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Language following Surgical Disconnection of the Hemispheres

R. W. SPERRY
M. S. GAZZANIGA
California Institute of Technology
Pasadena, California

A FEW YEARS AGO we reported some observations on a commissurotomized human patient, a patient, that is, with surgical separation of the hemispheres.[36,37,134] These observations jibed nicely with the functional picture of the neocortical commissures that emerged from the animal studies,[366] and also conformed to the general interpretation of the now well-known Geschwind-Kaplan case just reviewed.

Since that time, during the past two years, that is, we have been foolish enough to start the study of another commissurotomized patient[35] and after that another, with results that have proved to be rather upsetting for the picture we had described for the initial case. The results as they now stand would seem to require a considerable shift in our general outlook on the disconnection syndrome for man. Whereas formerly we had stood, I suppose, maybe half-way between the Liepmann[233] extreme, on the one hand, and that of Akelaitis[4] on the other, we now find ourselves obliged, from this later evidence, to shift our position on a number of the important features of the syndrome well over in the Akelaitis direction, although we still find direct contradictions on a number of points making the present picture rather a hodgepodge of the earlier views.

Apparently these later patients have not read the recent literature or they are just being deliberate nonconformists, because we find them doing things like the following:[125,127] writing legible meaningful material with the subordinate left hand; drawing correctly with one hand the shapes of objects held out of sight in the other hand, even to the point here of recognizing and writing correctly with the left hand block letters placed in the right hand.

We find these people are able to guide purposeful, directed manual movements from visual cues in the opposite half of the visual field. Tactile localization of points on the thumb, the wrist, the palm, and little finger of the left hand can be discriminated verbally by a firmly right-handed subject. If these implications are not immediately clear, I am going to spell all this out in more detail as we go along.

With the employment of proper testing methods, one can show that these people are not "word-blind" in the left visual field nor are they "word-deaf" in the disconnected minor hemisphere. Many months and hours of testing later, we have come to believe that these and similar phenomena are probably not ascribable to incomplete surgery and that they represent, instead, genuine features of the cerebral disconnection syndrome for man.

It is very obvious that what we should have done, as you can see, was to have quit after that first case when the whole picture looked much simpler. I think the easiest way to present our current views is to just let the evidence speak for itself; following this "say it with data" approach, I will try to run very briefly through a few examples of the kind of responses that we see in these people, related to language functions, with some brief comments on the conclusions to be drawn, as we see them today. I emphasize the word "today" here because our testing program is still in full swing, and the overall picture continues to change from month to month. Just as our working picture at the moment is rather different from that of a year or two ago, so that of a year hence may be different still. I suspect just a word of caution may be in order here in regard to any attempt to apply this current view to interpretations of clinical material or to global value judgments regarding historical developments in the field. I am not sure that we really have the definitive picture even at this moment that would enable one to pass the proper long-term judgment.

All these patients—there are now six of them all told—are presumed to have a complete midline section of the cerebral commissures, including the corpus callosum, the anterior and hippocampal commissures, and in two cases, at least, the massa intermedia; hence a fairly complete disconnection of the right and left hemisphere. What I have to say in the following is based mainly on three of these patients, and mostly on two of them, in particular, whom we have singled out for language testing because of the relative lack of secondary complications like associated brain damage which we have come to believe is probably *the* big stumbling block to accurate interpretation of cortical conduction syndromes.

Since these latter two cases have relatively clean surgical disconnections without much secondary cortical damage, we have felt it worthwhile to do as thorough an analysis as possible, even though we do not have statistical numbers to deal with here. Furthermore, in view of the controversial nature of this whole area—and we have seen a few glimpses of it, I think, in this Conference—and in view of the almost intellectually paralyzing complexities and contradictoriness of the literature in this whole field, we are very deliberately taking nothing for granted and are starting from scratch and working up the picture as we see it, in this population of two patients.

I am serving as spokesman here, for what has been very much a team project. All these patients are patients of Dr. Phillip Vogel of the California College of Medicine, who did the surgery at the White Memorial Hospital in Los Angeles to help control advanced epileptic seizures. Dr. Joseph Bogen has also collaborated extensively ever since he suggested the initial treatment. He does the medical aftercare and also most of the more standard neurological testing. Therapeutically the outcome at this date has been mixed. Three cases appear to have been definitely benefited; in the other three the results are dubious —or it is too soon to say. Dr. Michael Gazzangiga, who is present, has led the way in most of the functional testing I am going to describe, with myself collaborating in the background, and the two of us have collaborated about equally in the general approach and in writing up our joint material including that mentioned in the present discussion.

In defense of our West Coast Surgery (going back here to some remarks made yesterday) let me just insert at this point that case 3, like case 2, has made a good and rapid recovery. These two had not suffered any major brain damage prior to surgery, and this makes a difference. On the morning after surgery, case 3, a 13 year old boy, was able to recite "Peter Piper picked a peck of pickled peppers." He is a bright young fellow in many ways and also has a sharp sense of humor. That same first morning after surgery he was making quips to the doctors about having "a splitting headache." He and his family, of course, knew pretty much the pros and cons of what he was getting into.

Most of our tests relating to language have been conducted in the general testing apparatus illustrated in Figure 27. The subject is seated at a table on which is mounted a slanting shield that prevents the subject from seeing the top of the table. It prevents him from seeing the test items on the table, or his hands, or the examiner in the background. It also serves to hold a couple of ground glass viewing screens for the back projection of 2 x 2 slides set up in one or two automatic projectors in the rear. The shield also serves to hold cards and various other test items that one may want to set out in free view in front of the subject. Another examiner generally sits alongside the subject, recording his answers and his general reactions. Try now to keep this picture in mind, as I shall be referring back constantly in what follows to this general testing situation.

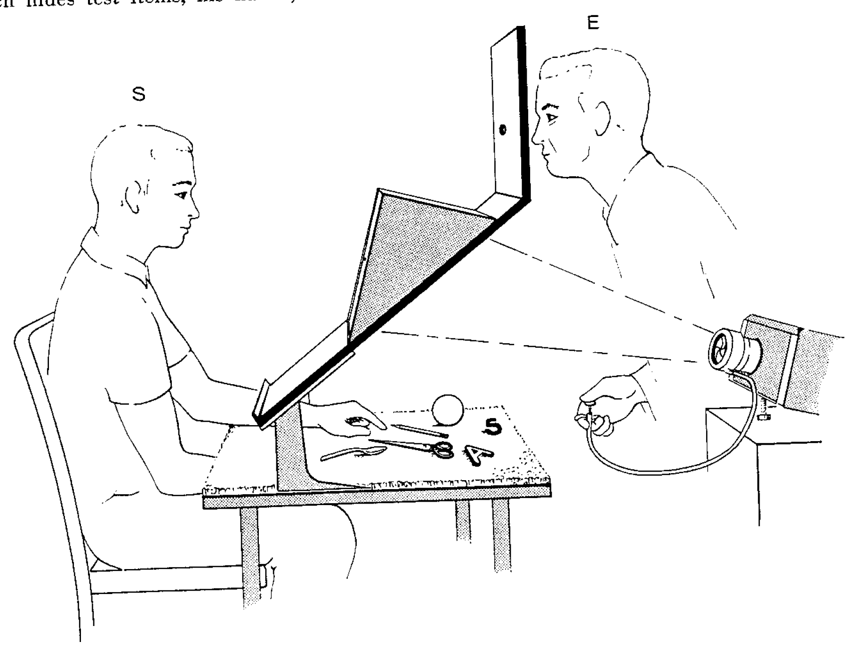
The subject is asked to fix his gaze on a central point on or between the screens. When the eyes are seen to be properly centered, one then flashes the visual stimuli, at a tenth of a second or less, too fast for eye movements. Two pictures may then be projected simultaneously, one to the left half field and one to the right half field, for example, a picture of a pencil on the left and of a knife on the right. This means, of course, that the pencil image goes to the minor hemisphere and the knife image is projected to the left dominant hemisphere.

If the subject is asked what he saw, he will almost invariably and literally, in hundreds of such trials, assert that he saw the knife only and make no reference to the pencil. Similarly, in this same test setup, if one asks the subject to write below the screen his answers, instead of speaking them aloud, he again writes only the names of those stimuli that are flashed to the right half field and makes no reference to the stimuli presented in the left half field.

Or if one flashes only a single picture at a time, pictures of objects, colors, arrows pointing in different directions, lines, dots, and so on, and projects these serially and at random into right or left half field, similar results are obtained. That is, the subject describes normally in speech and writing only that material that appears in the right half field.

When a picture is flashed to the left field, the subject tells you he saw nothing, or "just a flash." He knows by this time that this

Fig. 27. Apparatus used for language testing by Sperry and associates showing subject (S) seated before shield which hides test items, his hands, and examiner (E).



machine is rather erratic and that our series of test stimuli include blanks and plain lights to fool him.

One could draw quite a variety of different conclusions at this point from results of this kind. For the sake of brevity, let me forecast that the conclusion that seems to stand up in our testing experience is that these subjects are able to speak and write only about things seen in the right half visual field. In other words, with respect to the visual sphere of gnostic experience, verbal expression is possible only for that processed in the left hemisphere.

The same kind of result is obtained in this testing situation if, instead of using the two half visual fields, one tests the sensory surfaces of the right and left hands for stereognostic perception. The test objects themselves are now placed directly into the hand, the hand being held out of sight behind the shield. Again the patient does very well in naming and describing objects exposed to the right hand but is quite unable to describe items held in the left hand, the stereognostic centers for which are located in what we call, for convenience, the minor, that is, the right, hemisphere. These, and a large number of related tests, seem to support the conclusion that may be assumed to apply in what follows; namely that speech and writing in these patients, all of whom are right-handed, is firmly confined to the left hemisphere. Epilepsy apparently has not brought about any bilateralization of verbal expression in these cases.

The results are somewhat different within the same apparatus if, instead of having the subject tell you or write down what he sees in the projected slides, you have him reach out with one hand underneath the shield to search out blindly, by touch, an object that correctly matches the object pictured in the visual screen from among a series of ten or more test objects. Under these conditions, correct responses are obtained not only for the right half field but also for the left half field. The left field responses are correct, even though the subject denies verbally having seen anything and has to be urged and prodded to go ahead and put his hand out and give it a try. He then comes up with the right object.

In this test, however, it makes all the difference which hand is used to retrieve the matching object. The left hand can be used to gather items flashed to the left visual field and the right hand can be used to gather objects seen in the right field, but cross combinations do not work. If one tries to force the subject to use the right hand to find an object that he has seen pictured in the left half field, he is lost, and the converse is true here, provided that audible cues are eliminated. You have to be careful that the one vocal hemisphere does not start talking to the other to give the answer through auditory channels.

When the subject is thus made to use the wrong hand in this inter-modal task, the hand is moved proficiently enough, and from other tests we know that the objects it explores are perceived and recognized. However, the hemisphere that perceives in this situation does not know what it is looking for, and the hemisphere that knows what it is looking for does not get the correct feedback information. Consequently the two never match, and the performance fails.

From this and related tests we conclude that the minor hemisphere senses, perceives, learns, and remembers visual material, even though it is unable to talk or write about such experiences. The same conclusion applies for stereognostic discriminations performed with the left hand-minor hemisphere combination. And, as we will see shortly, it applies in the auditory as well as in the visual and tactual spheres. Let us say now that the subject has located correctly and is proudly holding up in his hand the correct item, say, a little flashlight bulb. He is asked casually what it is that he has selected. His reply is apt to be, in accordance with what we have said about stereognosis in the left hand, almost anything, like nail clip or cigarette lighter or what-not. Thereupon, as soon as the dumb hemisphere hears the vocal hemisphere reply with what the dumb, minor hemisphere recognizes to be an error, the subject will then usually wince and make another try. The next try at naming the object, however, will be as bad as the first one, and this kind of confusion continues. Such "confabulation" tends to be more prevalent it seems in the stereognostic sphere than in the visual. Another question arises here, as to whether some very simple, familiar, or emotionally toned words might not come out of that minor hemisphere. Simple "Yes," "No," swear words, lyrics and expletives, for example, might be possible. We have not pushed this question as yet and do not know the answer.

In this same testing situation if the subject if asked to write the names of objects flashed to left and right visual fields, using now the left hand instead of the normal writing hand, one finds that the subjects are able to write with the left hand at a rather clumsy and low level of penmanship, of course, but only for stimuli presented in the right half visual field. The same applies to left-handed writing of the names of objects placed in the left and right hands. It goes only for objects identified by the right hand.

From these findings and various tests not aimed specifically at language, it seems that the major hemisphere can govern the movement of the subordinate or homolateral hand. This is another example of what we reported earlier, the bilaterality in motor control. It follows, then, that the left-hand writing in these patients is not contradictory to the earlier conclusion that writing is organized in the major, left hemisphere only.

So now, with this general background, we can turn to some more specific questions concerning language comprehension, where verbal material, words, sentences, letters, numbers, and so on, are used as the stimuli. With free vision our two cases have no particular trouble in reading the page of a book, for example, or in reading signs provided they can scan adequately to the left, which they seem to pick up easily.

If words, letters, phrases, and numbers are flashed separately to right and left half fields of vision, and the subject is asked to read these, there is no particular problem with respect to the right half field. In the left half field, however, the subject appears to be alexic and word blind. The same applies to the stereognostic perception of cut out, blocked letters, numbers, and so on, presented to the hands. That is, the subject can read off such stimuli correctly only when using the right hand-major hemisphere combination but not when using the left hand. But remember now that these people lack verbal expression for any kind of mental activity in the minor hemisphere. This result therefore does not prove that the minor hemisphere is not comprehending this verbal material.

The big challenge in most of our testing, of course, is to find out what goes in that silent, mute, speechless minor hemisphere, and, particularly for the purposes of the Conference, how much, if any, language comprehension may be present there.

As I have already indicated, it is possible to show, with the use of adequate testing methods, that the disconnected minor hemisphere in these two patients is, in fact, not word-blind nor is it word-deaf, nor word-dumb, in the tactile sphere, if you want to use such terminology. Actually, even when applied correctly in the accepted manner, this terminology seems highly questionable. There really is not any blindness nor any deafness involved in the standard use of the term. We could use some better words here.

Let us look closer now at the comprehension problem in the minor hemisphere. The subject is asked to reach out blindly with his hand to search out an object that has been vocally named aloud by the experimenter, say, a rectangle, after a rectangular block has been placed out of sight behind the shield along with a series of other geometric shapes or other objects. There is no problem for the right hand in this, of course, but we find that the left hand also can perform correctly. The subject reaches out; he explores carefully among the test items, rejecting and bypassing maybe up to nine of them if necessary, until the hand finally contacts, explores, and holds up the correct item. Since other evidence tells us that stereognosis in the left hand is processed in the minor hemisphere only, it may be inferred that the minor hemisphere must, therefore, in this performance have perceived and comprehended the verbal instructions of the experimenter.

With this technic words like the following appear to be understood in the minor hemisphere: pyramid, cylinder, tack, coin, pliers, flashlight bulb, screwdriver, fork, cup, and so on, plus more complex phrases like "measuring instrument" for ruler or "eating utensil" for spoon. It also responds correctly to not so simple definitions like "used to drive nails" for hammer, or "kept in the bank" for coin, and so on. The minor hemisphere has at least a moderate vocabulary.

Since the spoken stimuli here are surely recognized also in the major vocal hemisphere, one always wonders if there is any way in which the minor hemisphere may be getting assistance from the other side, like feedback from subliminal speech or something of the type. We became somewhat worried about this the last time case 2 was in for tests of this kind. She had been retrieving objects correctly with the left hand to vocal descriptions like "writing instrument" for pen, "unlocks doors" for key, and so on for some seven correct out of seven trials. But when she directly sought out a quarter by touch from among some 15 other objects upon hearing "inserted in slot machines," this seemed to both Dr. Gazzaniga and me to be well beyond the expected capacity of the minor hemisphere—as if there must be something radically wrong either with our testing methods or our whole working hypothesis.

Upon indicating our surprise that words like "inserted" and "slot machine" should be so easy, the subject came back quickly, "What? Las Vegas! Where all our money goes!" (It seemed obvious that enough experience with slot machines had occurred even after surgery that we need not seek new hypotheses on this count.)

In any event, we find that this comprehension of the spoken and written word by the minor hemisphere proceeds under conditions in which only the minor hemisphere has the answer, unlike the foregoing case with auditory input. For example, if we flashed to the left half visual field-minor hemisphere combination a short word in print like spoon, cup, match, pin, comb, and so on, we find the subject is then able to reach out and identify the corresponding object, using the left hand, whereas he or she is not able to repeat that performance when made to use the right hand or to do the same task in separate trials with the right hand. This latter shows, you see, that the major hemisphere could not have read this material; it does not know the answer.

Furthermore, if the subject is asked, immediately following a correct response with the left hand, what the object is that he has chosen and is holding, he is quite unable, with the dominant hemisphere, to tell you what it is. In other words, the dominant hemisphere in such instances has no idea what the minor hemisphere has been doing in the performance of these tasks. We see this so consistently—that is, the complete agnosia in one hemisphere for the mental activities that have just taken place in the other—that we regularly rely on this in our testing procedures to check on cheating. For example, in presenting visual material, if the subject can tell you about something that was presented in the left half field, as may happen on rare occasions, you immediately suspect eye movements and discount that particular trial.

In another type of test a list of ten or more printed names of objects is laid out in free view in front of the subject for reading. Then pictures of these same objects are flashed one at a time into the left half visual field, that is, to the minor hemisphere. The subjects are then able to point out the correct name on the list for an object that was seen only by the minor hemisphere. This is also true for tests in which an object is placed in the subject's left hand with vision excluded. In tests of this kind the moment the finger comes up and points to a chosen name, the vocal hemisphere immediately reads it off, as if it also had known the answer all the time. But if you ask the subject to give you the correct answer before he has pointed, and before even his eyes have had a chance to fixate on the correct name, you then find that the major hemisphere is lost. Since the major hemisphere does not know the answer here, we deduce that the minor hemisphere is reading and comprehending the printed list of names. From such performances, we conclude, then, that the subjects are able to read and comprehend the printed list of words with both hemispheres, the minor as well as the major.

The minor hemisphere can also spell on a very low level, simple words like hat, how, dog, and what, when large, cut-out letters three to four inches high are presented in scrambled order, out of sight, to the left hand. It is not the major hemisphere that is doing the spelling here, because it vocalizes a running commentary on the progress of the left hand, like "This is A" when it really is "T," and so on. This vocal commentary is entirely off on the progress of the left hand, except for accidental coincidences. This in itself is of some interest here, namely, that the minor hemisphere can concentrate and carry on tasks of its own, ignoring the erroneous and distracting chatter of its better half. Other tests show that calculation is restricted almost entirely to the major hemisphere—and so it goes.

In general, as you can see, we have been concerned here mainly with the grosser features of interhemispheric integration. We have not applied as yet the more refined types of tests that might detect more subtle differences between the hemispheres, of the kind that Dr. Milner, Dr. Hécaen, and others have used.

In closing, I would like to emphasize just one further point. I understand there have been objections to speculations that we have made in years past regarding the coexistence of two rather separate mental entities operating simultaneously in parallel in the two disconnected hemispheres.[366,367,369] Eccles,[96] I understand, now favors the view—which goes back to a comment made by MacKay[269]—that consciousness in these cases remains single and is centered mainly in the major, the dominant hemisphere. The subordinate hemisphere is conceived to carry on in a kind of an automaton state.

Recall in this connection some of the points that I have mentioned here regarding the capacity of the minor hemisphere; it carries on inter-modal associations between visual, tactile, and auditory spheres and can even go from words, visually or audibly presented, to objects, and vice versa. It makes generalizations and certain mental associations that look like ideation. In the testing of mental associations, for example, it will go from "shoe" to "sock," from "cigarette" to "ashtray," from "hand" to "ring," from "dollar bills" to "metal coins," picking out these related items in each case from an array of others not related.

Furthermore, the minor hemisphere is superior to the major hemisphere in some performances like visual constructional tasks.[123] The minor hemisphere also shows emotional reactions in response to pinup shots.[122] For example, one flashes a series of pairs of pictures to right left visual fields and the subject reads off the names, but only, of course, for those that appear in the right half field. Into this series of paired presentations of triangles, umbrellas, horses, houses, cigars, and other neutral stimuli one then flashes a vivid pinup shot of a nude that projects into the minor hemisphere only. At the same time a tree or horse or some such appears on the right side. The subject says, of course, that she saw a horse—with no hesitation. But then you notice that a kind of sneaky grin has begun to spread over the subject's features, and even the tone of voice changes. This emotional effect then carries on through the next several trials. If you ask her what she is grinning at, she does not know, and says, "Oh, that light!" In this situation recall that the major hemisphere meantime is going along in parallel and is calling the correct names of these objects in the right half field.

To continue with the automaton interpretation, recall that the minor hemisphere learns and remembers, that it holds an immediate memory even when long delays are imposed in these retrieval tests that I have been talking about. A distracting conversation is deliberately interjected and the subject is allowed to get up and go down the hall and come back again. After this he sits down and again makes the correct response with the minor hemisphere.

The minor hemisphere carries out reaction times as fast as the major hemisphere where a visual discrimination of color is involved, and the other hemisphere is working in parallel just as fast as it can.[126] The minor hemisphere also triggers facial expressions, grimacing, and wincing when an error is made by the vocal hemisphere and where the correct answer is known only to the minor hemisphere. The minor hemisphere seems definitely bothered in the situation. One wonders if a mere automaton would be so annoyed by an error in this kind of testing situation. If all the foregoing represents the behavior of an automaton, one wonders if it will not be difficult indeed to show that the separated dominant hemisphere or even the undivided brain is more than an automaton.

DR. BENTON: Before you leave the podium, tell us about the patients. Where were their lesions? Are these epileptics?

DR. SPERRY: Yes, these are all advanced epileptics.

DR. BENTON: I wanted to know if there are foci in the left hemisphere.

DR. SPERRY: In that early first case there was major brain damage, prior to surgery, and seen at operation, in the minor hemisphere in addition to an apparent focus in the parieto-temporal area of the left hemisphere. We tried to warn our readers—I think Dr. Myers and apparently Dr. Geschwind probably did not see our warning sentence—to the effect that many of the symptoms described were presumably exaggerated by the presence of this brain damage. We probably should have italicized that. In case 2 the x-ray showed a small calcification beneath the right central cortex about a centimeter or so in diameter associated with a little hypesthesia in the left hand. The other patient I've been talking about, case 3, had no visible damage prior to surgery. The others have complications that make them less suitable for studying language.

DR. ETTLINGER: Are these patients more or less normal?

DR. SPERRY: Under ordinary conditions, yes.

DR. LENNEBERG: How did you make sure of the visual input?

DR. SPERRY: The image projected to the right side of a visual fixation point is projected to the left hemisphere and vice versa. This division, incidentally, runs very nicely down the midline with little or no central overlap or central sparing.

DR. LILLY: How did you maintain fixation?

DR. SPERRY: By eyeballing the eye. The subject is told to fixate and the examiner looking directly into the subject's eyes, watches his gaze, and clicks in the slide when the gaze is properly centered. Occasionally one sees eye movements, and, as mentioned, these can often be checked out.

DR. ROSENBLITH: Dr. Sperry, you said something about calculation being confined to the right hemisphere. Have you tried to do psychophysical scaling independently on both sides?

DR. SPERRY: All of this is pretty gross. Calculation tests for the minor hemisphere were run with one to four dots for visual input and one to four pegs for tactual input; the subject was asked to add or multiply using this input.

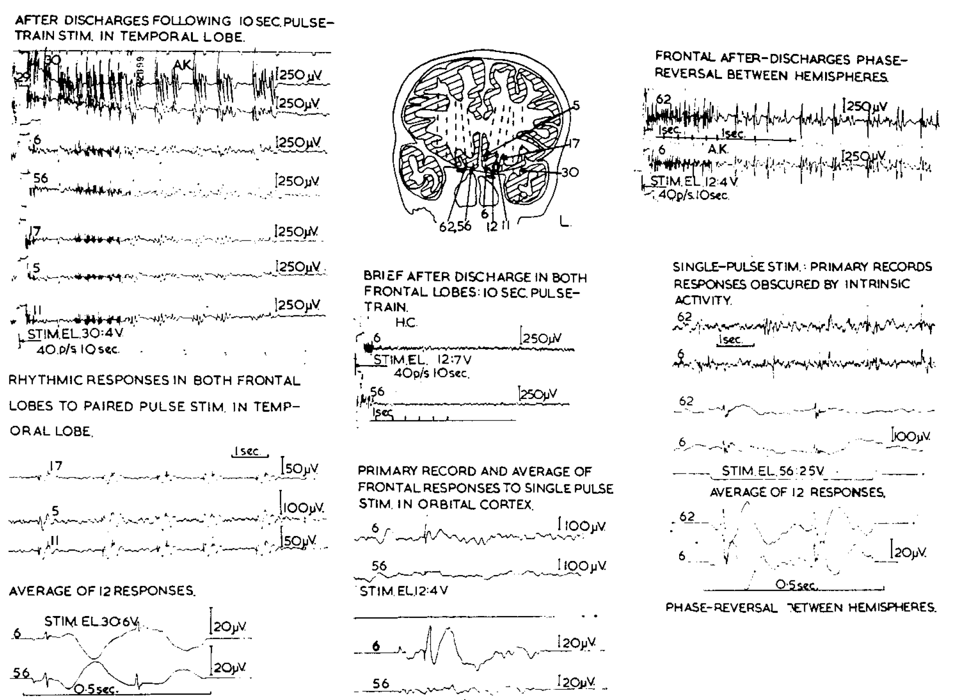
CHAIRMAN MILLIKAN: Dr. Grey Walter, will you continue please?

DR. GREY WALTER: Like Dr. Sperry, I would like to present some data from observations in human beings following surgical implantation of multiple chronic electrodes. I would like to skip the clinical aspects. These data relate to the general question of interhemispheric interaction and were derived from very tedious computations of responses to electrical and sensory stimuli by a colleague from Budapest, Imre Tomka, on a World Health Organization Fellowship. We have studied some thousands of electrode implants in the brains of organically normal patients and developed a kind of hypothesis. We have used electrical stimuli to the cortex, in all parts of the brain, covering a wide area in the frontal and anterior temporal lobes.

Figure 28 shows the general summary of results. The central diagram indicates the position of the electrodes. We have studied the electrical responses from all the electrodes, with a view to developing an idea of the connectivity of the human cerebral cortex. In simple terms, we are asking a topological question; we want to know how you get from here to there in the brain. Occasionally we get the answer of the peasant who when asked this, said, "If you want to get there, you shouldn't start from here."

In general, we do find considerable reciprocal connectivity in the cortex. For example, the record in the bottom left hand corner shows stimulation of electrode 30 in the left temporal tip, and responses at electrode 6, which is in the orbital frontal cortex on the

Fig. 28. General summary of results of study of the connectivity of the human cerebral cortex.



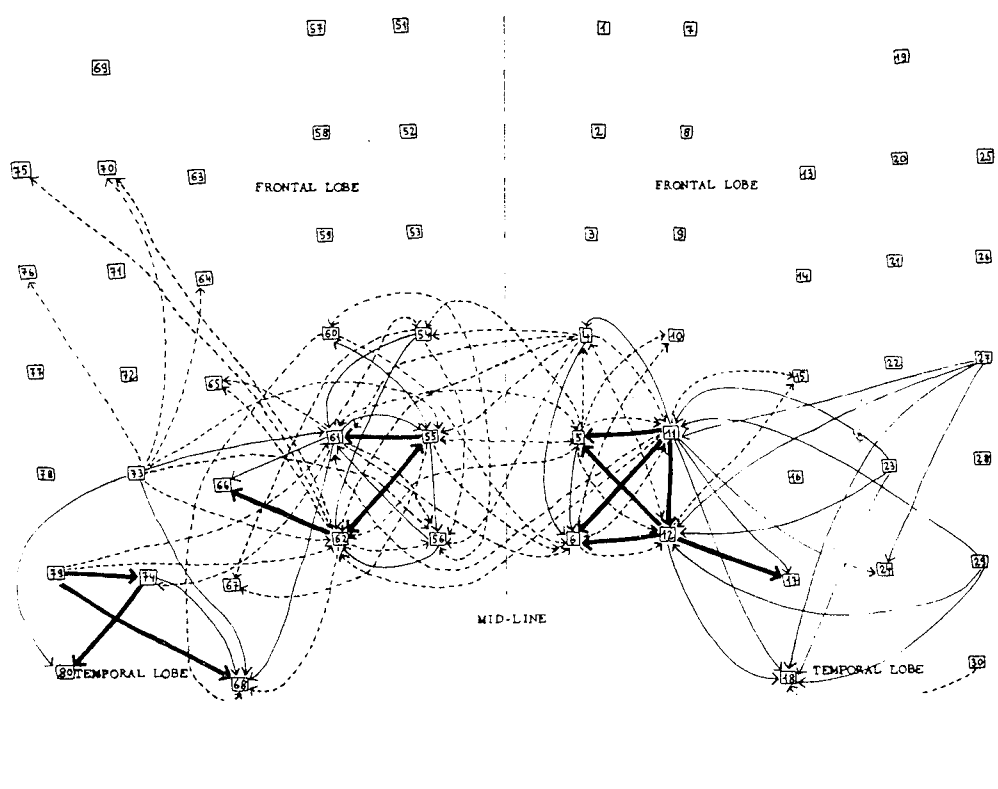
same side, and also at 56, which is in the homologous region in the other hemisphere. Similarly, in the bottom right hand corner stimulation of electrode 56, which is on the right side, produces responses at electrode 62 nearby and also across to 6 on the other side. We have made a very large number of such observations, with surprisingly consistent results. The first is that there is an enormously elaborate reciprocal connection between orbital cortex and anterior temporal lobe, and second, perhaps the most important, invariably in all these thousands and thousands of stimulations there is this peculiar inverse phase relation between the left and right hemisphere. With all the electrodes, the potentials are referred to the average of all the others, so this is not a question of one electrode being affected by inverted potentials.

What we think may be happening is that activity started out in the cortex by our electrical stimulation invades the adjacent cortex quite slowly. If one measures the latency of the responses in the opposite hemisphere, the response is not merely upside down but often starts slightly *before* the activity in the cortex near the stimulation point on the ipsilateral side, as though the activity had spread rapidly through a commissure, presumably the corpus callosum, and invaded the opposite hemisphere from the inside as it were through the white matter instead of spreading slowly through cortex as in the ipsilateral hemisphere.

Figure 29 is a diagram of these connections in one patient. This illustrates the pattern of connectivity in the temporal and orbital frontal cortex with lines running also from one hemisphere to the other, but not always to homologous regions and not always with reciprocal relations either.

Bearing in mind the consistency of these patterns and the peculiar time- and phase-relations between hemispheres, I would like to suggest that the hemispheres may act as a double storage-buffer in which information can be tossed from one side to the other and

Fig. 29. Diagrams of connections in temporal and orbital frontal cortex in one patient.



read out or registered in the process, possibly with destructive write-out. Thus, for any particular set of experiences one hemisphere would be accumulating the information for a while and would then transfer the relevant sections to the other hemisphere, clearing its register at the same time. This sort of procedure is used in some computers and can be an economical way of selecting and storing information in a system of limited capacity.

I wonder if some of Dr. Sperry's brilliant and provocative observations might be explained in terms such as this.

DR. EFRON: I do not know whether this is a question to Dr. Sperry or a statement describing my own confusion. It seems to me, unless I have misunderstood Dr. Sperry rather profoundly, that his point is very strongly confirmed by the fact that he is instructing his patient to use his left hand. Let's say the patient comes into the box on a given day; Dr. Sperry speaks to him; he has to communicate with the patient. He tells the patient to reach out with his left hand and do something. Since these patients have a callosal section their ability to follow this verbal command at the onset of the testing session must indicate that "the right brain must have understood the set of instructions." It would seem to me that the rather complex tasks Dr. Sperry has described merely confirm what could have been proved the moment the patient did the first task correctly. Have I misunderstood Dr. Sperry in this respect?

DR. SPERRY: There is the matter of ipsilateral control on which we may have different views and also various other factors in the testing situation that would make conclusions on this basis a bit shaky.

DR. LILLY: I have a question and a comment to Dr. Sperry. In any of your cases was there any evidence whatsoever that the nondominant hemisphere had had access to language and speech? Now I am talking about all of proto-speech, all of noise-making, and the elements of speech that we have discussed here, as well as concept formation, cognition, and so forth.

DR. SPERRY: We cannot be certain at this time that the minor hemisphere cannot utter some simple, familiar, or emotional material.

DR. LILLY: I just wanted to get that straight. Then I just want to report that recently we have found the dolphin can use two separate phonation mechanisms, one on the right, which is innervated completely from the left hemisphere, and one on the left, which is completely innervated from the right hemisphere, quite independently, and at least make noises of very high complexity equally with each side.

They can also, as we have recently discovered, link the sounds from the two sides so that one gets an apparent source which shifts from the right to the left and back again. This is most dramatically shown by stereophonic listening to a dolphin in air with two pick-ups, one on the right phonation side and one on the left. If one now listens with stereophones, one can hear sounds alone on the right, alone on the left, or an apparent source moving through one's head from right to left and back again.

I think that this suggests an experiment—and I hope some day Dr. Sperry will come and do it—of splitting the brain of the dolphin and seeing if one can disconnect, as it were, the stereovocalization and see if the two independent vocalizations still exist.

DR. EVARTS: I just wanted to pick up a point that Dr. Sperry mentioned, the point that the dominant hemisphere does, in fact, have some access to both sides of the body in terms of control of the hand. Didn't you say that, Roger? In terms of Dr. Efron's questions, one has to keep this in mind. I believe that Dr. Efron proposed that if a subject reaches out with his left hand in response to a verbal command, this means that the right hemisphere must have had access to the verbal information. One can propose, however, that for certain types of acts the left hemisphere can in fact control either hand.

DR. GAZZANIGA: Dr. Evarts is quite right and from some related studies of ours it is clear that each disconnected hemisphere can control with almost equal ability both the ipsilateral and the contralateral hands if one excludes from consideration the individual control of the fingers ipsilateral to the hemisphere in command. In addition, it is of interest to note that results from some animal studies show that split-brain monkeys demonstrate marked ipsilateral eye-hand impairments when, in addition to the pure midline surgery, unilateral lesions are made in motor and premotor areas.[128] That is to say, ipsilateral visuomotor control is dependent on the integrity of the motor cortex contralateral to the responding hand. This type of evidence goes a long way to explain the difference between our first case—as well as the Liepmann-Geshwind type—versus our latter two cases. It also hints at the underlying mechanisms of ipsilateral control. That is, these studies argue against the view that ipsilateral control is managed by only motor systems originating in the ipsilateral hemisphere. Rather they suggest that much of the ipsilateral control could take place in the opposite visually deprived hemisphere, which is possible because of a cross-over of target information originally established and determined by the ipsilateral hemisphere.

CHAIRMAN MILLIKAN: Dr. Sperry, do you wish to comment on that suggestion?

DR. SPERRY: Thank you, not now. I only hope we've not encroached on Dr. Milner's time as a result of this.

DR. ETTLINGER: I would like to ask a brief question. Do I correctly understand from your presentation, Dr. Sperry, that your data suggest the following types of organization for the minor hemisphere, namely, that the minor hemisphere cannot evoke names or language (which is what you had also previously reported for your other patients, and I understand that you have confirmed this) but the minor hemisphere can be used in the recognition or reception of language? The nominal aphasic patient cannot find the name but, given the name, he can recognize it from a selection. Also severe comprehension defects are more rare than severe disorders of expressive speech. I wonder whether you feel this information is correct or whether your observations imply that transfer can occur after callosal section in one direction between the hemispheres but not in the other.

DR. SPERRY: Yes, it would seem to be the executive and more motor or expressive aspects that are mainly lateralized. Other evidence shows this going in the reverse direction in visual constructional tasks in which the right hemisphere is more proficient.

DR. EFRON: To follow-up the same question: I think I am still confused. If you instruct the patient verbally, "Move your left hand upward if a coin is present; move your hand sideways if a dollar bill is present" what will such a patient do?

DR. SPERRY: There is no problem. He could do that from the one hemisphere, that is, comprehend the instructions, feel around, locate the coin, and respond accordingly. Presumably he does this all from the minor hemisphere. What was the rest of it?

DR. EFRON: That will do.

DR. MURRAY A. FALCONER: Dr. Evarts raised the question of bilaterality of representation in the hemispheres. In these cases that you were just talking about where the patient with split commissure can reach out with the left hand: that action must involve the right hemisphere and not just the left, because in patients after a right hemispherectomy, the only movements possible in the left arm are feeble movements of the shoulder and the elbow, while the finer movements of the hand go. Therefore if a patient, after the commissure is split, can reach out in purposeful directions, the action must be coming from the right hemisphere.

DR. SPERRY: We have shown in experimental work in monkeys and the same thing in the human that for efficient ipsilateral control, one hemisphere working the ipsilateral hand, you need the integrity of the contralateral motor cortex. In our first case we can probably explain poor ipsilateral control by the fact that he has quite severe extracallosal brain damage. In this regard, we notice there is no dysarthria in these patients. Where you do get dysarthria is with right hemispheric lesions. In order to control the speech mechanism, leave intact the right motor hemisphere.

DR. HIRSH: May I put a question about very fundamental neuroanatomy. We know about the confusing bilateral representation of the auditory inputs in the two cortices, but about the fine motor control of the speech mechanism, for example, the tongue and the laryngeal musculature: are the two sides of this speech mechanism represented separately in the same way that the two hands are represented separately on the two sides?

DR. GESCHWIND: There is some interesting evidence to show that there are separate pathways descending in both the left and right internal capsule for bilateral innervation of the speech musculature. The left is normally used but the right can substitute.

The evidence for this comes from the description by Bonhoeffer[38] of one of the early cases of callosal disconnection. On clinical criteria Bonhoeffer had predicted during the life of the patient the presence of a callosal lesion. In addition he had expected a Broca's area lesion because of the patient's aphasia. At postmortem the expected callosal lesion was found but Broca's area was intact. There was, however, an infarct involving the left internal capsule. Bonhoeffer interpreted this very astutely. He pointed out that lesions of the left internal capsule do not produce aphasia. The reason is that if this left-sided pathway is destroyed, you can still use the alternative pathway from Broca's area via the corpus callosum to the corresponding region in the right frontal lobe and eventually down the right internal capsule. In Bonhoeffer's patient the callosal lesion cut off this alternative route. This type of lesion is probably quite common but not in this neat form. Thus many subcortical lesions which are beneath Broca's area produce aphasia by the same mechanism. Although Broca's area is intact, the lesion simultaneously destroys descending fibers and callosal fibers and has the same effect as the two lesions in Bonhoeffer's case.

The same type of mechanism probably holds for other bilateral movements such as walking for which there is evidence that it can be triggered from either hemisphere alone.

DR. HIRSH: I put the question wondering whether some of the gentlemen who have patients of the kind described this morning ever observed anything like or anything analogous to the one-sided clumsiness Dr. Falconer just referred to, either with a canted tongue or one-sided phonation. Is the innervation so separate that this kind of articulation can be observed?

CHAIRMAN MILLIKAN: Can you respond to that question?

DR. SPERRY: Not in the cases that have the opposite hemisphere intact. Very briefly after the surgery there is a short period of recovery.

DR. EVARTS: I just wanted to follow this up. Dr. Sperry has said that one does not see this effect in cases where the opposite hemisphere is intact. Dr. Falconer pointed out that for a movement to take place, it is essential that the opposite hemisphere be intact. However, granting that the integrity of the contralateral hemisphere is essential to the operation of the extremity, it remains a possibility that information concerning guidance of movement could arise in the ipsilateral hemisphere. In the work I have done on hand movements in the monkey, the monkeys were trained to use either hand. The units I showed you yesterday were active in relation to the contralateral hand. However, when one records from PTNs in association with ipsilateral hand movements, one sees that there are certain neurons, small in number perhaps but definitely there, which are locked onto and related to the ipsilateral hand movements only. Thus, given the integrity of the contralateral hemisphere, the ipsilateral hemisphere may send down information which for certain sorts of movements, perhaps the elementary, is sufficient. The fact that the ipsilateral is able to provide information for certain kinds of movement, given the integrity of the contralateral, may explain some of these observations.

DR. HÉCAEN: This is just a very brief question about the recognition of a familiar human face, as in a picture, by the minor and the major hemisphere.

DR. SPERRY: This is one of the more subtle tests we have not gotten to. We are going to hear about it later on.

DR. LENNEBERG: Just a brief comment on the question of dysarthria. It seems to me that dysarthria is not a prominent feature of high lesions. In the patients that Dr. Penfield described, dysarthria is certainly not even a transient symptom according to the clinical descriptions. In the hemispherectomy cases reported in the literature, again, dysarthria does not seem to be figuring—correct me, if I am wrong—in the clinical picture. On the other hand, dysarthria is very prominent and dramatic in diencephalic lesions, surgical interference, and stimulation and also in mesencephalic lesions and stimulation experiments. I think all this indicates that motor integration is a very low phenomenon, and the role the cortex plays in just the motor output is something we do not really understand completely. It does not seem to be a matter of immediate integration of individual muscles. It seems to be something much more general. Possibly speech may be slowed down somewhat in the case of high lesions, but I do not think you really see dysarthria, strictly speaking. It is very much different from the dysarthrias of lower lesions.

CHAIRMAN MILLIKAN: Dr. Geschwind, a final comment.

DR. GESCHWIND: I was fascinated by the studies presented by Dr. Sperry. He says that these cases are much closer to the Akelaitis pole than to the Liepmann pole. I would like to suggest that in fact he has not moved very far from the Liepmann pole. As Dr. Ettlinger pointed out, he has in fact practically refuted Akelaitis on all major points. What is important is the evidence that in some callosal cases the minor hemisphere can perform to some extent, particularly in comprehension tasks.

The problem of variations among patients is one that has always concerned students of the higher functions. Thus Liepmann and Maas's[233] original case of callosal disconnection showed poor object handling in the left hand, yet the second case[252] handled objects well in the left hand. I cannot go into all the possible reasons for this. I would, however, suspect that many of these variations are not due to differences in the lesions but rather to pre-existing differences in the brains. There is evidence from other sources that the capacities of the minor hemisphere vary from patient to patient, particularly in its ability to comprehend language.

It is encouraging that individual difference need not be regarded as purely an *ad hoc* hypothesis since there is some evidence from animal experiments that shows such variation. I was fortunate to hear Dr. Myers present some elegant experiments which are relevant. Among a group of monkeys with the same lesion (cutting of the splenium) some were less impaired than the majority were but then showed impairment when an anterior commissure section was added to the splenium section. Hence the extent to which anterior commissure can support interhemispheric transfer of visual learning varies from animal to animal. I hope we will, similarly, be able to devise better techniques to study such variation in man.

CHAIRMAN MILLIKAN: We will continue with "Brain Mechanisms Suggested by Studies of Temporal Lobes." Dr. Milner.