TO ILLUSTRATE SIR VICTOR HORSLEY'S LINACRE LECTURE.

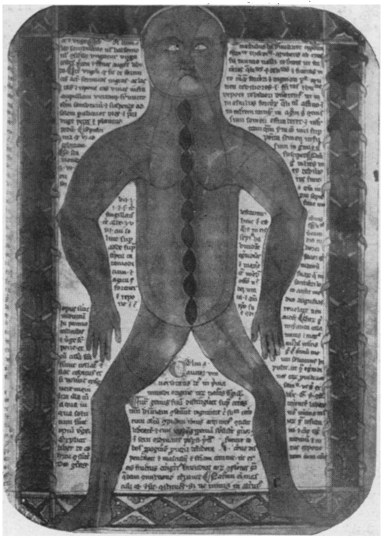

Fig. 1.—Thirteenth Century MS. (Bodleian Library) showing Aristotelian view of the nervous system as only consisting of nerves starting from the cardiac region and omitting the brain as of no importance. The original drawing shows, however, the two spinal roots discovered by Galen, though it does not connect them with the nerves.

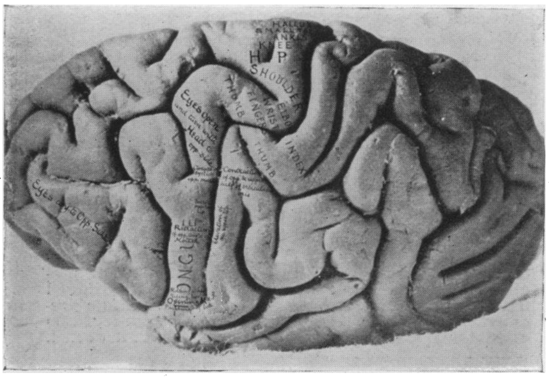

Fig. 2.—The hemisphere of an orang showing motor representation as found by excitation. (Beevor and Horsley, 1890.)

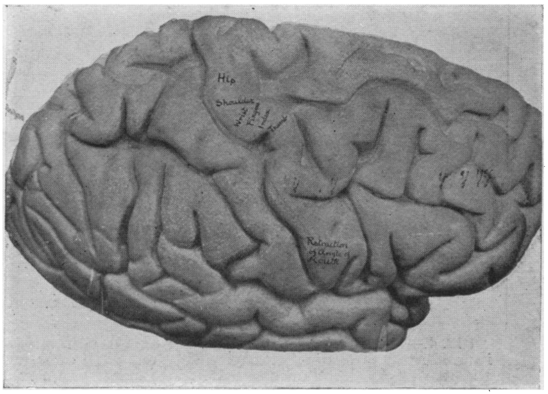

Fig. 3.—Motor representation as found by excitation in man. Isolated observations collected and entered on photograph of cast (Cunningham) of low type human brain. (Horsley, about 1895.)

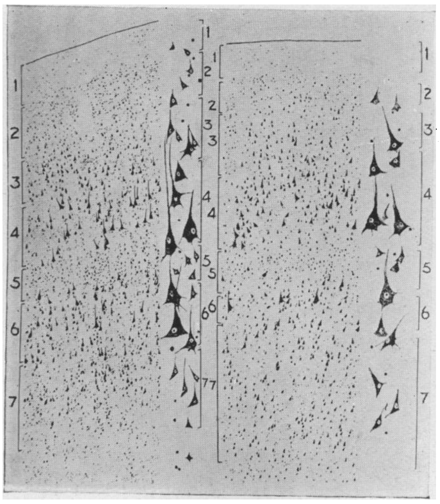

Fig. 6.—Cell lamination of the gyrus post-centralis. The section on the left of the reader is taken from just behind the upper end of the fissure of Rolando, that on the right is from the posterior edge of the gyrus, and termed by Campbell "intermediate post-central area." (Plate VI of Campbell's work.)

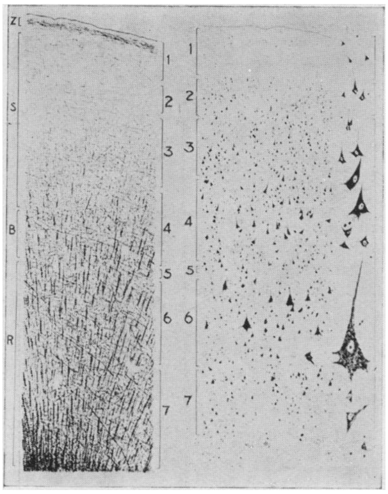

Fig. 7.—Fibre arrangement and cell lamination in the pre-central area. (Plate III of Campbell's work.)

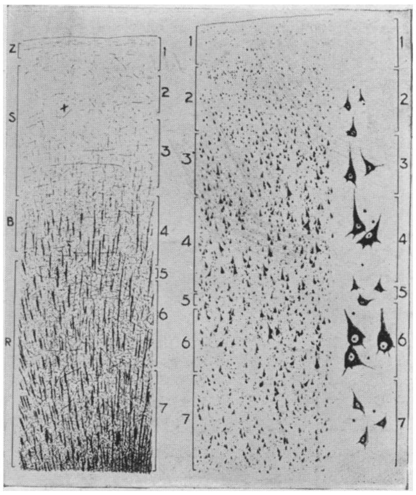

Fig. 8.—Fibre arrangement and cell lamination of Campbell's intermediate pre-central area, the dotted region in Fig. 5 in the front part of the gyrus pre-centralis. (Plate XXI of Campbell's work.)

Fig. 9.—Upper surface of head of patient (1886), with cicatrix of lesion in the upper third of the gyrus pre-centralis.

Fig. 10.—Side view of recently healed wound of case of tuberculous tumour (1886) removed from in front of the Rolandic fissure (marked with an aniline line in the middle of the flap).

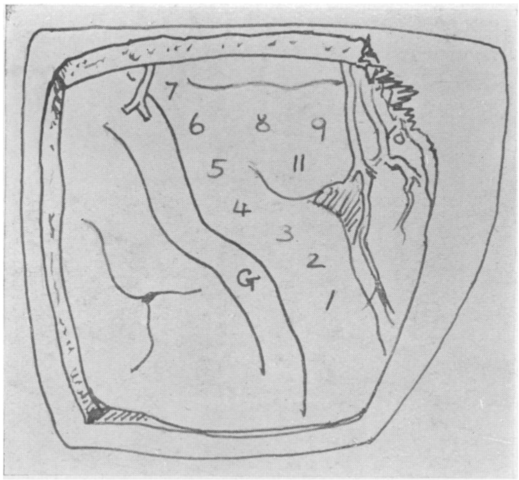

Fig. 4.—Sketch of operation field in case of Hn., made immediately after operation, showing cut edge of bone. Fissure of Rolando or central fissure passes in front of G. The sulcus pre-centralis inferior is shaded. The numbers indicate the points stimulated. (See text.)

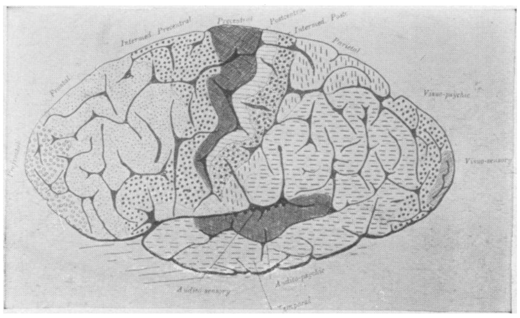

Fig. 5.—Campbell's general map (histological differentiation) of hemisphere in man. The "*motor*" or precentral area is shaded darkest in front of the central fissure. In front of it (dotted) is the *intermediate precentral* area. Behind the fissure the gyrus post-centralis consists of two parts, ruled horizontally and dotted. (Plate I of Campbell's work.)

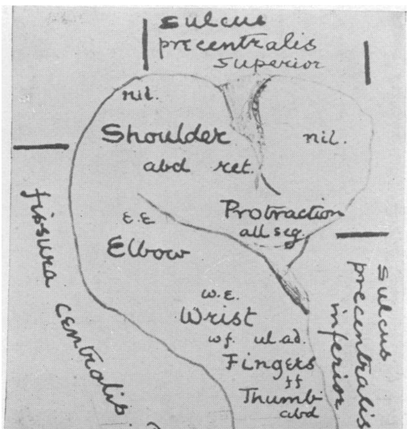

Fig. 11.—Outline of the gyrus pre-centralis removed. Abd., abduction; ret., retraction; e.e., elbow extend; w.e., wrist extend; w.f., wrist flexed; ul. ad., ulnar adduction; f.f., fingers flex.

Fig. 12.—Photograph of the gyrus pre-centralis fixed in formol. The scale is that of centimetres and millimetres. The points excitable may be transferred to this figure from Figs. 4 and 11.

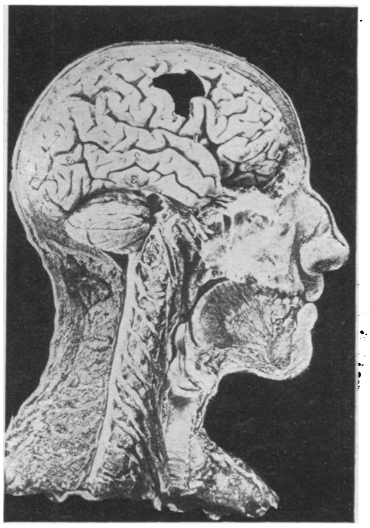

Fig. 13.—Reduced copy of plate from Professor Fraser's *Guide to Operations on the Brain*. The blackened area of the gyrus precentralis represents the part removed.

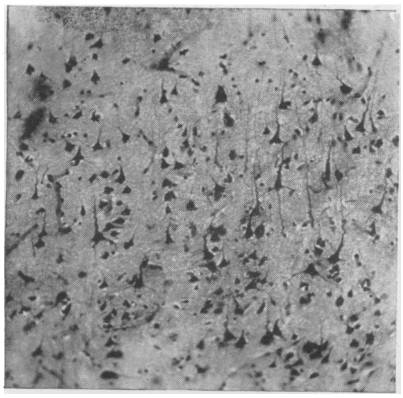

Fig. 14.—Hn. Low-power. Section of the gyrus pre-centralis, showing the third to the sixth layers of the cortex. The spiral dendrites are obvious under a lens.

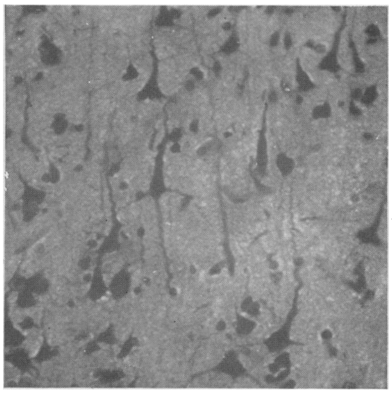

Fig. 15.—Hn. Medium power. Section of gyrus pre-centralis fourth layer, showing pyramids and their spiral continuations.

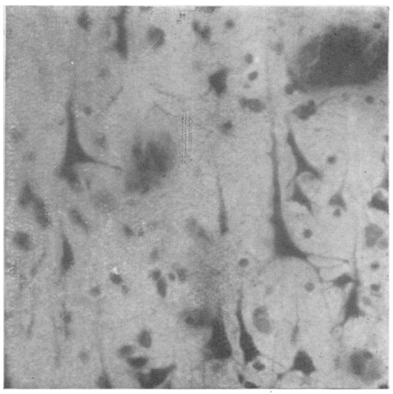

Fig. 16.—Hn. Section of the gyrus pre-centralis, showing normal median pyramids.

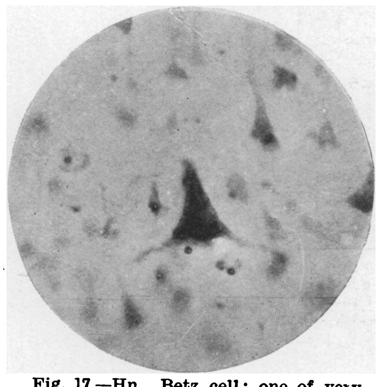

Fig. 17.—Hn. Betz cell; one of very few found in the area a little ventral to the sulcus pre-centralis superior.

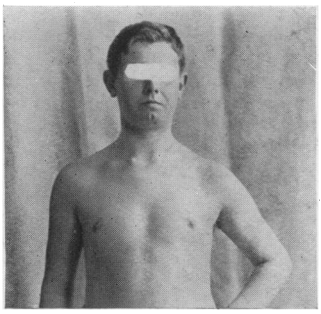

Fig. 18.—Hn. after operation. "Voluntary" movement of the left upper limb in placing the hand on the iliac crest.

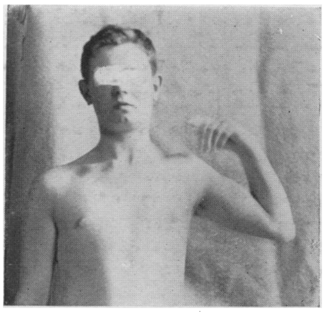

Fig. 19.—Hn. after operation. "Voluntary" flexion of elbow and abduction of shoulder. Fingers continuing to slowly flex.

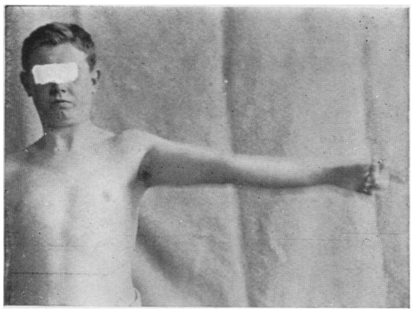

Fig. 20.—Hn. after operation. Forcible voluntary abduction and extension of limb, showing the effort causes contracture of the digits. (3 sec. exposure.)

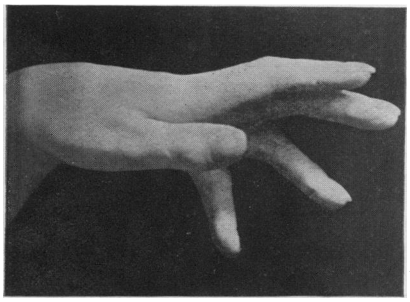

Fig. 21.—Hn. after operation. Fullest possible "voluntary" extension of the digits. (Instantaneous photograph.) Graded power of extension from thumb active, to little finger inactive.

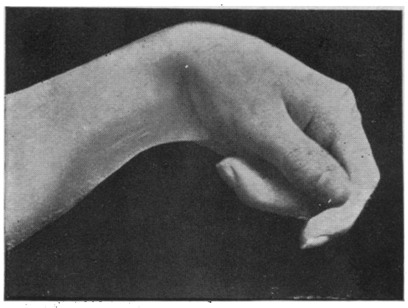

Fig. 22.—Hn. after operation. Fullest possible voluntary flexion of digits, the ring and little finger contracted by extra flexion of contracture out of sight. The concurrent hyperflexion of wrist (that is, absent normal extension) is well marked. (Instantaneous photograph.)

The Linacre Lecture

ON

THE FUNCTION OF THE SO-CALLED MOTOR AREA OF THE BRAIN.

DELIVERED TO THE MASTER AND FELLOWS OF ST. JOHN'S COLLEGE, CAMBRIDGE, MAY 6TH, 1909,

BY SIR VICTOR HORSLEY, F.R.S., F.R.C.S.,

SURGEON TO THE NATIONAL HOSPITAL FOR THE PARALYSED AND EPILEPTIC, LONDON; AND CONSULTING SURGEON TO UNIVERSITY COLLEGE HOSPITAL.

[WITH SPECIAL PLATE.]

THOMAS LINACRE, 1460–1524, Physician to Henry VIII, one of the benefactors of St. John's College, Cambridge, as well as Merton College, Oxford (see Professor Osler's Linacre Lecture, 1908), founded at both universities provision for medical teaching of which this annual lecture is now one of the units.

My appreciation of the honourable duty of delivering this lecture on the functions of a part of the brain is increased by the fact that Linacre lived just after a renaissance not only in religion but in cerebral physiology. The biological renaissance consisted in the recognition of the grave error made by Aristotle, who endeavoured to guess at function by observing structure rather than living action, and who thereby naturally failed to understand the meaning and purpose of the brain.

Fig. 1 on the plate is a reduction of a hand illumination from a thirteenth century MS. in the Bodleian Library, showing the anatomy of the nervous system, in which, according to the Aristotelian teaching, the brain is not represented, as being only an organ to cool the heart, and having no connexion with the nerves.*

It was reserved for the students and translators of Galen, among whom as a literary expert Linacre was himself pre-eminent, to learn the truths of neuro-physiology from the trenchant experimental method of the Roman physiologist. It is highly appropriate, therefore, on this occasion when Linacre's memory is being respected by his college, that a consideration of some important points in the history of brain function should be the object of the lecture, and the point I have therefore chosen is, What is the actual function of the so-called motor area of the brain?

The idea that localized—that is, restricted—parts of the cerebral hemisphere subserve among other functions definite movements of certain parts of the body, may be said to have commenced with Bouillaud's experimental observations on the vocalization of dogs, since by his researches it appeared that destruction of a certain part of the cerebral hemisphere was followed by loss of purposive vocalization movements of the larynx.

It was not, however, till many years later that the epoch-making discovery of Hitzig[4] and Fritsch opened up the larger field of research, which was extended by Ferrier,[5] until a map of the so-called motor area could be constructed for the surface of the monkey's brain and the various "centres" for the different parts of the body delimited.

Our knowledge of this region has become so increased by subsequent workers that for a discussion of the present state of science on the so-called "motor" area I must confine myself strictly to the consideration of but one part of it—namely, that for the representation of the upper limb—which part of the body, including as it does some of the most highly trained combinations of sensation and movement, is specially worthy of study.

It is also time that yet another protest should be raised against the expression "motor area" as untrue scientifically, and, like many unfortunately convenient expressions, so misleading as to hamper the progress of knowledge.

Dr. Bastian's[3,10] much more logical expression "kinaesthetic area" has, unfortunately, not found general adoption, and yet none better expresses the fact that there is no such thing as a purely motor centre in the cortex cerebri, the whole structure being, in Dr. Hughlings Jackson's language, sensori-motor, or a combined mechanism for the record and execution of afferent and efferent nerve impulses.

Physiologically, the term "motor" has doubtless been employed because of the movements obtained from the Rolandic cortex on excitation. But the term "excitable" area is equally inadmissible when used without qualification, not only because so-called "sensory" cortical regions—for example, the visual area—equally give motor, that is, efferent, results on stimulation, but also because the term leaves out of sight the sensory functions which I have shown are represented in the Rolandic gyri.

We will first briefly consider the topographical outline of the area for movements of the upper limb as determined by means of electrical excitation in the bonnet monkey (*Macacus sinicus*), the anthropoids (the orang and chimpanzee), and in man.

Ferrier's[6] map of the cortex of the Macaque monkey is well known, and represents the arm area as extending on both sides of the fissure of Rolando.

The work of the late Dr. Beevor and myself, begun in 1885, to further analyse more minutely the functions of the arm region, may be summed up as a catalogue of the movements of the different parts of the limb and of their successive order. Although we observed movements, especially of the thumb and fingers, to follow excitation of the gyrus post-centralis—that is, behind the fissure of Rolando—that gyrus we found was not always excitable, and the movements obtained from it were restricted and feeble. We believed at the time† that this was due to the main representation being in front of the fissure of Rolando.

As will be seen directly, this question of the excitability of the gyrus post centralis has now, in the light of modern anatomical research, become interesting on the question of the relation of structure to function, and to the anatomist, as far as the upper limb is concerned, the question of the presence or absence in both central gyri of Betz cells as necessary elements for the intentional movements of the arm segments.

In the first place I would say that I have electrically tested this gyrus either in lecture demonstrations or in the course of experiments in each of the twenty-four years that have elapsed since 1885. Physiologically there is no question that the gyrus post-centralis is more frequently excitable than not in *Macacus sinicus* and in large specimens of *Macacus rhesus*, and that it is less excitable as we ascend the evolutionary scale. But the same point has also been approached in a controlling method by Munk,[19] who, having excised the gyrus pre-centralis in twelve monkeys, found that the gyrus post-centralis was excitable. Grünbaum and Sherrington,[35] however, did not obtain this result in a chimpanzee. So also Rothmann,[48] who has devoted so much time and indefatigable work to the subject of the motor area and pyramidal system, found the gyrus excitable in twelve monkeys (chiefly *Macacus rhesus*), with one exception.

Brodmann,[18] on the other hand, obtained evidence of excitability only in two monkeys, in which he thought that the pre-central cortical structure was abnormally present in the gyrus post-centralis.

The most elaborate investigation of recent times—namely, that by Herr and Frau Vogt,[49] extending over a large series of different species of the lower apes—resulted in the practically invariable conclusion that the gyrus post-centralis is inexcitable. They employed the so-called unipolar method of excitation (see footnote, p. 126).

We will postpone for the present the consideration whether the positive results and efferent results obtained by such stimulation of the post-central gyrus are due to the excitation of a mainly sensory or a mainly motor cortex.

The first experiment in an anthropoid was a solitary

* See also my work on the Spinal Cord, 1892.

† *Phil. Trans.*, p. 158.

observation by Dr. Beevor and myself,[18] of which Fig. 2 (on the plate) is the record.

From it it will be seen that we only obtained evidence of excitability of the post-central gyrus at two points. This single experiment, confirmed in all other essential particulars, has been superseded by the extensive researches of Sherrington and Grünbaum, who were enabled to make a great many experiments on the orang, chimpanzee, and even the gorilla. They found that the gyrus post-centralis in the anthropoid was inexcitable to a stimulus which evoked* a response from the gyrus pre-centralis, but "facilitated" elicitation of movement from the gyrus pre-centralis.

In man the cortex cerebri has been frequently stimulated in order to guide the surgeon in various operations undertaken for the relief of conditions irritating this region. Up to the year 1890 Beevor and I collected the facts then available, and others have been contributed since by Lamacque, Keen, Lloyd, Mills and Frazier, F. Krause, Cushing, myself, and others. Inasmuch as the exact determination of the cortex stimulated has not always been possible under the special circumstances of an operation, I put together twelve years ago the points that I had myself noted and could be responsible for. From the photograph reproduced in Fig. 3 (see plate), it will be seen that in man I have never elicited a motor response by stimulating with a minimal current the post-central gyrus. Last year, desiring to remove the whole upper limb centre in a patient who was suffering from violent convulsive movements of the arm, I stimulated the Rolandic gyri, and Fig. 4 (see plate) is the rough sketch made immediately after the operation. The inferior genu of the fissure of Rolando is marked by a G, which is placed upon the gyrus post-centralis, and which was inexcitable to the current adequate for the points numbered (except 7) on the gyrus pre-centralis.

We may be certain, therefore, that the more essentially motor part of the kinaesthetic representation of the upper limb lies in the gyrus in front of the fissure of Rolando. We shall see presently that though this is the case, the Galenical method of experimentation, namely, the removal of this same centre, proves that this is not the only part of the cortex cerebri from which voluntary movement can be obtained, and that it is also the seat of highly important sensory as well as motor functions. (Cf. especially Mott[23].)

We may now examine the intensely interesting work which has been contributed of recent years to extending our knowledge of the anatomy of the different regions of the cortex cerebri. When the discovery of "motor centres" first attracted attention, Dr. Bevan Lewis,[6] as long ago as 1878, showed that the pre-central gyrus contained giant pyramidal cells in groups, and he mapped out this part of the cortex as being specialized for motion. Possibly because the groups of these giant pyramidal cells did not correspond to the foci of representation as demonstrated by the method of excitation, and possibly also because (as he showed) there are areas of the "motor" cortex where no such cells exist, his observations did not receive the attention they deserved.

A fresh impulse to the whole subject was given by Flechsig's myelinization method, but that method, which is essentially crude, did not produce results which commended themselves to most observers, and the subsequent alterations by Flechsig of his areas also did not strengthen his conclusions. At this juncture Campbell[41] began his remarkable work which, by the liberality of this University and the Royal Society, has been presented to the scientific world in full publication. Campbell's work has the further merit that it is in essential particulars in agreement with the independent and equally remarkably careful and thorough investigations of Brodmann.[34] The map (Fig. 5 on plate) of the cortex cerebri in man by Campbell will now make clear the point I have been dwelling on, and from it you will see that to include the whole efferent or motor area as determined by excitation we must take two of Campbell's regions, both his intermediate pre-central and pre-central areas, although he wishes, apparently, the term "motor" to be restricted to the latter. This suggested restriction of the term "motor," namely, because the giant pyramidal cells of Betz are to be found in only a certain (the major) portion of the pre-central gyrus, cannot be justified, since it would exclude the motor centres for the face, larynx, pharynx, and eye muscles, as well as part of the representation of head movements. It also disregards the anatomical rule that an efferent or motor cell varies in size according to the distance the axone has to travel in the central system—for example, the largest pyramids in the pre-central gyrus are in the leg area. Now, as regards the structure of the cortex, it may be seen from his drawings of vertical sections of the cortex cerebri that the cells of which it is built up may practically be divided into two sets—small and large. The innumerable smaller cells are grouped chiefly into two sets—polymorphic and granule—and the larger cells may be roughly divided into the giant pyramids or Betz cells, medium and small pyramids (Figs. 6, 7, and 8 on plate). The pyramid cells must be regarded as the outgoing stations in any part of the cortex, because their axones pass down through the central nervous system, and thus, again, it is not philosophical to consider the Betz cells as the only "motor" element in the cortex cerebri. The much more numerous small cells of polygonal and varying outlines forming the granule layers may be regarded as belonging to a mainly afferent or "sensory" receptive and associative system—that is, the mechanism underlying the preliminary stages of a cerebral motor response. This view of the polymorphic and granule cells of the Rolandic area which I put forward[18] at the Congress of American Physicians and Surgeons at Washington in 1888 on the somewhat slender grounds of homology, has now received the adequate criticism of research, and the receptive character of the cells may be considered to be established by the researches of Bolton, Ramon y Cajal, Mott, Watson, and v. Kappers, among many others. Moreover, the true method of regarding the anatomical construction of the cortex cerebri should begin by accepting the principle first enunciated by Hughlings Jackson from the consideration of the nervous system from the evolutionary standpoint—namely, that every centre in the nervous system must be sensori-motor. Such a thing as a pure motor centre could not exist, since it would be unfurnished with the causative sensory mechanism essential to the occurrence and production of the motor or efferent impulse; and, in fact, a muscular action would be an effect without a cause, an absurdity which indeed the old idea of psychic spontaneity of action involved.

The cortex itself affords a striking example of the disadvantage of any narrow discrimination of nerve centres into "motor" and "sensory." Thus, for the production of the movement of conjugate deviation of the eyes there exists a centre in the motor area so-called, and yet, as Schäfer[15] showed, excitation with a rather stronger stimulus will produce precisely the same movement from a so-called sensory centre—namely, the visual area of the occipital lobe. This latter, the area striata of Elliot Smith, though enormously rich in its granular layers, contains certain pyramidal cells (Meynert's) which are the motor or efferent element in the visual sensori-motor centre. It is obviously quite possible that the motor phenomena obtained from the post-central gyrus, and which can be obtained in different individuals of the Macaque species, may be also instances possibly of stimulation of a mainly sensory centre producing efferent, that is motor, phenomena through its medium sized pyramids.

We may now turn with advantage to Campbell's anatomical investigation of the post-central gyrus, and may remark in passing that Brodmann's description of the same only differs in a more minute subdivision of the cortex of the convolution. Campbell suggests that the post-central gyrus in its richness in small or granule cells, in the absence of Betz cells, and in the arrangement of its fibres, should be regarded as a sensory centre, and this raises at once an enormously large question, namely, What is the seat of the representation of all forms of sensation of the upper limb in the cortex cerebri? This is also particularly the moment to draw attention to the

*It should not, in my opinion, be assumed that the effect of a minimal stimulus, evoking, as it often does, but a single movement of one segment of a limb, is a criterion of all that is represented—that is, in that portion of the cortex cerebri. The response elicited from the cortex cerebri by a stimulus is within limits proportional (1) to the strength of the stimulus and (2) to the degree to which the movements of any given segment or part of the body are represented at the point stimulated. Consequently a minimal stimulus may only be adequate for one item of several represented in one portion of the cortex. It also must not be forgotten that, physiologically considered, an electrical stimulus is a crude method of exciting a nerve centre.

disadvantages attendant on the way in which this subject has been dealt with in textbooks and even monographs. As a recent paper by Mills and Weisenburg[46] shows, some neurologists still think of the nervous system as being made up of sensory centres and motor centres respectively. It appears to me that on this all-important question not only the general principles of Bastian and Jackson, but also the original teaching of Munk, are in danger of being overlooked in this country and, perhaps, in America. Munk[7] has always spoken of the so-called motor area as the "Fühlsphaere," and has regarded the cortex cerebri of this region as the mechanism for storing up the memories of movements—he holds, in short, no part of the cortex should be termed the motor area, since by implication the representation therein of those sensations and sensory disturbances which of necessity precede every muscular action is left out of sight. Every lesion of this region in man that I have seen during the past twenty-four years has served to confirm Bastian and Munk's mode of regarding cerebral function.

Attempts made, therefore, to discover areas of the cortex cerebri in which the representation of sensation (all forms) of parts of the body might be very strictly localized in sensory centres have hitherto failed in proving the existence of such areas. Schäfer and myself[17] observed reduction of sensibility in the limbs after lesions of the limbic lobe, a region which Ferrier had suggested might be a field of sensory representation other than osmotic; but it is possible that the effects we observed were due to deeper involvement of the corona radiata, and that thus the thalamo-cortical system was injured near its origin. Campbell has inadvertently represented me as relying on these few experiments as indicating a centre for somatic sensation. On the contrary, from the year 1886 onwards (see index of papers referred to) I have constantly demonstrated and published evidence to show that a considerable proportion of the sensory representation of the upper limb exists in the so-called motor or Rolandic region.

The first case by which I established this fact in 1886 was one of excision of a small traumatic cyst for epilepsy, which operation (with ligation of veins immediately surrounding) caused the following phenomena:

After the operation the patient was at first completely paralysed in the digits of the right upper limb, and for further flexion of the wrist and supination of the forearm.

Coupled with this motor paralysis there was loss of tactile sensibility over the dorsum of the two distal phalanges of the fingers.

He could not localize a touch anywhere below the wrist within the distance of one internode; finally, he could not tell the position of any of the points of the digits. Thus we have here apparently a distinct instance of loss of tactile sensibility and muscular sense, coupled with motor paralysis, all due to lesion of the cortex. (BRITISH MEDICAL JOURNAL, 1886, vol. i, p. 673.)

The lesion was by measurement estimated to lie in the centre of the upper third of the gyrus pre-centralis (see Fig. 9 on plate). The patient is (1909) in robust health.

A second case, published at the same time (BRITISH MEDICAL JOURNAL, 1886, page 670) was that of a country lad suffering from a strictly localized tuberculous tumour of the Rolandic gyri, the removal of which, however, affected the post-central gyrus. In this case exact localization was obtained, for the patient eight years later died of tuberculosis and the brain was photographed.

He not only exhibited the like sensory and motor defects, but also, without questioning, stated that (deep) painful impressions evoked by passive movement of the (temporarily) paresed arm ran up the limb, side of neck, and through the head to the seat of the extirpation, and he graphically indicated the actual spot by placing his finger upon the dressing exactly over the wound (see Fig. 10 on plate).

During the many years which have elapsed since these cases, I have had innumerable opportunities of confirming these observations, and have published the proofs of the same.

But although I have frequently observed the effects of comparatively small lesions in the pre-central and post-central gyri, it was not until last year that I obtained my first example of an absolutely pure lesion of one of these gyri alone, namely, the gyrus pre-centralis, and one which by repeated examination I am satisfied affords the final proof of the position here advanced, namely, the sensori-motor character of that convolution.

CASE.

The case was that of a powerfully developed boy, Hn., aged 14, the elder of two children of healthy parents. He had had no illness and suffered no accident, but at the age of 7 had gradually developed athetoid movements of the left hand, which then developed into violent convulsive movements of the whole upper limb, in which the arm was usually strongly flexed and adducted in jerks across the trunk, and more rarely flung out in abduction. The elbow was fixed in semi-extension, the forearm strongly pronated, the wrist flexed, and the fingers either in an interosseal position or flexing and extending independently. The movement was worse on walking, and when his attention or the attention of others was drawn to it. When the limb was quiet his purposive or voluntary movements were normal and powerful. The reflexes, superficial and deep, were everywhere normal; his sensation—all forms—was also normal.

Hn. was in a very distressing condition, and was referred to me by Dr. Risien Russell with the view of arresting the spasms by an operation. Having stopped athetoid and clonic movements in two previous cases by excision of the so-called "motor" area, I advised that the arm area in this case should be delimited by excitation and then removed.

OPERATION.

The operation was performed on March 20th, 1908. The shaved head presented a rather unusually globular outline; the bone was thick and vascular, and the dura mater was also hyperaemic. The bone was removed, as shown in the accompanying diagram, so as to expose completely the Rolandic region. The dura mater was tense, the vessels of the pia mater distended, and the brain turgid, even though the patient was under the influence of oxygen as well as the anaesthetic. The pia mater, especially in the sulcus pre-centralis, had a distinctly embryonic appearance. The cortex was then stimulated with a Kronecker graduated coil furnished with three dry Obach cells. The electrodes, bipolar, were 2.5 mm. apart; a current of 300 Kronecker units was just adequate to evoke a response occasionally from the gyrus pre-centralis, but it was found better to employ a current of 500 units to obtain constant results.

In the first place a current of this latter strength—that is, 500 units—produced no response from the gyrus post-centralis; this, as stated above, is in accord with the results I have previously obtained clinically on stimulating the cortex in man.

The gyrus pre-centralis was then thoroughly explored, and the results of stimulation at the points numbered in the accompanying diagram (see Figs. 4 and 11 on plate) were as follows:

Results of Stimulation.

1. Movement of the left side of the face.
2. Abduction of the left thumb, and to this on repetition of the excitation was added flexion of all the fingers.
3. Flexion of the fingers, flexion of the wrist, with ulnar adduction and late flexion of the elbow.
4. Extension of the fingers, ulnar abduction of the wrist, questionable flexion of the elbow.
5. Extension of the wrist, elbow held at a right angle in "confusion." (Beevor and Horsley.)
6. The same movements as 5, and in addition abduction of the shoulder.
7. No movement of the upper limb.
8. Elbow held at a right angle, powerful retraction of the shoulder.
9. Elbow at a right angle, protraction of the arm, and extension of the wrist.
10. Nil.
11. Protraction of the arm, elbow at an obtuse angle, extension of the wrist, and questionable extension of the fingers.

No other part of the cortex in the neighbourhood giving any response in the upper limb, the gyrus thus marked out was excised very carefully by making a vertical incision through the pia mater along the middle of the surface of the convolution, reflecting the pia mater to the sulci on each side and gently separating it to the bottom of the sulci so as to permit of excising the whole depth of the gyrus pre-centralis without any injury to the neighbouring gyri or even to the vessels in the sulci, beyond, of course, the laceration of the smallest branches entering the portion of gyrus removed.

Fig. 12 on the plate is a photograph of the arm centre thus excised with a millimetre scale appended, and in Fig. 13 its position is represented by the shaded area.

Structure of the Gyrus Removed.

After what has already been stated concerning the function of the pyramidal cells, the histological structure of the gyrus removed is of notable interest. At the operation I noticed that not only was the post-central gyrus unusually narrow, but that the vessels and membranes in the line of the fronto-parietal vein were of a somewhat embryonic type. Histologically also, as will be seen from the accompanying photographs (Figs. 14, 15, 16, 17, on plate), the pre-central gyrus differed in essential particulars from a normal convolution. Thus the depth of the layers of the cortex was reduced about 5 per cent.; the granule layers were not well differentiated and were poor in cells. There were a fair number of medium-sized pyramids (here and there arranged in groups); but the Betz cells were represented by extremely few specimens, only in the upper part of the area and in the anterior wall of the central fissure, none of which were perfectly normal in type or size and all somewhat shrunken in outline. Further, the apical dendrite of almost all the pyramids is seen to be altered in a spiral manner* more or less, and the cells show marked physical change, though still, in the large majority of cases, they exhibit normal tigroid bodies. The corkscrew shape of the apical dendron in lesions of the cortex cerebri has been described by Collins,[26] and his drawing (loc. cit., p. 382) shows a similar deformity of the pyramids from a case of chronic epilepsy.

The abbreviation in height of the cortical layers suggests that the increase in neuroglia which is evident may partly be responsible for the spiral outline of the dendrites and nerve fibres in the corona radiata, but Dr. Gordon Holmes has observed the same change in portions of cortex excised under like circumstances. It is possibly, therefore, an artifact due to manipulation and shrinkage.

The importance of the foregoing facts will be appreciated when it is remembered that the corresponding (left) upper limb was strong and muscular, and that all voluntary movements were readily and strongly performed when the limb was not the seat of violent spasm. If, therefore, the doctrine that the "motor" cortex is wholly dependent upon the giant pyramids or Betz cells were true, the pre-central gyrus in this case could not be accepted as the so-called motor centre for the upper limb or the source of its voluntary and spasmodic movement. Yet that it was so is shown by the gratifying fact that the spasmodic movements totally disappeared from the moment that the gyrus was removed, and have remained absent not merely during the short period of total paralysis of the arm but to the present time—that is, during thirteen months—and that since a month after the operation purposive (that is, voluntary) movements have returned and are developing in efficiency, in spite of the fact that the Betz cell area for the upper limb has been removed.

That the Betz cells are not indispensable for purposive muscular actions has also been shown by Brodmann. The precise rôle of these cells has yet to be defined; but that they furnish much of the pyramidal tract is well ascertained, especially by the recent researches of Holmes and Page May.[51]

Effects of the Excision of the Gyrus Pre-centralis.

Briefly summed up, the effects in Hn.'s case of the removal of the so-called motor centres for the upper limb in the gyrus pre-centralis may be stated as follows:

Immediate.—Disappearance of spasmodic movements.
Complete loss of voluntary movement of the left upper limb.
Post-axial and proximal atopognosis of the same.
Complete astereognosis of the left hand.
Moderate anaesthesia to all forms of sensation of the left upper limb, maximal at the periphery.

Remote (that is, a year later).—Permanent absence of spasmodic movements.
Partial recovery of voluntary movement of left upper limb.
Proximal atopognosis of left postaxial fingers.
Astereognosis of the left hand.
Slight tactile anaesthesia of the ulnar periphery of the left hand.

* In many cases the large pyramidal axones also presented a wavy outline.

Further detail of these phenomena must now be given, and it will be recognized that they are in full accord with the results arrived at in 1886, namely, that in the same region of the cortex cerebri sensory and motor representation exist together. The concluding paragraph of a paper I published[16] in the *Deutsche medicinische Wochenschrift* in 1889 expressed the position which I held then, and to which I would only now add the subject of topognosis.

> Every functional centre, at any rate, in the so-called motor part of the cerebral cortex is of a focal nature—that is, one finds that the centre is a definite point at which a given movement is most strongly represented and from which this is gradually diminished. Further, all such centres are in their nature kinaesthetic, and the kind of sensation which is thus localized in the same focus is of a twofold character—that is, a slight tactile sensibility and the so-called muscular sense (loc. cit., No. 38).

That, in fact, differentiation is one of degree and not of kind. A gyrus may justly be described as mainly sensory or mainly motor, but never one to the exclusion of the other, or, as Dana[12 22] puts it, "cortical anaesthesia is always accompanied with some degree of paralysis," and Förster,[32] in his monograph on cerebral anaesthesia, draws attention (p. 143) to the fact that the finest localization of sensation in the segments of the limbs is proportional to their mobility.

Before stating the facts found, a few general considerations on the questions of the kinds and mode of appreciation of sensory changes in cerebral lesions must be prefixed.

Of course, a motor phenomenon, from the nature of the construction of the nervous system and the wide representation of afferent impulses, must always exhibit localization in a more striking and concentrated form than a sensory phenomenon.

Probably this has led to the sensory changes in lesions of the so-called motor area being overlooked in the past. But another reason has been that the clinical testing of sensory changes has not only been rough in method but also employed without reference to other associated higher functions of receptivity. Thus Henri's[30] method, introduced in 1898 of simply recording the patient's knowledge of a point touched is often spoken of as though it provided an examination of the person's localizing power as regards tactility, whereas it only expresses the fact that the contact spot can be named. Loss of this knowledge means a very profound and extensive loss of sensory perception corresponding to complete peripheral nerve lesions, and therefore connotes, as far as the cerebrum is concerned, a widespread destruction of the hemisphere. Such anaesthesia, therefore, ought not to be expected from a limited lesion of the cortex cerebri, but, on the contrary, a loss of specialized function having direct relation to the co-ordination and execution of movements must be looked for.

Tactile localization means not only the defensive appreciation of a point of the body touched, but also the position of that point in space—that is, its spatial relation to the object touching.

From the list of sensory defects I observed in 1886 to follow removal of the so-called motor cortex, it was clear that we had before us precisely the kinds of anaesthesia which should be exhibited in accordance with Munk's views, that is, those sensory functions were disordered which are directly connected with the accurate evolution of a movement, and constitute his "memories of movements."

In following out this line of thought I used, in testing for loss of localization of touch, a method which should give not only the record of the spot touched, but also the appreciation and indication by the (vision screened) patient of the position of the contact spot in space—that is, its position in relation to the middle line of the body, its distance from the body, and above all its relation to the other parts and segments of the limb.

For the fulfilment of these requirements the method must obviously include indicative response on the part of the person observed, and I therefore caused the patient to indicate by placing the forefinger of the normal hand on the spot where he felt the touch applied to the opposite paresed hand.

This method immediately revealed the fact that lesions of the Rolandic region caused besides a loss of appreciation of the lightest tactile stimuli a more important loss of localization in space of the spot touched.

To this latter loss of function I applied the term "atopognosis."

I now wish to point out two facts in regard to the psychical groundwork of this error of atopognosis. The nature of the test depends on the fact that the vision-screened patient feels the touch. If he is asked as to where it is he may reply quite correctly and write it by Henri's method on a diagram—as, for instance, that it is on the ungual phalanx, and yet, if asked to denote the exact spot touched, he will put his indicating finger on the correct digit possibly but too proximally—that is, one or two segments nearer to the body. If the stimulating touch has been considerable in degree or accidentally excited deep sensibility, the person, when his indicating finger touches his hand at the wrong—that is, too proximal—spot, frequently recognizes his error and slides the finger down to the correct spot touched. The refinement of this form of anaesthesia testing is thus considerable, because being a loss of knowledge of position of the part touched as compared to other parts of the limb, it is a step in the psychical response to a stimulus higher than the mere appreciation or not of an excitation.

This is well shown by the following control observation. Inasmuch as the patient preserves a great deal of the sensation of the limb, the loss is purely relative between the segments of the limb, and, therefore, whether the hand, touched and tested, is placed directed down the body parallel to the sagittal plane or pointing upwards should not affect the result.

This is, in fact, the case, for the spot to which the stimulus is referred by the patient still is too proximal—that is, nearer to the body than the spot actually touched. A further interesting point also soon appeared among the results obtained by this method. Investigations on the muscular sense, and of joint or arthric sense in particular, have drawn attention to the fact that when the imperfectly anaesthetic segments of the limb are touched, the point indicated by the observed individual is frequently near to an intersegmental joint. This may be assumed to be due to the psychical record by the cerebral cortex of the joint or arthric localized sensory impressions which constitute such a large part of the so-called muscular sense. As far as I have seen, the reference to a joint is most pronounced in the case of the wrist, and in the next degree that of the elbow.

The second phase of error in topognosis found in lesions of the "Rolandic region," by which term I mean the two central gyri, is extremely definite, and occurred in the present case of Hn. I cannot say, however, whether it is represented in the pre-central gyrus so much as in the post-central. This error is one at right angles to the direction of the error of proximality. If the hand is tested as before, the patient's vision being screened off, it will be found that he places the indicating finger not merely incorrectly as regards proximality, but also as regards the distance from the median plane of the body. Thus in a marked case of this loss, if the index finger be touched the patient will indicate a spot on the third or on the ring finger. Much more rarely the error will be towards the middle line.

For many years I have referred to these two varieties of the transverse axis error in regard to the limb itself as post-axial and pre-axial respectively, and in rare cases of severe disease and destruction of the parietal region of the brain, in which there is a widespread loss or damage of the thalamo-cortical system, and possibly direct damage to the thalamus, there is an obvious reference towards the middle digit. Further discussion in detail of this and of its interesting resemblance to spinal cord representation is not necessary here, since it is dealt with at some length in a special paper by Dr. Colin Russel and myself,[45] but I must point out that this error in the transverse axis is not a simple question of spatial localization, since it includes two additional and governing considerations: (1) The degree of specialization of the first two digits, compared to the ulnar or post axial fingers; (2) the question of the true position of the upper limb at rest.

Of these I will on (1) only say now that the thumb is so intensely and widely represented in the arm area that it never exhibits atopognosis except in very extensive lesions consequently a limited loss is appreciated only on the ulnar side of the hand. The question of post-axial sensory representation I refer to again, but it is a subject worthy of a lecture by itself, if only that the most striking demonstration of cortical failure in a functional patient is the well-known numbness of the little finger (cf. also Bonhoeffer, Fischer, etc.). And on (2) that the ordinary acceptation of the so-called anatomical position of the limb—namely, extreme supination, palm in front—is unfortunately a constant source of fallacy, the real fact being that the forearm at rest is not supinated but pronated, and that consequently the dorsum of the hand is directed forwards, is of necessity more exposed to external contacts, and therefore more frequently the instrumental surface of spatial record.

The bearing of this is that since, as before stated, atopognosis is most readily demonstrated on the dorsum of the hand, a *post-axial* error is really one of direction away from the middle plane of the body. The important question of the relation of the surface of our body to the space immediately surrounding us, and the relation of the different points in space to the middle plane of the body, I discussed in the Boyle Lecture[42a] four years ago, and therein showed by a special plate method, which was subsequently more fully developed by Dr. Slinger and myself,[44] that inaccuracies in our knowledge of space, and consequently of the position in space of the various points on the surface of our body and limbs, increase as we pass from the surface of the body towards the extremity of the limbs and from the mesial plane of the body outwards to either side. All these determinations of the points in space being effected by exploration of the limbs, our knowledge of localization is, apart from visual impressions, a compound result of muscular, arthric, and cutaneous sensations. It now will again be obvious how these particular forms of sensation, namely, slight tactile sense, muscular sense, and topognosis, are inseparably bound up with the representation of movement in the same region of the cortex, namely, the so called motor area.

I was much interested to find a short time ago that Volkmann[2] in 1844 drew attention to the fact that if a normal person was blindfolded then touched lightly on one finger with a pointed instrument and asked to indicate with another point the spot touched there was frequently an error and that the direction of the error was in the long axis of the limb and amounted to a line or more. It is curious that in the few observations which Volkmann seems to have made he found the error to be more usually distal. My own experience with a very great number of observations, since they extend over many years, is the reverse, and that, both in normal people as investigated by my plate-test and in people the victims of cerebral lesions, proximality is the ruling character of the error and distality the exception.

CHANGES IN SENSATION OBSERVED IN HN. AFTER EXCISION OF THE GYRUS PRE-CENTRALIS.

We may now expand somewhat the brief summary given above of the effects of the operation in Hn. The temporary character of the severe effects observed directly after the interference proves that the sensory representation of the upper limb extends over a wide area of cortex—namely, at least both Rolandic gyri. Practically these provisional phenomena disappeared within three to four weeks after the operation, and, therefore, as fifteen months have now elapsed it is possible to determine accurately what permanent change or loss of function is coincident with the removal of the gyrus pre-centralis.

(a) Position of the Limb.

During the first twelve days after the operation the limb was motionless and flaccid. The patient was imperfectly aware of the position of the limb, and felt a "funny numbness" all down the left side, and mostly in the leg. This subjective numbness of the opposite side is, of course, typical of all lesions of the parietal cortex, whether functional or organic, and this instance may be compared to Fischer's closely studied case.[42]

At the end of the first fortnight he knew the general position of the whole limb by reason of his appreciation of the contrast between the temperature and roughness of the blanket and the surrounding objects. Nine months later, if the limb were kept at rest for some time, he lost knowledge of its position. He now (June, 1909) knows the general position of the limb in the dark.

(b) Position of Digits.

The position of the digits was correctly described, but not correctly imitated by the right hand until the third week.

Estimation of lengths and breadths by stretching the digits apart was at first entirely wrong (for example, 4 cm. distance described as 4 mm.), but gradually improved *pari passu* with the recovery of voluntary movement, until, nine months after operation, his error in estimates of separation of the digits was not more than about 30 to 50 per cent. (see stereognosis). The error is now reduced to about 30 per cent.

(c) Topognosis.

During the first fortnight atopognosis was very marked, and the first thorough examination at the end of the first fourteen days showed that the atopognostic error was:

(*a*) Proximal value, 2 segments (that is, distance too high);
(*b*) Postaxial value, 2 digits (that is, distance outwards from mid-line of body).

Similarly, as the recovery of movement has taken place, there has been some improvement in the patient's topognosis. By the ninth month the post-axial error almost disappeared and the proximal error was reduced to about 1.5 segments on the average.

Now, fifteen months after, he exhibits the typical atopognostic peripheral and ulnar distribution of response to the lightest touches thus:

Left Hand (Right Indicator).

5th	digit,	2 segments proximal error.
4th	,,	2 ,, ,,
3rd	,,	1 ,, ,,
2nd	,,	Correct.
1st	,,	Correct.

The illustrations 5 and 6 given by Fischer[42] (loc. cit., p. 105) would fairly apply to both the topognostic error as well as the diminution of tactility in Hn.

(d) Tactile Sensibility.

The slight loss of tactile sense (superficial, of course) which was evident in the first cases examined in 1886 has been present throughout in Hn. From the first, cotton-wool was felt on all hairy parts. Light touches were not felt on any ungual phalanx, and still are not on those of the fourth and fifth digits.

(e) Temperature Sensibility.

Fourteen days after the operation a test tube of water heated near the temperature of the hand was not felt on the ungual phalanx, was occasionally detected on the middle phalanx, and well appreciated as warm on the forearm. The cold tube was recognized as cold everywhere.

At the present time (fifteen months after) there is slight temperature hyperaesthesia to either heat or cold.

(f) Pain (Pin-prick).

Both the appreciation of the point of a needle and the localization of the same exhibited precisely the same diminution and topognostic error as the reaction to touch; a parallelism in representation to be referred to again later.

(g) Stereognosis.

The most profound sensory change produced by the removal of the gyrus pre-centralis was inability to recognize the form of objects. The subject of stereognosis, as originally investigated by Puchelt,[1] and later by Hoffmann,[8] has received a great deal of investigation, and by some it has even been regarded as a special sense, but, as shown by many authors, it is but a compound experience of several forms of sensation as well as of movement*—for example, tactility, muscle sense, arthric sense, temperature sense—in fact, is but the memorialization of exploration and tactility.

The allied subject of sense of volume I have alluded to above under position of the digits. In view of the current hypothesis that the postero-parietal lobule, or the gyrus post-centralis, is the centre for stereognostic perception (Cf. Mill,[46 etc] Bruns,[29] Redlich[21]), it was especially important to note what alteration occurred in the case of Hn.

Tested with all well-known domestic objects as being easier of recognition than geometrical figures, it was found that, after the operation, Hn. could recognize nothing (nail-brush, prayer-book, bottles, coins, knives, pipe, matchbox) when the objects were placed in his hand, and even when the fingers were pressed over them, though he once guessed a tumbler to be a bottle because it was cold.

When I was thus testing him for stereognosis three weeks after the operation he made the striking remark: "If I could only move my hand about I should know what the things were," thus showing under the stress of effort what the real basis of the stereognostic sense is—namely, merely a complex of tactile, muscular, and arthric memories of movements, which are, in fact, the compound experiences of grasping and feeling objects.

At the present time the astereognosis remains extremely marked. Thus, on April 24th, 1909, he could not recognize even a glass lens, keys, small box, etc., though he evidently could appreciate wider contacts of surface.

COMMENTARY.

It is thus quite clear that the so-called motor cortex is a sensori-motor structure, of which the motor element is the principal funnel-like outlet for afferent impressions coming from many parts, especially the gyrus post-centralis and optic thalamus.

Precisely similar observations have been made by Bonhoeffer[28 37] in lesions of the Rolandic region. Of these in his first case the destruction may have been limited to the pre-central gyrus; but as vessels in the pia were tied possible involvement of the gyrus post-centralis cannot be excluded, and therefore objection might be taken to it as an absolute proof of the pre-central representation of sensory function. This criticism also applies to the succeeding interesting cases in Bonhoeffer's paper, but he fully confirms the parallel relation between the loss of motor function and the diminution of tactile sensibility of the periphery, as well as the parallel degree of astereognosis.

Finally, seventeen years ago a most interesting demonstration of the sensori-motor function of the Rolandic cortex was made[20a] by Ransom, who proved that treatment, including direct excitation of points in the "motor" cortex in a non-anaesthetized patient, evoked (1) a vague tingling sensation, (2) increase of muscular sense, (3) muscular contraction. Ransom concluded his remarkable communication by urging the need of recognizing the two-sided constitution of a nerve centre—namely, sensori-motor.†

That the representation of the two sides of the activity of a nerve centre must be thus proportionately associated was, I believe, not fully accepted in Germany, in spite of Munk's teaching, until the appearance of C. Wernicke's[25] paper in 1895. The recent researches of Bonhoeffer,[37] Fischer,[42] and others, however, have placed on a firmer basis, among other points, the essentially peripherally and post-axially graded representation of sensation in the Rolandic cortex.

This brings me to the next question, What is the function of the hinder Rolandic convolution, the gyrus post-centralis, and at any rate that part of it which topographically is part of the arm centre? Since I am not cognizant of the post-central gyrus having ever been excised without injury to surrounding convolutions, it is only possible to surmise from clinical cases in which the Rolandic region is generally affected what additional neural loss is caused when the gyrus post-centralis is destroyed as well as the gyrus precentralis. Study of the effects of lesions of both the central gyri, of which I have seen many instances, fully supports the general view that the former constitutes part of the area of sensory representation of the upper limb in the cortex cerebri. The view that it is the sensory centre of the upper limb was put forward long ago by Mills,[14] who, on the basis of clinical cases, hazarded this hypothesis, as well as that it was the centre for stereognosis, and that while it was the sensory centre for the upper limb the pre-central gyrus was the motor centre. His latest

* As Long[81] excellently says of this factor in stereognosis, "la motilité elle même doit être suffisamment conservée pour permettre la palpation."

† Since this lecture was delivered, similar and differentially important evidence has been obtained by Cushing,[50] who by electrical excitation of the cortex, under circumstances which render localization accurate, elicited in two cases sensations of tactility from the gyrus post-centralis, and sense of muscular movement as well as actual movement from the gyrus pre-centralis.

monograph on the subject with Dr. Weisenburg[46] is founded on six cases, in only one of which was an autopsy obtained, and I am not aware of any case having yet been published in the literature of this important question, in which it was shown that a lesion* was restricted to the post-central gyrus. Under these circumstances it seems to me premature to formulate any final conclusions as to the function of this gyrus. But in view of Campbell's and Brodmann's demonstrations of its richness in granules and its architecture generally, together with the fact I have just stated, that lesions of both central gyri produce far more sensory disturbance than lesions of the pre-central gyrus alone, I think we may safely conclude that the post-central gyrus is part of the cortical area in which the sensory representation of the upper limb is located. Inasmuch as the sensory properties of the upper limb are all directed to the efficient action of its muscles, it is also not assuming too much to say that like the pre-central it is a centre for tactility topognosis, muscular sense, etc. As regards Mills's claim, that it is the sole centre for *stereognosis*, this clearly cannot be justified, as my present case and others in which the lesions did not involve the post-central gyrus prove.

Just as the disturbances of sensation which follow destruction of the Rolandic gyri are clearly due to loss of the pre-central as well as the post-central convolution, so it is now also certain from the case of Hn. that the pre-central gyrus is not in man the only out-going or motor centre for the voluntary movements of the upper limb. This, indeed, was already made probable, not only by many experiments on the lower apes, but also by the important experiments of Grünbaum and Sherrington[35] on the chimpanzee, in which animal these observers found that after the arm area in the so-called motor pre-central gyrus was excised, the purposive movements returned "in a few weeks," and, further, that this compensation was not effected by the opposite arm area in the contralateral hemisphere.

CHANGES IN MOTION.

I will now proceed to describe the precise recovery of voluntary power in the case of Hn.

(*a*) *Consensual Movement.*

The arm immediately after the operation was perfectly motionless, but by the fourteenth day, when on my request the right (normal) hand was strongly clenched by Hn., his left forearm slowly supinated, the wrist slightly flexed, and the fingers also very slightly flexed.

This extensive consensual response strikingly resembled that obtained in a case of chronic tuberculous disease of the "motor" cortex I observed[9] in 1884. Possibly the further analysis of this phenomenon will aid in the solution of the problem how recovery of "voluntary" movement is obtained after destruction of the gyrus pre-centralis.

(*b*) *Purposive or Voluntary Movement.*

At the end of the third week the power to abduct and adduct the shoulder returned. Next, flexion of the elbow, then extension of the elbow, and flexion of the wrist.

Recovery of power in the digits was especially interesting and important. Several days before the movement of the fingers and thumb returned he stated that he felt the power was returning, and that he would shortly move them. The control and exercise of the digits has now attained its optimum in the thumb, which can be slowly flexed and extended, while the fingers as regards extension follow in rapidly diminishing degree; thus, the index finger fairly extends, the middle finger much less, the ring finger hardly at all, and the little finger not at all. As regards flexion, the complication of hypertonia comes in, because the ordinary hypertonia or contracture affects as usual the most paralysed part, and therefore when the digits are flexed the small fingers curl up into the palm, and the wrist, instead of remaining extended, follows suit. The range of movements are shown in the accompanying photographs (Figs. 21 and 22 on plate), taken on April 24th, 1909. The hand assumes an athetotic posture, and the powerful effort made to keep the arm straight out from the shoulder and to extend the digits is well shown by the movement of the latter throwing them out of focus (3 secs. exp.), as well as by the synergic contraction of the face. Flexion of the elbow is easily performed, though slightly flail-like, and the rotation and pronation movements so well, that, as the photograph shows, Hn. can place his hand on the back of the iliac crest. He is able to use the limb as a help in dressing, but made the interesting statement that for two-handed work he finds there is so far a sense of discord between the hands, for example, in holding a cricket bat, that if possible he preferred at present to use one hand. I would only suggest in passing that this may be due to the fact that, as shown by extremely limited lesions of the cortex, the gyri are symmetrically connected with each other, and not heterotopically. The most comprehensive recent investigation of the question of the paths for purposive movement is by Rothmann, who has done so much to elucidate the phylogenetically older paths for the transmission of motor impulses other than by the fibres of the pyramidal tract. It proves that after complete exclusion of the pyramidal paths the arm region of the cortex is in monkeys still excitable, and that isolated movements could be perfectly obtained.

Comparison of the photographs of Hn.'s present voluntary movements with the valuable drawings furnished by Marinesco[36] of two cases of cortex excitation operated upon by Jonnesco will probably convince any one that they are of precisely the same origin. Unfortunately the localization of the gyri operated upon in Marinesco's cases is not certain, nor the extent of the excision, the effects of which were rendered probably more extensive by the ligature of veins.

* With the utmost respect for the opinions of the many distinguished writers on this subject who have published instances of lesions in this region, I venture to object to evidence derived from cases of extensive tumour as scientifically not valid for this purpose.

CONCLUSIONS.

It follows from what has just been said that the case of Hn. proves for man what has already been established by experiments on monkeys—namely, that so-called volitional movements are not alone generated from the brain through the "motor" area or pre-central gyrus, but must also be subserved by other parts. Further, from what has been already said it is reasonable to assume that, in the absence of the pre-central gyrus portion of the arm centre, the function of movement is executed by the representation of the upper limb in the gyrus post-centralis from which the fibres descend to the optic thalamus through the internal capsule. To Rothmann[48] we owe especially the demonstration of the part played in this restitution of function by Monakow's bundle, the rubro-spinal tract, which constitutes the large primitive efferent tract between the basal ganglia and the spinal cord, and further that by reason of its constituting an axial point in the path of nerve impulses ascending from the cerebellum to the mesencephalon and thence descending to the spinal cord, the red nuclear region is clearly the central point of Schiff's middle group of reflex centres. It would be interesting if it were possible to classify the movements which thus return after the complete destruction of the "motor" area. If we turn to earliest observations on this subject the most striking experiment is, of course, that initiated by Goltz, who removed in a dog the cortex and a large portion of the anterior region of the thalamus, and who found that the animal was able to stand and to walk. The same thing precisely is observable in the higher animal, and it has been suggested by v. Wagner that the pyramidal system which for the upper limb means chiefly the giant pyramids, or Betz cells and their fibres, is the part of the cortical efferent system which is reserved for learning new movements, while stock actions, such as progression, and which ought to be regarded as combinations of Munk's "Einzelbewegungen," can be adequately performed by the cerebellum, mesencephalon, and spinal cord acting together. In a general sense this view is probably widely accepted, consequently the pre-central gyrus must be regarded as part of the mechanism whereby new sensory combinations received from either the surface or deep structures of the upper limb are received and integrated.

HYPERTONIA.

The present case affords some opportunity for a study of the condition of hypertonia or contracture, but to which now only the briefest reference can be made.

In a general sense, from the time of Setschenow the higher nerve centres have been regarded as inhibiting the lower; and in the old sense of the word "inhibition" the higher centres controlled the lower and prevented their physiological activity being displayed. Consequently, if a higher centre were removed and a change in the muscular condition of the part represented followed, it was said to be due to loss of the influence of the higher centres. This crude view of inhibition was never really acceptable, nor did it at all explain the conflicting evidence obtained from clinical records of lesions of the cortex cerebri. This is not the occasion for full discussion of either of these conditions or their theoretical explanation, but it is evident that MacDougall's well-known view of inhibition alone adequately furnishes their interpretation. According to this view also it would follow that the occurrence of hypertonia in the muscles of the upper limb would be present in proportion to the degree to which they severally had lost their cortical representation. That this is the case will have been noticed in the photographs already shown, the hypertonia being most marked in the muscles of the ulnar fingers and diminishing as we move to the other parts of the limb.

Pain.

I cannot leave, also, the consideration of the function of the so-called motor area without shortly discussing the question as to how far pain is represented in the cortex cerebri. It seems to be rather too generally assumed that because the Rolandic region itself can be manipulated and apparently irritated mechanically without giving rise to pain impressions it is not a psychic organ for the conscious appreciation of pain. From an *a priori* standpoint this has always seemed to me somewhat unreasonable, because the rapidity and intensity of the defensive movements which result when a painful stimulus is applied to the upper limb, for example, and, further, the accurate localization in consciousness of the part which is stimulated, all shows that pain is appreciated as such by the same mechanism that co-ordinates conscious movements and the sensory disturbances which immediately precede them. It is, unfortunately, extremely difficult to obtain direct evidence on this subject, because the observations can only be made with certainty on the human being who can describe in terms the painful character of the afferent impulse, and we are not reduced to interpreting motor responses which in a large number of cases are of subcortical origin. The evidence I possess on the question would seem to show that the conscious appreciation of pain in the upper limb is partly represented in the post-central gyrus. Thus, when the temporary symptoms after the removal of the pre-central gyrus had passed off, the conscious appreciation of a point as a painful prick was found to be preserved, and yet after the free removal or destruction of the whole arm centre—that is, of both central gyri—it is notably diminished, though, like all forms of sensation, not totally abolished.* The second point of evidence lies in the very interesting fact that the localization of a painful impulse is topognostically the same as the sense of touch—that, in fact, the diminution in appreciation of a pin prick is similarly subject to a proximal error, exactly as a light touch is. Inasmuch as the reaction of the person to the stimulus, whether tactile or painful, involves conscious appreciation, we can only conclude that a precisely similar cortical mechanism provides for this particular functional activity—that is, that pain is considerably represented in the Rolandic gyri.

SUMMARY.

1. The so-called motor area of the human cortex cerebri is really sensori-motor.

2. The gyrus pre-centralis is in man the seat of representation of (1) slight tactility, (2) topognosis, (3) muscular sense, (4) arthric sense, (5) stereognosis, (6) pain, (7) movement.

3. The gyrus post-centralis is in man part of the arm area in which the sensori-motor representation is of the same kind as that in the gyrus pre-centralis, but in it probably provision for sensorial co-ordination is greater, and that for efferent impulses less.

4. The giant pyramids or Betz cells are not essential for the performance of purposive or voluntary movements.

5. Purposive or voluntary movements can be performed after complete removal of the corresponding part of the gyrus pre-centralis.

* To avoid being misunderstood by any who regard localization of nerve functions as implying a series of closed compartments, I would point out here that not only do the above observations show that the gyrus post-centralis is not the only part of the cortex in which pain is appreciated, but it is clear that a painful stimulus reaching the thalamus may be radiated to any perceptive sensory area—for example, the gyrus pre-centralis, or any other region of the cortex—and so arouse consciousness of the distress.

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