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Function of the deeper Sensibility and of the vestibular Organs in flying.

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The share contributed by the sensations originating in the deeper sensibility (muscle and joint sense) in creating the perception of the position and movement of an aeroplane in space can be, in many cases, only distinguished with difficulty from the rôle played by the vestibular organs (the semicircular canals and the otolith system).

The difficulty encountered in differentiating the two is not so great where the question concerns gyrations round an axis outside the machine (turns, loopings, spinning nose dives¹, tonneaux² by which the sensory nerve-endings of the semicircular canals, and, in a somewhat peculiar way, the otoliths also, are affected (quite apart from the question as to whether one is conscious of the effect or not) as it is where changes in the position of the aeroplane, (inclinations round a sagittal axis (banking), a frontal axis (rising and descending) and vertical up and down movements are concerned. Here we are unable to determine what rôle is played by the labyrinth on the one hand and the deeper sensibility on the other in our perceptions regarding the position and the movements of the aeroplane in space.

¹ A spinning nose dive (french: vrille) is a spiral, vertical descending movement of the airplane in which the nose of the machine is directed towards the earth and the very fast gyrations are made around an axis parallel to the sagittal axis of the machine.

² A «tonneau» is the same revolving movement around a horizontal axis.

We ought to make a sharp distinction between these changes in the position of an aeroplane which are combined with turning movements and those which are distinct from these.

It is to be noted that gyrations without inclinations, such as take place in a rotating chair, do not exist in normal flying.¹ Accordingly we must divide this article into two parts:

- I. Gyrations.
- II. Inclinations.

I.

Gyrations.

These may be divided into four, viz:

- a) Gyrations in a horizontal plane around a vertical axis outside the machine (turns).
- b) Gyrations in a sagittal plane around a horizontal axis (looping).
- c) Gyrations in a frontal plane (tonneaux) around a horizontal axis.
- d) Gyrations in a frontal plane around a vertical axis (spinning).

I. a) *Turns*.

In technically well-executed turns we have movements in which neither the superficial nor the deeper sensibility, nor the otolith system either, can inform us as to the nature of the movement or the position of the aeroplane in space. The inclination, namely, of the machine in these turns is proportional to the speed of the gyration (diameter of the circle made), so that there is neither inward nor outward slipping and consequently no side wind is perceptible (superficial sensibility). The centrifugal force produced by the gyration presses the airman upon his seat and notwithstanding the inclination of the machine, remains perpendicularly directed towards that seat (as in normal horizontal flight), while the force which influences the otoliths undergoes no change of direction with reference to the maculae. (Fig. 1 a and 3).

If we now exclude the function of sight by blindfolding the subject, we can examine exclusively the action of the semicircular

¹ Owing to the fact that an aeroplane is absolutely free in the air, a rudder movement without inclination would cause side-slipping, not turning.

canals and discover if it is possible and if so, to what extent it is possible for an aviator, without the help of his eyes, i. e. in clouds or mist, to perceive turning movements taking place spontaneously under these circumstances.¹

Fig. 1 a.
Aileron position for right-hand turn.

Such an accurate enquiry in the case of the isolated semicircular canal functions is only possible in an aeroplane and can never be realized with a spinning chair, as with the latter the influence of the superficial and the deeper sensibility can never be excluded.

With a two seater Spyker school machine, 4 series of experiments were carried out, during which I myself acted as pilot. In *series A*, experiments were made with a person who had absolutely no experience of flying, *series B* with a person who had very little experience, *series C*, with a person who had more experience (pupil-aviator) and *series D* with a person who was a very experienced aviator himself (800 flying hours). The bending inwards took place without any brusque movements so that the turning movement began very gradually, the angular acceleration at the beginning

¹ That he should be able to perceive the *position* in space of the aeroplane during such turning movements (when well executed) without the help of his sense of sight, is theoretically impossible. There is no sense impression or combination of sense impression which can render this possible.

Fig. 1 b. Left hand turn.

and the slackening at the end being thus very slight. The constant angular speed of the turning movement was reached about 5" after the beginning of the turn while it took also 5" to get the machine out of the movement into rectilinear flight again. The inclination of the machine in carrying out the turns changed — in proportion to the angular speed of the movement — from 45° to 75° and the angular speed from 4° to 12° per second.

The results were as follows:

Series A. 3 tests, angular speed 10°, 8°, 12°. Acceleration about 2°, 1,6° and 2,4° respectively. Inclination about 60°, 60° and 75°.

Result: *Not a single correct perception.*

Series B. 3 tests, angular speed: 10°, acceleration (and slackening) about 2°. 3 correct perceptions and after-perceptions.

6 tests, angular speed 8°, acceleration about 1,6°: 2 correct. 2 doubtful (sliding to the right and inclination to the right) and 2 quite incorrect perceptions.

Series C. 3 tests, angular speed 8°, acceleration 1,6°. 3 correct perceptions, and after-perceptions.

3 tests, angular speed 10°, 6°, 4°, acceleration 2°, 1,2° and 0,4° resp.: — in every case the perception were wrong.

Series D. 2 tests. Angular speed 8°. Acceleration 1,6°: 2 correct perceptions.

4 tests. Angular speed 10°, 8 ½°, 8° and 6°. Acceleration 2°, 1,6°, 1,2° resp.: *4 wrong perceptions.*

It must not be forgotten that, before every test, the person experimented with received an indication that a turn to the right or left was about to be made. By simply guessing, the possibility existed that out of the 24 tests, 12 of the guesses would prove correct.

Experience in flying seemed to be of no assistance. The person tested in *Series B*, although he had only a very slight experience of flying, gave by far the best results. In his case it seemed as if the threshold of conscious perception was at angular speed of 10°, i. e., about 2° acceleration per second, working during 5". Very remarkable also were the numerous instances of »after-sensation» such as are known in the spinning chair. (In stopping the chair, for example, there is a sensation of revolving in the opposite direction.)

It appeared also, as was to be expected, that the person experimented with remained sitting upright even when the machine was reeling over most so that in respect to the earth, he occupied a more or less vertical instead of a horizontal position. All the persons tested were shewn to possess a vestibular system which acted absolutely normally. A special investigation made into the subject gave the following results:

Duration of post-rotatory Nystagmus (10 revolutions in 20''):

Test person from Series A: R. 28", L. 31"			
»	»	»	» B: R. 26" L. 26"
»	»	»	» C: R. 31" L. 31"
»	»	»	» D: R. 16" L. 16"

Physiologically these results may be said to agree with those of previous investigators in this sphere, although we must remember that the minimum of perceptibility depends not only on the acceleration but also on the time during which this acceleration acts upon the subject. *Maeh* found a minimum of perceptibility with an increase of angular speed of 2° — 3° per second when this acceleration was maintained for 14—16 seconds. When the speed increase acts only for very short time (in some cases $\frac{1}{45}$ second) then *van Rossem*¹ found the average appreciation of the minimum acceleration at least 80° per second. *W. Mulder*² gives as average minimum for 3 persons tested, a speed increase of 2° per second, operating during 0,8".

That our experiments should prove that the limit is higher in the air, was to be expected. In an aeroplane only the semicircular canals are affected and the superficial and deeper sensibility play no part in the creation of perception (while they do play a part, in my opinion, in a spinning-chair). An aeroplane, moreover, hangs quite free in the air and the persons experimented with are continually subject to a great number of the most varied disturbances caused principally by small vertical rising and falling movements, which must have a most confusing effect.

¹ A. van Rossem. Gewaarwordingen en reflexen. Proefschrift Utrecht 1907.

² W. Mulder. Quantitatieve betrekking tusschen prikkel en effect. Proefschrift Utrecht 1908.

Speaking practically, the results, for those who have only a slight knowledge of aviation, are astounding. It is very difficult to imagine, when one sees an aeroplane in the air, standing almost vertically on its side, instead of in a horizontal position and making rather rapid turning movements, that the occupants perceive nothing of it when their sense of sight is eliminated. Yet we know that such is the case and that none of those with whom the series of experiments were made, had more correct perceptions regarding the position and movement of the aeroplane than they might have obtained by simply guessing.

Fig. 2. Rudder position for left turn.

These experiments *proved* that it is impossible to perceive inclination combined with turning movements when these are normally executed in the air, without the help of the sense of sight. Further tests seemed to me unnecessary, considering that such are involuntarily made nearly every day by aviators flying in the clouds. They all know that it is impossible, without the help of the sense of sight to restore an aeroplane to a horizontal position when it has lost that position through any cause and has automatically come to a turning movement.

With the machines used at present and which possess a considerable

able degree of inherent stability, it is only with great difficulty and by the application of a special method, which only a very sensitive and experienced aviator can acquire, that one is able to fly straight through the clouds for a short time and even then this is only possible when there are no strong or irregular air currents in the clouds, which very seldom happens.

Only by preventing, at all costs, any deviation from the horizontal position, is the aviator able occasionally to fly straight for a short time. Should the machine however, owing to one cause or another, deviate from the horizontal, it is impossible to recover the normal line of flight (except by using special instruments: f. i. the gyroscopic compass.)

The method which the aviator must follow is to enter the clouds in an absolutely straight line and with all his steering gear centrally

Fig. 3. A = Gravitation working on test person during horizontal flight
B = Gravitation + centrifugal force working during right turn. $B > A$.

adjusted. He must keep the steering gear continually in this position and redress the slightest inclination with his «stick» (i. e. by means of the *aileron*s) before this inclination results in a turning movement. It is absolutely essential that he should not allow his footrudder to alter its position (not to apply, therefore, the classic rule «Rudder to the side from which the side wind comes»), that he should be extremely sensitive to inclinations (without turning movements) and should know how to readjust quickly and in the correct degree. Should he allow the incli-

nation of the machine to remain a moment too long, the plane begins to turn and then no sense organ nor any instrument (except gyroscopic compasses) can help him in defining his position or movement in space. It is clear that only a very few aviators possess such a capacity for rapid and correct reaction and such a sensitive feeling for the vertical as to enable them in calm weather to maintain their bearings in the clouds for any length of time. For most aviators this is impossible, and a somewhat long flight in clouds or mist (i. e. for longer than a few minutes) is for them desperate business.

During my career as aviator from 1914- 1918, I repeatedly made flights in the clouds and came to the following conclusions: In calm weather (in the clouds) it is possible, by means of the method described above, based absolutely on one's sense of the vertical, to keep the machine in a horizontal position for a shorter or a longer period; should it, however, owing to some reason or other, deviate in any considerable degree from its horizontal position, then it is impossible to readjust it, and the best course then to follow is to descend as quickly as possible from the cloud. In executing these cloud flights I observed the appearance of a highly remarkable illusion which I have never yet seen described but which I learned, in the course of conversation with other aviators, is not uncommon. When one emerges from the cloud through which one has flown for some time, and when the transition takes place suddenly as generally happens in the case of cumuli cloud formation, one repeatedly gets the impression that the earth does not lie straight, as if the line of the horizon makes a sharp angle with the line which we imagine should be the real horizon. The explanation is clear: one enters the clouds in a horizontal position and in ones last glimpse of the earth, its expanse and the line of the horizon are parallel with the planes of the machine. For some reason or other, however, and without one's perceiving it, the machine adopts a sloping position in respect to the earth and in this position one emerges from the cloud and suddenly sees the earth again. Owing, however, to the fact that one was not able to perceive the change of position (inclination plus turning movement), one remains convinced that the machine is still lying horizontally in the air, while at the same time one perceives that the

planes of the machine form an angle with the expanse of the earth and the line of the horizon. The conviction, however, that the machine is lying in a horizontal position (no change of position having been perceived) is so strong that the fact that the earth and the machine are no longer parallel is wrongly interpreted and one gets the impression that the earth does not lie straight. At first, when one has not considered the situation and the cause of the appearance is not quite clear, it is only with some difficulty and reflection that one is able to realize the real state of affairs. One must force oneself to believe that the earth has not changed its position and that the reason for the disturbed parallelism is due to oneself and the aeroplane. Admitting that and acting on it, one sees clearly the earth gradually reassuming its horizontal position.

This illusion manifests itself the first few times one emerges from a cloud; with further experience it gives place to a vague feeling of having lost one's bearings in space. There are many aviators who have never noticed this phenomenon, but in opposition to these stand the positive statements of others for whom the illusion was very real and who were able to describe its whole course in detail.

The appearance of this illusion also proves, *a contrario* that when vision is excluded, no sense or combination of senses can inform us regarding the position of an aeroplane in space, for if we really did perceive a change in the position of the machine while in the cloud and knew that we were flying obliquely with respect to the earth, such an illusion would never take place. An incontrovertible proof of the fact that we can perceive normal turning movements of an aeroplane with our eyes alone and nothing else, is the following: when during the execution of a sharp turn one looks along the lower plane towards the earth, one receives, owing to the great distance, an ocular impression of a very slow turning, so that, even with a beginner, no trace of giddiness ensues. While executing a similar manoeuvre, however, and turning the eyes upward along the higher plane, you look into space without being able to define anything stable, you get the ocular impression that the upper plane of the machine is executing an extremely rapid turning movement against the sky. A severe giddiness now makes itself felt, at least in the case of beginners, and even more experien-

ced airmen are conscious of a feeling of discomfort, due to the fact that a want of harmony has developed between what one sees and what one feels. One sees a rapid turning movement but one does not feel it, and it is this which causes that disagreeable feeling of uncertainty, of having lost one's bearings which we know in the analogous case of the «haunted chamber» where the revolving walls awaken the (visual) impression of «looping the loop» while in reality, the floor only makes a slight swaying movement. Here again the want of harmony between the impression given by sight and that given by the other senses arouses giddiness, sometimes so violent as to cause vomiting.

Fig. 4. Turn, inclination about 45° .

That the above is the correct explanation of the giddiness which ensues when looking upwards along the higher plane during a turning movement and that the phenomenon has nothing to do with a «Drehschwindel» (excessive stimulation of the semicircular canals) intensified by an abnormal position of the head, as has been asserted, is proved by the immediate passing away of the disagreeable giddy feeling, on closing the eyes, without changing the turning movement of the machine or altering the position of the head.

We see from the above that, with the aeroplanes at present in use, it is difficult, if not impossible for a human being to fly

for any considerable time in clouds or mist when he has to depend solely on his organs of sense to inform him regarding his position in space. These alone are not sufficient and practice and experience cannot overcome the difficulty. The obstacle can only be removed with the help of special instruments (servomoteur or gyroscopic compass; plummet, level and magnetic compass are of no use and make only for confusion).

I. B. Looping. A turning movement on a sagittal plane around a horizontal axis situated outside the machine. As regards the vestibular organs, the two vertical canals are then stimulated the most.

In a well-executed looping, the machine describes an almost complete circle during which the «air-speed» of the machine ought not to change in any degree worth mentioning. The angular speed and the angular acceleration are shewn to remain below the limit at which perception takes place, while the forces which affect the body (gravitation and centrifugal force) change in power only and not in *direction* in relation to the seat of the pilot in the machine. The otolith organs and all the sensory functions are therefore not able to solve for us the problem of determining the position and movement of the machine, so that we see that a blindfolded person during a well-executed loop, experiences nothing of the manoeuvre and that when he possesses aviatically well trained perceptive powers he is conscious only of a vague impression of ascending.

As experiments, looping movements are useless for collecting data serving to extend our knowledge regarding the physiology of the semicircular (in casu the vertical) canals, seeing that with the machines used at present it is impossible to increase the speed sufficiently at which these turning movements are executed. That the stimulus is not great enough, during very rapid loops to cause vertigo in the case of an experienced aviator is proved most clearly by the so-called record of the French airman F r o n v a l, who, in an attempt at making the greatest number of loops in the shortest possible time, succeeded within a space of 3 hours, 52 minutes and 10 seconds, in executing 962 of these turning movements without the slightest feeling of giddiness. (The time average in this looping performance was 14,5", that is, with an angular speed of 25° per second.)

Experiments, in which I myself, blindfolded, acted as the test person, gave the following results: the time necessary for describing a full circle was respectively $7\frac{2}{5}$, 7, 8 and 9 seconds (timed with a stopwatch) that is, with an angular speed of between 40° and 50° per second, the turning movement being carried out designedly with as great a speed as possible. The radius of the circle described may be calculated if we allow that the average air-speed (recorded by the speedometer which the machine contained) was 120 K. M. per hour. We then arrive at the following calculation:

$$2\pi R = \frac{120,000}{3,600} \times 7\frac{2}{5} (7, 8, 9,)$$

$$R. = \text{circa } 35 \text{ m. } (40, 45 \text{ m.})$$

Fig. 5. Loop.

With the eyes closed, I did not succeed in detecting a loop. Twice I thought that the aviator had carried out a sudden steep, ascending movement while, as a matter of fact, a complete loop had been executed.

1. *C. Tonneau*. (roll, sideways loop.)

A tonneau is a turning movement round an axis parallel to the sagittal axis of the machine, which axis is horizontal with reference to the earth. To put it more simply the machine flies hori-

zontally, turns 360° round itself and then resumes its horizontal flight.

Owing to the fact that the rotatory axis lies outside the machine, a centrifugal force also acts in this case, causing the intensity but *not* the *direction* (against the bottom) of those forces affecting the body (and the otoliths in the labyrinth) to change, so that sensibility and the otolith organs are mechanically excluded from imparting a correct perception of the movement executed. The turning speed, including both the increase and the decrease of speed at the beginning and end of the manoeuvre is much greater however, than in the case of a loop, for example. It is, however, usually impossible to execute more than two tonneaux consecutively so that in tests, during which I myself acted as the person tested, I did not succeed, with my eyes closed, in getting a correct perception of the movement. Repeatedly I only got the impression of rising swiftly without being in any way conscious of a turning movement.

During the experiments (airman and aeroplane being the same as in the looping tests) the tonneau was made in 6", that is with an angular speed of 60° per second.

I. *D. Vrille.* (spin, spinning nose dive.)

The turning movement in a vrille is identical with that described in the case of the tonneau. The nose of the machine, however, is now directed towards the earth so that the axis, round which the turning movement takes place (which axis is parallel with the sagittal axis of the machine) is in a vertical position in respect to the earth.

Of great practical importance, however, is the fact that a vrille can be continued for some time and that the turning speed is very great, as a consequence of which vertigo may develop and very often does, the result several times being an accident.

It was found impossible to time the turning speed of a vrille exactly, as it is so difficult to count the number of turns made. Only once, with a stopwatch, did I succeed in measuring exactly the time of five successive turnings.¹ These measured 15 seconds, from which one arrives at an angular speed of 120° per second.

¹ Later on I succeeded in making more exact experiments and measured 2".3, 2".5 and 4" per 360° . In very fast vrilles we see therefore that the angular speed almost reaches 180° per sec.

Owing to the fact that in a vrille — the same being also true of a loop and a tonneau — the regular turning movement takes place at an enormous speed, the increase of angular speed, i. e. the acceleration, only acts for a fraction of a second, and in my opinion, it is in this direction that one must look for an explanation as to why all these turning movements are not perceptible when the eyes are closed.

It only remains for us now to determine which pair of semicircular canals are especially stimulated during the various turning movements mentioned above, in which plane these turning movements take place and in which plane vertigo will manifest itself when the turning movement ceases.

We know from experiments made in the spinning-chair that vertigo in a horizontal plane, such as can be set up by stimulating the horizontal canals, i. e., by causing the person tested to revolve with his head bent 30° forward, causes very little inconve-

Fig. 6. Tonneau.

nience. When the chair ceases to revolve one has for a time the sensation of revolving in the opposite direction, but it does not occasion the so-called «falling» reaction.

The case is quite different, however, when vertigo is experienced in a vertical plane, whether frontal or sagittal in relation to the head of person tested. Such a vertigo can only be excited in a spinning chair in a very artificial way. If the person tested is made to revolve, with his head bent forward 120° (which practically means that his head is between his knees) then the anterior vertical canals are stimulated in a frontal plane. As long as the subject keeps his head in this position, the frontal plane on which the turning movement takes place, is horizontal and affords the vertigo, which makes itself apparent when the chair ceases to revolve, no occasion for any special reaction. Should the person sit up, however, as soon as the chair comes to a stand-still, the frontal plane

in which the vertigo manifests itself changes from horizontal to vertical and a «falling» reaction now reveals itself, owing to the fact that he has an after-sensation (illusion) of revolving in a frontal vertically situated plane in a direction opposite to that of the original turning movement. If the revolving movement, with head bent forward, were to the right, he feels a vertigo to the left and counteracts it by falling or rather by throwing himself to the right. On the spinning chair one can stimulate the vertical canals on the sagittal plane by laying the head of the person with whom the experiment is made on his shoulder. As long as he holds his head inclined in this manner, the vertigo which occurs when the chair stops, takes place in the horizontal plane. Should he raise his head, however, the plane of the vertigo becomes vertical and he experiences the very strong and confusing illusion of falling forward or backward (vertigo in the vertical sagittal plane).

To sum up, we may say therefore that vertigo in a horizontal plane has a less confusing and disagreeable effect than vertigo in one of the vertical planes (frontal or sagittal) while by changing the position of the head (90° bent downwards or to the one side, we are always able to change a vertical vertigo into a horizontal.)

If we now apply this to the turning movements of an aeroplane, as described above, we see as follows:

During sharp turns and spirals, the vertical canals are stimulated and that in an almost horizontal plane, because the machine is strongly inclined and the occupants, as we have seen, do not change their position with respect to the machine.

When the machine emerges from the turn or the spiral, the inclination at the same time ceases, and the aviator again assumes the upright position. A resulting vertigo should now take place in a vertical sagittal plane; in other words, the aviator, at the conclusion of the turning movements may have the feeling of falling backwards or forwards and in his attempt to right himself he may cause the machine to ascend or to descend. Although we have seen that even very rapid turning movements (angular speed 10° to 12° per sec.) do not stimulate the canals in question above the limit of perception and do not cause vertigo, one must not exclude the possibility of machines being constructed which will be able to execute still more rapid turning movements and that in such a

case vertigo would manifest itself (which is all the more probable, should the vestibular apparatus of the aviator be hypersensitive). In that case it is useful to remember that the aviator, after a sharp turning or spiral movement, can change the troublesome vertical vertigo into a harmless horizontal one by bending his head sharply down on his shoulder, by which he renders the sagittal vertical plane of vertigo, a horizontal one.¹

In a loop, the turning movement takes place in an absolutely sagittal plane. (In a bend or spiral this plane is only then absolutely sagittal in relation to the head of the person who is undergoing the experiment, when the inclination becomes one of 90 degrees.) The two vertical canals (anterior and posterior) are thus stimulated and the vertigo which then makes itself felt occurs in the sagittal plane, placed vertically. This vertical vertigo can again be made to disappear by laying the head on the shoulder.

In the tonneau the turning movement takes place in a frontal plane placed vertically. Vertigo which may possibly occur after the turning movement has terminated, takes place in the same plane and can occasion a falling reaction to right or left, but the aviator can convert it into a horizontal vertigo by bending his head downwards 90 degrees.

The vrille or spinning nose drive is at this moment really the only aviatric manoeuvre in which advice to airmen, founded on a physiological basis, can be of any practical use, as the turning speed reached is so great that vertigo repeatedly takes place and may prove fatal to the aviator. In a vrille, the turning movement takes place on a frontal plane, placed horizontally (such as takes place in the spinning chair when the person experimented with, lays his head on his knees). When the manoeuvre is ended, the machine (with the pilot) rights itself and the plane of the vertigo is now fron-

Fig. 7. Spin.

¹ Experience has proved the effectiveness of this measure in the case of loops and vrilles; this has hitherto not been the case as far as turning movements and spirals are concerned.

tal, but placed vertically. Just as in the spinning chair, a «falling» reaction takes place in the same direction as the late revolving movement. If the vrille were to the right, the aviator would feel the inclination to throw himself to the right (having an illusion of turning to the left in a frontal plane, he seeks to resist) and there is a great risk of his making the same movement with his steering-gear by which he would bring his machine once more in a vrille or sharp spiral.¹

This has been repeatedly observed and has cost the life of many an aviator.

It is of great practical value, therefore, either to completely prevent this vertical vertigo or to change it into a horizontal one.

Prevention is possible, if during the turning movement, one bends one's head 90 degrees forward (practically by looking at the floor of the machine), the head thus assumes the position of «upside down», and the horizontal canals are stimulated throughout the turning movement. When the vrille is ended and the machine changes its position from vertical to horizontal, one must sit up straight; by doing so the stimulated horizontal canals remain horizontal (90° by the righting of the machine and 90° by righting of the upper part of the body), and the vertigo acts in this plane.

Should one remain sitting upright during the vrille, the vertical canals are stimulated; the turning movement, it must be remembered, always takes place on a frontal plane and the nose of the machine is directed straight downwards towards the earth. When, at the end of the vrille, the machine is righted, the plane of the vertigo² becomes vertical when the head comes into a normal upright position. By bending the head 90 degrees forward, however, the plane of this vertigo becomes once more horizontal and one has no longer the feeling of being rotated in a frontal plane, and thus avoids the «falling» reaction (the inclination to throw oneself to the right or left).

These two methods, which my own experience teaches are very easily applied, render any vrille absolutely safe.

¹ The movement takes place to the same side as the preceding vrille. The American conception with regard to this (Air Service Medical, P. 261) is incorrect.

² The plane in which the illusion of revolving takes place.

Experience, of course, can teach one to overcome, to some extent, the troublesome and confusing effects of vertigo. One learns to regard as an *illusion* that feeling of turning in the opposite direction when the original revolving movement ceases, and one learns to suppress the inclination to act on this illusion, as is seen, for example, in the case of dancers. One adapts oneself to the new condition and is no longer the victim of incoordinated sensory impressions.

This capacity, however, acquired by experience, by which the higher centres are able to control the troublesome, sensory stimuli, can be weakened under the influence of illness or other circumstances injuriously affecting the mental functions, and we see then that an experienced aviator who has executed innumerable vrilles without any trouble from giddiness, on a certain day, for example, when not completely recovered from a serious attack of influenza, is so severely affected by vertigo after a vrille, that he immediately throws his machine into a similar spin from which he finds it impossible to extricate himself and may occasion a very bad accident. I have witnessed such a case at very close quarters in which the causes of the accident were in all probability such as are described above, and I am convinced that had the very able aviator bent his head downwards when the vertigo attacked him, he would have found a way of preventing the accident.

H e n r y H e a d¹ describes a great number of such cases and gives the reason as follows: «Anything which diminishes the power of concentration tends to lessen control over the reactions 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 completely recovered, may fall back to his original mode of reaction and be unable to carry out any acrobatic 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».

Thus we see that here also applied physiology on the one hand

¹ The Sense of Stability and Balance in the Air. Medical Research Committee Special Reports. No. 78, 1919, P. 18.

can be of great use to the aviator, and on the other hand that regular medical control, based on the principles set out above, can contribute to the saving of life.

II. *Inclinations.* The perception of the change in the position of an aeroplane (ascending or descending; banking) which is *not* combined with any turning movement takes place normally with the help of the eyes. Should the sense of sight for any reason be excluded — clouds or mist — then the aviator must rely on his vestibular organ and his deeper sensibility. At the same time — and this is of very great practical importance — very simple instruments (plummet, level, speedometer) inform him immediately with regard to any deviation from positions of *this* kind and with their assistance he can keep the machine horizontal (i. e. so long as the machine has not got into a turning movement).

It seemed to me of theoretical interest, however, to enquire into the question as to what degree of deviation was felt — when the sense of sight was excluded — and also which sensory organ — vestibular organ or deep sensibility — contributed most towards this perception.

Apart from the question regarding the more or less importance of the two above mentioned sensory functions and in order to determine the minimum perceptibility for these changes of position, I made at first a number of experiments with blindfolded persons (the same as in Series A. B. C.) of which the results were as follows:

With a person without any experience of flying, the minimum perceptibility for inclination around the frontal axis (forwards, backwards) lies at about 10° and for inclinations around the sagittal axis (banking) at about 20° .

With the test person of Series B., who had a slight experience of flying, the minimum deviation perceived was 5° in ascending and descending and 10° in banking, while the figures were the same for the test person of Series C. (pupil aviator).

American experiments¹, based on a more or less similar method, arrived at the following results:

¹ Air Service Medical, P. 251.

Normal persons without experience of flying	{ descending, minimum 9° ascending, minimum 17° banking, about 35°
Professional aviators	{ descending, minimum 4° ascending, minimum 6° banking, varying between 5° and 9°.

These experiments prove nothing as to what share the vestibular apparatus on the one hand and the deep sensibility on the other, have in the formation of these perceptions.

To attain this knowledge we should require to make tests in an aeroplane with blindfolded persons who had no trace of vestibular function (some types of deafmutes) by means of whom we could then examine the functions of deep sensibility in a state of isolation. On the other hand, experiments could be made with persons without deep sensibility (the nearest approach to whom would be patients in an advanced stage of *tabes dorsalis*, preferably of the dorso-lumbo-sacral type) in whom everything depends on the action of the vestibular system. In this way we should at least be able to form an approximate judgment, although we must never lose sight of the fact that in such experiments we have to do with abnormal persons who, both physically and mentally, differ to such an extent from those who possess absolute control of all their senses, that the result, of these experiments could only be, with the greatest reservation, made applicable to normal persons, and it is only normal persons whom, ultimately, we have to consider.

American enquirers¹ have indeed, carried out experiments in lifts as well as in aeroplanes with deafmutes possessing no trace of vestibular reaction²; in lifts, in order to enquire into their powers of perception in the case of linear up and down movements, and in aeroplanes to examine how far they were able to perceive changes in the position of the machine in space.

In the lift it appeared that deafmutes whose vestibular system is inert were better able to perceive an increase or slackening of

¹ Air Service Medical, p. 227.

² How this was established is not quite clear.

speed and the termination of a movement, than normal persons, and that they were not, as was the rule with normal persons, subject to the illusion of a reversed movement with a change of speed or when the lift stopped. Up and down movements with equal speed were no more correctly perceived by the abnormal than by the normal persons. The absence, in the case of these deafmutes, of the illusion of reversal of motion by alteration in the speed of the car, I would attribute, in opposition to the American idea, which speaks of an increased function of the deeper sensibility, to the elimination of otolithic stimulation (or endolymph movement?) which with normal persons, by the stopping, for example, of a vertical upward movement, gives rise, owing to the inertia factor, to a perception (in casu illusion) of a movement in the opposite direction. With regard to linear up and down movements, therefore, these American investigators show clearly that in this respect deafmutes without vestibular function have the advantage over normal persons. In these movements they are better able to perceive what really happens. Tabetics seemed to perceive increase and slackening of speed and stoppings only with great difficulty and to be subject in a considerable degree to the «illusions» described above.

As to experiments made in America with deaf-mutes, in an aeroplane, it must be remembered that these were only of value in as far as they concerned a perception of ascending and descending (turning around the frontal axis). The perceptive power for inclinations around the sagittal axis (banking to right or left), which as we have seen above is of such practical value, was not investigated in America *lege artis*. From the description given it is perfectly clear that coincident with this inclination, a turning movement took place. For example they say that the angle of banking reached 80° , which is completely and technically impossible in aviation without a turning movement. We have shown above that this quite alters the position of affairs owing to the action of centrifugal force.

Thus there remain the experiments the object of which was to determine the perceptive powers of deaf-mutes without vestibular function for ascending and descending movements in the line of flight, with inclination of the machine around a frontal axis.

Those also, however, were not quite sharply carried out, as the changes of position were effected very brusquely (sudden room upward; almost vertical dive downward, p. 248 l. c.) which occasioned not only changes in position but marked differences of speed. Where it therefore appeared that by »markedly quick movements of the plane», the perceptive powers of deaf-mutes were slighter than in the case of normal persons (70° by ascending, 40° by descending, against resp. 17° and 9° with normal persons), the conclusion drawn by them: ¹

»The striking differences between these deaf-mutes and the normal candidates and the still more striking lack of improvement in all their subsequent flights seem to be fairly convincing that for purposes of *appreciating changes of position in space* a properly functionating vestibular apparatus is of great importance and further, that but little can be expected from deep sensibility when it alone senses motion», is not justified.

From the experiments from which this conclusion was drawn, I only gather that normal persons perceive changes of position *which go with considerable linear acceleration* and slackening of speed, better than do deaf-mutes without any trace of vestibular function. Whether normal persons, however, perceive changes of position which are *not* or only in a very slight degree, coincident with changes of speed, as happens with a normal flying machine, better than deaf-mutes who depend alone on their deeper sensibility, is not shown.

It is, however, very probable, that in this artificial manoeuvre, the superiority shown by normal persons was not due to their better perception of changes in position but to their more correct perception of linear increase and slackening of speed, and if this is the case, and I think it very probable, then the American experiments prove nothing with regard to the share contributed by the deeper sensibility on the one side, and the vestibular organ on the other, to the causing of perceptions regarding the position of a machine in the air. And that is just the point, for by »the feel of the airship» we mean the exact perception of position and change of position of a machine with which we are endeavouring to fly hori-

¹ Air Service Medical, p. 252.

zontally and with which, therefore, no increase or slackening of speed worth mentioning, takes place.

In view of the above reflection, I cannot therefore agree at all with the conclusion that »the feel of the airship, which is the sense complex that makes for a first class pilot requires normal vestibular motion sensing». I do not agree with it, chiefly because »the feel of the airship» does not depend on a »*motion* sensing» but on a perception of a change of position, *unaccompanied* by any considerable change in speed.

In order to study more closely the problem of the relative importance of the deeper sensibility and the vestibular organ in connection with perception of change of position, a problem which has not been solved by the American investigations, we can make enquiries in two other directions. On the one hand, we can try as far as possible to exclude all sense functions with the exception of the labyrinthine, as has been done by S. G a r t e n¹ in a series of experiments, in which he examined the vestibular function almost isolated. On the other hand, we can proceed more empirically and indirectly by examining a number of *good* aviators — whose powers of position-perception have thus been practically demonstrated — with regard to their deeper sensibility and vestibular functions, in order to discover whether a decrease of sensibility in the one or the other sphere — and in which — is consistent with a keen power of perception for change of position. If for example, it were possible to discover whether with decreased vestibular sensibility, aviators still possessed keen powers of perception for changes in the position of an aeroplane, this would strongly support the hypothesis that the deeper sensibility played a preponderating rôle in this, while if the reverse were proved — that is, if a correlation were found to exist between a hypoeccitable vestibular organ and inferiority as an aviator — it would be difficult to deny the existence of a special function of the labyrinth in steering an aeroplane.

G a r t e n attempted to investigate the isolated vestibular function by plunging his subject, seated in the rocking chair into

¹ S. G a r t e n: Über die Grundlagen unserer Orientierung im Raume. Band XXXVI Abhand. der math. phys. Klasse der Sächsischen Akademie der Wissenschaften N:o IV, 1920.

(salt) water, by which means he almost entirely eliminated the effect of gravitation, so that neither the superficial nor deeper sensibility could contribute in any degree towards forming a judgment with regard to the position.

These experiments proved that the course of action followed resulted in the subject, with a completely intact vestibular organ, almost entirely losing his bearings and that changes in position of 8° and once even of 18° were perceived either not at all or incorrectly (the normal is $\pm 4^{\circ}$, see page 21) thus proving that, in the case of normal persons, a weakening of the superficial and deeper sensibility, causes a very considerable decrease in the capacity to perceive changes of position.

That the weakening of the superficial sensibility plays scarcely any part in this, is shown by a series of experiments in which by means of novocaine injection the skin of the thighs and gluteal region was rendered anaesthetic without this having any noteworthy influence on the sensitiveness of the perceptive powers in this respect. On the result of these experiments, G a r t e n bases his conclusion that the deeper sensibility is of much greater importance for the perception of changes in position as is the labyrinth, the more so as it also appeared to him that deaf-mute children without vestibular function, do not differ in any remarkable degree from normal persons in exactness of perception with regard to position. Against this last argument, however, the objection is permissible that although the absence of semicircular canal function has been proved, that of the otoliths has not, as no satisfactory method of doing so has so far been found, at least where human beings are concerned.

Making use of the material at my disposal, I myself made, for practical reasons, an enquiry in the other direction indicated above and endeavoured to discover whether any connection existed between ability to fly and the quality of the vestibular function, and more especially whether a weakening of the vestibular function (determined by duration of post-rotatory nystagmus, falling reactions and past-pointing) indicated a decrease in the capacity to steer an aeroplane or not.

First let it be noted that all the persons tested were subjected to a preliminary examination in the equilibrium chair (Garten's

Neigungstuhl) and the results obtained were generally speaking, the same, (about 1 to $1\frac{1}{2}$ degrees average deviation) so that in this respect they can all be regarded as equal (quite apart from the question as to what their perception of position was due).

The difficulty exists, naturally, of defining what is understood by a *good* aviator. I judge him to be one who, during a period of at least one year, has betrayed no single peculiarity while flying, has caused no accident which had any connection whatever with a weakness in perception as to position and had manifested no deviation from the normal in certain circumstances (map-reading, control of instruments and serving a machine-gun, in which he is entirely dependent on his sense of equilibrium) while I allow myself to be guided entirely in judging a medium or a bad aviator by the deviation noted by his instructor, with regard to poor power of position perception («hanging over in the air», «allows the machine to climb steadily without perceiving it», etc., etc.) As has been said above, they were all equal in the equilibrium chair.

In enquiring into their vestibular function, the following method was adopted:

a. 10 x round in 20", with closed eyes, head bent forward 30°, once to the left and once to the right. When the spinning chair stopped, the eyes were opened and the duration of the nystagmus noted.

b. 5 x round in 10" with the head on the knees (90° bent forwards). When the chair stopped, head and body were raised and the nature and strength of the «falling» reaction estimated (absent, weak, strong, excessive).

c. Notes were also made of the other objective and subjective phenomena which developed after the turning movement had ceased (paleness, perspiration, nausea, vomiting, etc). The «past-pointing» test was not employed here, as it does not give, in my opinion, any clear idea of the vestibular excitability, however suitable it may be for indicating how the person tested reacts consciously and with a coordinate movement after a stimulus of the labyrinth. The result of this past-pointing depends in normal cases on two factors which cannot be separated: a process of consciousness (generally speaking), a reaction upon the illusion of turning in the opposite direction (i. e. away from the point to be

touched), and a vestibular reflex; it is strongly influenced by practice and teaches us in this matter nothing with regard to semicircular excitability.

It is thus seen that the method of enquiry is just the same as the American method as described in Jones'¹ «Equilibrium and Vertigo» and in the «Air Service Medical»² (in which the average duration of the postrotatory nystagmus, in the case of normal persons (such as are accepted for the air service) is found to be 23,1 sec. after turning to the right and 23,1 sec. after turning to the left) so that we may generally, compare their results with our own.

For this purpose I examined 63 aviators in the manner indicated above and arrived at the following results. The average duration of the postrotatory nystagmus was 21,6 sec. If we now divide these 63 aviators into «very good» (instructors and stunt flyers), «normal» and «sub-normal» then we get 13 «very good», of which 9 have a nystagmus duration *below* the general average. Of the 37 «normal», 24 remain below the general average and 13 above it. Of the 13 «sub-normal» there are 6 below and 7 above the average. The average of the three categories given separately is as follows: Very good, 21"; normal, 20,4"; sub-normal, 24,9". The only two cases noted of excessive «falling» reaction occurred among the sub-normals.

We see from these figures that the average duration of nystagmus in the case of the «very good» (21") is about equal to that of the normal (20,4") but that it rises to 24,9" in the case of the sub-normal (more or less bad) aviators, and although I would refrain from drawing any far-reaching conclusions from these relatively small numbers, it is still quite apparent that there can be no question of mutual relationship between a low vestibular excitability and poor flying ability. On the whole the enquiry showed, that with Dutch aviators at least, the shortest duration of nystagmus was shown with the best aviators and the longest duration with the worst³.

¹ I. Jones, «Equilibrium and Vertigo». I. B. Lippincott. Philadelphia and London. 1918.

² L. C.

³ The same results were reached by Anderson from an examination which he made of 100 English aviators: «Having treated by rotation over a hundred pupils and skilled pilots, the author cannot come to any definite conclusion with regard to the value of duration or degree of nystagmus, except that perhaps, if any, the most experienced give a shorter duration».

On the grounds of the very thorough experiments of G a r t e n with the »Wasserstuhl» (equilibrium chair) and the results of my own examination of good and indifferent aviators, I feel myself justified in concluding that in judging without the help of the sense of sight, the changes in the position of an aeroplane (inclination) which are *not* accompanied by turning movements or by considerable change of speed, the deeper sensibility plays the greatest rôle and that the more or less sensitiveness of the vestibular organ (as clinically defined) is of no demonstrable importance. The results of the American experiments, obtained with persons with an absolutely non-functioning vestibular organ¹, do not contradict this conclusion, as we know from the investigation of E w a l d, the great influence exercised by the labyrinth on the muscle tonus and it is also known that some varieties of deaf-mutes, in addition to their lack of labyrinth function, reveal a series of other abnormalities, viz. a low muscle tonus, so that their weak power of perception might just as well have been due indirectly to an unfavorable influence acting on their deeper sensibility through this weak muscle tonus as directly to the complete absence of labyrinthine functions.

If we now consider the two sections of this chapter, that is, inclinations plus turning movements and inclinations without them, we then see from my experiments described under A that in turnings the vestibular organ plays no particular rôle (in other words it fails to enlighten us regarding the position and movement of the aeroplane: in curves (I) probably because the angular acceleration is too slight, in loopings, tonneaux and vrilles (II) owing to reasons not yet exactly known (isolated semicircular stimulation without change in the *direction* of the pressure or the pull of the otoliths or owing to the fact that the time is too short for the stimulation to take effect).

From the American experiments it is seen that completely suspended vestibular function leads to a considerable decrease in the power of perceiving inclinations around the frontal axis (ascending

¹ The value of such experiments, however, must be considerably discounted, seeing that they were made with deaf-mutes who were for the first time in the air. The »Air Service Medical» itself rightly remarks: »The injection of so many extraneous influences such as apprehension, fear, excitement, inability to focus attention, deviates to a considerable extent the value of the findings.» P. 258.

and descending) when such are accompanied by great changes in speed.

Garten's experiments with the »Wasserstuhl» justify the conclusion that the sensing of change of position is chiefly due to the deep sensibility.

My tests undertaken with good and indifferent aviators proved that no connection existed between reduced capacity for flying and hypoeccitable vestibular function. On the contrary it proved that the best aviators showed lower values with regard to the excitability of their labyrinths than did inferior ones¹. Deviation in the interpretation of, and in the responses to stimuli due to the deep sensibility² were, however, in many cases, accompanied by decreased capacity for flying.

* * *

In view of all this, I consider it proved that the vestibular organ is of no *special* significance for the aviator — viz. that it does not enable him to steer an aeroplane in clouds or in mist — but that on the contrary, a correct and rapid response to stimulation proceeding from the deeper sensibility is of most importance for him.

Naturally this does not mean that the vestibular organ is of

¹ The American conclusion: »One who shows good responses in the turning chair, shows good detection of movement in the air one who shows poor responses in the turning chair shows poor detection of movement in the air. There is this relation between the chair and the air and the air and the chair», is however picturesquely expressed, quite untrue and is supported by no data derived from experiment.

² Here it is necessary to point out emphatically that when we speak of a diminution of deep sensibility we do not mean a diminution of sensitiveness as regards muscle or joint sense, etc. but rather an incorrect interpretation of and response to the action of such senses. It is quite clear, and H. H e a d in his work »The Sense of Stability in the air», points it out repeatedly, that persons exhibiting the so-called symptom of reduced deep sensibility, expressed in their case by the impossibility of maintaining their equilibrium when standing on one foot, with closed eyes or of balancing a staff on a board (tests for aviation candidates), deviated in no way from those who were able to do so, as far as their appreciation of passive movement in the various joints, was concerned. Amongst the pilots and pupils who were unable to stand on one foot with the eyes closed, I didn't 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. (L. C. p. 6.)

no importance at all to the aviator. It is just as important for him as for the person walking on the ground, but neither quantitatively nor qualitatively does the labyrinth play an exceptional rôle, with *one* exception and that is when, owing to some reason or other, it is over-sensitive and causes vertigo, which may have much more disastrous consequences for the aviator than for the person on the ground. When the labyrinth, therefore, plays an exceptional rôle for the aviator, the effect is unfavourable, confusing and dangerous.

* * *

As regards the practical side — by which I mean the testing of pupil aviators — the most important lesson that all this teaches us, is that a so-called hypoeccitable vestibular organ is in itself no reason for rejecting a candidate. The English¹ and Italian² investigators are here in agreement: the Americans, however, fix an underlimit (at least 16" postrotatory nystagmus) which is based on purely theoretical grounds and is supported by no single datum derived from experiment³ and reject no fewer than 2 % of all their candidates for this reason, after which they are astonished that several of those rejected by them were accepted for the English and French flying corps and became excellent aviators.⁴

It appeared also, chiefly as the result of Italian investigations which embraced 3000 aviators, that a short duration of postrotatory nystagmus is no absolute proof of a reduced vestibular irritability. Nystagmus may be entirely absent or be of very short duration, and yet, after a turning, violent vertigo and other well-marked symptoms of labyrinth irritation (falling, vomiting, perspiring, etc.) may make their appearance.

From the results obtained from my investigations with good and medium aviators, in relation to what we have seen from the

¹ H e n r y H e a d: The Sense of Stability in the Air. P. 14.

² «Mancano elementi per decidere se l'ipoeccitabilità labirintica sia o no incompatibile col pilotaggio». R a o u l H a h n. Ricerche biologiche.

³ «It was decided to reject applicants, whose vestibular apparatus gave evidence of motion-sensing acuity below a certain degree, albeit it was fully recognised in establishing this limit that it in no way represented a line of demarcation between acuities of this perception compatible with and incompatible with flying».

⁴ In the Dutch flying corps, I should have been obliged to reject two of our best aviators if I had followed the American method.

analysis of air-acrobatics, strong *hyperexcitability* calls for prudence. I should not reject a candidate, however, for this reason alone, and my opinion is strenghtened by the fact that the only candidate (out of about 100 tested), who showed a very long period of postrotatory nystagmus (41") and an excessive falling reaction, showed no sympom of vertigo during a test in the air in which loopings, vrilles, etc. were made and also after his acceptance performed his duties satisfactorily.

As a result of similar observations, the Italians cancelled their upper limit of 50" ("in molti soggetti abbiamo notato che il nystagmo si prolunga per 50" — 80" talora 110—120" senza che questo fatto abbia significato patologica». G. B i l a n c i o n i, Ricerche biologiche, L. C. p. 165). The American regulation, on grounds which are not quite clear to me, admit of no candidate with more than 36" postrotatory nystagmus.

It seems to be desirable, however, in the case of candidates who show, after turning, a nystagmus duration of longer than 50" or other deviating vestibular symptomis (excessive »falling«-reaction, vomiting, perspiring, etc.) to take them into the air and study their reaction during and after turning movements of the acroplane.

The test in the spinning chair has then, in my opinion, only a tentative and certainly not a definite value, while in addition, the general reaction of the candidate to the spinning movements is of much more importance than the duration of his postrotatory nystagmus. On the other hand an enquiry into the extent to which a man knows how to make use of the knowledge supplied by the deeper sensibility and the manner in which he responds to this with a coordinate movement, gives a certain insight into his prospective capacities as an airman. I consider therefore the tests which have been established for this purpose (the equilibrium chair, the balancing of a staff on a board, the standing blindfolded on one leg, walking blindfolded in a straight line) to be of very great importance in the examination of aviation candidates, in which we must also not forget to institute an enquiry into the rapidity of the response (the »reaction time«) to changes of position, taking into consideration the fact that in our observations with regard to flying in clouds and mist, we saw that everything depends on as rapid as possible a per-

ception of each inclination before this develops into a turning movement.¹

Pathological affections of the labyrinth occur very seldom in that class of men from which our aviators are recruited. Of practical importance, however, is the fact, emphasized by American writers² among others, that syphilis seems to affect the 8th nerve often very early in the disease expressing itself in a diminished acuity of hearing and an abnormal response to turning movements. When a very short duration of postrotatory nystagmus therefore, is established, special measures ought to be taken to ascertain whether any luetic infection has occurred.

The Ménière symptom complex, however caused, is nearly always accompanied, when it occurs in young people, by a (for their age) abnormal acuity of hearing. As for other reasons, however, a satisfactory acuity of hearing is demanded from an aviation candidate, very little risk is run of a sufferer from Menières syndrome being accepted for the aviation service.

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Indirectly we see that abnormal labyrinthine reactions occur in cases of nervous exhaustion, all too common among aviators. It seems to me that these abnormal reactions are not so much the result of an increased vestibular irritability as of a diminished power of resistance to the stimuli proceeding from the labyrinth, which renders the aviator more susceptible than would otherwise be the case, to vertigo, as the result of turning movements and air acrobatics. The labyrinth proper is not affected, but coincident with a decrease in general power of resistance (not always as a result of nervous exhaustion but sometimes also due to medicinal treatment.³) the aviator loses the power of responding adequately to

¹ We measured the reaction time to changes of position with the so-called «l'auteuil Broca» also used by the French medical aviation service and described in «Bulletin officiel de la Direction des Recherches scientifiques». Imprimerie Lahure, Paris, Novembre, 1919.

² Jones l. c. p. 47. «It has been known for years that the syphilitic toxin shows a marked affinity for the VIII nerve. Actual impairment of hearing or even deafness has been observed in many cases very early in the disease».

³ I remember hearing of a fatal accident which in all probability was due to an attack of vertigo in the air, after an injection of salvarsan a few hours previously.

the vestibular stimulus. In his work which we have already referred to several times, »The Sense of balance in the air», H. H e a d gives a number of striking examples of this (p. 17, seq.) while the *Ricerche biologiche* (p. 147 seqq.) describes a number of similar cases. It is here that the vestibular examination can assist us greatly in discovering this »regression», for it concerns aviators whom we examined when they entered the Flying Corps and whose vestibular reaction we noted when they were in good condition. We saw the slight importance of the *absolute* value of the falling reaction, the past-pointing test and the duration of the postrotatory nystagmus, but in these cases it is not with absolute values that we have to deal but only with relative ones. Should we find, for example, in re-examining a certain aviator (whose vestibular reactions are known), after an illness or who complains of vague, nervous symptoms, a longer duration of nystagmus, a more severe falling reaction or considerable deviation in the past-pointing test, then we know that danger threatens. Flying in his case should be prohibited and permission not again granted until the reaction mentioned above regain what is *for him* their normal value.

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Finally a few words must be said, concerning a direct labyrinth stimulus which in the case of aviators can occur mechanically as a result of rapid descents and ascents, in circumstances which we will proceed to discuss further.

We know that in ascending, the air pressure gradually becomes less until at 5,500 metres, it is only about the half of what it is on the ground. In normal cases, the air pressure in the middle-ear, at the various levels, is equal to the outside pressure, chiefly because the action of swallowing opens the tubae Eustachii, thus establishing for a moment communication between the tympanic cavity and the nasopharynx. In ascending, which generally takes longer than descending, the over-pressure in the middle-ear, also between two swallowing movements, enables air to escape outwards through the tubae. In descending, however, the equalisation of pressure depends solely on swallowing or yawning movements, seeing that the anatomical structure of the tubae prevents the air in the

interval from penetrating from without inwards into the tympanic cavities.

There are occasions, however, when it is impossible to establish communication between the middle-ear and the outer air, when for some reason or other — this is practically almost always a cold — the tubal mucous membranes are swollen and the tubae do not open, even with repeated swallowing and yawning movements.

In ascending, the difference in air pressure will not now be so great; owing to the relatively long duration of a climb air will be absorbed and moreover, notwithstanding the swelling of the mucous membranes, it will mechanically escape through the tubae. During a rapid descent, however, the position is quite different. After remaining for a time at a height of, for example, 5,500 metres, there will be $\frac{1}{2}$ atmospheric pressure in the middle-ear (equal to the pressure existing at that height). Should the aviator now descend, however, in a few minutes to for instance a height of 100 meters, the pressure in the tympanic cavity is still $\frac{1}{2}$ atmosphere while the external pressure is 1 atmosphere. There exists, therefore, an over-pressure of $\frac{1}{2}$ atmosphere on the tympanic membrane, which is directed inwards. This pressure is so disagreeable for the aviator, (and so dangerous also, as it diminishes his acuity of hearing considerably) that he does everything he can, by means of swallowing and pressing with closed nose and mouth (Valsalva), to open his tubae, which as a matter of fact he succeeds in doing at a given moment. The outer air now penetrates with great force and rapidity into the middle-ear and the over-pressure on the tympanic membrane, which is bent inwards, suddenly ceases. Apart from the danger of an infection of the tympanic cavity through the sudden sucking in of nasopharyngeal mucus and pus teeming with micro-organisms, it is obvious that the sudden change of pressure conditions in the tympanic cavity and the changed direction of the strain on the tympanic membrane (together with the malleus, incus and stapes) lead to labyrinth irritation, the more so when the process is one-sided, as often happens. We then see intense giddiness occurring, accompanied by violent stabbing pains in the ear (with sometimes bleeding into the membrane), often with fatal consequences for the aviator who, in these circumstances, is no longer able to make a good landing.

Such a case occurred not long ago at one of our Dutch aerodromes, where the aviators were at that time not under medical control. One of them, unaware of the danger of flying high when suffering from a cold, descended suddenly from 4000 metres and only succeeded at a height of 1000 metres in opening his left Eustachian tube, with the result that, at that height, he experienced a violent pain in his ear («as if it had been stabbed with knives») and developed haemorrhage into the tympanic membrane, while he had only his great skill in flying to thank that he succeeded in bringing his machine safely to the ground.

I will close this article therefore with an earnest warning to aviators not to fly when they are suffering from a cold and, if they do, never to fly high or descend suddenly.