient caught a cold in the head, although his auditory apparatus was otherwise normal.

Case No. 1. 2nd Lieut., aged 19.

He first went into the air in September 1917 and had flown for 13 hours solo on Avros before he felt any discomfort. In December 1917 he caught cold, when sleeping in a canvas hangar with snow upon the ground. He went up one morning, with a cold in the head, and suddenly 'felt dizzy'; his head seemed 'to be whizzing round inside', and he 'felt strange'. He went up frequently during the next few days and was 'giddy' on several occasions. He did not vomit and was not nauseated. Throughout this period he was deaf.

He went away on leave, and recovered entirely. On returning to his squadron, he flew solo for 9 hours in perfect comfort, and graduated on April 9, 1918.

He was then transferred to another squadron to fly service machines. Here he caught another cold, and one day, when in the air, whilst suffering from headache and running at the nose, he felt himself becoming giddy at 3,000 feet. He shut off his engine, but does not know how he came down. He was flying an Avro and, according to the report of his Wing Commander, started to spin. He stalled the machine at about 30 feet, and broke some struts in landing, but was not hurt.

He was seen by me in September 1918, four months after the last occasion on which he had been in the air.

He was then a well-built young man with somewhat narrow nostrils. He had been operated on successfully for adenoids at the age of 11 years, and there was no obvious abnormality in his throat or nose. His hearing was good, and the membranes were normal and not retracted; but he said that, whenever he caught a cold, something went wrong with his ears.

Respiratory and cardiac tests showed no gross abnormality, but his balance on one foot was bad. He failed three times in succession to stand on the right foot for 15 seconds, and succeeded with difficulty in doing so on the left. He balanced the rod on the flat board at the first attempt with the right hand, when his eyes were open, and on the second attempt with the left hand. But with the eyes closed, he failed altogether to carry out this test with the left hand, and only succeeded on the second attempt with the right. And yet, on testing his power of appreciating passive movement, he could recognize 1° at all joints of both upper and lower extremities.

When he was rotated, he did not deviate definitely in either direction, and touched the spot on the table perfectly. But he complained that, as soon as he rose from the chair, he felt as if he was 'moving backwards and

forwards'. He seemed to move 'first from right to left, and then back again from left to right'. The window in front of him 'seemed to be doing the same, wavering backwards and forwards'. He was not giddy, and felt perfectly normal, as soon as the 'wavering' passed off. There was no nausea or headache.

From this case there is an easy transition to such a one as the following, where the throat was in an obviously abnormal condition.

Case No. 2. Lieut., aged 27.

He joined the R.F.C. in June 1917, and went to France on January 31, 1918, flying S.E. 5. He began to notice that, when coming in after high scouting, he was a little deaf in the left ear. When he descended from a height, he had to 'blow up his ears', and 'sometimes they would stay plugged for three or four days'.

On April 3, 1918, whilst coming home to the aerodrome, he got into a backwash and went 'dizzy'. He spun from 4,000 feet to 2,500 feet, but did not lose consciousness. He knew what was happening, pulled his machine out of the spin and followed the others home. On alighting from his machine, the giddiness continued for some time.

I saw him nine days later and his tonsils were red and swollen, the left more so than the right. The membranes were normal, and he was not then deaf.

Both these cases are examples of the ill-effects produced by uncorrected changes of tension within the auditory apparatus. Sydney Scott has shown, from careful examination of a large number of pilots at the front, that such abnormal conditions in the middle ear are amongst the commoner causes of giddiness in the air. A healthy man is suddenly exposed to unnatural stimulation of the essential sensory mechanism due to uncorrected tension in the auditory apparatus; he responds in a normal manner with a more or less acute vertigo. Here it is not the reaction of the individual or the response of his semicircular canals that are in fault, but the abnormal and unequal tension in the middle ear.

But 'giddiness' may occur in aviators apart altogether from such external stimuli. In such cases their abnormal state in the air must be due to one or two causes. Either the sensory impressions evoked by changes of bodily posture must be excessive, or the general resistance to the uncontrolled acceptance of such impulses must be profoundly diminished. This defective power of integration and control may be acquired or constitutional. Such cases are of profound diagnostic and scientific importance, and form the subject of the next two sections of this chapter.

3. *Giddiness in the Air with no abnormal conditions in the Auditory Apparatus.*

Most healthy persons can be made giddy, provided the rotatory movement is sufficiently violent, and especially if the head is held in some abnormal position. This reaction is not a patho-

logical condition; it is a normal response to an acute disturbance of equilibrium. But the ease with which it can be evoked varies greatly; some, in childhood, were not able to swing without discomfort and were sick on a train journey. As they grew up, however, this response was evoked less easily, and, provided the stimulus was not unusually severe, they differed little from their fellows.

In the same way many normal men become giddy when first exposed to rapid changes of posture in the air. After a few turns the instructor carries out some aerobatic evolution and, when first looped, rolled, or spun, many pupils become uncomfortable and a certain number vomit. But the majority rapidly recover and may become expert and bold aviators. They have adapted themselves to the new conditions; the stimuli from the peripheral end-organs no longer dominate the field of response. They are controlled or suppressed, not by the will, but by that power of adaptation which is one of the most potent factors in the activity of the central nervous system. In the course of evolution the lower centres have come increasingly under the dominance of those of higher functions and more recent development. Actions, which in lower animals can be carried out by the spinal cord alone, become impossible in man without the co-operation of the centres in the mid-brain.

Even in the fully developed nervous system of man the acquisition of some new aptitude is associated with an increasing control of higher centres. We learn to adapt ourselves to the conditions around us and cease to be the victims of unco-ordinated sensory impressions.

In order that any of these acquired aptitudes may be carried out in a perfect manner attention must be concentrated on the end and object of the movement, and the motor act must become as nearly as possible automatic. A man shoots his best when his eye is fixed on the bird and he is not conscious of his gun. In the same way an aviator must be able to concentrate on the evolution he wishes to perform and carry out the necessary acts automatically. To turn a corner on a bicycle or to bank an aeroplane 'you just lean over' and the desired change occurs without further thought. The man who flies by verbal rules is a bad pilot and will certainly come to grief.

Anything which diminishes the power of concentration tends to lessen control over the reaction of the lower centres to sensory stimulation. An attack of influenza, a 'crash', domestic worry or fear, all act in the same direction. A pilot who was giddy when he first went into the air, but recovered completely, may fall back to his original mode of reaction and be unable to carry out any aerobatic evolution. Such persons are no longer normal, not because the response is a pathological one, but because, for a time at any rate, they have been reduced to a lower level of functional efficiency.

My first example is that of a perfectly healthy man, who never recovered from the tendency to become giddy and to vomit in the air. The case is an instructive one, because he succeeded in concealing his disability and was only saved from death in France

by the prompt assistance of two colleagues. Moreover, since he was marked unfit for flying, he has repeatedly been in the air as a passenger during the course of his work, and appreciates exactly the conditions which render him uncomfortable.

Case No. 3. Capt., aged 23.

After serving in the Infantry he was transferred to the R.F.C. and began to fly on June 15, 1917. He graduated in October and went to France as a Scout pilot on November 14, 1917, flying Sopwith Camels. He did 150 hours in the air, of which 50 were in France.

The first time he was taken into the air on an Avro he vomited at about 2,000 feet. So long as he flew straight he managed without difficulty, but when he turned rapidly or 'threw the machine about' he was attacked with nausea and occasionally vomited. By coming down whenever he was uncomfortable, and by doing as little 'stunting' as possible, he managed to conceal his disability and was sent out to France after 80 hours in the air.

Here he felt no discomfort at first, because his duties consisted mainly of patrolling at about 10,000 feet. One day, however, he was attacked by the enemy and compelled to turn rapidly in the air; this caused him to vomit severely. He was so ill that he could not look about him, and the enemy were on his tail, firing into his machine before he realized what had happened. Two of his companions saved him and drove off the Germans. On coming down safely he was obliged to go to bed for two or three hours. He went up three times after this adventure, but vomited on each occasion and was sent home.

As a child he disliked swinging, and was easily made sea-sick. At the age of 14 he was swung upon a gate and was so sick that he was obliged to go to bed.

I saw him on his return from France. He was well built, strong, and healthy. He seemed so completely normal that I took him to the Candidates Board, and the examiners kindly put him through all the tests for me without asking any preliminary questions. He passed without qualification.

When, however, he was rotated in the chair the general reaction was excessive, although the visible response was normal in character. After ten turns clockwise, he rose and deviated to the right; the room seemed to be moving in a direction opposed to that in which he had been turned. After a pause of ten minutes, he was rotated counter-clockwise; he then staggered to the right and to the left unsteadily, whilst the room seemed to go round with the hands of the clock. This response was not abnormal, but the general reaction was disproportionately great. He was attacked with profound nausea, his face and hands sweated, and he said he felt exactly as he does in the air.

He was a highly-trained scientific student and was therefore given employment in the Technical Department. In the course of his work he frequently goes into the air as a passenger, and suffers from no discomfort so long as the flight is steady. But on one occasion recently he was up in a D.H. 9 with a B.H.P. engine, which gives off unpleasant fumes near the observer's face; the air was 'bumpy', and the combination of the two conditions caused him to vomit.

This is an example of a perfectly normal man, who has never been able to adapt himself to disturbances of equilibrium. The actual response to rotatory stimuli was normal in character, but the reaction it evoked was excessive.

The next case is one where the profound reaction to change of posture was one aspect only of a congenital want of nervous control, in a man of unusual physical strength and athletic ability.

Case No. 4. 2nd Lieut., aged 23¾.

He served for three years in the Infantry, and gained his commission from the ranks. He was splendidly built and had been a professional football player; but he had always noticed that if he looked up as he ran, he became giddy and tended to fall.

It is interesting to notice that, in spite of his build, appearance, and fighting record, he had always been 'nervous'. As a child he could not sleep without a light and was terrified of the dark. He always dreamt unpleasantly, and on waking 'saw big ugly faces' in the room. This occurred frequently up to the age of 16. During the last twelve months his unpleasant dreams had recurred; they mostly took the form that he was with the Infantry, and that 'they were in a tight place'.

After joining the R.A.F. he noticed that he did not suffer in the air so long as he flew straight, but turning made him giddy. He was most uncomfortable when the nose of the machine was put down, but banking always upset him. After several trials he was finally rejected as permanently unfit for pilot or observer.

This man's behaviour to the usual tests was in striking contrast to those of No. 3. He could not support himself for 15 seconds on either foot with the eyes closed. He failed altogether to balance the rod on the flat board, either with the eyes open or closed. But he showed equally gross defects to the respiratory tests, and could not support 40 mm. of mercury for more than 30 seconds; his pulse-rate behaved in a normal manner throughout, showing that this failure was not due to any cardio-vascular inadequacy.

From previous experience of such cases, I suspected that he might react violently to rotation, and I therefore turned him five times only in each direction; an interval of five minutes elapsed between the two observations. On being rotated he became so giddy that he sat coiled up clinging to the arms of the chair, unable to move. He did not even attempt to rise, but said he felt extremely ill, exactly as when he was in the air.

This is an example of an excessive reaction to sensory stimulation, due to lack of central control. In spite of his unusual physical development, this man was endowed with a psychopathic temperament, and the response to unusual stimulation of the vestibular apparatus was manifested in the form of a minor anxiety neurosis.

The next case shows that a pupil who starts with giddiness and vomiting in the air may overcame his disability and develop into an able pilot. But anything which diminishes general control may cause him to regress to his original condition.

Case No. 5. Lieut., aged 22.

After 3 years and 11 months in the Infantry he joined the R.F.C. During his first dual flight on an Avro he felt sick and vomited. He recovered entirely, quickly gained his wings, and went to France to fly Sopwith Camels. He had no giddiness, nausea, or other discomfort, even when 'stunting'.

But, after 90 hours war flying, he was shot down in aerial combat and chased from 9,000 feet by his opponent. On reaching the ground he found himself unhurt, but pinned under his machine, which had turned over.

Six days later he resumed flying and discovered that he had lost all confidence. He flew for 20 hours, but could not face the fighting and was sent home. After two months' rest he seemed to have recovered entirely, and was posted as instructor to a Training Squadron at home. He went up three times with the Wing Instructor and on each occasion vomited violently.

As a child he disliked swinging, and felt 'dizzy' and 'sick'. On a railway journey he cannot sit with his back to the engine without feeling 'squeamish'. All the members of his family react in the same way, both to swinging and to travelling by train.

The only one of the general tests which he carried out badly was balancing the rod with the eyes closed; he succeeded on the third attempt only with the right hand, and with the left failed altogether. He showed no excessive reaction to rotation; when turned ten times clockwise or counter-clockwise he deviated in the opposite direction, exactly like a normal person, but recovered himself quickly. The room seemed to be moving horizontally opposed to the direction of rotation. He did not suffer from nausea or any discomfort.

This was an instance when, in spite of an hereditary tendency to giddiness and nausea, the pilot adapted himself to the new conditions perfectly. But, with the shock of being shot down, he regressed, and all his old disability returned in spite of the fact that he was physically in perfect health.

In the following example the patient had a natural tendency to vomit in the air, but gained sufficient control to fly as an observer for more than three months in France and to take part in much aerial fighting. He suddenly regressed in consequence of acute fear.

Case No. 6. 2nd Lieut., aged 19.

He began his training in the air as an observer in April 1918 on a D.H. 4, and vomited three times in six flights. The nausea started about ten minutes after he left the ground with 'a drawing in the stomach up to the throat'; and as soon as he experienced this sensation he knew he must vomit. When it was over he felt better, and could go on flying comfortably.

The nausea came on apart from any aerobatic evolution; but when rolled, looped, or spun, he was 'dizzy' and 'sick' all the time.

He went to France as an observer and flew for 3½ months in a Bristol Fighter, under war conditions. So long as he was not heavily 'stunted', he enjoyed his work and did not vomit. But, of all evolutions, rolling upset him most.

At the end of August 1918 he suddenly went to pieces under the following circumstances. His Squadron was going to take part in a combined attack during the afternoon. In the course of the morning a new pilot went up for a turn in the air and dived into the earth on the aerodrome, killing himself and his observer. Shortly afterwards a second pilot and observer were killed in the sight of the patient and his companions. But the pre-arranged military operation could not be postponed, and he was obliged to go up with his squadron the same afternoon. He was intensely frightened and vomited in the air. From that time onwards he was sick whenever he went up, even when flying straight; finally he was so ill that his pilot brought him back shortly after starting.

He could never swing as a child, because it made him giddy, and he always vomited in a train, and sometimes even in a tramway car. When

uncomfortable in the air his sensations were exactly those he experienced in childhood before he was sick in the train. He had often suffered from sea-sickness.

Physically he was in perfect health, and was not tremulous. He passed all the usual balancing tests, and had no difficulty in supporting 40 mm. of mercury by blowing for 40 seconds. The pulse did not react abnormally to this form of effort.

But when rotated in the chair his reaction was characteristic. Turned ten times clockwise, he rose, stood with his feet apart, leaning forwards, shaking. He did not deviate, but moved slowly and unsteadily directly forwards to the table. He said that the room was not going round, but that his 'feet seemed to be rocking'. 'I had the drawing feeling in my stomach up to my throat, that I know so well in the air.' After a pause of ten minutes he was rotated in the opposite direction with exactly the same result. He stood unsteadily, in the same attitude, with his feet apart, quaking as if in fear.

Here, a healthy young man, relatively over-susceptible to disturbances of equilibrium, succeeded in adapting himself sufficiently to carry out his work as an observer under war conditions. But, with the development of an anxiety neurosis, due to an acute state of fear, the physical reaction became severe and overwhelming.

In the following case the patient had never experienced any discomfort until he attempted to fly after an attack of influenza. He then became giddy and vomited repeatedly in the air.

Case No. 7. 2nd Lieut., aged 19½.

He thoroughly enjoyed flying from the first, and had never had an accident. He obtained his wings without difficulty and was preparing to go to France, when on June 30, 1918, he had an attack of influenza. He was in bed for ten days with no complications and then went on leave.

On July 27 he went up for the first time since his illness as a passenger and vomited at 1,500 feet. 'I was giddy; my eyesight seemed bleary and full of specks, and it was like a bad bilious attack.' He was so determined to conquer this feeling that he went up again the same day and again vomited. This was a simple straight flight in an Avro.

As a child he thoroughly enjoyed swinging, and he has never been sea-sick, even when fishing from a small boat.

I saw him at the beginning of September 1918 and he was then easily tired, even by a short walk. He had lost a good deal of weight since the attack of influenza, but there were no abnormal physical signs in the lungs or heart. The balance of his hands was poor, and he was unsteady when standing on one foot. He had considerable difficulty in raising the rod on the flat board, especially with the eyes closed. But the respiratory tests were fairly well carried out [U-tube 45 secs.], and the pulse did not react abnormally to effort.

When turned ten times clockwise, he rose, deviated slightly to the left, but touched the spot on the table without difficulty. The room seemed to be revolving in the direction opposite to the rotation. He said he felt giddy, and looked it. The reaction, when turned ten times counter-clockwise, was exactly analogous; he deviated to the right and the room seemed to be going in the same direction.

In neither case was the visible response abnormal. But its effect upon his general condition was excessive. Throughout the rest of the day he felt

sick; his appetite was not impaired, but he had a continuous feeling of nausea. He also complained of an abnormal sensation, as 'if something was pressing down in the back of my head'.

This seems to be a case where the response to rotation was not abnormal; but owing to the diminution of general resistance, due to influenza, normal sensory impulses evoked an unusual general reaction.

The next case illustrates how a flying officer, who had never known discomfort in the air, may become giddy and vomit as a sequel to a gastro-intestinal disturbance. It also shows the close relation between the two conditions 'vomiting' and 'fainting' in the air.

Case No. 8. 2nd Lieut., aged 29.

He began to fly in Canada in January 1918 and enjoyed it extremely. In June he was posted to a Squadron in England, and whilst there, during the first week of August, suffered from a short attack of diarrhoea. Throughout the four days of its duration he continued to fly, but felt so weak that he was forced to use two hands to the controls on steep turns; suddenly, at about 1,000 feet, he was attacked with 'dizziness' and thought he was about to vomit. After resting for a few days, he seemed to have recovered entirely and took two short flights without ill effects.

He was then posted to another Squadron and began to suffer from indigestion, with 'wind', 'cramps in the stomach', and 'some pain shortly after taking food'. He was given a laxative, and this started another attack of diarrhoea. He did not fly for a week, but on September 8, 1918, after 20 minutes in the air, he became 'dizzy'. His head seemed to 'swim', his vision became hazy, and at about 100 feet everything 'went black' for a few seconds.

After a good night's sleep he went up again next day and was perfectly comfortable, so long as he flew straight; but as soon as he began to circle round a ground target he became 'dizzy'. 'The target started going round with me.' He felt sick, broke out into a sweat, and repeatedly put his head over the side, partly because he was certain he was about to vomit, and partly in the attempt to obtain fresh air. He kept on swallowing and felt all would be right if thereby he could prevent something coming up from his stomach.

He has never been sea-sick, and could swing with pleasure as a child.

I saw him in October 1918. He was still suffering from flatulent dyspepsia; his bowels were opened once or twice daily, and the motions were always somewhat loose. The tongue was clean, the teeth were fairly good, and there was very slight gingivitis. There were no abnormal physical signs in the heart or lungs, but he had distinctly lost weight. He slept well, and did not dream unpleasantly.

He passed all the tests for balance without difficulty, but rotation in the chair produced a characteristic reaction. On turning him ten times clockwise, he rose, swayed with eyes half closed, and appeared dazed; but he stepped forwards and touched the table without deviating definitely in any one direction. He said: 'Things seem to start going to the right and yet I seemed to be able to control it by blinking. Everything went misty just as it does in the air, and my stomach felt funny.' On rotation in the opposite direction, he rose slowly and staggered to the right, pulled himself together and moved to the left, finally touching correctly. He said: 'This time it was more as if I could not get where I wanted and misjudged my

distance. I thought I was right on the point, when I was a long way off. This is just like my landings after an attack in the air.' He added that he felt 'squalmy' in the stomach.

In this case the abnormal reaction took at one time the form of giddiness and nausea, and at another time that of partial unconsciousness; it forms a transition to the next group, where the pilot is said to 'faint in the air' at low altitudes.

4. *'Fainting' in the Air.*

In the previous section I have described a series of cases where the reaction to disturbances of equilibrium took the form of giddiness and nausea. Another not uncommon abnormality is what is usually called 'fainting' in the air. A 'mist' or 'haze' comes before the eyes and 'all goes dark'. It is not an unpleasant sensation, and is said to resemble closely the early stage of an anaesthetic. This passes into complete insensibility and the pilot may fall forward on to his controls; but if he is strapped in sufficiently tightly his hands leave the stick and his feet no longer act on the rudder. Should he be spinning on a stable machine, he may come to himself some miles away flying on a level keel.

Case No. 9. 2nd Lieut., aged 20.

He began flying in February 1918, and obtained his wings in July of the same year. From the first moment he thoroughly enjoyed being in the air, and flew well without discomfort or difficulty.

But, in the middle of July 1918, he was in bed for two days with a short attack of influenza. Four days later he was flying an R.E. 8 when he 'felt faint' at 5,000 feet. He came to himself at about 1,500 feet, to find he was in a spin; he managed to right the machine, but broke an axle on landing.

I saw him in October 1918, after a prolonged period of leave and ground duty. He was then a healthy young man of rather poor physique. Heart and lungs were normal. He could sustain the mercury in the U-tube for 40 seconds. During this test his pulse volume became rather small and the tension poor; the rate, however, was in no way excessive, and recovery occurred within a normal period after the close of the effort. The balance tests were carried out perfectly.

Rotation produced a normal response. On turning ten times clockwise, he rose, deviated slightly to the left, but touched the spot on the table easily. He said he was giddy and that the room seemed to revolve against the hands of the clock, but he was not in any way uncomfortable. Turned in the opposite direction, he deviated slightly to the right; the room seemed to go the same way, but he recovered rapidly. He suffered from no nausea, headache, or other discomfort.

This is the case of a man of somewhat poor physical development who 'fainted' in the air after an attack of influenza.

The next example of this condition is a pilot with long experience and 250 hours war flying in France. He became chronically tired and, at the end of a long patrol, 'fainted' in the air.

Case No. 10. Capt., aged 20½.

He joined in August 1916, and went out to France as a pilot in December of that year.

In July 1917, after 250 hours flying under war conditions, he was returning from a long patrol when he 'fainted' in the air. But, knowing he was going on leave, he said nothing about it and came home on July 28.

After three weeks he was posted to a Training Squadron as instructor. He began to notice that he had lost all keenness for flying and that he 'started at a noise'. One day in December 1917 he was suffering from neuralgia in his face and went up in a D.H. 6. He 'came over foggy and silly', and became unconscious at about 4,000 feet. He 'woke up' at about 1,500 feet and flew the machine back to the aerodrome without difficulty.

He then went to hospital for a fortnight and, after three weeks' leave, returned to his Squadron feeling perfectly well. He was extremely keen and thinks he never taught better; he instructed thirteen pupils in a month. He was then transferred to another aerodrome, where he remained for four months. At the end of that time he found he could not stand 'stunting'.

In July 1918 he was given ground duty. He came before me in November because he was anxious to return to flying. He could walk 20 miles without discomfort, aud had been playing two rounds of golf daily. At first he noticed that he was off his game; his normal handicap had been 4, he was now playing 8, though improving daily.

When I saw him he was in splendid physical condition, and passed all the respiratory and balance tests perfectly. On opening his eyes, after ten turns clockwise, the room 'seemed to take half a turn to the right and then stand still'. He rose, walked straight to the table and touched well. He added, 'It was just like coming out of a cloud; I felt I was going to pull out at once.' On being rotated counter-clockwise, his sensations were *mutatis mutandis* identical. He experienced no discomfort of any kind.

Evidently this was a case where 'fainting in the air' was associated with exhaustion, consequent on the strain of excessive flying under war conditions. It is interesting to record that this pilot had never 'crashed' since he obtained his wings.

The next case shows that 'fainting in the air' may be the terminal phase of a long period of loss of confidence.

Case No. 11. Capt., aged 27.

This pilot flew before the war in a training school, and was given his wings when he joined up in January 1916.

On July 20 of the same year he suddenly lost confidence under the following conditions. When taking a machine across country he was compelled to make a forced landing in a field. He tried several times to get out, but could not clear the surrounding trees. On landing, after the seventh attempt, he noticed twigs from the trees in the tail and under-carriage of this machine. This brought home to him how near he had been to disaster, and he became so frightened that he left his aeroplane and returned by train. Next day he tried to fly, but failed twice; every little bump 'set my heart going, and I used to wonder if I should come down again'.

He was discharged in August 1916; but in December he began to fly again as a test-pilot. In March 1917 he was given a commission in the

R.F.C., and flew so confidently and well that he was made Flight Commander to a Training Squadron.

On October 27, 1917, he went to France in charge of a section for issuing machines. On December 22 he was testing an S.E. 5, when he 'fainted' at about 5,000 feet. 'Everything seemed to go black all at once.' He recovered himself at about 1,000 feet, but lost consciousness again. He next remembers that he was on the ground, hanging upside down from the machine, which had turned over. He could not release his belt, but was not injured in any way.

After a short stay in hospital, and some months of ground duty, he began to fly again at the end of April 1918. He then became sleepless and frequently suffered from nightmares; these consisted of a recurrent dream that he saw a machine falling without wings. He was never the victim of the accident, but always seemed to be watching some one else falling in this manner.

When he went into the air he felt 'timid' and, if the air was still, he became drowsy. When this sensation came on he felt exactly as if he was 'sitting in an easy chair in front of a warm fire and falling off to sleep'. The 'fainting' came on suddenly, but the onset of the 'drowsiness' was gradual.

He sometimes had this feeling when he played lawn-tennis or billiards, or when he concentrated his attention on a book. We set him to play lawn-tennis under observation, and he was certainly unnaturally slow. When he wanted to take a backhand stroke, he could not bring his racquet across quickly enough to hit the ball. He complained that he found exactly the same difficulty in the air; he could not 'correct bumps', and was 'slow in adapting'.

Up to the time when he 'fainted' in the air he knew nothing of the abdominal sensations experienced by many persons when they descend in a lift. But he then began to be conscious of the 'feeling in the stomach', not only with any small displacement in the air, but also when going down in the lifts of the Tube Railway. He is certain that he never experienced this sensation of 'bumpiness' until February 1918. Since then he has never been free from it with the smallest drop or vertical bank. Moreover, when he had finished a spiral turn, the horizon continued to rush by for a long time afterwards in the direction in which he had been turning. This was another new experience.

When I saw him in August 1918 he was a well-built man of normal appearance, with no tremor of the hands or other signs of disease.

He walked a line and turned badly. He supported himself with difficulty on one leg and could not stand for more than 10 seconds on either foot. He failed entirely to balance the rod on the flat board with his eyes open or closed.

After ten turns in the chair he deviated strongly in the opposite direction to that in which he had been rotated, and did not reach the table at all. He staggered and fell into my arms as if drunk, and said he could not see anything distinctly enough to say in what direction the objects in the room seem to be moving.

5. *Comparison of the two reactions, 'Giddiness' and 'Fainting' in the Air.*

Any normal man can be made to suffer profoundly in the air if the rotatory alternations are sufficiently intense, and particularly if the head is held in some abnormal position. For example,

to look upwards at the top plane during a rapid spin is a certain means of inducing giddiness and nausea. In the same way, Major V. B. could provoke at will the preliminary symptoms of 'fainting' by executing evolutions which produced unusually intense rotatory stimuli.

Such reactions are not in themselves abnormal; but, in the examples I have quoted, they could be evoked with undue ease and were unusually violent. Sometimes the disturbance, due to changes in equilibrium, assumed the character of a true vertigo, accompanied by nausea and vomiting. In other cases it consisted of a withdrawal of consciousness, usually spoken of as 'fainting in the air'; this does not begin with a true vertigo, but with a feeling like that of passing under an anaesthetic. Surrounding objects grow distant, the 'horizon seems dark', and the actual loss of consciousness may be preceded by a drowsy state, in which it is impossible to act. The final event, as far as the pilot is concerned, depends on the stability of the machine. If it is of a type that passes out of a spin naturally on releasing the controls, the pilot may come to himself to find that he is flying far away from the point at which he lost consciousness; or he may have dropped several thousand feet. On the other hand, with many quick scout machines, which require an active effort before they cease to spin, the result is not uncommonly a more or less severe 'crash'.

Both the true vertigo and the loss of consciousness are the direct consequences of changes in equilibrium. What, then, are the underlying causes of this diversity of reaction? From an analysis of fifteen cases of 'giddiness' or 'fainting' in the air, where I was able to subject the pilot to exhaustive examination, I should like to put forward the following solution.

Out of ten pilots and observers who came under my care for giddiness and vomiting, all but one suffered in this way when they first went into the air; many of them succeeded in adapting themselves more or less successfully to the new conditions, until some factor arose which led to diminished control. They then regressed to the earlier reaction, and adaptation was no longer possible. It is interesting to notice that all nine patients had been unable to swing with pleasure in childhood, and many of them had been habitually sick in the train.[1] As they grew up, they gradually conquered this childish reaction; but, on being exposed to changes of equilibrium in the air, it returned. In most cases it was again brought under control, reappearing, however, with any cause which lowered the general resistance of the central nervous system. In the one case where the pilot had not suffered in the air during the early stages of his training, he

[1] It is interesting to notice the close association of rotatory vertigo and train sickness. For it is obvious that the latter is evoked from the visual apparatus, whilst the former is due to vestibular stimulation. The reaction is identical in spite of the diverse nature of the peripheral excitation. Another example of this order is the giddiness and nausea induced by rotating the walls of the room so that the victim, seated on a chair at rest, obtains an illusion of movement. One of the principal functions of the vestibular apparatus is to maintain the balance of the eyes; if this is disturbed, giddiness will follow although the semicircular canals have remained at rest.

began to vomit after an attack of influenza; this produced severe loss of weight and was followed by a constant feeling of fatigue. He had been, moreover, an unusually nervous child, and was not able to sleep without a light until he was sixteen years of age.

Giddiness and vomiting in the air are an expression of undue susceptibility to changes in equilibrium. This is usually constitutional; it may be so severe that it can never be corrected (No. 3), but in most cases adaptation is possible. The tendency to be giddy in a swing or to vomit in a train are overcome on the passage from childhood to adult life; in the same way, the reaction to disturbances of equilibrium may be controlled with the gradual acquisition of facility in the air. But any disturbance, physical or mental, associated with diminished general resistance in the central nervous system, will cause regression; the patient reverts to his original mode of reaction.

On the other hand, none of the five patients who 'fainted' in the air suffered from any discomfort on learning to fly; all enjoyed it from the first. Not one of them had ever been giddy in a swing or suffered in childhood from train-sickness. Evidently they were endowed with the power of controlling the effects produced by changes of equilibrium on the vestibular apparatus; vertigo, with its accompanying nausea, was absent. But when the impulses from the semicircular canals became too violent to be held in check they expended themselves by producing a withdrawal of consciousness. This begins with a narrowing of the field of attention, which may culminate in complete oblivion. Such a reaction may make its appearance in normal pilots, provided they push the rotatory stimuli up to unusual limits, as was the case with Major V. B. during his technical experiments. But under the conditions of normal flight fainting in the air at low altitudes is always evidence of diminished general resistance. Sensory impulses, which should be controlled, become capable of evoking an abnormal general reaction. This may be due to stress of war-flying (No. 10), to fear and anxiety (No. 11), to some gastro-intestinal condition (No. 8), to the after-effects of influenza (No. 9), and probably to a multitude of causes, which act in a similar manner.

But amongst the group of pilots who faint in the air, the natural resistance to vertigo is high; the impulses evoked by disturbances of equilibrium do not show themselves, therefore, in giddiness and nausea, but in a disturbance of consciousness.

This difference in reaction to changes of equilibrium in the air can be demonstrated by observations on the rotating chair. The effect produced upon those who were 'giddy' in the air was in sharp contrast to that produced in the group who had 'fainted'. Of the ten who had been 'giddy' and vomited, nine reacted excessively to rotation in the chair; they became more or less giddy, sweated, and suffered from nausea. The actual form assumed by the physiological response was not abnormal, but it induced an excessive general reaction with undue ease. In one instance only was this not the case; he had been shot down in aerial combat and his regression was assuming an almost pure psychopathic form.

On the other hand, of the five pilots who had 'fainted' in the air, three suffered from no discomfort of any kind after rotation in the chair; in two cases 'everything went misty'; and both patients complained that they felt exactly as they did in the air.

It would seem as if those who have a natural tendency to become giddy on rotation, react to disturbances of equilibrium with nausea and vomiting. Others can dominate the vertigenous aspect of the impulses from the semicircular canals; in them rotatory stimuli, if sufficiently severe, evoke the condition known as 'fainting'. How far the tendency of the reaction to assume this form depends on a predisposition to react to any severe shock by cardio-vascular disturbance, must be determined by future research. It may be found that even the 'fainting' induced by lack of oxygen is the same reaction of the central nervous system to stimuli of an entirely different order. My cases, however, are too few in number to afford an answer to this important question in applied physiology.

Wider experience may show that there are other forms of reaction which may occur in the air. Physiological responses are not inevitable and rigidly-defined manifestations. Such a case as No. 8 shows how closely related are the two reactions, 'fainting' and 'giddiness' in the air; for although the patient is classed under the first heading a violent dive on to a ground target induced nausea and many of the symptoms of 'giddiness'.

6. *Attacks of minor Epilepsy in the Air.*

In the early days of the war, before we were familiar with the pathology of 'fainting' in the air, some neurologists attributed the condition to minor epilepsy. But further experience has shown that this must be an excessively rare cause of pathological states in the air. I have met with one undoubted instance only; but the symptoms form such a striking contrast to the commoner form of flying disability, that the case seems to me worthy of record.

Case No. 12. Sergeant-Pilot, aged 24.

He joined the R.N.A.S. in September 1914, and went to Egypt in June 1915. Very shortly after his arrival, he was seen by the Medical Officer in an attack of minor epilepsy. He returned to England and was discharged on August 15, 1915, with this diagnosis.

He then learnt to fly at his own expense, and applied for a commission in the R.F.C.; he was, however, rejected on his previous history.

But in September 1916 he succeeded in joining without a Medical Board and, after passing through a theoretical course, went to a squadron as 2nd air mechanic. Here he rapidly learnt to fly, and gained his wings after about 20 hours in the air.

In March 1917 he went to France, and had his first and only severe accident in May of that year. He was flying a Sopwith two-seater. All he remembers is that, on rising 300 to 400 feet from the ground, he suddenly felt his arms and legs growing 'powerless' and he lost consciousness. He does not remember hitting the ground; but not more than a few seconds later he climbed out of his machine and helped his observer, who was hurt.

He had no conception of what had happened, and says he felt exactly as if he were a spectator, who had come to the rescue.

He did not fly for three weeks and then went to another squadron in France as a test pilot; there he remained for six months. He had no trouble in the air, but one evening, when walking with a friend, he suddenly became unconscious and fell to the ground.

In March 1918 he came to England and acted as ferry pilot; but he had many small attacks on the ground, and in September had a severe seizure in the street. He fell and became absolutely unconscious; he remembers walking on the pavement and then found himself in a tramway car with 'people fussing round' him.

He has been subject to these attacks ever since he was about 14 years of age. He 'suddenly loses count', becomes dazed, and then recovers to resume his work as if nothing had happened. When in the street, he has dropped things from his hands and walked on oblivious of his loss. He has never wetted himself or bitten his tongue.

In 1911 he had an attack whilst riding a motor bicycle. This led to a bad spill, and he severely injured three fingers of his left hand.

He enjoys flying intensely, and never feels better than when he is in the air. A long period of ground duty makes him depressed, and leads to a considerable increase in the number of the attacks. He has had one 'crash' only; but sometimes on long journeys, when acting as a ferry pilot, he has 'felt queer' in the air. He has always been fortunate 'to be high enough to come to myself all right, though I have lost height several times'.

One brother and one sister have similar attacks, and his father, who died of pneumonia, drank very heavily. The patient himself is a teetotaller.

He was a well-built rather nervous looking man. His heart was normal, and the pulse showed a perfect reaction to measured effort, returning with normal rhythm in one minute and a half.

His hands showed some irregular tremor, and his tongue was not steady. He could stand on either foot for 15 seconds on the first attempt, but could not balance the rod on the flat board, either with the eyes open or closed.

The pupils were of medium size but oscillated widely when his eyes were fixed on a distant point. The reflexes were normal, and there were no signs of gross disease in the nervous system.

This case differs from all those previously described in this chapter by the fact that the attacks occurred before the patient took up flying. Moreover, the majority happened on the ground and were associated with the usual manifestations of minor epilepsy. With care it should not be difficult to exclude even epileptics of this class from the Flying Services.

7. *Conclusions.*

Giddiness, vomiting, and fainting in the air may occur from many different causes apart from physical or chemical deficiencies in the atmosphere.

Candidates who show any signs of disease of the ear, nose or throat, are excluded from the flying branch of the Air Force. But the most careful examination cannot ensure that the pilot will not suffer from inequalities of tension in the middle ears on rapid changes in altitude. This is particularly liable to

occur if a cold or sore throat leads to partial or complete blocking of one or other Eustachian tube. This temporary change in the conditions of tension, external to the labyrinth, is a potent cause of giddiness, especially in scout pilots engaged in war-flying. It is characterized by the fact that it continues for a time on the ground after landing and is frequently associated with pain (Sydney Scott).

But there are many cases of giddiness and fainting in the air which bear no relation to abnormal conditions of those portions of the auditory apparatus external to the receptive nervous mechanism.

Any normal man can be made giddy during aerobatic evolutions, such as spinning, if he holds his head in certain unusual postures. We can bear with impunity certain violent disturbances of equilibrium if the stimulus is expended on certain parts of the vestibular apparatus, but not if it falls on other combinations of the semicircular canals. In the same way, provided a normal pilot is not unduly susceptible to giddiness, he can induce at any rate the preliminary stages of fainting in the air by pushing rotatory stimulation experimentally to abnormal limits.

But machines are so constructed, and pupils are taught to carry out aerobatic evolutions in such a manner, that the majority of normal men do not suffer from these symptoms in the air. There are, however, some in whom the physiological response is so violent that it can never be overcome, and they are always giddy and nauseated whenever there is any sudden or considerable change in equilibrium. Others suffer at first, but may overcome the reaction as they acquire facility in the air. Such persons are liable to regress under the influence of any condition, physical or mental, associated with diminished central control.

The majority of these patients could not swing with comfort in childhood and habitually suffered from train-sickness. When rotated on a chair the larger number were uncomfortable and suffered from nausea and sweating.

On the other hand, the pilots who came under my observation for 'fainting' in the air had all enjoyed flying from the first. They had experienced no discomfort in childhood, either when swinging or when travelling in the train. In two out of the five cases I was able to evoke that 'mistiness', which is one of the preliminary stages of fainting, by rotation in the chair; the others showed no abnormal reaction to this method of stimulation.

Epilepsy is one of the rarest causes of 'fainting' in the air. One definite case only has come under my observation during the later stages of the war, since the institution of a strict medical examination for admission into the Air Force. This is reported on p. 29. Differential diagnosis should not be difficult, for in this case, as might be expected, the larger number of attacks occurred on the ground under conditions that excluded any form of vertigo.

Chapter III. Sensations experienced by Normal Persons in Machines heavier than Air.

1. *Introduction.*

Balance in the air or on the ground depends primarily on the character and intensity of many diverse sensory impulses. Changes in the posture of the body as a whole affect the vestibular apparatus, the spacial aspects of vision, and the afferent mechanism of joints and muscles. If these various sense-organs function normally, the basis is given for those actions necessary to ensure stability, whether on the ground or in the air. Any external condition which produces an abnormal series of responses in any part of this complex sensory mechanism will lead to defective equilibrium. Giddiness, due to unregulated tension in the middle ear, and the disastrous effects of heterophoria are examples of such aberrant stimulation of normal sense-organs.

If want of balance were merely a matter of irregular external stimuli, or of some defect in the peripheral sense-organs, the question would be easy of solution. But I have been able to show that an abnormal reaction may be caused not only by faulty sensory impressions but by lack of what, for want of a better word, may be called 'higher control'. A man's 'muscular sense' may be perfect; and yet, when his eyes are closed, he may be unable to stand on one leg or to balance a rod on a flat board. His vestibular response, when rotated on a chair, may be normal, but the sensory impressions evoke nausea or the preliminary stages of fainting. Two factors must be considered in all observations on sensation, the character of the primary response and the nature of the final reaction.

Moreover, physiologists have long been familiar with the fact that a constant physical stimulus does not evoke in every case an identical physiological response. More mechanically-minded investigators are accustomed to assume that a strictly regulated physical stimulus must be followed by a directly proportionate functional response. On this hypothesis a body at a certain temperature should always produce an identical sensation of heat or cold; but this is notoriously not the case. A temperature of 30° C. may seem at one time hot, at another cold, according to whether the hand has been previously soaked in cold or in hot water.

Again, the impression produced by a physical stimulus, however carefully selected, is not of necessity simple, but is frequently extremely complex. It may evoke impulses which are incompatible with one another from the sensory point of view. Thus a temperature of 45° C. stimulates the heat-, the cold-, and the pain-spots; normally it produces a sensation of heat. If the mechanism for the reception of heat-stimuli is absent, 45° C. seems to be cold; if the part is insensitive to both heat and cold, pain alone follows the application of this temperature although it normally excites pleasant heat. In this case a physically simple stimulus evokes complex and incompatible

impulses, which must be sorted and integrated before they can form the underlying basis of a sensation.

Even then the struggle is not over. For it may happen that the mind is not at the moment attuned to accept a sensation of this kind; it is therefore suppressed, and does not enter the focus of consciousness. Under such circumstances some other group of sensory impressions may become dominant, to the exclusion of those more naturally anticipated. For example, we all know how certain forms of toothache are relieved by taking food. The physical cause of the pain is not influenced by the mechanical act of deglutition; but the neuralgia is inhibited for a time by the massive impulses poured into the central nervous system from the upper gastro-intestinal tract.

An identical stimulus can evoke in the same individual a varying response; what wonder that the action of the same physical forces may produce the most diverse effects upon different people. A good example of such differences, drawn from daily life, is the sensation produced by descent in a lift. Many people experience a peculiar 'sinking in the stomach' or 'feeling as if my stomach was being left behind' when moving downwards. Others have never been conscious of this sensation, unless the lift moves with a rapidity unusual in this country. Between these two extremes lie those who recognize this 'feeling' if the movement starts somewhat suddenly, but not under ordinary conditions. This sensation, like giddiness in the air, can be acquired. One young pilot knew nothing of any such 'feeling in the lift' until after an attack of influenza; the first time he travelled on the Tube Railway, on recovering from his illness, he noticed that the descent of the lift produced a peculiar effect he had never experienced before. When he returned to duty ten days later he found he had lost all confidence in the air and was 'gripping his controls tightly and tensely'.

Thus between the impact of the physical stimulus on the sense-organs and the final production of a sensation, lie innumerable possibilities of variation in the physiological and mental reactions. What wonder that the sensations induced by flying a machine heavier than air differ fundamentally in different persons, though the stresses and strains may be identical.

These individual differences start from the moment the machine leaves the ground. In some the uncomfortable bumping, caused by 'taxy-ing' across the aerodrome, gives place immediately to a feeling of profound security. If the passenger is strapped in with a well-fitting belt and his pilot is expert in correcting 'bumps', the machine seems to be the stable centre of the universe; it is the earth and sky that shift and move. A vertical bank produces no sensation beyond the feeling that the country with its roads, woods and houses is tilting in a peculiar and definite manner. Even during a flat spin it is the horizon that races round like the rim of a rotating bowl. An expert pilot talks in terms of a moving universe; he says, 'I came out to find the earth rushing up and so I pulled my stick back'; or 'My horizon was crooked, so I knew I was flying one wing down'.

In those who are fortunate enough to experience this stability from the first, it transcends any security obtainable on earth or sea. But many first-rate pilots have been frightened and unhappy on their first flight; they cannot believe that any one felt secure from the first moment he left the ground. With them confidence is acquired. But since it has been gained by practice it can also be destroyed by any condition which lowers bodily or mental vigour; and this is the case, not only with those who have adapted themselves to conditions in the air, but also with those in whom such confidence is innate.

Any experience which induces anxiety or fear may destroy the confidence of even the finest pilot. To be shot down in aerial combat, or to land in flames, is sufficient to upset the sense of security in any one, and may lead to subsequent want of adaptation to changes of equilibrium in the air. But should the concussion produced by the 'crash' abolish all memory of the events directly preceding the accident confidence may remain unimpaired. For this reason some who have passed through a terrifying experience can subsequently fly as well as ever. It has left no trace on the memory; the whole episode, including perhaps events of some hours before the ascent, has been entirely wiped out.

On the other hand, the sudden realization of danger may destroy all feeling of confidence on the spot (No. 11). The pilot not only feels himself insecure, but may become clumsy in his actions and suffer from abnormal sensations in the air. The anti-aircraft guns of the enemy produced more harm by undermining confidence in the air than by the actual destruction of machines; for when a pilot began to dream of 'Archies', he was near the end of his flying career at the front.

2. *Actual Experience during Aerobatic Evolutions.*

It is a matter of everyday experience that the same physical stimulus does not produce an identical effect on different human beings. But the physicist finds it hard to believe that the strong mechanical forces in action during aerial flight may lead to no conscious effect; and yet from a physiological point of view this might have been exactly anticipated. The more perfectly the passenger feels himself part of the machine, the more he will tend to translate changes of posture into some alteration in the position of surrounding objects. Stresses and strains disappear so long as there is perfect physiological adaptation to changes in equilibrium. In this way we gain a rapidity of action which would be impossible if every physical alteration entered consciousness and necessitated a corresponding action of the will. A good pilot does not fly by rule nor does he depend entirely on his instruments. When he wants to 'bank' he says, 'I just lean over and it comes,' exactly as when rounding a corner on a bicycle.

The following figure gives the actual forces to which the machine is exposed during various evolutions, as shown by means

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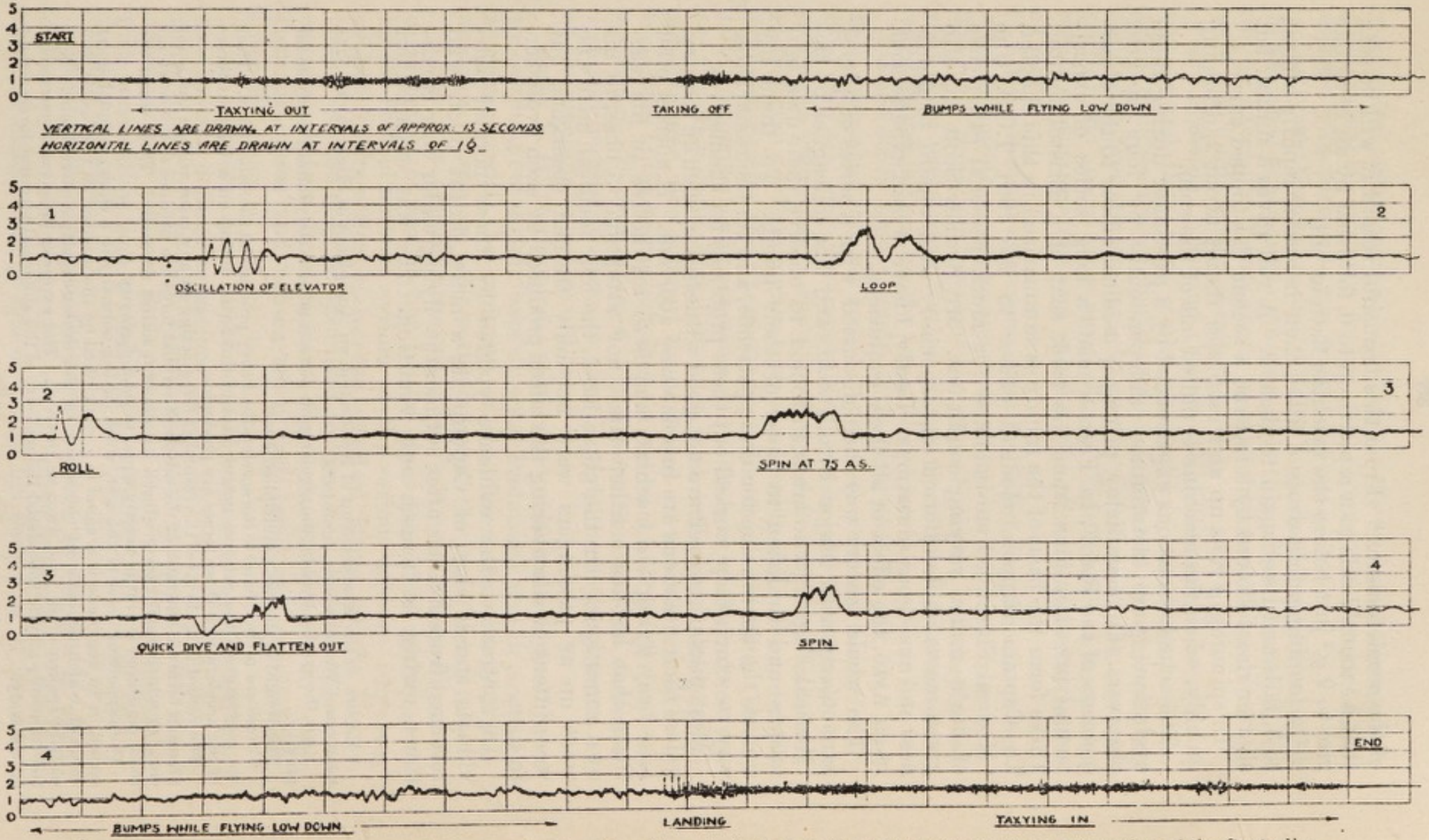

(Reproduced from the Reports and Memoranda, No. 469, of the Advisory Committee for Aeronautics, by permission of the Controller, H.M. Stationery Office.)

of the accelerometer.[1] From this beautiful record it will be seen that a 'zoom' leads to a rapid drop to 0, followed by an irregular rise to 2 *g*,[2] just before the machine flattens out.

On looping, *g* first drops a little, then increases rapidly almost to 3, falls and rises again to about 2. A roll gives a similar but shorter rise, followed by a fall and a second flat-topped curve.

In spinning *g* runs up and oscillates round about 2, dropping quickly, when the machine is pulled out of the spin.

The actual sensations experienced by a passenger during these evolutions were determined independently by four medical observers. Colonel Birley, principal medical officer to the Headquarters of the R.A.F. in France, made a long series of experimental investigations from the back seat of a Bristol fighter. These form the basis of the inquiries summarized in this chapter. To Captain Rippon, medical officer to the 29th T.C.S. (the 'Medical Flight'), I am indebted for much personal experience of flight under varying conditions. Mr. Sydney Scott has also given me valuable information, especially with regard to giddiness and analogous sensations. Lastly, I have myself experienced, in an Avro, the effect of all these evolutions.

The whole matter was then discussed with a series of pilots, particularly with Major Bird, D.S.O., and his colleagues of the 'Medical Flight', who are accustomed to observe their own sensations and to listen to those of their pupils. To them my sincere thanks are due for their patience, and for the remarkable way in which they worked out these problems for themselves.

Most pilots, however, are not good witnesses in such an inquiry, unless their reactions are in some way aberrant. A normal pilot is so busy flying his machine, and is so instinctive in his reactions, that he has neither time nor attention to observe his own sensations. On the other hand, the four medical men who went up as passengers were not only trained observers, but were intent on discovering the effect produced by each evolution in turn.

In contrast to the evidence yielded by these normal individuals stands that of Captain H., a most skilful pilot, who returned from France, after six months' flying under war conditions, owing to nausea and vomiting. He was engaged on

[1] Report on the Measurement of acceleration on Aeroplanes in Flight, by G. F. C. Searle and W. Cullimore, June 1918.

[2] *g* is the symbol used for the acceleration per second of a body falling freely under gravity.

The weight is the mass multiplied by *g*.

Forces are proportional to the accelerations they produce on the same mass. Thus we may express the relative magnitudes of the forces acting on a body in terms of the accelerations these forces are producing.

The record (Fig. 1) gives the resultant force acting on any mass within the aeroplane in terms of the ratio of the acceleration that force can produce to the acceleration (*g*) which would be produced by gravity, acting normally. Thus, when the force registered is 1, it is exactly equal to that of gravity.

The supporting force of the seat, when sitting normally in a chair, is equal to *g*; seated in an aeroplane it is equal to *g*, multiplied by the number on the record, the value of which depends on the nature of the evolution being carried out. It is usually spoken of as 'one, two, or three *g*'. The excess or deficit above or below the value of *g* may be considered the measure of the abnormal physical forces acting on the body.

mechanical experiments in the air for the technical branch, and gave valuable evidence before the Committee on Accidents, especially in answer to my cross-examination.

Lastly, my thanks are due to Major V. B., another officer engaged in technical experiments, who was able to produce fainting in the air by excessive disturbances in equilibrium. He supplied me with many interesting details.

(a) '*Zooming*'. During this evolution the machine is dived steeply and then rises almost vertically in consequence of the great acceleration of momentum. Sometimes on quick-flying scouts the preliminary descent may be eliminated; the essential part of the 'zoom' is a steep climb. This throws an enormous strain on the machine and exposes the pilot to violent changes in stress.

All the medical observers, however, failed to notice any sensation during this manœuvre, and the three pilots of the 29th Training Squadron were of the same opinion; but they added that there was a sensation 'as if you were loose on your seat', when flattening out on the top of the 'zoom'.

On the other hand, Captain H. insisted that he felt his 'head being squashed into his body'; 'you feel you are being forced into your seat and it is impossible to move your legs though you can move your arms.' Here we find the first flat contradiction in testimony. Four highly-trained scientific observers and three pilots chosen for their perfect adaptation to conditions in the air, failed to perceive any sensation until the end of the manœuvre. On the other hand, a skilled pilot, with technical knowledge of a high order, who suffered from nausea in the air, was acutely conscious of the physical forces acting on his body during this evolution. In fact he said, 'If I were to lose this sensation, I should be worried, because then I might be putting forces on to the machine which would break it'.

Major V. B., the technical pilot who could make himself faint by carrying out certain experimental evolutions, was in complete agreement with the majority of the observers. He said that during a 'zoom' he 'felt nothing except the joy of doing it'.

Thus it is evident that what we call perfect adaptation to disturbances of equilibrium in the air is associated with control by the central nervous system of the various afferent impulses, evoked by the action of intense physical forces on the human body. Should they be permitted to rise into consciousness and cause sensations during normal flight, the pilot tends to suffer from giddiness and nausea when they reach any considerable intensity.

(b) *Looping.* None of the medical witnesses experienced any giddiness or definite sensations during an ordinary loop, and the three pilots of the 29th Training Squadron agreed with these observations. Colonel Birley noticed that, after the fourth or fifth consecutive loop, a sensation gradually came on of 'being loose in the seat'.

As might be expected, the account given by Captain H. again differs profoundly from that of the other observers. He feels that his head is being squashed into his body; as if he were

being forced into his seat. 'It is impossible to move your legs although you can move your arms freely.' This alternates with a feeling of 'decreased gravity'; 'it makes me feel as if my stomach was coming up. I sweat and may have nausea. I have put my head over the side but have never been sick.'

Major V. B.'s experiences are particularly interesting. He feels no sensation whatever during a perfect loop; but if he makes a short loop, a mist comes before his eyes like the early stage of going under an anaesthetic. If he makes five or six perfect loops consecutively he loses his horizontal and comes out to find he is flying wing down. 'You haven't the power to get her right unless you can get your head clear again. Something goes wrong after the third or fourth loop, which spoils their perfection.'

Here again we see the same difference in central control. In perfectly adapted persons simple looping produces no sensation, whilst Captain H. was sensible of the physical forces acting upon him throughout. These sensations came to Colonel Birley after a fifth or sixth consecutive loop only, and then in a mild degree. Major V. B. experienced nothing unless the loop was imperfectly performed, when he felt in a slight degree the preliminary sensations of fainting; a series of perfect loops disturbed his power of flying horizontally unless he made a definite corrective effort.

(c) *Spinning.* The effect produced by spinning in normal persons depends greatly on the position of the eyes and head. Pilots vary profoundly in the attitude they adopt; some keep their eyes on the instrument board and do not look outside the fusilage, others fix some point on the ground. Many pilots contend that if the eyes are thus directed throughout 'you remain conscious of your position in space, but if you look inside the fusilage you don't'. Both are safe methods and should not cause giddiness in normal persons.

Colonel Birley, who has made many observations to investigate this point, found that when he looked downwards during a spin he knew his position in space, but was conscious of forced movements. Thus, when spinning to the left (counter-clockwise), it would have been an effort to do anything to the right.

However well adapted a pilot may be to rotatory stimulation, he suffers from giddiness and frequently from nausea if he looks up at the top plane during a spin. Colonel Birley found that, on looking up, he 'lost himself entirely' and suffered from acute vertigo. 'I could not have done anything, and should have been incapable of all effort.' He was not, however, nauseated. Looking at the wing-tip is said by some to be even worse, and to be spun facing the tail is worst of all.

The account given by Captain H. is most instructive. During a spin he always looks straight forward at his instruments, and never lets his eyes wander outside the fusilage. On emerging from a spin he does not know where he is, but 'pulls out by rule'. He then finds that the 'horizon is crooked'. 'Something inside me would make me fly the machine one wing down.' During one set of experiments he looked up obliquely to the

left in order to count the turns by means of the sun, and was extremely uncomfortable. When he came out of the spin he was reading his instruments with great difficulty. 'I forced myself to do it; but it was a jolly big effort.' After coming out he stalled the machine badly and then dived; this was an unintentional manœuvre due to his state of mental confusion. He did not suffer from giddiness, but after it was all over felt sick. 'I felt bunged up and was unable to think clearly; I couldn't reason.' He is so familiar with this state that he has learnt by heart and repeats to himself exactly what he has to do, 'so that I mayn't have to think it out at the time'.

During these same experiments he carried out several more spins and nearly vomited. 'I felt something, under my lower jaw-bone, was being drawn upwards, and whenever I have felt this before I have always been sick. In this case I put my head over the side; but the drawing-up feeling below the tongue grew less and finally disappeared. I was not sick, though the feeling of nausea persisted for some time after I landed. I was very sick during the following night.'

Major V. B., a highly expert pilot, had the following experience whilst carrying out some experiments for the Technical Department. After an unsuccessful attempt to discover the smallest horizontal banked circle in which a Sopwith triplane could be spun, he got the machine into a turn at 3,000 feet. On starting the second turn 'the sky appeared to go grey'. 'A mist gradually arose like going under an anaesthetic,' and he 'fainted'. It was not an unpleasant sensation. When he came to himself, he was flying over a village about a mile away from the place of the experiment. The unconsciousness must have lasted about 20 seconds. During the first turn *g* reached 4·5, during the second 4·6. The turn was of about 140 feet at a speed of 114 miles an hour.

This pilot found experimentally that, whenever the acceleration (*g*) was pushed up to a high figure, he experienced the characteristic darkening of the sky which was preliminary to fainting. On another occasion he was looping and diving a D.H. 4 during a mock fight, when these preliminary sensations reappeared. He realized his danger and struggled against losing consciousness. First came a feeling of pressure in the head; then a mist gradually approached and spots rose before his eyes. He felt faint, chiefly at the bottom of the loop, and was quite conscious at the top. Then 'daylight' returned during the dive, and he came down about three minutes later feeling perfectly well. This preliminary sensation is distinctly pleasant, but is associated with inability to make an effort; 'it requires a definite struggle to right the machine.'

3. *The Human Element in Aeroplane Accidents.*

(a) *The Physiological Effects of disturbances of Equilibrium.* Normal human beings differ profoundly both in the intensity and in the character of their reactions to changes in equilibrium. Rotation in a chair, with the head erect and the eyes closed, is

usually followed by a tendency to deviate, and, on opening the eyes, surrounding objects seem to be moving in a direction opposed to that of the rotation. Thus, if a normal man has been turned clockwise, the apparent rotation of the room goes counter-clockwise, and the deviation takes a form determined by the position of the head during the turning. The average human being in perfect health rapidly overcomes these after-responses, and recovers his stability in a few seconds; moreover, he does not suffer from nausea or other abnormal sensations.

Such a patient as No. 3 (p. 19) was classed as abnormal, although he was in perfect physical health, because he invariably became giddy and was incapacitated by stimuli to which the majority of men could adapt themselves without difficulty. Such a classification is, however, purely arbitrary. Aeroplanes are so constructed that they can be flown by any healthy young man without producing vertigo or other disturbing symptoms; it would be possible to build 'freak' machines that required the talents and training of an acrobat to resist the giddying effect of their evolutions. Thus the criterion by which we judge whether an aviator is normal or abnormal depends ultimately upon whether he can adapt himself to those disturbances of equilibrium to which he is commonly exposed in the air.

Giddiness and forced movements are not uniformly proportional to the rotatory stimuli acting on the body. For exactly the same physical forces, which produce intense vertigo when looking upwards, may be without effect if the head is held in the usual position and the gaze is directed horizontally forwards. This can be shown by the following experiment. Whilst standing in the normal position, rotate the head rapidly from side to side; most persons experience little or no vertigo. But, if the eyes are directed to the ceiling and similar lateral movements are carried out, the majority of healthy people become giddy and rock on their feet. The physical forces are the same in both cases; but in the former they are exerted with the head in its usual posture, whilst in the latter the position is one to which we are not habitually accustomed. In the same way even a normal pilot can be made profoundly uncomfortable by looking upwards during a spin.

An even more insidious danger is the mental state which accompanies the physiological changes induced by rapid rotation. Colonel Birley found that, when he was spun counter-clockwise with his eyes fixed on a spot directly below him, it became difficult 'to do anything' to the right; if he looked upwards during the spin, he became incapable of all voluntary exertion. Sydney Scott came to the conclusion that some persons do not come out of a spin because they cannot realize that they must make a definite mental effort to pull the machine into a state of normal stability. Several pilots of experience bore out this suggestion. One of them said that in putting on the rudder to stop a spin he is reluctant to substitute 'a state of strain for a state of ease'; his tendency is to continue spinning too long. Another spoke of this condition as a 'sort of mental coasting'. Major V. B. was particularly explicit on this point; he has been

throughout so conscious of the danger of this pleasant mental state that, as soon as he feels it beginning, he cuts short the manœuvre.

So long as the machine is one which will come out of a spin when the controls are released, the pilot may become unconscious and yet no accident happen. But if a definite act is required to terminate the rotation, as on a Camel, it is obvious that the machine may spin into the ground because the pilot has been rendered incapable of the necessary voluntary effort. The more rapid the turns the more likely is it that this condition will be induced; and it is not improbably responsible for some of the accidents on very delicate scout machines such as Camels. Where, however, the pilot is seen to fall into a spin, to come out again and to spin into the ground in the opposite direction, it is possible that forced movements are responsible for the reversal of rotation after the first recovery.

(b) *Regression.* Flying, like the ability to play games, is definitely acquired and maintained by practice, and the measure we apply to all such human activities is the extent of functional efficiency. Now all action is based upon reflexes, which are controlled by the activity of higher centres; these in turn are dominated from above, and the active life of the central nervous system is comprised in a hierarchy of functions. Finally, consciousness stands as commander-in-chief over a vast number of subordinate activities, each of which is itself in authority over some more lowly mechanism.

To refer everything to the central authority would be a slow and laborious method of action; power is therefore delegated to the various departments to act without reference to the central administration. The lines of action are, however, laid down from above; we acquire a new aptitude by conscious effort excited through lower motor and sensory mechanisms. When learning to play the piano the fingers are laid consciously on each key and a complicated apparatus is thrown into action which strikes the note. Soon, with practice, the fingers move automatically and consciousness is occupied in reading the musical symbols on the printed page. Finally, with increased facility even this becomes almost automatic; the expert musician scarcely sees the page, for the nature of the musical phrase suggests to him the sequence of the accompanying harmonies.

First, the mechanical apparatus must function perfectly; the strings must be in tune and the levers which move the hammers perfectly adjusted. The fingers must learn to strike the right keys and the two hands be co-ordinated and controlled. This after long practice becomes automatic. At the same time there must be perfect comprehension of the musical notation and strict combination of mind and hand. Finally, in the supreme state of functional aptitude, the printed page suggests a musical thought which is automatically manifested as a series of sounds.

In the same way the aviator slowly acquires increasing facility in manipulating a complicated apparatus. At first he laboriously flies by rule and has to memorize the steps by which each evolution is induced. As he becomes more expert he has but to desire

some movement and it occurs; for a good pilot flies automatically and not by formula. He corrects, and may almost be said to anticipate, 'bumps' by instinct.

This power over the machine has been gained by conscious effort, during which a series of functional adaptations become engulfed in the automatic activities of the central nervous system, as soon as they are acquired. Movements laboriously learnt become unconscious reactions. But this supreme control can only be maintained by constant exercise and perfect physiological efficiency. Any influence which tends to diminish the power of concentration or to disturb the acquired mastery over sensory and motor impulses will lower ability to fly. The pilot becomes aware that he has lost his certainty in landing or is inclined to make flat turns. He does not know why he is no longer master of his actions, and complains 'I do everything that used to make me land perfectly, but it only comes off once in three or four times'. Like a golfer, he is 'off his game'. He does not know what is wrong because, when perfect facility has been acquired, the act has become automatic.

It is a well-known physiological law that when the control by a higher centre over some lower activity is diminished the character of the reaction tends to take on a more primitive form. The lower centres released from control are free to exercise their activities unchecked. For example, in hemiplegia the paralysed arm is frequently in a condition of great rigidity. This is due to the loss of that control usually exercised by the cortex of the brain over the lower motor centres. In the same way removal of the dominant influence of the sensory cortex on the afferent activities of the optic thalamus causes the paralysed half of the body to become over-sensitive to all painful or pleasurable stimulation. This phenomenon is usually spoken of as the 'release' of lower centres.

Here one crude structural centre of later development dominates another with more primitive reactions. But a similar law governs the inter-relation of a series of functions, each of which has been in turn acquired by practice and conscious effort. On the piano the fingers must first be taught to strike the right keys; then the two hands must work in a co-ordinate manner. As each new facility is gained it becomes automatic and disappears from the focus of consciousness. But with loss of control, movements once performed without thought require an effort of attention, and both mind and hand make apparently inexplicable mistakes. If the error takes the form of some fault previously overcome by practice we speak of 'regression'. The sufferer has fallen back on some previous method of reaction.

This unexpected return to some previous habit is one of the commonest human errors in all mechanical activities. Innumerable instances can be gathered from games and from daily life. A man who has driven a motor-car with the levers to the left, and then becomes habituated to the more ordinary form with a right-hand brake, may find in an emergency that he is groping to the left. A golf-player who is 'off his game' finds that he has fallen back to some long-conquered fault. This might be called

mechanical regression; some action, which has been acquired in perfection and has become automatic, may be disturbed by failure of control and is consequently carried out in an inferior manner.

But regression may be manifested not only in a motor act, but also on the sensory side. A tendency to giddiness in the air may be overcome with the acquisition of aptitude to fly. The physical stresses and strains to which the pilot is exposed remain the same, but the afferent impulses they cause are integrated and controlled. If, however, the general physiological resistance of the nervous system is lowered, or the power of mental concentration diminished, sensations of unusual intensity may be aroused accompanied by giddiness and nausea. A pilot may regress to the form of reaction which troubled him when he first went into the air.

The war has furnished frequent examples of the mental aspects of regression. A soldier is sent home suffering from the stress of fighting; he complains of horrible dreams, which take the most diverse and individual forms. Night after night he wakes in fear. But after suitable treatment these terrors cease and his dreams are occupied with the petty worries of the day. Suddenly all the old horrors return in consequence of some great sorrow or anxiety, such as the death of his wife or illness of a child. He has regressed to a previous psychical reaction in consequence of diminished mental control.

Not uncommonly all aspects of regression are manifested in the same patient. A pilot finds he is no longer flying with certainty; he is obliged to think of what he is doing instead of carrying out the manœuvre automatically. This frightens him, and the fear causes widespread regression. He may become giddy or faint in the air, and will probably 'crash' unexpectedly. He complains of frequent nightmares; these may be concerned with horrible events, previously forgotten, which occurred when he served in the trenches. Or he may be haunted by visions of a machine falling in flames, the reappearance in symbolic form of an old fear on first flying over the lines.

Thus regression may lead to the loss of mechanical aptitude, to an abnormal reaction due to the uncontrolled activity of sensory impulses, or to the reappearance of some less efficient form of mental activity. It is of profound theoretical interest, and probably explains certain apparently incomprehensible accidents in the air.

General Summary.

1. Conscious stability and comfort in the air depend primarily on the normal response of three groups of sense-organs. These are the vestibular apparatus, the eyes, including the eye muscles, and the proprio-ceptive system with its endings in muscles, tendons, and joints.

But of all the afferent impulses evoked by the impact of physical forces on these various mechanisms, those underlying the projected aspects of sensation are alone of significance in the

present inquiry. We are interested in those impressions which lead to recognition of the position of the body in space.

2. Defective responses from any one of these afferent end-organs will disturb the sense of equilibrium in the air, and may lead to actions that affect the stability of the machine.

3. No candidate for service in the R.A.F. is accepted who shows gross abnormality of any one of these primary organs of sensation.

But in the course of flying a machine heavier than air, an otherwise healthy man may suffer from disorders of vestibular and visual sensibility due to temporary causes. He may not be able to regulate the tension in the middle ear with sufficient ease during a rapid descent and consequently becomes giddy; or his eye muscles may no longer function strictly in unison, and he may develop heterophoria with its resultant lack of visual orientation.

4. The tests at present in use by the Examining Boards for estimating the sense of balance may reveal the existence of some abnormal functional state, but are not otherwise an indication of ability to fly.

5. Standing on one foot with the eyes closed, walking a line heel to toe, and balancing a rod on a flat board, are not tests for 'Muscle Sense' or 'Vestibular Stability', in the class of young men from whom the pilots and candidates of the R.A.F. are drawn. Failure to pass these tests, however, indicates some want of afferent or efferent central control.

6. The presence of Tremor, especially of the hands, is of great importance; it points to some distinct defect in static control, and is definite evidence of disordered function.

7. In some men, otherwise normal, rotatory stimuli produce a more powerful reaction than in the majority of their fellows. They become giddy easily. As children they could not swing with pleasure, and some of them were habitually sick in the train. Such persons are not suffering from a pathological condition; their disability arises from the fact that sensory impulses from the semicircular canals are not checked and controlled to the same extent as in the majority of healthy individuals. Consequently, when exposed to disturbances of equilibrium to which a normal man would adapt himself unconsciously, they suffer from discomfort, become giddy, and may even vomit in the air.

8. Many who were giddy when first exposed to aerobatic evolutions, succeed in conquering this disability. They learn to fly with ease, and the acquisition of this new facility is associated with control of the primary afferent impulses from the auditory and visual apparatus.

Any condition which produces diminished control by the highest faculties over the activity of lower centres, is liable to lead to regression to the earlier mode of reaction.

9. All healthy men can be affected if the intensity of the rotatory stimulus is pushed up to a sufficiently high degree. This may occur either from the fact that the head is held in some unusual position, as for example when looking upwards during spinning, or the actual rotation may be mechanically increased in rapidity.

In some cases the reaction to such excessive stimulation takes the form of giddiness with or without nausea; in others it is associated with that withdrawal of consciousness known as 'fainting'. When a man is made giddy he is in a state of confusion with regard to his relations in space. In the preliminary stages of 'fainting' his horizon is restricted and the world around disappears. Both states, pushed to the limits of endurance, end in unconsciousness.

10. Complete adaptation to disturbances of equilibrium in the air is associated with automatic control of the afferent and efferent activities of lower levels of the central nervous system. A perfect pilot desires that his machine shall behave in a certain manner, and the evolution occurs, exactly as an instrument in the hands of a skilled musician emits the appropriate sounds as soon as he becomes conscious of some harmonious phrase.

11. This acquired facility can be disturbed by any condition which leads to diminished control. Just as a golfer can be 'put off his game' by some physiological or mental state, so the aviator may lose his capacity to fly in consequence of conditions that vary so widely as a gastro-intestinal attack or domestic anxiety. Exhaustion, insomnia, the distress of war flying, anxiety or fear, can all lead to defective afferent and efferent control. Efficient automatic response is no longer possible, and the pilot begins to fly badly and to make bad landings.

12. But this loss of control over the activity of lower levels may be manifested not only in bad management of the machine, but in some dangerous reaction such as 'giddiness' or 'fainting' in the air.

13. Should this abnormal reaction assume the form of giddiness and nausea, it will be found in most cases that the patient has suffered from some discomfort when he first went into the air. Inquiry will usually reveal that he was unable to swing with pleasure as a child, and that he tended to be sick when travelling by train.

On the other hand, all the five pilots who came under my care for 'fainting', enjoyed their first flight and could swing with pleasure.

In the first group rotatory impulses, when released from control, manifested their influence in giddiness, usually accompanied by nausea. Amongst those who 'fainted' in the air the resistance to vertigenous impressions was high and no excessive giddiness resulted; but they induced the effects of shock with undue facility.