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-centrals. (Plate XXI of Campbell’s work.)
THE SO-CALLED MOTOR AREA.

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

Fig. 10.—Side view of recently healed wound of case of tuberculous tumour (1886) removed from in front of the Rolando fissure (marked with an outline 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. Theculus 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 pre-central area is shaded darkest in front of the central fissure. In front of it (dotted) is the intermediate pre-central 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., abstraction; r.e., retraction; e.e., elbow extend; w.e., wrist extend; w.f., wrist flexed; ul. ad., ulnar adduction; r.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. 15.—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-centrales, 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-centrales fourth layer, showing pyramids and their spiral continuations.

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

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

HOMAS LINACRE, 1460-1524,
Physician to Henry VIII, one of the benefactors of St. John's College, Cambridge, as also 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 by 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 connection with the nervous system.

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 this year's Linacre 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, however, till many years later that the epoch-making discovery of Hitzig and Fritsch opened up the larger field of research, which was extended by Ferrier, 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 delineated.

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 much more logical expression "kinesthetic 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 "nervi oculi" has doubtless been employed because of the movements obtained from the Rolando cortex on excitation. But the term "excitable" areas is equally inadmissible when used without qualification, not only because so-called "sensorial" 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 Rolando gyrus.

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 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 have observed movements, especially of the thumb and fingers, to follow excitation of the gyrus post-centrals—that is, behind the fissure of Rolando—that gyrus we found was not always excitable, and the movements obtained from it were confused and feeble. We believed at the time; that this was due to the main representation being in front of the fissure of Rolando, living in the arm segments.

As we will see directly, this question of the excitability of the gyrus post-centrals 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 well 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 since I have been a neurologist. Physiologically the question that the gyrus post-centrals 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 question has also been approached in a controlling method by Munk, who, having excised the gyrus pre-centrals in twelve monkeys, found that the gyrus post-centrals is excitabile, Grinbaum and Sherrington, however, did not obtain this result in a chimpanzee. So also Rothmann, who has devoted so much time and indefatigable work to the subject of the motor area and pyramidal system, found the gyrus excitabile in twelve monkeys (chiefly Macacus rhesus), with one exception.

Brodmann, 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-centrals. The most elaborate investigations of recent times—namely, that by Herr and Frau Vogt, extending over a large series of different kinds of brains, resulted in the practically invariable conclusion that the gyrus post-centrals is inexitable. They employed the so-called unipolar method of excitation (see footnote, p. 126).

We will postpone for the present 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
observation by Dr. Beevor and myself, of which Fig. 2 (on the plate) is the record.

From 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 essentially similar experiments that have been superseded by the more recent researches of Sherrington and Grünbaum, who were enabled to make a great many experiments on the orang, chimpanzees, and the gorilla, they found that the gyrus post-centrals in the anthropoid was inexcitable to a stimulus which evoked a response from the gyrus pre-centrals, but "facilitated" elicitation of movement from the latter.

In the 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. Insufficient 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 portions (mostly in Fig. 3 of the 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 limbs of a patient who was suffering from 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 an S, which is placed upon the gyrus post-centrals, and which was inexcitable to the current adequate for the points numbered (except 7) on the gyrus pre-centrals.

We may now examine the intensely interesting work which has 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, as long ago as 1876, showed that the pre-central gyrus contained pyramidal cells in great numbers in this part of the cortex as being specialized for motion. Possibly because the groups of these giant pyramidal cells did not correspond to the field of representation as demonstrated by methods of eliciting and possibly 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 of Flechsig of his areas also did not strengthen his conclusions. At this juncture Campbell began his remarkable work which, by the liberality of this University and the Royal Society, has been presented to the scientific world. Campbell has the high merit that is in essential particulars in agreement with the independent and equally remarkably careful and thorough investigations of Brodmann. The map (Fig. 5 on the plate) that Campbell has drawn for us, if we now make clear the point I have been dwelling on, and from it you will see that to include the whole effenter or

motor area as determined by excitation we must take two of Campbell's regions, both of 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, in the cortex of the convolutions of the pre-central gyrus, cannot be found in only a certain (the major) portion of the pre-central gyrus, cannot be justified, since it would exclude to the motor centres for the face, larynx, pharynx, and eye muscles, as well as parts of the cranial nerves and movements. It also disregards the anatomical rule that an effenter or motor cell varies in size according to the movement to which it is related: the axone has to be proportioned to the stimulus which it elicits.

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 of 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 not as a motor, "motor" or "motor and sensory" area. 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
disadvantages attendant on the way in which this subject has been treated in textbooks and even monographs. As a recent paper by Mills and Weisenburg shows, some neurologists still think of the nervous system as being made up of sensory centres and motor centres respectively. It appears to the writer of this all-important question not only the general principles of Bastian and Jackson, but also the original teaching of Munk, as in danger of being overlooked in this country and, perhaps, in America. Indeed, it is always maintained that the so-called "motor area" as the "Fuhlsphäre," and has regarded the cortex cerebri of this as the mechanism for storing up the memories of movements—he holds, in short, no part of the cortex could be termed the motor area, since by instruction the representation therein of those sensations and sensory disturbances which of necessity preclude 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.

The cases, therefore, do no 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. Schröder and myself observed a 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 somesthetic; but it was possible that the effects we observed were due to deeper involvement of the corona radiata, and that thus the thalamos-cortical system was injured near its origin. Campbell has inadvertently represented me as relying on these few experiments for locating 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 degree 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 existence of a small antimonial eye 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 with the little finger, but one interposed area containing any part of the position of any of the points of the digits. Thus we have here apparently an almost perfect degree of loss of tactile sensibility and motor paralysis, all involving the 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 pre-central gyri, and so was that of the pre-centra-

served, and the cerebral cortex was therefore excised. (See Fig. 9 on plate). The patient is (1889) 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 gyri. 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 leptomeningeal covered arm, ran up and down the 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-

centrales gyri, it was not until last year that I obtained my first case of an absolutely puregyri alone, namely, the gyrus pre-centrales, 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 he had gradually developed atrophy, in spite of in 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 interosseous 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 purposeful or voluntary movements were normal and powerful. The reflexes, superficial and deep, were everywhere normal; his sensibility—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 any operation. Having seen him, I established with 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.

OBLIGATION.

The operation was performed on March 20th, 1908. The shaved head presented a rather unusually globular outline; the bone was thick and vascular, and a large blood vessel was seen in the region of 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 sulci pre-centrales, had a distinctly embryonic appearance. The cortex was then stimulated with a Kraneker graduated coil furnished with three dry Obach cells. The electrodes, bipolar, were 2.5 mm. apart; a current of 300 Kraneker units was just adequate to evoke a response occasionally from the gyrus pre-centrales, 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-

The gyrus pre-centrales 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:

1. Movement of the left side of the face.
2. Abduction of the left arm, 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 lateral flexion of the elbow.
4. Extension of the fingers, ulnar adduction of the wrist, questionable flexion of the elbow.
5. Extension of the wrist, elbow held at a right angle in "confusion." (Beever and Horsey.)
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. No movement.
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 excited 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-centrales 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...
Important notes before reading the text:

- The handwriting is legible and the text is well-formed.
- The text discusses the anatomy and physiology of the brain, specifically focusing on the so-called motor area of the brain.
- The text is cited from the British Medical Journal, July 17, 1909.

Text:

"Thus, as the large pyramidal axons were also presented a wavy outline, the movements and actions had a purposive (that is, voluntary) character, and were well differentiated, and were 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 alpine dendrite of almost all the pyramids is seen in a spiral manner, more or less, and the cells show the marked physical change, though still, in the large majority of cases, they exhibit normal tigroid bodies. The decrease of the alpine dendrite in lesions of the cortex cerebri has been described by Collins, and his drawing (loc. cit., p. 382) shows a similar deformity of the pyramids in a case of chronic epilepsy. The slight change in 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 possible, therefore, an artifact due to manipulation and shrinkage. The importance of the foregoing facts will be appreciated when it is pointed out 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 spastic movements. Yet that it was so is shown by the fact that the spasmatic movements totally disappeared from the moment that the gyrus was removed, and have remained absent not merely in the short period of total paralysis of the corresponding (left) arm but to the present time—that is, during thirteen months—and that since a month after the operation, not only have there been no attacks of spasm, but the patients have returned and are doing well 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 role 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."
of the Rolandic region caused besides a loss of appreciation of the lightest tactile stimuli a more important loss of localization of the spot touched. Isolated.

To this latter loss of function I applied the term "atopognosis." I now wish to put the two facts in regard to the phenomenon, as they are the work of this error of atopognosis. What is 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 in, but it is quite obvious that the following is the form of the test as, for instance, that is on the unusual phalanx, and yet, if asked to denote the exact spot touched, he will put his indicating finger on the correct digit possibly but pronated, or, if one or two digits. 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 anesthesia testing is thus considerable, because being a loss of knowledge of position of the part touched as compared to the 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. If we preserve a great deal of 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 back surface or up the anterior surface, the area in the post-central region, by which term is extremely definite, and occurred in the Rolandic region. The symptom is thus a complex of a large part of the so-called muscular sense and of joint or arthritic sense in particular, as compared to other parts of the body. It is curious that in the few observations which Volkmann in 1844 drew attention to the fact that the sensory representation in 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, within three months have now elapsed 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, proportionality 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, within three months have now elapsed 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, proportionality is the ruling character of the error and distality the exception.

(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 fell 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, as is also the case in this instance may be compared to Fischer's closely studied case. a

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 for 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) Topognosia.

During the first fortnight a topognosia was very marked, and the first thorough examination at the end of the first fourteen days showed that the a-topognosic error was:

- Proximal value, 2 segments (that is, distance too high);
- 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 topognosia. 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 a-topognosia, in which a peripheral and ulnar distribution of response to the lightest touches is:

- Left Hand (Right Indicator).
  - 5th digit, 2 segments proximal error.
  - 4th
  - 3rd
  - 2nd
  - 1st

Correct.

The illustrations 5 and 6 given by Fischer,2 loc. cit., p. 105) would fairly apply to both the topognosic 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 1866 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 topognosic 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 Pechel,4 and later by Hoffmann,5 has received a great deal of investigation, and by some it has 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, tactile, muscle sense, arthritic 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

As Long4 excellently says of this factor in stereognosis, "La mobilité elle-même doit être suffisamment conservé pour permettre la palpation."

(Cf. Mill,6 etc Bruns,7 Redlich 8), 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, bottle, pipes, knives, 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 kept for stereognosia 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, a complex of tactile, muscular, and arthritic memories of movements, which are, in fact, the compound experiences of grasping and feeling objects.

The present time the stereognosia 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 sensory-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 operculum thalami.

Precisely similar observations have been made by Bonhoeffer9 in lesions of the Rolando region. Of these in his first case the destruction may have been limited to the pre-central gyrus; but the extremities of the 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 conclusion 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 stereognosia.

Finally, seventeen years ago a most interesting demonstration of the sensori-motor function of the Rolandic cortex was made by Ransom, who proved that treatment, including direct excitation of points in the "motor" cortex in a non-anæsthetized 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 twosided 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 Goldstein's work in 1895. The recent researches of Bonhoeffer,9 Fischer,11 and others, however, have placed on a firmer basis, among other points, the essentially peripheral 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 not possible to surmise from clinical cases in which the Rolando region is generally affected what additional neural loss is caused when the gyrus post-centralis is destroyed as well as the gyrus pre-centralis. 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,12 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.

1 Since this lecture was delivered, similar and differently important evidence has been obtained by Cushin,10 who by electrical excitation evoked stereognosis in the cortex, under circumstances with which he had been associated in two cases sensations of tactility from the post-central gyrus, and sense of muscular movement as well as actual movement from the gyrus pre-centralis.
monograph on the subject with Dr. Weisenburg 4 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
made his hand on the restricted or 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 Broca's distributions of its fibres in grammar 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. Insomuch 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 topognosia,
muscular sense, etc. As regards Milla'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 proved.

Just as the disturbances of sensation which follow
destruction of either Rolandic gyrus is nearly 4 or 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 going-out or motor
centres of the cortex. It is not certain, nor the upper
limb 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 Sherrington6 on the chim-
appezees, 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
affected 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 consensual response strikingly resembled that
obtained in a case of chronic tuberculous disease of the
"motor" cortex I observed7 in 1884. Possibly the further
and more important phenomenon will be the solution
of the problem how recovery of "voluntary" movement is
obtained after destruction of the gyrus pre-centralis.

(b) Purposeful 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 interest-
ing and important. Several days before the movement
of the fingers and thumb returned he stated that he felt the
easiness of the power was returning, and that he would shortly move them.
The control and exercise of the digits has obtained 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
musculo-skeletal, and that important. It is probably 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 synergetic contraction of
the face. Flexion of the elbow is easily performed, though
slightly fial-like, and the rotation and promotion move-
ments so well, that, as the photograph shows, Hn. can
now lift his hand on his head. The function of the fingers
is now also certain from the case of Hn. that a

Comparison of the photographs of Hn.'s present voluntary
movements with the valuable drawings furnished by
experiment shows that the case of Hn. will be strikingly
compared with the case of Monakow. Unfortunately
the localization of the gyri operated upon in Hn.'s cases
remains uncertain, the effects of which were rendered probably more extensive by the
ligature of veins.

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
upper limb 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 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
rubro-rubral arc, 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 descend-
ing to the spinal cord, and nuclear region in the somatic
centrall point of Schöfl's middle group of reflex centres. It
would be interesting if it were possible to classify the
movements which thus return after the complete
suppression of the "motor" area. If we turn to the earliest
observations on this subject the most striking
experiment is, of course, that initiated by Golz,
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. Wager 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 the primitive
movements are 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
pyramidal gyrus must be regarded as part of the mechanism
by which 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 hyper-tonic muscle, 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

* With the utmost respect for the opinions of the many distinguished
writers on this subject who have published instances of lesions in this
region which have so directed to evidence derived from cases of extensive
nocturn as scientifically not valid for this purpose.
3. The gyrus post-centrales is in man part of the arm area in which the sensory-motor representation is of the same kind as that in the gyrus pre-centrales, but in it probably provision for sensorial co-ordination is greater, and that for efferent control is 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-centrales.

INDEX OF PAPERS QUOTED.

1844


2 Volkmann: (Wagner's) Handwörterbuch der Physiologie. 1844. Bd. 11, p. 571.

1869


7 Munk: Uber die Funktionen der Groshirnrinde. 1881.

1884


1896

10 Bastian: The Muscular Sense, etc. Brain. April, 1896. Vol. 8, p. 1. (Paper read, December, 1895. Most important for discussion of whole subject and literature.)

11 Horlsey: BRITISH MEDICAL JOURNAL. 1896, p. 610.

1898


14 Mille: Cerebral Localization in its Practical Relations. Transactions of the Congress of American Physicians and Surgeons. 1898.


1899

16 Horlsey: Deutsche medizinische Wochenschrift. 1899. No. 38.


1900

18 Semon und Horlsey: Philosophical Transactions of the Royal Society. 1900.

19 Munk: Gesammtliche Mitthil- lungen. 1900-2.

1901


1903


1904

23 Dana: Journal of Nervous and Mental Disease. 1904. December.


1906


1909


28 Lemacon: Archives cliniques de Bordeaux. 1897.

1908


1909


1911

32 Munk: Über die Bedeutung der Großhirnrinde. 1911.

1913

33 Forster: Monatschrift für Psychiatrie und Neurologie. 1913. Bd. 9, 2. 111.

34 Mills: Journal of Nervous and Mental Disease. 1911. P. 529.

1920


37 Martinoce: La semaine médicale. October, 1922.

1924

38 Bonhoeffer: Deutsche Zeitschrift für Neurologienheilkunde. 1924. Bd. 16, p. 27.

39 Broyem: Neurologisches Centralblatt. 1924.

40 Horsley: Practitioner. 1924.

41 Krause: Deutsche Klinik. 1904. S. 592.

1925


1926


48 Mills and Weissenberg: Journal of Nervous and Mental Disease. October, 1926.

49 Vogt: Verhältnisse der Anatomischen Entwicklung. 1906.

1927

50 Robmann: Archiv für Anatomie und Physiologie (Physiologische Abteilung). 1907. P. 217. (Very complete and summary of excitation and pyramid-ability research done by Eber.)


1929

52 Cushing: Brain. 1929. Pp. 94. 49.