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*SOME MECHANISMS OF CONSCIOUSNESS DISCOVERED DURING ELECTRICAL STIMULATION OF THE BRAIN**

BY WILDER PENFIELD

MONTREAL NEUROLOGICAL INSTITUTE, MONTREAL, CANADA

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This great National Academy embraces many sciences—almost as many, in fact, as there are members—for this is the day of diversity of thought and specialization of technique. But, although there are many sciences, there is only one scientific method and only one brain. Surely, there is no problem in any field more vast than the problem of the mechanisms of the brain and its relation to the mind. In these unstable times scientists would do well to give some thought to the nature of man himself.

The first function of a physician is to cure men and women of their diseases and to comfort when he cannot cure. But that is not enough. He must help to create a true science of the body and the mind of man. It was a physician who first introduced the scientific method into the study of nature. That was in Greece in the fifth century before Christ, when Hippocrates, an Asclepiad of Cos, opposed the philosophers who strove to explain all natural phenomena by "unprovable hypotheses." Indeed, the word "hypothesis" is said to make its first appearance in his writings. Observe and record the ways of nature, he told his disciples. Then conclude as best you can, for "life is short, the art long, opportunity fugitive, experience deceptive, judgment difficult."[1]

It was evidently as the result of study of epileptic patients that Hippocrates drew his own conclusions about the brain. For it was in his lecture on the scared disease—the Greek term for epilepsy—that he turned away from the current conception of the heart as the organ of reason. Listen to his words: "Men ought to know," he said, "that from the brain and from the brain alone, arise our pleasures, joys, laughter and jests, as well as our sorrows, pains, griefs and tears. Through it, in particular, we think, see, hear—and distinguish the ugly from the beautiful, the bad from the good, the pleasant from the unpleasant." Perhaps this summarizes well enough the knowledge of the human brain for the average man today. In Figure 1 you see the human brain removed from the skull and stripped of its covering membranes. If Hippocrates were here tonight, what could I tell him about the mechanisms within this master organ?

For our recent gains in knowledge we owe a debt of gratitude to workers in the physical sciences. Nevertheless, in this talk I shall assume that no one here has any knowledge of the brain more recent than the statements of Hippocrates.

I shall use terms so simple that they will be comprehensible even to physicists whose minds have slipped away, bemused, into outer space.

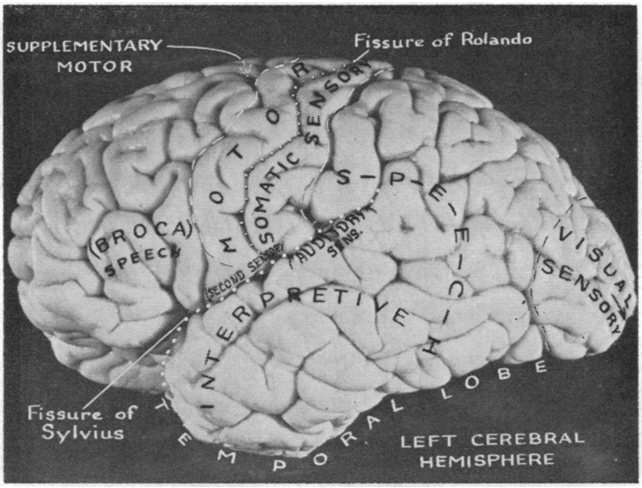


FIG. 1.—Human brain

As a neurosurgeon, it has been my lot to watch the experiments which only disease and injury can carry out upon the brains of unfortunate men and women. Of recent years my special province has been the surgical treatment of epilepsy, removing abnormal areas of the brain, areas in which the unbridled electrical discharges arise that produce epileptic seizures. There are many brain areas that can be removed with little or no detectable functional loss.

During such surgical procedures, the skull is opened and the brain exposed under local anesthesia, while the patient lies on the operating table fully conscious. Only thus is the cause of the attack to be found, and the surgeon's hand guided. The patient talks and answers the surgeon's questions while he maps out the various functional areas by applying a gentle electrical stimulus here and there on the cortex. The pattern of fissures and convolutions which you see in Figure 1 is never twice the same. The electrode is needed for orientation.

Sir Charles Sherrington,[2] in whose laboratory I was once a graduate student of physiology, said that brain function is made possible by "transient electrical potentials traveling the fibers of the nervous system."

The transient potentials travel along these fibers from the sense organs to the brain—from the eye and ear, joints, muscles, nose, and skin to the brain. And from the brain, potentials travel outward along other nerve fibers to the muscles to cause them to move in voluntary action. This seems clear enough except that Hippocrates would not have understood the meaning of "potential" or of "electricity." I must confess that I don't either. Here we would have had something in common.

Our present problem is to single out within the total function one small mechanism after another. There was little valid evidence of any localization of function within the nervous system, in spite of the amusing claims of the phrenologists, until Paul Broca,[3] a French surgeon, proved by autopsy in 1861 that a small area of destruction in an otherwise normal brain had produced loss of the ability to speak without loss of other abilities. The lesion he described was in the third convolution of the frontal lobe of the left hemisphere (Fig. 1). This is the so-called dominant hemisphere for a right-handed man.

After Broca, the next great advance was the demonstration by Fritsch and Hitzig,[4] in 1870, that an electric current, applied by an electrode placed on the cerebral cortex of a lightly anesthetized dog, caused one leg alone to move on the opposite side of the body. Fritsch and Hitzig reasoned hopefully that they had found the very place where spirit and body could meet. This, they wrote, was "the place of entry of single psychic functions into material."

Then it was that the neurophysiologists, led by Ferrier, came crowding into the newly opened field of brain localization. During the past century they have had their heyday. With the recent help of electronic engineers and neuroanatomists, their barns are bursting now with new-found facts. The meaning of these facts is not so simple. Much grain remains to be threshed.

There is a visual, auditory, and somatic area for sensation in the cortex of each side. There is another area on each side that is clearly motor, as Fritsch and Hitzig pointed out. This motor area has to do with voluntary, rather than reflex, movement.

The experimentalists, led by Sherrington in one school and Pavlov[5] in another, have come to understand many of the mechanisms of subconscious reflex action, by their study of laboratory animals.

The cerebral hemispheres are covered by a gray carpet of millions of nerve cells, the cerebral cortex. In the central portion of the brain is the brain stem, made up of gray matter and interconnecting nerve fibers.

The integrative activity that comes between sensory input and motor output must obviously depend in large part upon the connections of the cortex with the underlying brain stem. The central or centrencephalic organization of electrical potentials constitutes the physical basis of the mind. But the detail of its action remains a mystery. To approach this mystery we must study man himself.

Electrical stimulation of the cerebral cortex of conscious men has verified and amplified the mapping of motor and sensory areas of the cerebral cortex as worked out in laboratory mammals. But it has done something else; and that forms the subject of this address.

Experiential Responses to Stimulation.—Twenty-six years ago I was operating upon a woman under local anesthesia in the Royal Victoria Hospital and was applying to different points on the temporal lobe of her brain a stimulating electrode. She (E. W.) told me suddenly that she seemed to be living over again a previous experience. She seemed to see herself giving birth to her baby girl. That had happened years before, and meanwhile the girl had grown up. The mother was now lying on the operating table in my operating room, hoping that I could cure her attacks of focal epilepsy.

This, I thought, was a strange moment for her to talk of that previous experience, but then, I reflected, women were unpredictable, and it was never intended that men should understand them completely. Nevertheless, I noted the fact that it was while my stimulating electrode was applied to the left temporal lobe that this woman had had this unrelated and vivid recollection. That was in 1931.

It was more than five years later when a somewhat similar psychical state made its appearance during electrical stimulation. This time, however, it seemed certain that the stimulus had somehow summoned a past experience.

The Montreal Neurological Institute was opened in 1934, and a patient, J. V., a girl of fourteen years, was admitted there in June, 1936.[6] She was complaining of seizures during which she sometimes fell unconscious to the ground in an epileptic convulsion. But, immediately preceding such an episode, she was aware of what seemed to be a hallucination. It was always the same, an experience came to her from childhood.

The original experience was as follows: She was walking through a meadow. Her brothers had run on ahead along the path before her. A man following her said to her that he had snakes in the bag he was carrying. And she was frightened and ran after the brothers. This had been a true experience. Her brothers remembered, and her mother remembered hearing of it.

Afterward, for some years, the experience came back to her in her sleep, and she was said to have a nightmare. Finally, it was recognized that this little dream was a preliminary to an epileptic seizure that might come on at any time, day or night. And the dream sometimes constituted all there was of the attack.

At operation, under local anesthesia, I mapped out the somatic sensory and motor areas for purposes of orientation, and I applied the stimulator to the temporal cortex. "Wait a minute," she said, "and I will tell you." I removed the electrode from the cortex. After a pause, she said: "I saw someone coming toward me, as though he was going to hit me." It was obvious also that she was suddenly frightened.

Stimulation at a point farther forward caused her to say, "I imagine I hear a lot of people shouting at me." Three times, at intervals and without her knowledge, this second point was stimulated again. Each time she broke off our conversation, hearing the voices of her brothers and her mother. And on each occasion she was frightened. She did not remember hearing these voices in any of her epileptic attacks.

Thus the stimulating electrode had recalled the familiar experience that ushered in each of her habitual attacks. But stimulation at other points had recalled to her other experiences of the past, and it had also produced the emotion of fear. Our astonishment was great, for we had produced phenomena that were neither motor nor sensory, and yet the responses seemed to be physiological, not epileptic.[7]

We have recorded many examples of psychical responses to stimulation in recent years. Let me illustrate:

Case D. F.[8] was a young woman of twenty-six years, who worked as an office secretary. She had epileptic attacks, which were ushered in by a warning feeling of sudden fear. The cause was abnormality of the right temporal lobe due to asphyxia in childhood.

Operation was carried out, under local anesthesia, in the right temporal region. I shall describe the steps as simply as possible: An incision was made in the scalp, as outlined in Figure 2. The bone was cut and turned down with its attachment to the scalp, to be replaced and fastened in position after operation. The brain was exposed, as shown in Figure 3.

A gentle electrical current was then applied at one point after another. Those

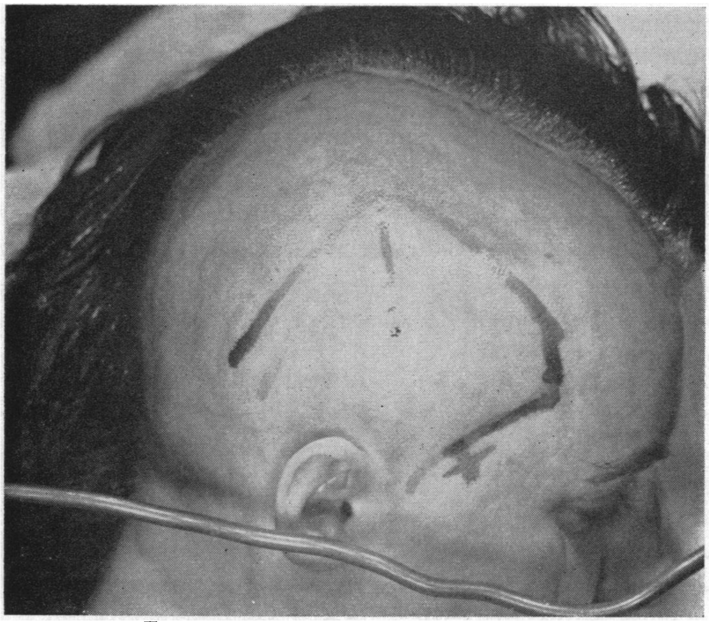


FIG. 2.—Patient, D. F., on operating table

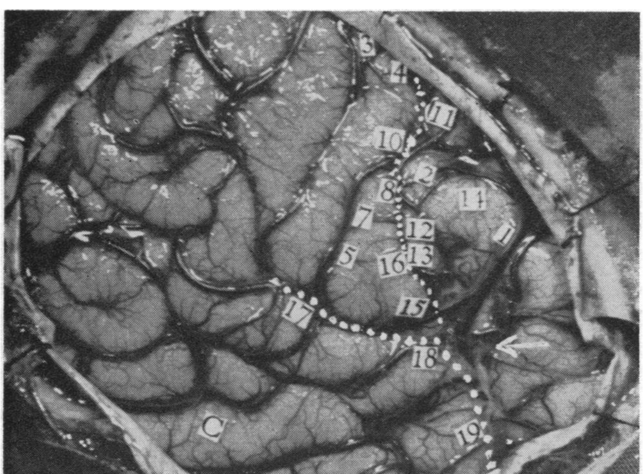


FIG. 3.—Case D. F. Right hemisphere exposed by osteoplastic craniotomy under local anesthesia. Arrow points to cortical abnormality which was more marked on the mesial surface. Numbered tickets indicate points at which electrical stimulation produced positive responses.

points at which stimulation produced some effect were marked by dropping a numbered ticket on the cortex, as shown in Figures 3 and 4. The nature of the response was dictated by the surgeon to a secretary who sat behind glass in the viewing stand. Bodily sensations were produced, in part, as follows:

3. "Tingling" in the left thumb.
10. A "jumping" sensation in the lower lip on the left side.
15. Numbness in tongue.

Motor responses occurred, in part, as follows:

13. Twitching of left side of face and slight protrusion of tongue.
11. The patient opened her mouth and vocalized with a steady vowel sound: A—A—A until the electrode was withdrawn.

It was now clear that we had located the central fissure of Rolando, as indicated by the line of white dots, with motor gyrus in front of it and the somatic sensory gyrus behind.

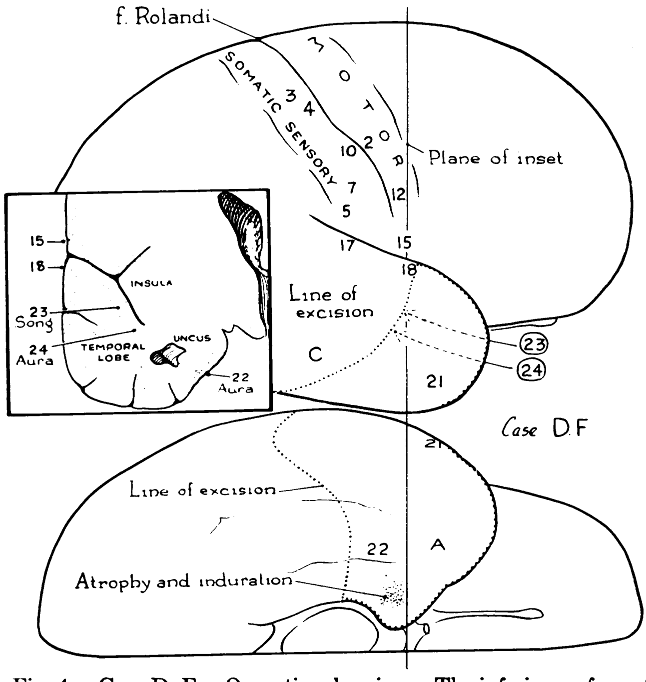


Fig. 4.—Case D. F. Operative drawing. The inferior surface of temporal lobe is shown below and a cross-section in the inset.

Next, an attempt was made to produce the warning of the patient's attack by stimulating different points on the temporal lobe below the fissure of Sylvius, which is marked by the horizontal line of white dots. This failed, until the temporal lobe was elevated and the electrode applied at point *22*, as shown in Figure 4. Then she felt the warning that she had called fear, "the one," she said, "I get before an attack."

This, together with the abnormal spontaneous electrical activity that my associate Dr. Herbert Jasper, reported in his electrograph when I placed a recording electrode at point *A* not far off, made it obvious that the general origin of the seizures had been located. And so the anterior end of the temporal lobe was removed along the dotted line, as shown in Figure 4. A vertical cross-section of the temporal lobe, in the line of removal, is shown in the inset.

When the electrode was applied in gray matter on the cut face of the temporal lobe at point *23*, the patient observed: "I hear some music." Fifteen minutes later, the electrode was applied to the same spot again without her knowledge. "I hear music again," she said. "It is like radio." Again and again, then, the electrode tip was applied to this point. Each time, she heard an orchestra playing the same piece of music. It apparently began at the same point and went on from verse to chorus. Seeing the electrical stimulator box, from where she lay under the surgical coverings, she thought it was a gramophone that someone was turning on from time to time.

She was asked to describe the music. When the electrode was applied again, she began to hum a tune, and all in the operating room listened in astonished silence. She was obviously humming along with the orchestra at about the tempo that would be expected.

Other points were stimulated with no result, except at three points, quite close to *23*, where the same song was reproduced.

After the patient had returned home, she wrote to me on April 16, 1950. The letter was, in part, as follows:

"Today is a year that you operated on me, and I suppose you are wondering how I am coming along....

"Now to answer your questions: I heard the song right from the beginning, and you know I could remember much more of it right in the operating room....

"There were instruments.... It was as though it were being played by an orchestra. Definitely it *was not* as though I were imagining the tune to myself. I actually heard it. It is not one of my favorite songs, so I don't know why I heard that song. I finally got ahold of a copy of this piece and played it on the piano the other Sunday.

"Thanks again for better health."

In other patients, there have been other similar examples of music production. Stimulation of the surface of the temporal cortex on one side or the other has caused the patient to hear an organ, a complete orchestration, a voice, or a piano. One patient heard the music and saw the man that was playing it at a piano. A boy reported men sitting in chairs singing. Always it was the reproduction of a previous experience. The tempo of the music was neither faster nor slower than was to be expected.

A young woman (N. C.) said, when her left temporal lobe was stimulated anteriorly, at point *19* in Figure 5, "I had a dream, I had a book under my arm. I was talking to a man. The man was trying to reassure me not to worry about the book." At a point 1 cm. distant, stimulation at point *20* caused her to say: "Mother is talking to me." Fifteen minutes later the same point was stimulated: The patient laughed aloud while the electrode was held in place. After withdrawl of the electrode, she was asked to explain. "Well," she said, "it is kind of a long story, but I will tell you...."

After an interval of time, the electrode was applied again, without warning, at point *20*. The patient spoke quietly while the electrode was kept in place: "Yes, another experience," she said. "A different experience, a true experience. This man, Mr. Meerburger, he—oh well, he drinks," etc. Stimulation at *23* caused her to hear music.

One must conclude that there is, hidden away in the brain, a record of the stream of consciousness. It seems to hold the detail of that stream as laid down during each man's waking conscious hours. Contained in this record are all those things of which the individual was once aware—such detail as a man might hope to remember for a few seconds or minutes afterward but which are largely lost to voluntary recall after that time. The things that he ignored are absent from the record.

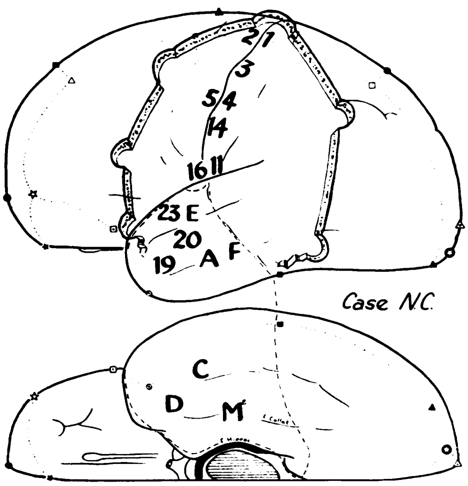


FIG. 5.—Case N. C. Drawing of operation. Numbers indicate the positive responses to stimulation. Letters indicate sites of spontaneous epileptic electrical abnormality determined by electrocorticography.

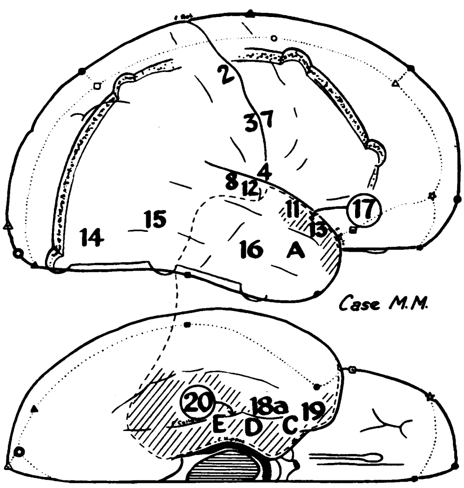


Fig. 6—Case M. M. Drawing at operation. The shaded area indicates abnormal area of cortex, considered epileptogenic. Operative removal carried out along the broken line.

Years ago, William James (1910)[9] described the "stream of consciousness" as a river forever flowing. Its content, he pointed out, was never the same from moment to moment. The record of this stream, as we have brought it to light with the stimulating electrode, might better be compared to the sequence on a wire recorder or to a continuous filmstrip with sound track.[10]

As compared with motor and sensory responses, these might be called psychical or experiential. The psychical responses may be produced by threshold stimulation without ensuing afterdischarge. They have never been produced by stimulation of the frontal or occipital lobes, nor in the central area. One must assume that the epileptic state tends to sensitize the temporal cortex so that it will respond more easily in a positive manner to the stimulating electrode. When a source of epileptic discharges is near the sensory or motor areas of the cortex, they too, become more easily stimulable. The experiences reproduced are usually unimportant ones. They had often been "forgotten," although the subject never seemed to doubt that they were his own experiences. In the great majority of cases, these experiences formed no part of any previous epileptic attack.

The experience that appears as the first experiential response when stimulation is begun in any case seems to depend on chance. It may be recent or it may come from childhood many years before. When a response has been produced, however, it seems to have an immediately facilitating effect on the result of subsequent stimulations. A second stimulus at approximately the same point, if not too long delayed, is apt to reproduce the same experience, beginning at the same moment of time. This was true, you remember, in the case of D. F. described above. She heard the playing of a certain song, the same song, each time the electrode was applied.

If restimulation of the same point does not reactivate the same strip of time, it is apt to produce an experience that is similar in content or subject. For instance, a boy, R. W., heard his mother talking on the telephone when two points 3 cm. apart were stimulated twice in quick succession. After a lapse of time when the electrode was set down between the two points, he heard his mother talking with his brother. The similarity of the experience produced does suggest a greater availability of experiences that are related to one another by some common characteristic.

This is borne out by the results of stimulation in the case of M. M. She heard "a mother calling her little boy" when point *11* on the first temporal convolution was stimulated (Fig. 6). When it was repeated at once, without warning, she heard the same thing. When repeated again twice at the same point, she heard it each time, and she recognized that she was near her childhood home.

At point *12* nearby, on the same convolution, stimulation caused her to hear a man's voice and a woman's voice "down along the river somewhere." And she saw the river. It was at a place "I was visiting," she said, "when I was a child."

Three minutes later, while the electrode was held in place at *13*, she exclaimed that she heard voices late at night and that she saw the "big wagons they used to haul the animals [of a circus] in."

Eleven minutes later, the original point, *11*, was stimulated again. She no longer heard the mother calling her little boy. Instead, she heard "the voices of people calling from building to building."

Later still, when a coated electrode was inserted at *17* so as to stimulate the first temporal convolution deep in the fissure of Sylvius, she said, "I had. . .a familiar memory, in an office somewhere. I could see the desks. I was there, and someone was calling to me, a man leaning on a desk with a pencil in his hand."

The time had changed and the scene. It was at least 10 years later, evidently after she had become a stenographer, and yet the calling was common to all the experiences.

Discussion of Experiential Responses.—Curiously enough, two experiences or strips of time are never activated concurrently. Consequently, there is no confusion. There seems to be an all-or-nothing organization which inhibits other records from being activated.

This is not a memory, as we usually use the word, although it may have some relation to it. No man can recall by voluntary effort such a wealth of detail. A man may learn a song so that he can sing it perfectly, but he probably cannot recall in detail any one of the many times he heard it. Most things that a man is able to recall to memory are generalizations and summaries. If it were not so, we might find ourselves confused, perhaps, by too great a richness of detail.

Many a patient has told me that the experience brought back by the electrode is much more real than remembering. And yet he is still aware of the present situation. There is a doubling of consciousness, and yet he knows which is the present. He may cry out in astonishment that he is hearing and seeing friends who he knows are far away. J. T., realizing that he was on the operating table in Montreal, cried out: "Yes, doctor, yes, doctor! Now, I hear people laughing—my friends in South Africa." It seemed to him that he was laughing with them.

In general, it may be said that if the experience of that previous time, now so strangely under review, was accompanied with fear or amusement or admiration, he has those same reactions again.

The responses of these patients have been verified and checked in every way possible. Unexpected statements are proved by restimulation without warning and sometimes by warning without stimulation, before they are accepted. The brain has no sensation of its own. Consequently, the patient has no possible means of knowing when the electrode is applied, unless he is told or unless he is aware of a positive physiological effect.

The Ganglionic Record.—How is this record of the past stored in the brain? and where? One may assume that at the time of the original experience electrical potentials passed through the nerve cells and nerve connections of a recording mechanism in a specific patterned sequence and that some form of permanent facilitation preserves that sequence so that the record can be replayed at a later time, in a manner analogous to the replaying of a wire recorder or tape recorder. But this remains a supposition.

Reconsideration of Stimulation Responses.—In the Sherrington Lecture delivered in Liverpool last January,[12] I reviewed all our records of stimulation of the human cerebral cortex, to see whether I could answer these questions of how and where. The number of such patients operated upon under local anesthesia was then just short of a thousand.

Many stimulations—the majority, in fact—are greeted by silence. Not all areas of the brain can respond, because of the nature of their function. The normally responsive areas are often in a state that seems to block translation of electrical pulse into physiological activity. There are many things that stimulation can never produce. No constructive thinking is produced, no willed or purposeful behavior. In general, application of this crude electrical current seems to interfere with the normal functional employment of the cortex itself in the area to which the electrode is applied.

For example, if it is applied to one of the speech areas of the dominant hemisphere, such as Broca's convolution, the patient is silent. No words can be produced that way. If the patient is asked to answer while the electrode is still applied, he discovers, to his surprise, that he is aphasic. That is, he can no longer find words to express his thought. But they come with a rush when the electrode is lifted and he says, then, the things he was trying to say while the electrode was interfering with his employment of the speech area of cortex.

My conclusion is that the electrode can produce a positive physiological effect only in those areas of cortex that normally send currents of neuronal impulses to distant collections of nerve cells to activate mechanisms there. Apparently the local electrical state of the cortex must be converted into a physiological corticofugal conduction of electrical potentials.

If an electrical stimulus of 60 pulses per second, for example, is applied to his visual sensory cortex (Fig. 7), the effective stream of neurone impulses passes centrally, not back to the eye. It passes into the subcortical vision-receiving center

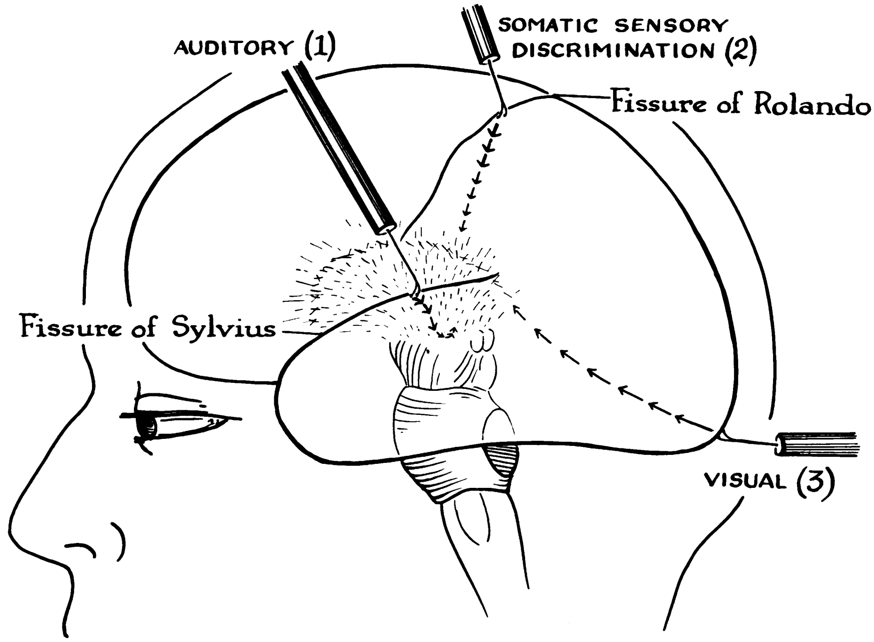


FIG. 7.—Sensory responses to stimulation of sensory areas of cortex: (*1*) auditory, (*2*) somatic sensory, (*3*) visual. Electrical stimulation produces sensation by means of dromic neuronal conductions from each cortical area to a corresponding subcortical receiving center.

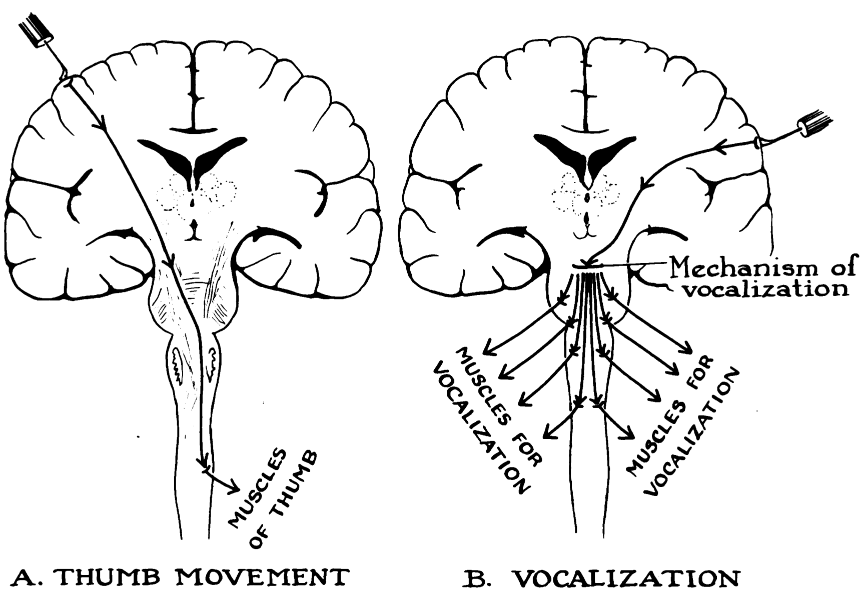


FIG. 8.—Motor responses to stimulation of the pre-Rolandic motor convolution produced by corticofugal neuronal conduction to *A*, anterior horn cells of spinal cord, and *B*, vocalization and respiratory mechanism of brain stem.

because the visual cortex normally serves as a way-station in the pathway of normal potentials that leads from eye through the cortex and on into the centrencephalic circuits of organization in the brain stem.

Exactly the same current applied to the auditory area of cortex, or to the somatic sensory area, sends a stream of neurone impulses inward (Fig. 7), and the patient seems to hear or to feel.

This flow of neuronal pulses produces crude sensations of vision or hearing or tactile sensation. No man is seen, nor is any voice heard to speak. If more clever stimulators could be constructed to vary the time and place of stimulation in a properly planned pattern, the patient might be made to see a man or hear a voice, perhaps. But there would be no sense of familiarity. It would be a synthetic man and a synthetic voice, like the products of the art of Walt Disney.

When the stimulating electrode is applied to the motor convolution just in front of the fissure of Rolando, there are two types of response, one gross and simple, the other complicated. In the first instance (Fig. 8, *A*), a stream of neuronal impulses passes down through the corticospinal tract and out to the peripheral muscles. If the point touched was the thumb area of the motor gyrus, the thumb flexes or extends and remains in that position. He is helpless to resist. He cannot use that thumb, although he can reach across and seize the thumb with the other hand.

If, however, the electrode was placed on that small portion of the motor convolution that is devoted to vocalization (Fig. 8, *B*), the patient, quite helplessly, carries out a very complicated movement—opening his mouth, contracting his diaphragm, and uttering a vowel sound—*A*—*A*—*A* until his breath is gone. He then stops, and, after taking a breath, he continues. In this case the stream of neuronal impulses passes directly to a vocalization and respiratory mechanism in the brain stem. There is nothing one-sided about the movement of this mechanism. It can also be activated by stimulation in the supplementary motor area of the same hemisphere and at the two homologous points in the opposite hemisphere.

Thus a complicated performance can be produced by an electrode on the cortex, as well as simple performances. But the stream of neuronal potentials must be caused to pass away from the area of stimulus along a route of normal neuronal conduction.

It seems evident, then, that in the case of sensory and motor stimulation the conduction must be dromic, that is, in the direction of normal functional flow. If this is accepted tentatively as the rule governing such reactions, we may return to the temporal cortex.

I would conclude here, too, that when activation of the stream of previous consciousness is produced by stimulation, there is conduction away from the neighborhood of the stimulating electrode. The ganglionic record of past experience must therefore lie at a distance from that area of temporal cortex. But the key that can unlock the past is to be found there and apparently only there. The following observations bear out this suggestion.

Interpretive Responses to Stimulation.—In addition to the experiential flashbacks (A in Table 1), which we have been discussing, there is one other type of response. This response may follow stimulation of the same general area of temporal cortex and only there. When the electrode is applied, the patient has a sudden "feeling" about the present situation (B in Table 1). It is an interpretation of the present, but not one that the patient thinks out deliberately. It is a signal, for example, that the present situation is familiar, that it has been experienced before. Or it is strange, perhaps. It may be a signal that things seen are growing larger or sounds heard are louder, a signal that something is approaching. Or it may be the opposite—things going away. It may be a signal of change in the erectness of things or in perspective. It may be a sudden feeling of fear, an interpretation that the present situation is dangerous.

TABLE 1

PSYCHICAL RESPONSES TO ELECTRICAL STIMULATION OF INTERPRETATIVE AREAS OF CORTEX

A. *Experiential Flash-back:* Random re-enactment of a conscious sequence from the patient's past.
B. *Interpretive Signaling:* Production of sudden interpretations of the present experience, such as familiar, strange, fearful, coming nearer, going away, etc.

TABLE 2

INTERPRETIVE ILLUSIONS: ALTERATIONS OF PERCEPTION OF THE PRESENT

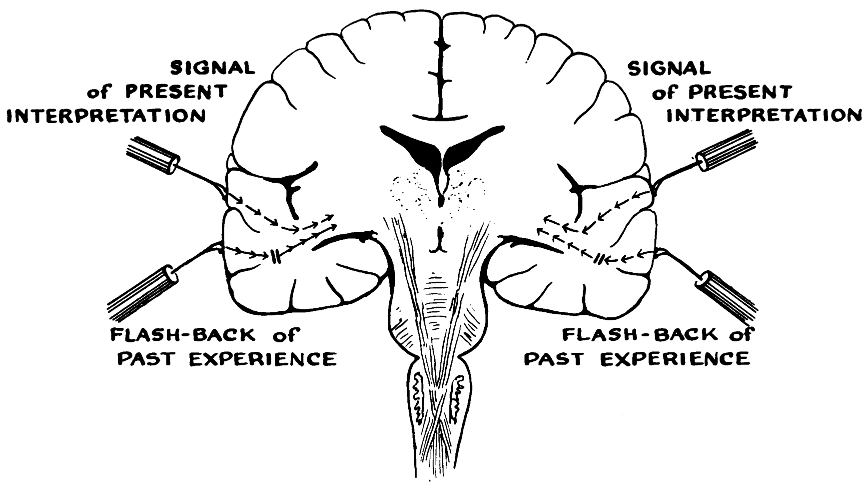
1. Auditory Illusions
   Distance, Loudness, Tempo
2. Visual Illusions
   Distance, Dimension, Erectness, Tempo
3. Illusions of Comparison
   Familiarity, Strangeness, Unreality
4. Illusional Emotions
   Fear, Loneliness, Separation, Sorrow, Disgust

For example, the patient M. M. (Fig. 6) said, when point *14* on the posterior limit of the right temporal lobe was stimulated, "The whole operation now seems familiar." The "feeling" passed when the electrode was lifted. She was then told that the stimulation would be repeated, but no stimulus was applied. "Nothing," she said. Then point *15* was stimulated, and she said, "Just a tiny flash of familiarity and a feeling that I knew everything that was going to happen in the near future." To explain this, she added, "as though I had been through all this before."

When these interpretations of the present are produced by the electrode, we call them illusions, since they are false interpretations[13] (see Table 2). But in normal life and under normal conditions these feelings are not illusions. They are true. They are reliable signals that can rise into consciousness only after a comparison is made between past records and the present experience. How else could the sudden awareness that this has happened before come to us with true meaning? Or how else could we know that this or that brings danger before we have had "time to think"?

Cortex for Comparative Interpretation.—Thus it is evident that the temporal cortex, on stimulation (Fig. 9), yields two types of response which are psychical rather than sensory or motor. The two forms are (1) a flash-back of past experience and (2) a signaling of interpretation of the present experience. The two types of response would seem to form parts of one subconscious process, the process of comparing present experience with past similar experiences.

The area of cortex from which these responses are obtained in both hemispheres is one to which no function has been assigned. It covers most of the superior surfaces of the temporal lobes, as well as the lateral and probably the inferior surfaces. For the purposes of further study this area of the cortex might be given a name to distinguish it from motor and sensory areas and the speech areas. This seems to be the area for *comparative interpretation* and might be called that or, more briefly, the *interpretive cortex* (see Fig. 1).



RIG. 9.—"Psychical" responses to stimulation of the (comparative) "interpretive" cortex of temporal lobe. The lines of arrows indicate the hypothetical pathways of neuronal impulses leading into the circuits of centrencephalic integration. In the case of the "flash-back" pathway, the interruption by vertical lines represents the ganglionic record of the past without attempting to indicate its position.

I surmise that the interpretive cortex makes its normal functional contribution in situations such as the following:

When you meet an acquaintance of years gone by, whom you might have thought forgotten, you may be startled first by a sudden signal of familiarity, because of the sound of his voice, his smile, his way of walking. Almost instanteously some strange mechanism of the brain is providing you with a standard of comparison. You see how this present man differs from the acquaintance in the past—the man you have not thought of for many years. A moment earlier you could not have pictured him. Now you can compare the past with the present in great detail. You detect the slightest change in face or hair. You note that his movements are slowed, the hair thinned, alas! the shoulder stooped. But his laugh, perhaps, has not changed.

I would assume that the comparative-interpretive cortex of the temporal lobes has somehow managed the selection and activation of the short strips of past conscious experience in which this man was once the focus of your attention. It makes possible the scanning process by which past experiences, however scattered they may have been in time, are selected and made available to the present, for the purpose of comparative interpretation.

The problem now is to understand how these functional areas are employed in the total integration of the traveling potentials. That integration constitutes the neural basis of consciousness. The problem is to work out the centrencephalic circuits and ganglionic centers of the higher brain stem which play an essential role in the co-ordination of the action of the cortical areas.

Summary.—There is a permanent record of the stream of consciousness within the brain. It is preserved in amazing detail. No man can, by voluntary effort, call this detail back to memory. But, hidden in the interpretive areas of the temporal lobes, there is a key to a mechanism that unlocks the past and seems to scan it for the purpose of automatic interpretation of the present. It seems probable also, that this mechanism serves us as we make conscious comparison of present experience with similar past experiences.

Conclusion.—The discovery of this interpretive cortex is one step forward. Another territory on the map of the cerebral cortex can be named. But, seen against the vastness of the problem of the mechanisms of the mind, this is a very small step indeed.

These observations that I have reported of the temporal cortex show us another mechanism that must play its part in the total function of the human brain. It is a mechanism that can be separated out by local epileptic discharge or electrical stimulation. Like the discovery of Fritsch and Hitzig that the electrode could move the dog's leg, this discovery that the electrode can cause the past to flash into consciousness again and also provide signals of present interpretation should open a new chapter in the physiology of the brain.

This seems to constitute one of the mechanisms of consciousness. Perhaps Hippocrates would say that this is a mechanism employed by the brain to distinguish "the ugly from the beautiful, the bad from the good, the pleasant from the unpleasant."

* Public lecture, National Academy of Sciences, Caspary Hall, Rockefeller Institute, New York, November 18, 1957.

[1] *The First Aphorism—Hippocrates*, trans. W. H. S. Jones (London: Loeb Classical Library, 1923).

[2] C. S. Sherrington, *The Integrative Action of the Nervous System* (Cambridge: Cambridge University Press, 1947), pp. 274–276.

[3] P. Broca, "Sur la siège de la faculté du langage articulé," *Bull. soc. anat. Paris*, 2d ser. **6**, 355, 1861.

[4] G. Fritsch and E. Hitzig, "Ueber die elektrische Erregbarkeit des Grosshirns," *Arch. Anat. Physiol.*, **37**, 300, 1870.

[5] I. P. Pavlov, *Conditioned Reflexes: An Investigation of the Physiological Activity of the Cerebral Cortex*, Trans. and ed. G. Anrep (London: Oxford University Press, 1927).

[6] This case was reported by Penfield. W. Penfield, "The Cerebral Cortex in Man. I. The Cerebral Cortex and Consciousness," *Arch. Neurol. & Psychiat.*, **40**, 417, 1938; also in French (trans. Professor H. Piéron, in *l'Année psychol.* Vol. **39**, 1938).

[7] J. V. was not cured by that operation, although we managed to remove some of the abnormal area. During the twenty-one years that have followed, we have gradually learned a little more about temporal lobe epilepsy. It is now recognized as constituting the largest single group among the different forms of epilepsy. So J. V. returned for three subsequent operations, and at last she seems to be cured of the attacks.

[8] The patient is described in detail by Penfield and Jasper. W. Penfield and H. Jasper, *Epilepsy and the Functional Anatomy of the Human Brain*, [Boston: Little, Brown & Co., 1954], (Case Index, p. 882).

[9] William James, *The Principles of Psychology* (New York: Henry Holt & Co., 1910).

[10] The electric current that I have employed during recent years is produced by a square-wave generator at a frequency of 40–100 pulses per second. We usually use a pulse of 2–5 milliseconds duration and a current of 1–5 volts. It is our custom to place recording electrodes on the cortex

during stimulation, so that my associate Herbert Jasper can study the electrical condition, before and after simulation, on his electrograph placed outside the glass of the viewing stand.

[11] W. Penfield, "The Role of the Temporal Cortex in Certain Psychical Phenomena," *J. Ment. Sc.*, **101,** 451, 1955.

[12] W. Penfield, *Physiological Observations in the Human Cerebral Cortex—a Study of Conscious Responses to Stimulation of the Human Brain,* (Fifth Sherrington Lecture) (Liverpool: Liverpool University Press; Springfield, Ill.: Charles C Thomas, 1958).

[13] My associate, Sean Mullan, analyzed the cases of 217 of our patients who came to operation for relief of temporal lobe seizures (Mullan and Penfield, to be published, 1958). Of these, 38 had such interpretive illusions either at the onset of their attacks or as a result of cortical simulation or, more often, both.