

## THE FUNCTIONS OF THE FRONTAL LOBES.

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[*Translated from the original MS. by A. de Watteville.*]

THE experimental problem raised by the question we are about to discuss is of recent origin, and aroused the attention of observers soon after the discovery of motor and sensory centres. On electrical examination of the cortical surface, the anterior frontal lobes were found not to be excitable; and whilst ablation of other areas was followed by more or less evident loss of movement or sensation, that of the præ-frontal region gave rise to but slight, or doubtful, disturbances.

These negative results are the cause of the small amount of attention paid to the physiology of the frontal lobes, as compared with the activity displayed in experimentation on the motor zone. But I hope that the experiments I am going to describe, conducted on those more rigorous lines adopted by our modern science, will, to a certain extent, make up for the deficiencies of the previous results. I think, however, that we may pass over the researches of Müller, Longet, Vulpian, Lussana, and others; they vainly strove to transfer into the domain of the positive school, the results of the reaction against Gall's organology, such as that intellectual activities (images, memories, ideas) are not localised in any particular areas of the cortex.

The classical work of Hitzig<sup>1</sup> afforded a more secure starting point, and by new methods opened a new phase in the evolution of our knowledge of præfrontal functions. He observes that anatomically the development of the frontal lobes is found to keep pace with that of the intellect, being less in the cat, for instance, than in the dog, and still more so than in the monkey; hence the author concluded, naturally enough, that they are really the seat of the highest intellectual faculties. But Hitzig's experimental results did not confirm this very plausible argument. His dogs never showed intellective disorders, either after superficial lesions, or after complete extirpation, of the frontal lobes.

Ferrier<sup>2</sup> next attempted to solve the problem, on the strength of a more abundant experimental material. He assumes that all in front of the sigmoid gyrus represents the frontal lobes in dogs and cats; in monkeys, what is in front of the centre for the movements of the eyes and face and the opening of the lids and dilatation of the pupils. Electrical excitation of this region has always been negative, except in one monkey, in which ocular movements were observed.

Mutilation of this region gives negative results in dogs. Monkeys (three in number) showed no alteration in their movements, sensations, instincts, feelings, or emotions. There was, however, some alteration in the temper and behaviour of these animals, says Ferrier, though it is difficult to specify its nature. They took less interest in their surroundings; showed less of their natural inquisitiveness; were apathetic, somnolent, responded only to momentary impressions, and had lost the power of attentive observation. Ferrier attributed motor functions to the frontal lobes on account of their connection with the corpus striatum; they are inhibitory centres, whose activity is exerted on influencing the actual motor centres. Inhibition thus understood is nothing but attention, which is thus to be considered as a function of movement. Hence his conclusion that the frontal lobes are the centres of attention.

<sup>1</sup> "Untersuchungen ueber das Gehirn," 1874.

<sup>2</sup> "The Functions of the Brain," London, 1876.

Ten years later, in his second edition, this author comes to nearly identical conclusions. He confirms the absence of electrical excitability of the part of the frontal lobe placed anteriorly to the eye and head centre (No. 12 of his diagram). He relates new experiments on the destruction of the præ-frontal region, remarking, concerning one of them, that notwithstanding the bilateral lesion, there is complete absence of symptoms, either motor or sensory. The animal feels contact over the whole body, the special senses are intact, and the movements of the head and eyes are completely preserved.

Extirpation of the anterior extremity of the frontal lobe having produced the same deviation of the head and eyes as that of the region immediately behind (marked 12 in the diagram), Ferrier was led to consider the two as essentially the same functionally, viz., as motor of the head and eyes.

It is impossible to anyone familiar with these experiments not to look upon this conclusion as premature. Ferrier was too much impressed by the phenomena observed immediately after the operation. We now know how many errors are committed by this cause, as Goltz pointed out long ago. Nor does the argument derive much support from the fact of the anatomical relationships shown to exist between the frontal lobe and the pons and medulla by the microscopical examination of brains thus operated upon. For nothing proves that a centre of higher function cannot have relations with the pons, cerebellum and medulla; and that a degenerated tract traced through the internal or mesial part of the internal capsule and pes cerebri must necessarily subserve movements. And even if the frontal lobe were motor, it does not follow that it must be considered as the centre for the head and eyes, as are the roots of the superior and middle frontal convolutions.

This criticism is the more founded, as we find that in one of the experiments, destruction of the frontal lobes gave rise to no symptom, though secondary degeneration was traced through the internal capsule.

Even in this second series of experiments, however, Ferrier

succeeded in showing evidence of a mental deterioration. The monkeys, after the operation, had lost the power of attentive observation. But this fact was much less evident when, through antiseptic precautions, the animals were enabled to survive for a long time. At any rate, as the author says, this fact was more apparent than real. But, adds Ferrier, the frontal lobes are not the seat of intelligence; this would be an absurd statement, since intellect and will have no distinct localisation, but are the resultant of the functions of the whole cortex, and are correlated to the harmonious development of its various portions.

Thus Ferrier conciliates his first hypothesis, that the frontal lobes are the centre of attention with the views promulgated in his second edition, according to which it is so because it is a motor centre, and makes part of the motor zone.

Moolmann's researches added nothing to the doctrine propounded by Goltz, in whose laboratory his researches were conducted. Here are his conclusions: disorders consecutive to destruction of one frontal lobe do not differ as to persistency from that of any other part of the cortex; partial destruction of the frontal lobes causes but insignificant symptoms. When both frontal lobes are completely removed, the consecutive disturbances are the same as those observed after ablation of the parietal lobes, which means, according to Goltz, of any other part of the cortex.<sup>1</sup>

Goltz<sup>2</sup> so far recognised that the animals deprived of their anterior lobes, without being actually paralysed, cannot bring into play the complex processes of innervation necessary to the normal performance of actions, and lose their power of voluntarily moderating their bulbar and spinal reflexes.

Hitzig returns to the subject, and by new experiments on dogs, combats Munk's theory, and asserts that ablation of the frontal lobes is never followed by any motor disturbance.<sup>3</sup>

<sup>1</sup> *Pflüger's Archiv*, Bd. xx., 1879.

<sup>2</sup> *Ibid.*, vol. xxxiv.

<sup>3</sup> "Achte Wanderversammlung d.S.W.D. Neurologen," *Neurol. Centralbl.*, 1883.

We now come to Munk's researches, which were favourably received in Germany, with reference not only to frontal functions, but also to the sensorimotor localisations of the cortex generally. He used dogs and monkeys. Here is a summary of what he says of a dog: Three to five days after a unilateral operation the animal is as lively as before. It manifests no disorder as to vision and hearing under any test or circumstance. It sees, hears, tastes, understands when called. Internal sensations are normal; likewise general sensation and intelligence. A dog thus mutilated cannot be distinguished from a normal animal. It walks, runs, jumps, moves its eyes, ears, tongue and tail as before the operation. It barks, bites, feeds as before. The movements of the trunk alone show some disturbance. If the extirpation has been carried out on the left side, the dog can walk and turn to the right and to the left. But when it turns suddenly it forms an arch, whose convexity is towards the right side, the body is arched on the left, the vertebræ forming a convexity to the right. On running it can describe large curves to either side, but sharp curves are possible to the left only.

Thus far Munk. Extirpation of the left frontal lobe causes nothing but slight trunk paralysis, of long duration, persisting for months. Extirpation of both lobes produced an abnormal arching of the dorso-lumbar spine; especially on walking slowly or rising from the ground the animal displayed this symptom (cat's back), but not on running or jumping. No disorder of intelligence nor of the various forms of sensation were observable, whenever the excision involved the frontal lobe lying in front of the chief frontal sulcus (Hauptstirnfurche). Similar results were obtained in analogous experiments on monkeys. After the direct effects of the operation had passed away, the animals deprived of their frontal lobes lost their smell only when the olfactory lobe had been also injured. The trunk muscles alone were affected; no disorder of sensation, sensibility, nor intellect was noticed. The animals could not bend their dorso-lumbar spine to either side in the performance of the smaller movements. They could not straighten the back,

which remained inflected, with approximation of the anterior and posterior limbs. What Ferrier observed (apathy, somnolence, unrest) is, therefore, attributed by Munk to the effects of the lesion itself, to encephalo-meningitis.

Munk, therefore, looks upon Ferrier's experiments as failures, denies the existence of any loss of attention, perception and thought, and states that there is no failure of that inhibition which Ferrier takes to be the physiological substratum of attention. He found that a monkey so operated was kept, by a mere look or gesture of menace, from touching a much coveted morsel of food placed before it. This monkey used to take a piece of carrot held between the thumb and index, but not between the thumb and middle finger until the index had been drawn back.

Luciani<sup>1</sup> reports only two experiments on dogs which were deprived of one frontal lobe only. In both cases he observed nothing but a paralysis of the dorsal muscles and sensory troubles, with paralysis of the anterior limb, ascribed by him to a lesion of the anterior limb of the sigmoid gyrus.

The researches of Horsley and Schäfer<sup>2</sup> are not at all conclusive, because the mutilation was confined to the anterior third or fourth of the frontal lobes. None of the seven monkeys showed any disturbance of motion, or special sensation nor intellect. These results are wholly contradictory to those of Munk, and partially to those of Ferrier, who in a recent publication,<sup>3</sup> restates his former position without any modification.

Lastly, Groszlik<sup>4</sup> has just published a paper, in which the bibliographical references are incomplete. His experiments have been performed only on dogs, and are therefore undecisive on such a question. He reaches the same conclusion as Munk in so far as the frontal lobes are the common centres of the neck and back, but on the other hand he maintains that the motor troubles of the spine are not persistent.

<sup>1</sup> Luciani e Seppilli, "Le localizzazioni funzionali del cervello," 1885.

<sup>2</sup> *Philosophical Transactions of the Royal Society*, 1888.

<sup>3</sup> "Croonian Lectures," 1890.

<sup>4</sup> Groszlik, "Zur Physiologie der Stirnlappen," *Archiv für Anatomie u. Physiologie*, 1895.

Let us now summarise the various opinions hitherto propounded on this subject :

(1) The præfrontal lobe is the motor centre of the eyes and head on the opposite side ; and in consequence of the close relationship between the movements of these parts and attention, it is also the centre for attention.—(Ferrier.)

(2) It is the centre for the highest psychical functions. Destruction of it involves a real decadence of psychical activity.—(Wundt, Hitzig, Bianchi.)

(3) It is part of the so-called “Fühlspähre,” and as such is the motor centre of the dorsal muscles. Its highest development is not correlated with that of intellect, but with that of the dorsal musculature.—(Munk, Luciani.)

Such were the various hypotheses concerning the frontal functions when, with wholly unprejudiced mind, I began my own researches in 1888. I have been prosecuting them ever since, making short communications to the Royal Medico-Chirurgical Academy of Naples (1889), to the Society of Italian Alienists (1890),<sup>1</sup> and to the Congress of Internal Medicine in Rome (Oct., 1892). My experiments were made on monkeys and dogs, after the method of free cranial openings and exposure of the lobes, rigorous asepsis and observation of the animals for several months or even years. I took no account of the symptoms during the first week, which must be systematically overlooked in researches on the cortical functions by the method of extensive mutilation.

I used twelve monkeys and six dogs, and never lost an animal immediately after operating, even after total extirpation of both frontal lobes. I lost a monkey in my laboratory at Palermo, from consecutive hæmorrhage ; and one last year, a rickety subject, with a thick skull that offered great difficulties in operating. In determining the præfrontal zone, I have not, as did Munk, taken the sulci as landmarks, first, because they never demarcate the physiological areas of the cortex ; secondly, because even if such were the case the experimenter cannot always strictly follow their indications.

<sup>1</sup> See abstract in “*Untersuchungen z. Naturl. d. Menschen u. d. Thieren,*” *Moleschott's Arch.*, vol. xiv.

Hence I have not always hit upon the præcentral sulcus in monkeys, nor upon the extremity of the chief frontal sulcus (sigmoid fossa) in dogs.

I have taken as my chief guide the electrical reactions of the frontal region, exploring it repeatedly with an exciter connected with a du Bois Reymond's sledge apparatus. I used to test the strength of current on my tongue, always keeping to the same intensity of sensation, which corresponded to 9 or 10 mm. of the scale. I avoided the use of the galvanic current for fear of trophic alterations in the cortex. On account of the slight individual differences in the motor localisations, especially in the monkey as compared with the dog, I thought it best to carry out the incision two or three millimetres in front of the excitable areas of the arm, face and jaw. I thus almost always in monkeys hit upon the areas, excitation of which produces dilatation of the pupil and lids, and turning away of the head more than of the eyes.

On account of the obliquity, from below upwards, of the Rolandic fissure, it is evident that a greater portion of the upper escaped, than of the middle and lower frontal convolutions.

I did not make any special efforts to spare the olfactory bulb in monkeys, in whose psychical life it plays but a subordinate part; but I always preserved it in dogs. In these animals the line of section fell at less than a millimetre behind the sigmoid fossa; the anterior arm of the sigmoidal convolution being almost always involved.

I shall not dwell upon the results of the electrical excitation of the zone thus removed; they mostly agree with those of other observers; the surface of the frontal area situated in front of the motor area of the head and neck, and of the iris is quite unexcitable with currents of equal strength. I shall only remark that such an excitation of the foot of the upper frontal convolution produced (in monkeys and dogs) not only a slight rotation of the head to the opposite side, but also some lateral displacement of the trunk at the level of the lumbar region.

Conjugate movements of the eyes did not always accompany rotation of the head. Excitation of the inferior area

produced raising of the eyelid along with dilatation of the pupil. In one case this dilatation in the opposite eye could be observed fifteen minutes after the stimulation, which, as I have already stated, I used only in order to fix the line of incision. The latter was not identical in all experiments, on account of individual or of operative differences, hæmorrhage or adynamia compelling me occasionally to hasten the operation. Three to five days after the operation the animals were fit to undergo all the investigations required to determine functional losses.

The following statements summarise the results obtained by unilateral extirpation of the frontal lobe.

(a) During the first and second week I often observed, in monkeys oftener than in dogs, rotatory movements, the truncal concavity being towards the mutilated side. No concomitant oculo-motor disturbance is observed. These symptoms do not always occur, and rarely last beyond the second week.

(b) Paresis of the opposite arm, not evident in associated movements (climbing, seizing a stick, shaking objects), but obvious in more delicate movements, when the monkey uses the other hand (for picking up a fruit or other food, catching fleas). The animal then uses the paretic only when the other is immobilised. This paresis also disappears after a few days—three weeks at most. In some of the subjects it has not been observable, or only slightly so.

(c) Tactile sensibility remained normal, except in a dog, in whose opposite limb it was for a time distinctly diminished, and in a monkey who showed some hyperæsthesia in the opposite ear and face. All the animals scratched themselves equally on both sides, and the monkeys hunted for fleas with their usual and characteristic precision.

(d) In one case (a monkey) I found diminution of hearing on the opposite side.

(e) Taste appeared normal, as well as smell, so far as could be ascertained in so difficult an investigation.

(f) In all cases, monkeys and dogs, I noted visual disturbances. I shall quote the observations made in one instance:—"The opposite eye being closed, the monkey

walks, runs, without ever coming in contact with any of the obstacles placed in his way; he avoids them all without uncertainty. But let him be kept immobile, and his attention be directed on fruit held at from 30 to 40 cm. in front of him; if then a piece of sugar, of which he is extremely fond, be suspended by a thread and gradually brought from the right inwards into his visual field, the animal sees it only when the sugar is nearly in a line with the visual axis. It is only then that the animal perceives it, and seizes it with a rapid and precise movement of the left hand. This does not occur when the right eye is kept closed; as soon as the sugar passes the physiological boundary of the visual field the animal's attention is excited, and the action of seizing the object is instantly performed. This experiment never failed on repetition; the difference between the two eyes is striking. The results were the same a fortnight, as they were a week, after the operation. Generally, these visual disturbances last from two to three weeks.

No perceptible differences were noted in the behaviour or psychical manifestations of animals mutilated on one side only.

I shall now give some details concerning the psychical condition of one dog, and of three monkeys operated bilaterally.

(a) Dog whose two anterior lobes were removed on April 16 and on May 16 respectively. The sensory and motor functions of the limbs remained normal. On June 21 the following notes were taken:—As soon as the door of the room in which it is confined is opened, the animal walks out. It goes with eyes downcast, and head bent down, almost touching the floor with its nose. It hovers about heavily, aimlessly; picks up in its mouth all what it finds (leaves, branches, filth, &c.), dropping it out again. If its way is barred with a hat, it is frightened, stops, but does not try to turn the obstacle. On finding a basin in the middle of an alley in the garden, it turns round about it excitedly, first in one sense, then in another, and so on. It starts impulsively to run, but gets entangled in the chain of another dog (amblyopic through occipital mutilation), and gets bitten. Frightened, it doubles itself up, without any attempt to escape from the attack. On being helped out by the attendant it begins to run about furiously, avoiding obstacles; but gets entangled and bitten again, and howls desperately until helped again. The animal, however, eats, drinks, and recognises its kennel.

(b) Chacma (*Cynocephalus Porcarius*). Adult intelligent female. Walks on all fours, or on the posterior limbs only, to command. Renders military salute, seizes and drops a stick, understanding words without gesture. Quick at new spontaneous adaptations; *e.g.*, raising and dropping the latch of a door through which she wants to get out. Distinguishes various foods, picking out without hesitation the preferred kinds. Observant and friendly; showing affection to another male cynocephalus recently operated, but without any erotic tendency even during the menstrual period, taking him in her arms, almost kissing him, pressing him to her breast with a satisfied and almost ecstatic look. This expression is still more evident in the case of two puppies, which she adopted from the first, and treats in a motherly way. These are the notes taken six days before the operation:—

*May 23, 1892.*—To-day a puppy accidentally got near her. She first looked at him with surprise and curiosity, then took him up gently on one arm, caressing him, and showing all the care and devotion which a mother shows to her child. She put him on the floor, followed him about as far as her chain would allow, gently picked it up and carried it back; then, fearing to lose it, she would keep it in her arms, or on her lap with one arm passed under the chest. Nothing induced her to let it go. If, when the puppy was on the floor, one called or whistled it to come, she understood the signal at once, picked it up and kept it close to her body. If one threatened her with a stick or otherwise, she became frantic, holding the puppy firmly but yet tenderly, and climbing to the top of the grating for safety. With great difficulty it was removed from her, but was restored soon after. She showed great pleasure, and as if grateful to me, came several times near me, holding out her hand for a caress.

A second puppy was placed near her, and began to prowl around. She examined, touched and sniffed it, but did not pick it up. But, when it began to move away, she seized it by the tail and pulled it to her; this was repeated several times. When she moved about she kept holding one of the puppies under one arm, and pulling the other along by the tail with the other hand.

It was impossible to get them away from her; and when anybody came near, she held both, each with one arm, and endeavoured to place them out of reach. In order to make her release them it was necessary to resort to a jet of water, of which she has the greatest horror, the very sight of the apparatus throwing her into the wildest excitement. Now, in spite of the

jet, she for a considerable time stuck to the two puppies, trying to shelter herself anyhow. At last she dropped the second puppy and climbed to the top of the grating with the other under her arm. Tired out at last, she gently deposited it on the ground and again climbed to the top.

*May 29.*—Operation on the left frontal lobe. About  $3\frac{1}{2}$  grammes of cerebral tissue were removed, occupying over 2 sq. cm. in front of the foot of the first and second frontal convolution. Slight hæmorrhage; strict antiseptic precautions.

The next day she was feverish in the morning; but the temperature became normal in the afternoon. She was rather in a low state, but still could be fed.

*June 2.*—Right paresis. She uses the four limbs to walk, but is strong enough not to fall on the weakened side. In climbing, she uses the left limbs as chief points of support; the right hand, is stronger than the corresponding arm, which affects a paralytic posture during rest. Even with threats one does not elicit the military salute; she cannot pick up objects with the right hand, and when made to use it, she makes great efforts, and the object easily falls from the hand; she cannot carry it to her mouth. The posterior limbs are flexed; she cannot, as before, stand upright on her feet.

The external segment of the visual field is much enfeebled in the right eye; the nature of objects presented is not recognised therein, as it is in the internal segment. The experiment is decisive when a cherry is offered to her.

*June 5.*—Walks well; no “*mouvement de manège.*” Does not use the left hand, only as when a cherry is seized or she tries to open a door, or raise herself to see what is on a table. She no longer gives the right hand, nor salute (*i.e.*, stands on the hind legs, seize the tail with the left hand, and carry the right to the forehead military-wise). The diapason is heard on both sides equally. The cherry is clearly perceived only on arriving from outwards to the middle line, or visual axis, of the right eye. She scratches the right side of the head and face with the right foot or left hand.

She is still susceptible of feelings and new adaptations. Her favourite puppy being offered, she takes it up, hugs it tenderly with the left arm only. She hunts for fleas with the teeth and left fingers; and resents any attempt to remove the dog. She cannot climb on a chair with the puppy; she places it on the chair first, and climbs afterwards. She did not care for, and avoided, the second puppy. Out of four she cares only for the

one she had previously taken to, and keeps it closely when they are called away.

*June 26.*—The paretic limbs have been recovering strength; for fine movements she still prefers the left hand; when compelled to use the right she is still uncertain. Vision is not yet perfect in the affected region.

*August 16.*—Second operation on the right frontal lobe. The trephine is applied to the point corresponding to the root of the frontal convolutions. Faradic excitations are followed by contractions of the left limbs, face, and peri-cranium respectively. Movements of the ear alone can be elicited by excitation of a point near that where movements of the peri-cranium and ear are obtained. About four grammes of frontal brain substance are removed. The incision falls accurately in front of the first and second frontal convolutions; and all the substance so separated is carefully removed. Much hæmorrhage. Two hours after the operation the animal drinks a glass of milk.

*August 19.*—Considerable swelling over the seat of the operation; no fever. The animal stands on its hind legs, but the left gives but uncertain support. On walking on all fours, the left arm drags. Tendency to rotation to the right.

Aimless instability of action. Reflexes exaggerated on both sides. Moderate excitations (by touching) produce generalised disorderly spasms. Left eye almost completely blind.

*August 24.*—Less rotation to the right. Still much instability; the animal climbs up and down a chair placed near, upsets it, pulls and shakes it about, opens and shuts a grating, pulls about her chain, and begins to rotate when not engaged in some of these actions. All this is done in a listless, automatic manner. She avoids impending falls or hurts, but immediately exposes herself again to the same accidents. She takes no interest in her neighbours and their actions, does not respond to calls, and manifests a quite unusual feeling of terror. She is even afraid of the other cynocephalus, whom she previously used to hug with evident pleasure. She has lost her previous interests, *e.g.*, in the puppy, of whom she is even afraid if placed near her.

Reflex hyperexcitability diminished. Slight hyperæsthesia on the left side. The right ear seems more sensitive to the diapason than the left. In order to test taste, two similar pieces, of sugar and plaster respectively, were offered; she took the one nearer to her—the plaster—chewed it, and swallowed it, without apparent feeling of pleasure or pain. The same happened with

the sugar, which she chewed and swallowed automatically. The experiment gave the same results a second time, when she again took the plaster without paying any of the minute attention to it as she used to do when any strange food was offered.

Vision was tested by different methods, and considerable impairment was constantly proved to exist. A fig, after being carried over a wide area of the external visual field of the left eye only, was placed close to its left hand, without the animal taking any notice of it; whilst it immediately made efforts to seize another fig placed at some distance on the right side. This absence of perception was noted in all meridians of the visual field of the left eye; the object was seen only on entering that of the right eye.

*October 20.*—The same automatism and semi-consciousness are still observed in all the psychological and motor manifestations of the animal. Rotation to right still considerable. On a loud call she shakes herself; and, after much practice, she attempts the military salute; and shows some feeling when caressed, and avidity when offered some food, but only for a short time together. The habitual state is still one of indifference; and she speedily relapses into an aimless, automatic mode of life, without any interest in her surroundings. Under novel conditions she is not capable of new adaptations, as she used to be. She no longer plays with her two companions (cynocephali), and remains indifferent, or pays but transient attention when they come near. She is not jealous when they are petted. Threatened, she evinces fear, but does not show any of the signs of self-defence and revolt she used to evince with so much energy. A feeling of indefinite and baseless terror is manifested, as soon as anyone goes near her, or her automatic agitation is suspended by a sudden call, or by any other new impression.

The movements of the left side are more precise, but not quite normal, though she uses it to take food, or steady herself in saluting. The vision of the left eye has, to a great extent, returned; but, though it is difficult to determine the degree with precision, it is certain that the internal portion of the visual field is more acute.

She continued much in the same state till January 21, 1893; and still has some tendency to rotation. She does not use much the left arm. She walks with agility and shows no trace of paralysis, using for that purpose the left arm. Sensibility intact in every sphere. She is killed with chloroform.

The left hemisphere looks larger than the right. The middle

and inferior frontal convolutions are destroyed as far as their insertion into the anterior Rolandic gyrus, which is almost intact. (fig. 1). The superior frontal has hardly been touched as far as its anterior extremity. In the right hemisphere, the superior frontal has been destroyed up to its root, excepting a small portion communicating with the rest of the brain by a narrow bridge (2 mm. in width). The second, or mid-frontal, is more extensively destroyed; of the third frontal, only the anterior and central portions are less destroyed (fig. 2).

(c) A young female cynocephalus, had been an inmate for about two months, whilst she was well treated and had become domesticated. She first menstruated during this period, and is much attached to one of the servants. She is docile, obedient, inquisitive and lively.

On *August 2*, 1893, I freely expose the right anterior hemisphere. Faradic excitation provokes no contraction in front of the points *a* and *b*. In *a*, movements of the trunk and pelvis were observed; in *b*, movements upwards and forwards of the ear, of dilatation of the palpebral slit, with elevation of the upper lid, and of dilatation of the pupil (chiefly on the same side). Repeated observations constantly gave the same results. Slight increase of current strength, or displacement of the electrodes 1 or 2 mm. backwards, movements of the hand (extension of the fingers chiefly) ensued. By a deep incision with a sharp curved blade I remove all the portion, one millimeter, in front of the points *a* and *b*. About six grammes of cerebral substance are removed. The wound was cleaned, under strict antiseptic precautions, and closed in the usual manner.

*August 3*.—Sleepy the whole day. Sits, does not lie down. No deviation of head and eyes. Uses the hands, preferably the right; walks about the cage normally. Drinks some milk.

*August 4*.—Same condition; is sick once.

*August 7*.—Has recovered from the operation; the wound has healed by first intention.

This animal is to all intents and purposes in a normal condition, save in two particulars, which only a searching examination can reveal. She is subject to fear, and has left external hemianopsia. She walks well; no rotary movements. Turns the head about with no difficulty to either side; is as rapid and agile as before. She perceives contact equally all over, including head and neck. Sudden prickings with a fine needle are followed with the most lively reactions.

If vision is prevented by means of sub-palpebral membranes of india-rubber (after cocainisation), the animal is found to have normal muscular sense. A peach brought near her hands is seized, bitten, skinned, and the pieces carried to the mouth with either hand, and with perfectly accurate movements. The sound of a diapason is heard, and causes fear, at the same distance of either ear. Smell and taste were not systematically tested.

From the day of the operation a defect of sight on the opposite side was noted. She was held by an attendant, whilst another kept her attention fixed on a point in front of her. From behind I bring a piece of peach to 10 or 15 cm. from the lateral or upper part of the visual field. When the object, travelling from outside towards the external angle of the right eye arrives in the field, it is immediately perceived, and sometimes rapidly seized and eaten. A similar piece brought towards the left eye has to be brought much farther forwards, almost as far as the median vertical plane, before it is perceived.

*August 12.*—On repeating the examination, the difference between the two eyes is found to be less precise and definite. She perceives something, but recognises it only when it reaches the left median vertical plane, the vision of the right eye being normal as before.

*September 11.*—She is still alert, agile, observant; she unties the string which closes the door, and pulls back the bolt and comes out. She is fond of tobacco. The end of a lighted cigar is thrown to her; she picks it up with left hand, burning herself; she speedily lets it go and licks her fingers; soon after she picks it up cautiously by the wet end, examines it, unrolls the leaves, which she chews one by one.

Up to January, 1894, no changes were observed, except that she was more irritable.

*January 31, 1894.*—Under morphia and chloroform, the anterior left hemisphere is exposed. The ascending frontal and the posterior portion of the first frontal convolution remain covered. Faradic excitation provokes contractions in the third frontal, where in front of the face centre (contractions in the inferior half of the face) a vertical rectangular area is determined, extending upwards to the second convolution, in which excitations arouse feeble opening of the lids, a slight raising of the eyebrow, and dilatation of the pupils, especially on the opposite side. At the origin of the first frontal, and a little in front, excitations provoke rotation of the head to the opposite side. No other movements could be elicited. (Repeated excitations of

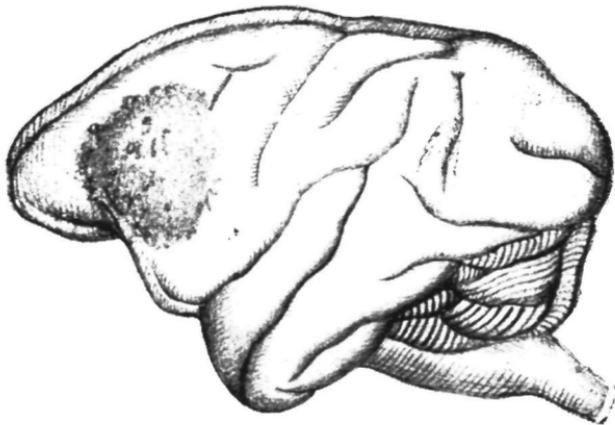


FIG. 1.

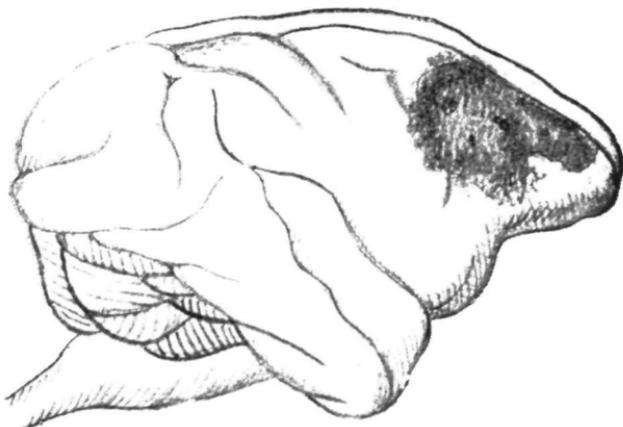


FIG. 2.

The Fissure of Rolando should be prolonged further down.

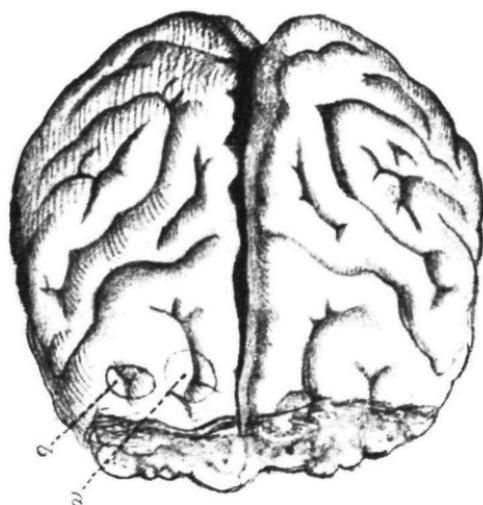


FIG. 3.

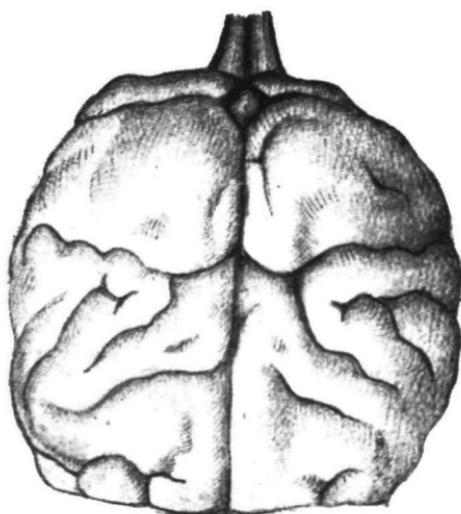


FIG. 4.

the pupillary centre produce persistent opening of the opposite lids, lasting about ten minutes.)

The incision is made immediately in front of the face centre, and behind that of the dilator iridis, and all the anterior portion of the brain (excepting the posterior third of the first frontal) is removed. Little hæmorrhage; antiseptic dressings. The animal remains for some hours in a somnolent condition; but opens the eyes when called. No vomiting nor fever.

*February 2.*—Remains in the cage with head bent, eyes half open, sleepy but sitting. When called she raises her head, slowly opens her eyes, looks about, and relapses into the same condition. When touched she wakes up, sometimes with a start or a cry, but does not try to escape nor looks alarmed. When let loose in a room, she walks about with measured steps. No deviation of the trunk nor paralysis, except in the right inferior half of the face.

*February 9 and 14.*—The notes of these two days may be taken together. Facial paresis not so marked, though evident. On walking, the lower part of the body looks arched. She can turn to either side, bend on herself, runs, without any trace of paralysis. Both sides of the body seem equal. Only she has lost her normal elasticity and suppleness; she is duller, heavier, more relaxed, even when urged on. She uses either hand, but preferably the left; there is still a certain precision but less decisiveness and security in the use of the right. No neck paralysis; all movements of the head, in every direction, are possible. She eats well, with avidity, swallows and utters cries as before. Tactile sensation preserved; she reacts to sudden contact of every portion of the body. Perhaps she feels less when the left ear is touched or pricked, as she does not move the part, or starts when it is done to the other ear. She scratches herself, and looks for parasites on both sides and with both hands. The muscular sense appears thus to be intact; no ataxia on walking, or performing delicate movements has been noticed.

As to sight, closure of the left eye does not interfere with walking, or running, all obstacles being accurately avoided. If, however, whilst she is at rest, a piece of sugar, tied to a string, is brought from the outside inwards, into the right visual field, it is perceived only when it is in a line with the visual axis. She then rapidly seizes it with the left hand and sometimes with the right, though it is less mobile. This experiment gave constant results. On the other hand, when the right eye is closed, the sugar is perceived and the movement for seizing it made the instant it is brought into the left field of vision. No marked difference be-

tween the upwards and downwards extent of the two fields of vision; the left internal field could not be examined on account of the fatigue.

*Intellect.*—Attitudes stupid, loss of physiognomical expression; apparently aimless walking. She runs incoherently from one end of the room to the other; when she reaches the wall she stops, returns to the opposite angle. Noticing a defect on the wall, where bits of plaster have become detached, she picks them up, chews and swallows them; the same with bits of filth on the ground. Pieces of plaster offered to her are taken and eaten as if they were sugar. It is not because she does not distinguish between these substances; for she takes longer to chew the plaster and seems at times to hesitate whether to go on or not; but she cannot resist the idea of sugar, which the appearance of the plaster has evoked. In all her actions there seems to be a defect of perception, which seems to be reduced to a more elementary level and lack some of the factors necessary to the formation of a more complete judgment. Her psychical life seems to be reduced to the existence of actual sensations.

Reflex excitability is exaggerated; every noise startles her, and she has lost her courage. On a threat she runs away, with incontinence of urine, or huddles herself up in a corner uttering lamentable cries. She displays no resource in her flight or attempts to hide herself, does not turn on the assailant; experience does not profit her, and as often as a sham attack is made upon her, she goes through the same actions as if she did not remember what had happened just before.

Formerly she used to cling affectionately to the legs of the attendant, caressed him, and nestled on him with the expression of the utmost pleasure and love. Now all seems indifferent; she stops at nothing; looks at everything but without fixing herself to anything. Her senses are excited but not attracted. She remains in this condition for months.

On *May 4* she was chloroformed. The extent of the lesion is shown in *fig. 3*. No damage to the olfactory apparatus.

(*d*) *Cynocephalus*, female, good size, agile and cheerful. On close examination no defect of the senses, organs of motion, or of any other kind was discovered. She is inquisitive, cunning, acute, attached to her keepers. During the menstrual periods, which are regular, she is more excited and mobile than usual.

*May 20, 1893.*—Under morphia and chloroform she was trephined over both frontal lobes, one cm. in front of the Rolandic

sulci. Little hæmorrhage. The brain was exposed and two lines marked symmetrically on each side, passing in front of the roots of the frontal convolutions nearly corresponding to the præfrontal sulcus. Faradic excitations in front of these lines provokes no contractions, either in deep chloroformisation, or in mere morphinic somnolence. The whole of the brain substance in front of the lines was removed, and the wound dressed, under strict antiseptic precautions, in the usual manner.

*May 21.*—Stupor; marked reflexes to the least noise. She dips her snout in milk, hardly drinking any. Internal temperature  $38.6^{\circ}$  C. The next day the symptoms remained much the same. Appetite better. She was kept in her bed, and a clyster given.

*May 27.*—More awake, but the whole head is œdematous. She can, however, be examined. Sensation to pain and touch exaggerated, especially on the left side. The least contact, even to the tips of the hairs, is followed by reflex movements of the whole body, and turning of the head and eyes to the excited side. The slightest pinch, or pin-prick, elicits loud cries. A diapason suddenly set vibrating on either side astonishes her; she moves the head as if to avoid the strange noise. If the hand or any other object is brought towards the eyes, from whatever point in the visual field, she blinks and withdraws the head in fear. If a cherry, of which she is fond, is thrown, she fixes her eyes on it. If, suspended to a string, it is brought from above, or from the outside, into the visual field, she recognises it, and tries to take it, her movements being appropriate and co-ordinated with the mouth or the left hand. She walks badly, swaying, with head and body bent; the left leg drags, and the right arm little used. She hardly ever leaves her bed, nor takes any interest in things; but starts, emitting cries as if afraid or angry, to any noise, contact, or whenever she is attended to.

*June 3.*—The swelling has gone down. There is a local suppuration, and a superficial abscess has to be opened, cleaned and dressed. Her condition remains much the same; but she eats more, resists better, and walks, though with some uncertainty. The right leg is much paralysed.

*June 7.*—Suppuration has stopped. Wound granulates, and is still dressed antiseptically. No fever since the operation. The animal astonishes us all by its novel behaviour. She remains in the position given to her. No curiosity nor interest in what goes on. She spends hours sitting with head bent, as in a lump, often asleep. If a noise is made she shakes herself up, often with

a cry, raises the head, looks about, and relapses in her previous condition. The same occurs three or four times together if the same noise is repeated, until she is used to it. The only thing that excites her interest and makes her move is the sight of some favourite fruit dropped at a short distance. She then rises and runs to seize it. But if it is dropped further off she does not move; and it is difficult to say if it is because she does not see it, or through apathy. She occasionally scratches herself, but no longer hunts for fleas with her former rapidity and precision of movement. She resists if pushed away, and if she can cling to the place she occupies, she sticks to it. If pushed along by the nape of the neck she walks along semi-automatically, preferably along a wall, and stops in a corner, where she remains for a long time. When called aloud she looks up, but soon the head falls again, with frequent escape of saliva. She is very dirty, and does not move when passing her urine and faeces in which she sits. Placed with another menstruating female cynocephalus she stopped automatically, quite insensible to the erotic and lascivious manifestations of which she was the object, with no sign of sexual or racial interest whatever. And yet a noise startles and frightens her; a threat with a stick terrorises her, whilst her companion evidently recognises the sham nature of the demonstration. Fruits, sugar, and the like excite her more, but yet she lacks discrimination. A cherry into which a solution of quinine has been introduced is given to each monkey. The normal animal, after a bite or two, spits it out with a disappointed and irritated look, cleans her tongue with her hand, and crushes the deceptive fruit on the ground until no trace of it is left. The other chews, but stops after a while, salivating abundantly, and after some hesitation ends in swallowing it. After giving to each some good fruit, I give to each a cherry, dipped in the bitter solution. The first animal, as soon as it has tasted it, spits it out in anger; but soon after, seeing that the fruit is whole, picks it up again, examines it attentively, opens it carefully, eats the flesh and throws away the skin. The second goes through the same process of chewing, stopping, and finally swallowing the fruit.

A piece of sugar was given to the normal monkey; next a piece of plaster of the same shape and size and appearance. The animal picks it up, looks at it, sniffs it, and throws it away without tasting it. After giving it some natural cherries, I presented to it one made of wax. The monkey likewise scrutinizes it thoroughly, drops it as if to test the sound, tries to rub it, and

finally leaves it alone. The operated animal in both experiments displays a striking want of discrimination; it eats and swallows the plaster as it had done the sugar, and without any examination tries to chew a piece of wax, though not of the same shape as a cherry, giving us trouble when we tried to remove it from its mouth.

*July 15.*—This monkey has been kept under observation with reference to the changes in its temper, character, instincts and intellect. Her behaviour is altered, her physiognomy stupid, less mobile; the expression of the eyes is as if uncertain and cruel, devoid of any flashes of intelligence, curiosity, or sociability. Shows terror, even by shrieks and gnashing of teeth, when threatened or hurt, but never reacts aggressively. She is in a state of unrest; when placed in a large closed room, it walks aimlessly round it, always in the same direction, without stopping near any object or person. Any action done with apparent purpose remains incomplete, unfinished; if she runs towards a door she stops near it, goes back, runs to the door again, and so on several times.

She shows no affection nor gratefulness to people whom she previously loaded with caresses, as these animals are wont to do; she does not seem to know them, though they are ever ready to attend to her wants. Whenever approached for a caress she shows fear. When the attendant brings her food or fruit, she comes near and violently seizes the object of her avidity. None of her former friends can now caress her any longer. She is unsociable with the other monkeys, does not play; cannot overcome the least difficulties in her way by new adaptations, nor learn anything new, nor recover what she has forgotten. She picks up and takes to her mouth whatever she comes across. She is, however, somewhat cleaner.

The sexual instinct seems to be present; but the periods are less regular and abundant. She occasionally manifests impulses of cruelty quite foreign to her kind. One day whilst she was menstruating, another female cynocephalus came near her. She at once manifested her desire; but finding the other unable to satisfy it, she attacked her companion so furiously that she would have killed it if the keeper, armed with a stick, had not at once interfered.

A new psychomotor "tic" has recently been observed; every ten or fifteen minutes whilst walking, she stops suddenly, and placing the foot on the nape of the neck, bites her right buttock (sometimes the left also). Occasionally she proceeds to bite also

one heel, then the other, after which she quietly resumes her walk. No apparent local cause can be discovered for these actions, which are always identical, almost rhythmical. It is possible that at the outset some abnormal sensation has given a start to them, and that they afterwards were persevered in, governed by an uncontrollable automatism.

*August 15.*—Psychical state unchanged. Her movements have a stereotyped character, but are faultless. New adaptations remain impossible. She walks about, sits, looks for parasites all over the body, remains indifferent to everything but to the sight of her food. She often puts the parasites into her mouth, which she used not to do before. She also eats dry leaves or flowers. She no longer expresses her desire, at the time of menstruation, as she used to, by appropriate sounds and gestures.

No sensory defects are noticeable, on the closest investigation. But discrimination, and the higher co-ordinations of sensory factors on which the more complex psychical manifestations depend, and which are necessary to the preservation of the individual and the species, are reduced to mere rudiments. She now differentiates between a sugar plum and a piece of plaster. She eats the first with avidity; the second she breaks in pieces with her teeth, but spits them out on the floor. But then she takes one up to her mouth, throws it down again, and so on several times, at last swallowing it with avidity; she next takes a second, and so continues until the whole number has been disposed of. The whiteness of these fragments and their resemblance to those of a sugar plum have prevailed over her sense of taste. Her rudimentary inhibitory power has been overcome by the visual image; the other sensory factors did not intervene in the act of identification, in the judgment of analogy. She has crude sensations, but no co-ordination of simple presentations, into representations of higher complexity. Another monkey takes the plaster plum, examines and smells it, and either rejects it at once, or, if deluded by the visual resemblance into chewing it, spits it out and ignores the fragments; its comparative judgment and memory are certain, and spare it the struggle which, in the abnormal subject, was followed by a victory of the more elementary sensation, and by an irrational impulsive action.

*August 23.*—No change. The animal is chloroformed, and the right hemisphere exposed. Electrical examination of the cortex proved the existence of all the normal motor centres of the limbs and face. The brain is shown in fig. 4.

*Conclusions.*

Granted the objective accuracy of the facts just related, it will not be difficult to give a plausible explanation of the phenomena observed after ablation of the frontal lobes. But even if such a hypothesis be not universally accepted, the value of the observed facts will not be thereby diminished.

It is useless to discuss at great length Munk's views on this subject. Paralysis of the trunk-muscles does not always occur, especially when the incision falls accurately on the frontal lobes; and is in any case but temporary. Moreover, what connection can there be between such a paralysis and alterations of temper? It is strange that the Berlin physiologist should assign to such a function a centre so vast as to constitute a true province, far wider than that of the arm with its prodigious scope for movements of the highest complexity. And it is surprising to find the paralysis disappear some weeks or months after the experiment performed to disprove the narrow limits ascribed to the cortical area of a so much higher function.

We readily understand Munk, when with Meynert, Ferrier, and Goltz he refuses to admit a centre for a so-called intelligence, as he expresses himself. But it is astonishing that such an acute observer should have overlooked so many psychical symptoms, whilst attributing to the extensive frontal lobes, a function shown by Schäfer and Horsley to be localised in a much more modest region (internal aspect of marginal gyrus).

No scientific man at the present time dreams of galvanising into life the dead body of Gall's organology. Every one of the several sensori-motor areas of the cortex combines with the others in the formation of the psychical personality, whatever its characteristics may be; nay, the whole of the nervous system takes part in it. Nobody will contest Munk's thesis in this particular; but these remain to account for all the phenomena observed after the destruction of the frontal lobes, and which are not explained by the occurrence of a temporary trunk-muscle paralysis.

Neither does Ferrier's hypothesis satisfy us. Our facts point to more than a simple defect of attention correlated as much with a paresis of the ocular and cervical muscles as with a non-existing cause. Dogs and monkeys, a few weeks after the operation move their heads and eyes in every direction ; and there remains nothing of this paralysis to explain the deep psychological changes observed by us. Such disorders, therefore, depend upon the absence of the frontal lobes, not as the motor centres of the head and neck, but as the anatomical substratum of special functions on which the formation and manifestation of psychical personality depend. The frontal lobes are not centres of inhibition. We speak too assuredly and too lightly of attention, and of inhibition, and one may feel surprised to find Ferrier identifying certain muscular co-ordinations with the very essence of attention, being thus led to spread over the whole frontal area the motor centres of the head and neck, in order to assign to it the functions of cortical seat of attention.

But we may ask ourselves whether there exists really any centre the function of which is to inhibit, hence whether there exists a faculty of attention. I reply distinctly, No.

Without attempting to go fully into the theories concerning inhibition and its centres, it will be granted that inhibition depends upon a general psycho-physiological process, and that every part of the nervous system becomes, under different circumstances, either an inhibitory or an inhibited centre. I upheld this view in 1885 in an essay on the act of walking, in which I modified in a more physiological sense the theory of Lauder Brunton, who explained inhibition by the law of interference. Taken in its strict sense, interference bears no likeness to inhibition : we must rather speak of an afflux of nerve-waves into a region excited by some definite stimulus or psychical representation, which afflux weakens the aptitude of other regions to fulfil its function. This mechanism can be illustrated by the action of any of the various centres, auditory (as when we are absorbed in listening to a musical performance), visual (as in presence of a great picture or object of scientific

interest), or motor (as in the case of a juggler or acrobat engaged in wonderful muscular display). Each respective cortical area becomes in its turn an inhibiting centre for the others. Physiology and psychology swarm with facts showing the error of those who assume a special cortical centre for inhibition.

We know how, when the mind is busy with a scientific problem, one becomes, as it were, deaf and blind. But if the auditory or visual centres are then strongly excited by a voice or an image, and a perception aroused, the flow of ideas is arrested or weakened as long as the psychical disturbance persists in another portion of the brain.

Thought, even when at work in the domain of pure conceptions, has in most men an inhibitory power. This is due to the fact that abstractions are resultants of very numerous psychical elementary factors, and determine the same dynamo-molecular processes in the innumerable nerve elements which co-operate in the formation of each concept. Hence the frontal lobes are no more centres of inhibition or attention than they are motor centres for the trunk, or head and neck muscles.

Overlooking the possible contention of some objectors, that the serious mental disturbances observed in the mutilated animals, depended on interference with the senses of taste and smell, my hypothesis is that the frontal lobes are the seat of co-ordination and fusion of the incoming and outgoing products of the several sensory and motor areas of the cortex. As the nervous waves from peripheral organs of reception (retinal rods, tactile organs, &c.) are transmitted from neurons of the first order to neurons of the second (mesocephalon, thalamus), and from these again to neurons of the third order (cortex), thus we may suppose that from the last-mentioned, nerve impulses travel to the frontal neurons of the highest order. The frontal lobes would thus sum up into series the products of the sensori-motor regions, as well as the emotive states which accompany all the perceptions, the fusion of which constitutes what has been called the *psychical tone* of the individual. Removal of the frontal

lobes does not so much interfere with the perceptions taken singly, as it does disaggregate the personality, and incapacitate for serialising and synthesizing groups of representations. The actual impressions, which serve to revive these groups, thus succeed one another disconnectedly under the influence of fortuitous external stimuli, and disappear without giving rise to associational processes in varied and recurrent succession. With the organ for the physiological fusion which forms the basis of association, disappear also the physical conditions underlying reminiscence, judgment, and discrimination, as is well shown in mutilated animals. Their agitation and motor incoherence depend upon the reflection of nerve impulses set up by stimuli through small sensori-motor arcs, without the intervention of the previously accumulated psychical co-efficients.

Fear is an immediate result of psychical disaggregation, from defective sense of personality, and unbalanced perception and judgment. As the oyster closes its valves on the approach of a cloud, thus the operated monkey trembles at the simulated hostility of its keeper, ceases to read on his face the smile of kindness, does not improve by past experience, nor perceive the means of escape at hand. Courage rests upon the treble basis of self-conscious force, rapid perception of the enemy's powers for offence or defence in relation to one's own, and the influence of certain feelings; our animals show an absence of all these characteristics. (We must not mistake for courage the impulsivity of certain animals; or men, insane or epileptic.) On the one hand, their effective nature, friendliness and sociability is impaired; on the other, their avidity becomes reckless and insatiable. From cleanly they become dirty; and their sexual functions are perturbed; the females menstruate irregularly; the males become, if not incompetent, at least incapable. All these symptoms depend not upon motor deficiencies in the head, neck, or trunk muscles, but upon a dissolution of the psychical personality.

But even should a more acceptable hypothesis to explain the facts observed be hereafter framed, I feel at any rate certain of the accuracy of the observations themselves.