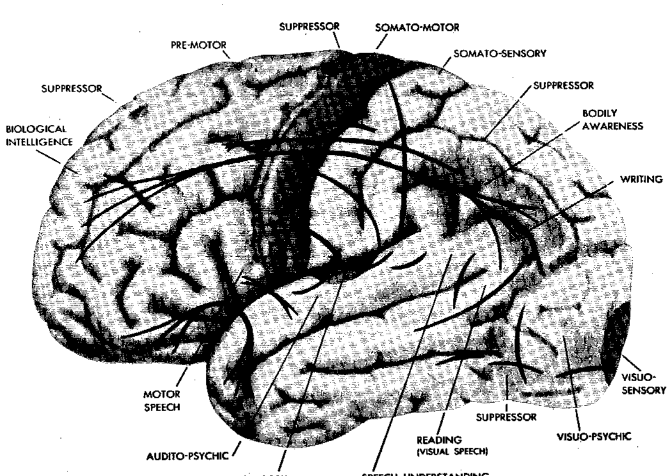
The Elusive Right Hemisphere of the Brain

by Eran Zaidel

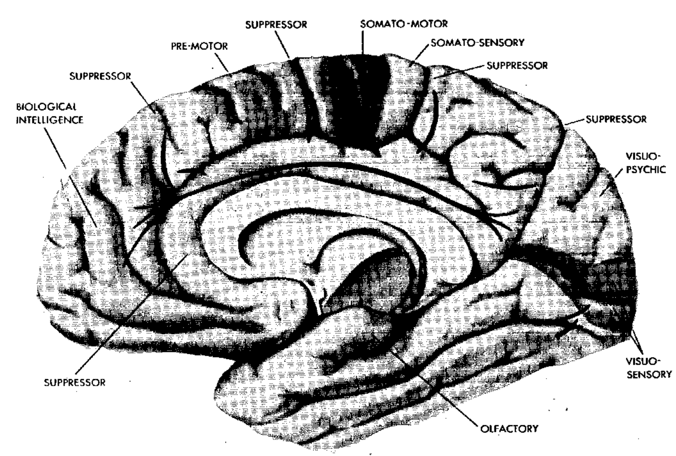
The backbone of our knowledge about hemispheric specialization has been accumulating since the mid-19th century. It consists of clinical observations of patients who have suffered focal damage to one hemisphere (i.e., one-half) of the brain. The damage may consist of a stroke, a tumor, or a gunshot wound. These studies have accelerated after each major war because of the availability of fresh experiments of nature. Given the current state of human nature and of world politics, clinical neuropsychologists are not likely to be out of jobs for some time to come.

Each hemisphere of the brain (below) can be divided somewhat arbitrarily into four parts. The frontal lobe, whose function is still very much a mystery, seems to have a special role in planning and motivation; it also contains the motor areas that control the opposite half of the body. The temporal lobe has auditory, linguistic, and memory functions. The parietal lobe has some of the sensory areas for the opposite half of the body, and association centers for integrating information across sensory modalities and for processing spatial information in particular. Finally, there is the occipital lobe, where the primary visual reception areas are located.

Exposing the medial aspect of the brain reveals the massive fiber system that connects the two cerebral hemispheres: the corpus callosum with some 200 million nerve fibers in it, the anterior commissures, and the hippocampal commissures. This group of connecting cables has been sectioned surgically (that is, cut through) in a special group of neurosurgical patients. They are called split-brain patients, and over the last 17 years they have been the subjects of intensive neuropsychological study.



A view of the outside surface of the left cerebral hemisphere of the human brain.



A medial view shows the fiber system called the corpus callosum, which connects the two hemispheres.

Recent research on the right hemisphere indicates that it has unexpectedly rich linguistic structure—a fact that may help us understand some forms of language disability

The classical neurological model of language representation in the brain is about 100 years old. It says that, at least in most right-handed adults, the left hemisphere is specialized for language and for speech, so that only damage to the left hemisphere can result in a language disorder—so-called aphasia. Today we recognize several distinct forms of aphasia. Though really quite complex, three common syndromes may be oversimplified for purposes of illustration as follows. In Broca's aphasia—named after the French pathologist Paul Broca, who was the first to publish the view that the left hemisphere is specialized for language—we have a predominantly expressive disorder with poor articulation, telegraphic speech consisting mainly of content words, and with impoverished or impaired grammar. If you ask a Broca's aphasic how he has spent the Easter holidays, he may answer something like this: "Uh, uh, uh, Easter . . . ho, ho, ho, holiday . . . I like . . . eat turkey . . . many lights . . . people . . . very good." The speech is very labored and effortful. The patient seems acutely aware of his own deficit, and he may become quite depressed about it. Lesions that produce Broca's aphasia are often in the frontal part of the brain.

A second main syndrome is Wernicke's aphasia, named after the German neurologist Carl Wernicke. Here we have impaired auditory language comprehension with fluently articulated but nonsensical speech. The patient's speech has good melody and uses complex though often incorrect syntax. If you ask a Wernicke's aphasic how he spent the Easter holidays, and if you don't listen too carefully, he may sound quite normal. But some attention reveals semantic jargon. "Oh, yes, we have done it. Could be different but nevertheless done. Go, go, gone. And however successful, it still fails. I wish indeed. Good morning." So here the disorder is predominantly one of meaning rather than of syntax or phonology. The patient is very often quite unaware of his own deficit and will deny it vehemently. Today it is believed that the responsible lesion tends to be more posterior.

A third main syndrome is anomia or amnesic aphasia. Here we have a predominance of word-finding difficulties in both spoken and written language, and in the context of fluent, grammatically well-formed speech and relatively intact auditory language comprehension. It is easier for the patient to evoke over-learned serial speech such as the alphabet or the days of the week. The localization is often temporal parietal. For example, if you point to a fork and ask the patient to name it, he may respond with, "It's a, ah, ah . . . (eating motions). It's a spoon. No. No. I mean it's a . . . You eat with it, a, ah, I can say it." You ask him then, "Is it a knife?" And he will say immediately, "No. No." And if you cue him by starting, "Use your knife and ————" he will often be able to complete it, "fork." Here the disorder is one of reference—i.e., of the relation between words and the things in the world that they stand for.

These three aphasic syndromes—considerably simplified—are all attributable to left hemisphere lesions. The right hemisphere has generally been believed to have no role in language whatsoever. Rather, since the 1940's it has become increasingly associated with visual-spatial information processing. For example, it is now believed to be specialized for the recognition of faces, for three-dimensional constructions in space, and for topographical orientation. But as far back as the 19th century the British neurologist Hughlings Jackson believed that the right hemisphere does have some role in language, especially in serial, automatized, and emotional speech. By now it is clear

Self-portrait by the German painter Anton Raderscheidt, done five months after he suffered a cerebral stroke, shows a severe neglect of the left side.

Courtesy of Prof. R. Jung

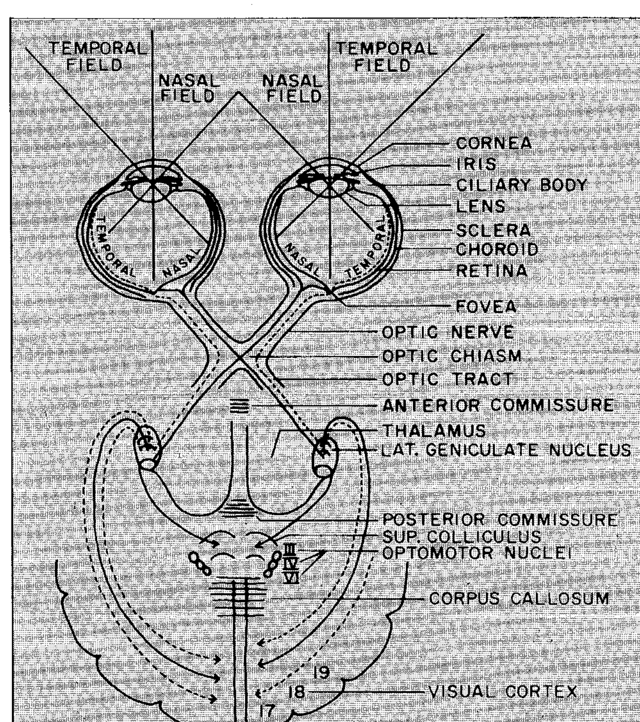
that the standard neurological view needs to be qualified. In fact, we have found that the right hemisphere has an unexpected and unusual form of natural language.

But first let me illustrate a characteristic non-verbal right hemispheric deficit as it has expressed itself in the drawings of the German painter Anton Raderscheidt. He was born in 1892 and died in 1970. In September of 1967, at the age of 75, Raderscheidt suffered a cerebral stroke to the right hemisphere, due to thrombosis of the posterior branches of the middle cerebral artery of the right hemisphere. Since then he had suffered from left homonymous hemianopia, a blind left-half visual field in both eyes. He also had a severe neglect of the left half of space, which subsided gradually. The parietal lesion had characteristically made him unable to recognize faces. At first this was so extreme that he confused even his closest relatives, but this condition also cleared up spontaneously. A self-portrait by Raderscheidt (above), done five months after the stroke, shows a severe neglect on the left side. This neglect could not be explained simply in terms of the blind half-field, because the patient could move his eyes and see the missing part.

This kind of neglect typically happens with lesions to the right hemisphere, but almost never in a severe form with lesions to the left hemisphere. Sometimes this can be very dramatic. For example, the patient may ignore completely the left half of his own body. He may get dressed using only one sleeve but ignoring the other side of a jacket. He may comb his hair on the right half of his head but ignore the left half.

There are several quite serious methodological problems with trying to find out the functions of each hemisphere by looking at patients who suffered damage to one or the other side of the brain. For one thing, it is very difficult still to assess the location, size, and severity of the lesion in the brain. It is even harder to match two patients with exactly the same lesion on the left and on the right side. In any case, it's a bit suspect to infer functions from deficit. One solution seems to be to compare the positive competence of one half of the brain with the competence of the other half in the same patient, so that the two halves are automatically matched for age, sex, education, and so on. This is exactly what a split-brain preparation allows us to do. In addition, since the 1960's we have increasingly become able to look at hemispheric specialization effects in normal subjects. One of the most common techniques used involves an elementary understanding of the visual system.

In the normal visual system (below) the left and the right eye look at the same point. The left halves of the visual field of each eye project to the right halves of the corresponding retinas. The information then goes through the optic tract and on to the occipital lobe in the



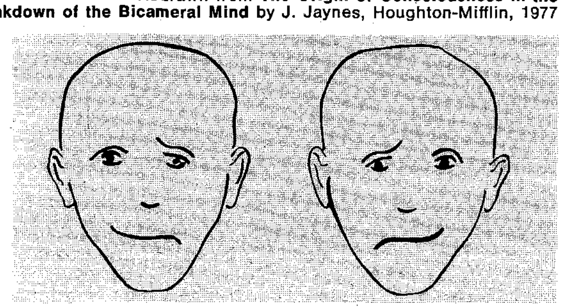
A schematic diagram of the visual pathways from eye to brain.

back of the right hemisphere. The two right halves of the visual field project to the left halves of the retinas and then to the left hemisphere. In a normal subject all you have to do to get information to one hemisphere first is to tell the subject to fixate on a central dot. Then you flash a picture very quickly either to the left or to the right of that fixation point. You have to do it fast enough (for not more than 100 to 150 milliseconds) so that he has no chance to move his eyes. It takes about 200 ms to initiate a saccadic eye movement. If you flash the picture to the left half of the field, it goes to the person's right hemisphere. If you flash it to the right of the fixation point, it goes to his left hemisphere. Of course, the information will also travel between the two hemispheres through the corpus callosum. But the response to information that reaches the processing and responding hemisphere directly will be faster and more accurate than the response to information that comes through the corpus callosum. We use this technique to establish laterality effects—hemispheric specialization effects—*in normal subjects.*

Incidentally, you don't have to flash pictures to see some of these effects. Look at the two pictures below. Which one looks happier? Almost everyone will say that the left picture is happier because the left side of the mouth turns up. The point is that these two pictures are essentially mirror images of each other. So why do we associate the expression with the left half of the picture? Presumably because this is the part that goes to our right hemisphere, which specializes in analyzing faces.

Let me move on now to the kind of experiment we have done with split-brain patients in Professor Roger Sperry's lab here at Caltech. These patients of Dr. Joseph E. Bogen have literally had their brains split surgically. The operation is called complete cerebral commissurotomy, and it is done as a last resort to alleviate intractable epilepsy. In these epileptic patients the number and severity of seizures got higher and higher and could not be controlled by medication. There was reason to believe that by interrupting the mutually reinforcing symmetric epileptic foci in the two hemispheres this situation would be alleviated. Indeed, in general it was; in some of these patients the epilepsy has disappeared completely, and in most it is now controlled by medication.

Redrawn from **The Origin of Consciousness in the Breakdown of the Bicameral Mind** by J. Jaynes, Houghton-Mifflin, 1977



Which one looks happier?

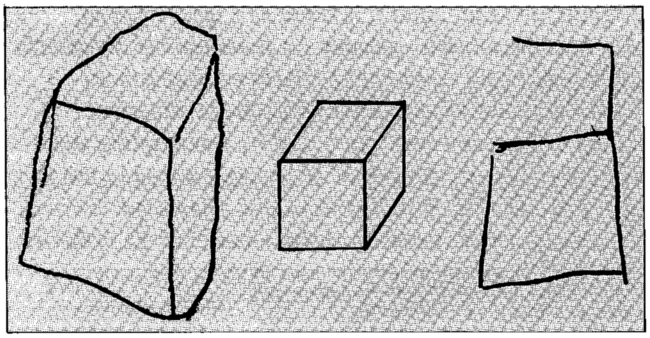
In this surgery the neurosurgeons, Phillip J. Vogel and J. E. Bogen, usually retract the right hemisphere, and in one stage they section all the cables connecting the two hemispheres. What does a person behave like after he has had split-brain surgery? Well, if you met such a person, you wouldn't be able to tell him from your next-door neighbor. And he is quite aware of his condition. One patient, when asked how he was doing on the day after the surgery, said, "Oh fine, except for a splitting headache." Another patient, when she is asked "How are you doing today?" frequently says, "Which half of me?" So there is at least a superficial awareness of the condition. However, it takes subtle psychological testing to find the massive deficits that occur in these patients in terms of crossing of information from one hemisphere to the other.

For example, if you close the eyes of a split-brain patient and put an object in his left hand and ask him what it is, he will not be able to tell you. This is because the right hemisphere controls the left hand and feels the object. The left hemisphere, the one that has speech, cannot tell you what it is because it has no information about it. But if you then take the object away and mix it with other objects and ask the patient to retrieve it, still without seeing it, he will be able to do so with absolute certainty. In other words, the right hemisphere can recognize the object; it just can't tell you about it. During a fairly short-term period after the surgery, when you ask the patient to copy a spatial design or three-dimensional figure, he will often do a better job with the left hand than with the right.

On the next page is a drawing made by a patient three years after split-brain surgery. The model was the figure in the middle. The drawing on the left was done with the left hand; the drawing on the right, with the right hand. Now, remember, the left hand is controlled by the right hemisphere, the one presumably specialized for visual-spatial abilities. And it is definitely superior.

We do also occasionally have the dramatic

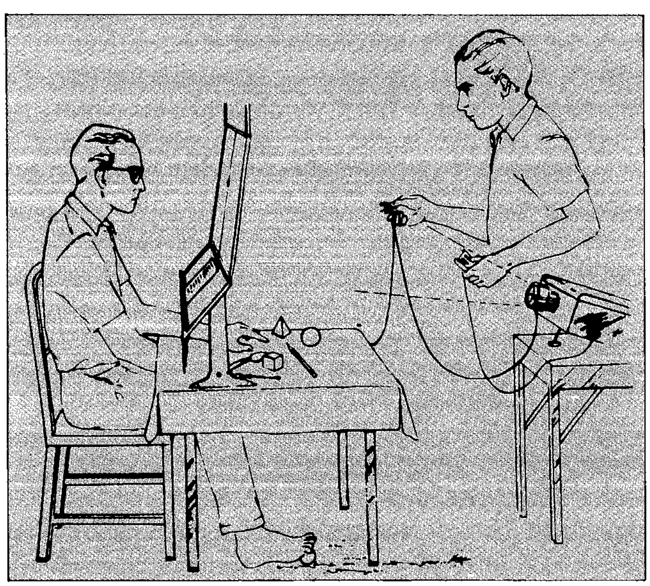
The Elusive Right Hemisphere



A drawing made by a commissurotomy patient three years after brain surgery. The model was the figure in the middle. Drawing on left was done with the left hand, that on right with the right hand.

phenomenon of some antagonistic behavior between the two halves of the body of the same patient, so that some patients complain that they find themselves buttoning their shirt up with one hand and unbuttoning it with the other. But this is not frequent.

The main technique for studying these patients, developed and used by Dr. Sperry and his associates for some 18 years now, uses the tachistoscope (below). The word, from the Greek, means "quickest view," and the instrument has been used in various forms for about 100 years. The patient sits in front of a screen with his hand under the screen, out of view. The examiner then flashes a picture of, say, a cube, to the left half of the visual field, using an electronic shutter that opens up for



The time-tested technique for studying split-brain patients uses an instrument known as a tachistoscope.

100 milliseconds. When you ask the patient what it was, he will deny that he has seen anything. That is the left hemisphere talking. But if you ask him to retrieve with the left hand (or foot) the object whose picture was flashed, he will do so very readily.

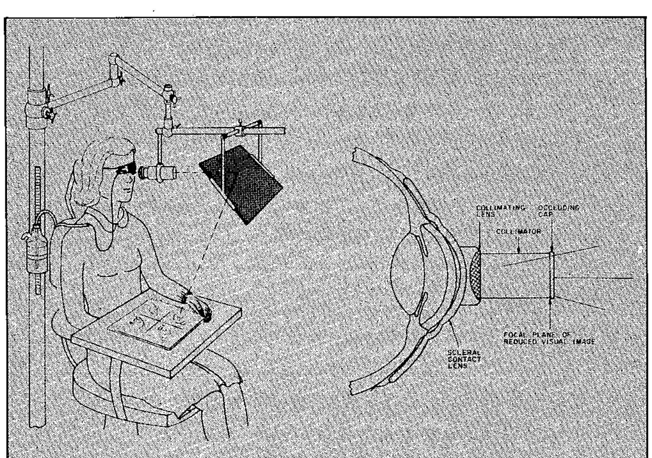
About three generations of graduate students have been working with these patients. From 1961 to 1969 the pioneering generation of Mike Gazzaniga and Joe Bogen, working with Roger Sperry, showed the dramatic splitting into two spheres of cognitive operation in the left and right hemispheres, each one having its own perception, memory, and consciousness. From 1969 to 1972 there was a new crop of graduate students —Jerre Levy, Bob Nebes, and Harold Gordon— topping each other in finding new tasks for which the right hemisphere is superior. And they found quite a few such tasks.

In summarizing the results of the first two generations, we may say that they found the left hemisphere to be linguistic, analytic, logical, sequential, and constructive. The right hemisphere was believed to be visual-spatial, gestalt, synthetic, and perceptual. And what was known about right hemisphere language? Of course, the clinical dogma was that there is no language in the right hemisphere of normal right-handed adults, but from the beginning of the split-brain research there was some evidence that the right hemisphere does have some language after all. To be sure, the left hemisphere is dominant, especially for speech, but there was also some auditory language comprehension in the right hemisphere. Nouns were believed to be comprehended better than verbs in the right hemisphere, and it was believed that the right hemisphere had no grammar at all. There was apparently some selective reading and writing, but nobody knew exactly how much. In particular, there was virtually no data on sentences or longer phrases, because there was no easy way to get all the information to one half of the brain at a time.

This is why in the summer of 1970 I developed the contact lens technique that enables us to get complex and prolonged information to one hemisphere at a time. As shown at the right, the patient sits in a dental chair. A picture, in her lap, is reflected by a mirror, reduced by a photographic lens and projected as an aerial image very close to her eye. On her right eye there is a very stable triple-curvature contact lens of the kind Derek Fender uses for research in visual perception at Caltech. The contact lens is scleral and covers about a third of the eyeball. Attached to this contact lens is a little aluminum tube called a collimator, about half an inch in length. At its base there is a very powerful lens, whose focal length is 1 cm. So here is what happens. The picture that the patient is looking at is reduced and projected at the end point—i.e., the focal plane—of the collimator. But when the patient looks through this whole system the collimator blows up the picture again, and its virtual image appears to him to be of normal size and at normal distance. The catch is that right near the end point of the aluminum tube there is also a little half-circular screen that occludes precisely one-half of the visual field, so that the patient can actually scan the picture quite freely with the contact lens, but at each point the half-circular screen follows the eye movements faithfully and thus permits visual information to enter only one hemisphere. The patient can even monitor his own manual performance on the board by visual guidance.

The reason I came to work on the problem of language in the right hemisphere was probably philosophic. There is a perennial problem in philosophy concerning the relationship of language to thought, and it occurred to me that a right hemisphere makes an unusually interesting model for studying this relationship, because in the right hemisphere you have thought without language.

The first task was to find out how much language there is in the right hemisphere. It turned out to be a substantial amount, and of a very special kind. Thus it is interesting to study right-hemisphere language as a clue to normal, natural language precisely because it is



This contact lens technique enables researchers to get complex visual information to one hemisphere at a time, allowing it to scan the information freely.

organized in a very unusual way.It is, so to speak, in a process of partial structuration, just like a child's language or language after brain damage to the left hemisphere. There you can sometimes study how the components of the cognitive system are put together much more easily than in the fully mature and complex brain of the normal adult. Also, data about right-hemisphere language may have implications for the question of how hemispheric specialization develops in normal children. It may also have important consequences for the potential of the right hemisphere to recover or compensate for language loss after damage to the left half of the brain.

Let me describe a series of experiments on the right hemisphere's ability to do linguistic analysis by describing the scores of the right hemisphere of three patients—LB, NG, and RS—on a battery of tests.

LB is a split-brain patient who was 21 when I tested him. He was 13 when he was operated on, and about 3 when the epileptic seizures first started.

NG was a 40-year-old woman when I tested her; she was 30 when she was operated on, and she was about 18 when the seizures started.

RS is a different sort of a patient; she had her whole left hemisphere removed at the age of 10 in order to prevent a tumor from spreading to the other side. The symptoms first occurred at age 8, and I tested her throughout a long period, but for these particular tests at the age of 14. She was severely aphasic—able to use or understand spoken language only with difficulty, and without the ability to read and write. The main tool that she used for language expression and comprehension was meanings, semantics. Her grammar was relatively poor. Her comprehension was much better than her speech, and she had excellent melody, singing, and non-verbal imitation, which she often used to help her communicate with people around her.

A good way to analyze the scores of the right hemisphere of a split-brain patient is to compare them with the scores of the left hemisphere of the same patient. In the case of RS, I compared her with the scores of DW. He is a patient whose right hemisphere was removed surgically. This was done at the age of 8, symptoms occurring at about 6½, and I tested him when he was about 15. So in many respects DW can serve as a matched control for RS.

First of all, can the right hemisphere recognize the meaning of pictures, of simple common scenes or drawings? Here is one way to find out. Look at the

Visual Reception subtest
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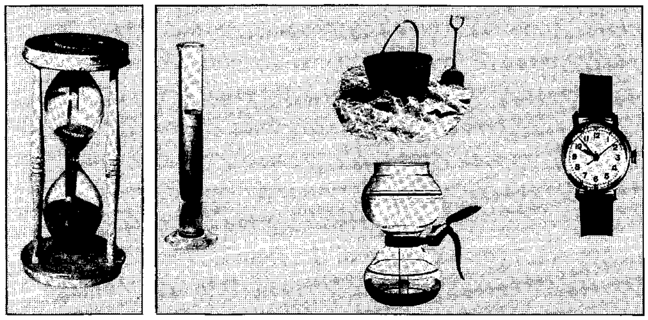
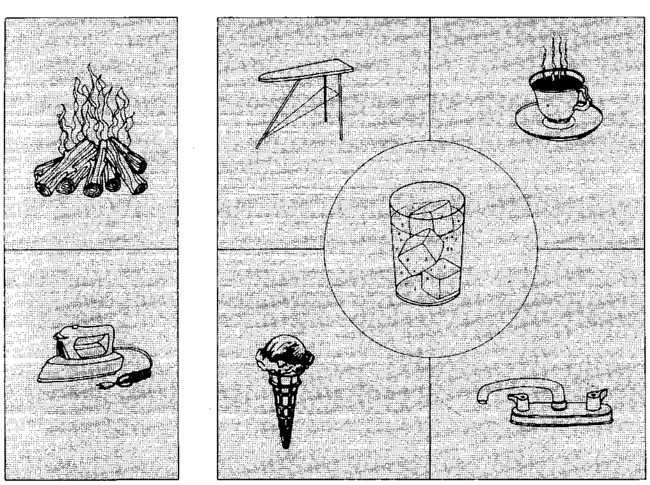


Look at the object on the left, then find one (that performs the same function) among those on the right.

object on the left above. Then match it with one in the group of objects on the right. In the actual test it is made clear that we are asking for functional similarity rather than perceptual similarity. Thus the patient should be aware that we are asking him to match the hourglass with the watch rather than with the coffee pot that looks more like it. The scores of the three right hemispheres in this test are about on the level we would expect from a normal 5-to-6-year-old child. (These are the first scores shown on the graph at the top of page 18—which also gives successive scores for the tests that follow.)

We can make the test a little more complicated by presenting a visual analogies problem. Look at the drawing below. Which of the four items on the right is related to the middle item on the right in the same way that the top item on the left is to the bottom one?

Visual Association subtest
From the Illinois Test of Psycholinguistic Abilities



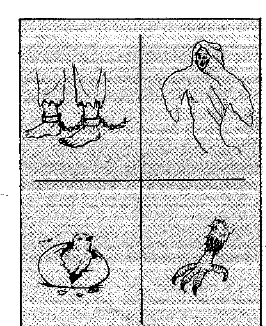
Which of the four items on the right is related to the middle item on the right in the same way that the top item on the left is to the bottom one?

Whenever I try this test at Caltech, I get many more answers than I care to hear. The semantic relationship I want you to recognize here is that of equal temperature. Both the iron and the burning wood are hot, whereas the ice cream and ice water are cold. Again, the scores are around the normal 5-year-old level.

How well can the right hemisphere understand single spoken words? The examiner says a word aloud —for example, "back." Four alternative choices are shown only to the right hemisphere, so although both hemispheres hear the word, only the right hemisphere can see the pictures, and if the right hemisphere then points correctly with the left hand to the correct picture, this means both that it has understood the word and recognized the correct picture. (In this case, the task is a little more difficult because the names of the alternative pictures all rhyme with back—jack, tack, and pack.) The scores of the three right hemispheres range from about 5 to 8 years of age.

We can make the test even more difficult by superimposing a background of conversational noise on the stimulus word. The words are not as clear then; the signal-to-noise ratio is lower. In that case the right hemisphere suffers a certain detriment when compared to a normal child. The left hemisphere, it turns out, actually benefits from this, relative to a normal child. In other words, the right hemisphere makes more additional errors in this noisy version of the test than in the quiet version compared to a normal child who had the same number of errors in the quiet test. The left hemisphere, on the other hand, makes fewer such additional errors than a normal child.

But how well can the right hemisphere understand a single spoken word without any competition or noise? Here is an item from a very commonly used test—the



In this test for children suspected of having language disability, the examiner says the word "emerge," and the patient has to point with the left hand to the correct picture.

Reproduced from the Peabody Picture Vocabulary Test with special permission of the author, Lloyd M. Dunn, American Guidance Service, Inc.

Peabody Picture Vocabulary test. It is used with children who are suspected of having language disability. And it is used because it requires no speech in order to respond. The examiner says a word aloud—for example, "emerge." And the patient has to point with the left hand to the correct picture.

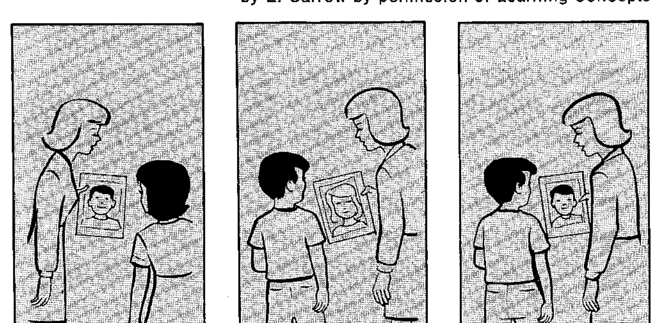
The scores of the same three right hemispheres on this test came as a big surprise. They range all the way from 12 to 17 years of age. That's remarkable for a hemisphere that is not supposed to have any language. It turns out that the right hemisphere can recognize any part of speech equally well, as long as the word frequency is the same. By word frequency I mean the number of occurrences of the word in a typical passage of written or spoken language.

When we plot the performance of the left and the right hemispheres as a function of word frequency, we get parallel curves showing progressively fewer correct responses in both hemispheres as the words get less frequent, i.e., more difficult. But the right hemisphere has a constant decrement of performance relative to its sister left hemisphere. Words that are very frequent occur at the rate of 100 or more per million; infrequent words occur about once per million. An example of a word that is very infrequent is "vitreous." ("Vitreous" is a word I didn't know, but the right hemisphere of one of our patients did. So I remember it very well. It turns out to mean "glassy"—not "liquid," as I thought.)

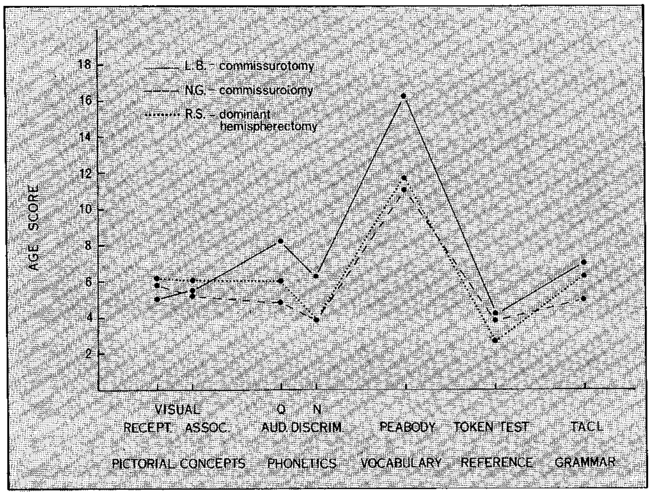
How well can the right hemisphere recognize longer phrases? There is one particularly interesting little test called the Token Test that is very sensitive to the presence of aphasia even when it occurs in a subtle form or when it is already in remission. The test is very simple. There are 10 or 20 chips in front of the patient; they occur in one of two shapes (square and circle), one of two sizes (large and small), and one of five colors (white, red, yellow, green, and blue). The patient has to perform instructions of increasing complexity spoken to him by the examiner. For example, "Point to a large one"; or "Point to a green circle"; or "Point to a large square and a yellow circle"; or "Point to a large green square and a small blue circle." The left hemispheres of these patients perform normally—100 percent on this test. Children who are about 11 also obtain perfect scores. But not the right hemispheres. They perform at about the level of a 4-year-old child. I know this for sure because there are no norms for this test for such young children, so that I had to administer it myself to my son's class in All Saints Day Care Center in Pasadena. These then are the upper (Peabody) and the lower (Token Test) limits of the linguistic ability of the right hemisphere. Why can the right hemisphere not understand the longer phrases? Presumably because this requires a short-term verbal memory, the kind that you use to remember a phone number between the time that you look it up in the phone book and the time you dial it. Short-term verbal memory is a rehearsal buffer that apparently requires phonetic analyzers, precisely what the right hemisphere does not have.

What about the ability of the right hemisphere to understand grammar? This allegedly it cannot do at all. Below is an item from a typical test. In this case the examiner says: "She shows the girl the boy." The correct picture is on the left. This particular sentence measures direct-indirect object relations. How well can the right hemisphere comprehend grammatical constructions? Well, at a respectable level—certainly not what you would expect from a hemisphere that has no grammar at all. Actually, when you compare the performance of the right hemisphere of, say, patient LB to that of a 6-year-old normal child, who has the same total score, you find that the error pattern is quite different. The 6-year-old child will tend to be much more sensitive to the linguistic complexity of the message, the parts of speech, the syntactic complexity. The right hemisphere, on the other hand, seems to be much more sensitive to the perceptual complexity, to the redundancy, and to the memory load of the message. At any rate, if this is how well the right hemisphere can do in a very non-redundant and carefully controlled test situation, imagine how well it can do in a freer, and more redundant normal conversational situation.

Reprinted from **Test of Auditory Comprehension of Language** by E. Carrow by permission of Learning Concepts



Which picture illustrates the phrase "She shows the girl the boy"?



The "mental age" profile of three right hemispheres (two of split-brain patients, one of a patient who had dominant hemispherectomy) on a battery of language tests.

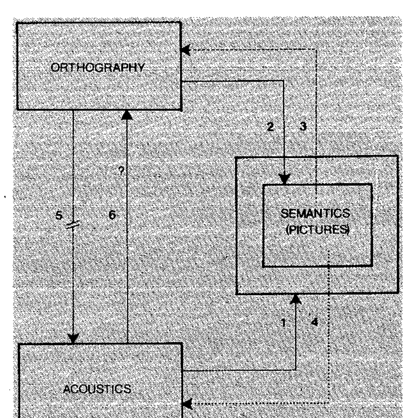
Now, take a look at the graph above that summarizes all these results. What can we say about this mental age profile? It certainly looks very curious. It is not the case that the right hemisphere is uniformly at the same age level for all the language functions sampled. This at once refutes one of the common views on how hemispheric specialization develops in the normal brain. According to that view, both hemispheres develop equipotentially up to a certain age, the age depending on who you read (some people say 5, some say 10, some say 13). At that point the left hemisphere goes on to develop further its language abilities, the right hemisphere goes on to develop visual-spatial abilities. But the prediction, therefore, is that the right hemisphere will remain arrested uniformly at a 5- or 10- or 13-year-old linguistic level. Well, it certainly does not. In some functions it goes on to develop into adulthood; and some functions such as speech it doesn't have at all.

I actually believe what is becoming increasingly accepted today, that hemispheric specialization is specified at birth. We now know that anatomical asymmetries are evident to the same degree in the brains of normal adults and young children, infants, or even fetuses. We also have electro-cortical evidence that these asymmetries occur just as strongly with little children as they occur with adults. What seems to be decreasing with age is the plasticity of the brain, its ability to compensate for damage to any part. So if extensive damage to either hemisphere occurs very early, up to the age of 5, say, then the child will suffer some transient language loss but will almost always recover most of the language. If, however, the damage occurs past the age of 13, some disability will usually be permanent. In right-handed adults deficit occurs only with damage to the left hemisphere.

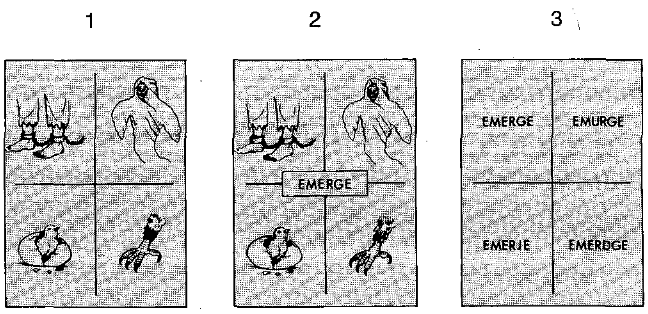
So we now have the following view. Rather than say that language is specialized to the left hemisphere uniformly, we have a continuum of specialization of language functions to the left hemisphere. Speech is indeed highly specialized to the left hemisphere. Even in the split brain it requires unified control so that the disconnected right hemisphere cannot have any speech. Reading is more bilateral, especially for single words, as we will see in a minute. Auditory language comprehension, especially for single words, is heavily bilateralized, and probably involves inter-hemispheric interaction in the normal comprehension process.

There is another way to look at this exotic model of language in the right hemisphere. How can you represent a word or a concept? Well, there are at least three ways. One is with the printed word—that is the orthography, or the spelled word. One way is with the acoustic or auditory form of the spoken word. And one way is with the picture that stands for what the word denotes. All of us, and every normal child past the first grade, can change from any representation to any other easily. We can match a picture with the word that stands for it, and a spoken word with its printed form. But can the right hemisphere do the same? Well, from the Peabody test we already know that the right hemisphere can associate the spoken word with the correct picture. So we have this connection—#1 (below).

A word standing for a thing can be represented by its sound, by its printed form, and by a picture of the thing the word stands for. This diagram shows that the right hemisphere can go from some representations to others but not equally in all directions.



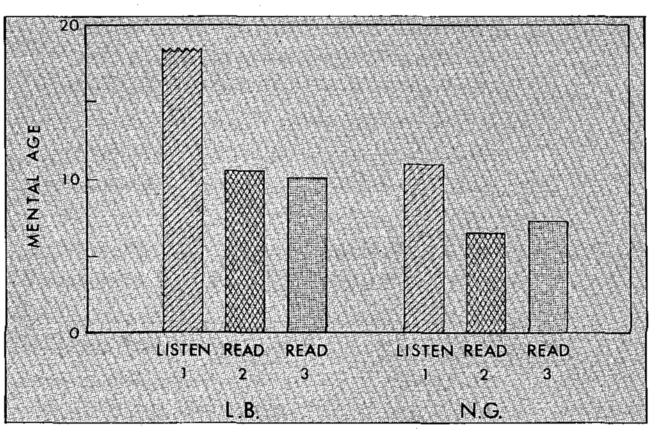
What about the ability of the right hemisphere to read single words? Here are three tests—all of them given to the right hemisphere. The test on the left, shown for comparison, is again the Peabody Picture



Three tests given to the right hemisphere for measuring the comprehension of word meanings—spoken, reading, and spelling.

Vocabulary test, the one we have met before. The examiner says a word aloud, "emerge," and the patient has to point to the correct picture with the left hand. The second test, however, is a reading version of the same test. Exactly the same stimuli are used, but here instead of saying the word aloud, the word is printed in the middle of the page. Finally, we have a spelling test, where the examiner says the word and the patient has to choose the correct spelling from the four provided. The alternatives are actually chosen because they are common spelling errors made by beginning spellers in the first and second grades. Remember that only the right hemisphere can see the visual multiple choice displays during the test.

How well can the right hemispheres do in this test,



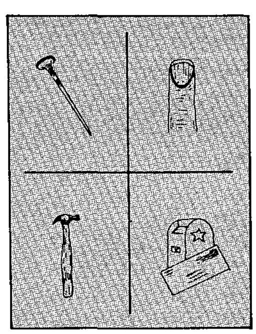
These equivalent ages of two disconnected right hemispheres show that they can comprehend more spoken words than printed words.

in terms of equivalent ages again? As we have seen before, on the standard auditory version of the Peabody test the right hemisphere of patient LB is very good, like that of a normal 17-year-old. For the reading version, he has a definitely lower ability, but still like a respectable 10-year-old, and so it is for the third test. Patient NG has the same pattern in her right hemisphere but lower scores throughout. Her auditory vocabulary is at the level of a 12-year-old; her visual vocabulary is at the level of a 7- to 8-year-old. It is significant that I have never found one case where the right hemisphere of any patient could read a word without being able to understand it when it was spoken. But the reverse is very common.

So we now have connection #2 from the printed form of the word to the meaning, to the picture. And I denote the fact (on page 18) that the visual vocabulary is a proper sub-set of the auditory vocabulary, by showing it as a smaller and dotted square.

What about the ability of the right hemisphere to write, to evoke the printed form from the meaning of the picture? Well, we suspect that there is some of it (connection #3); we know that there is a little bit of it in any case, but not exactly how much. This remains to be found.

Can the right hemisphere associate the sound image of a word with a picture? You may ask, what could I mean by that question? We know that the right hemisphere cannot speak. So how can it evoke the sound image if it cannot speak? Well, it may. Here is one way to find out. This is an item from the homonym test,

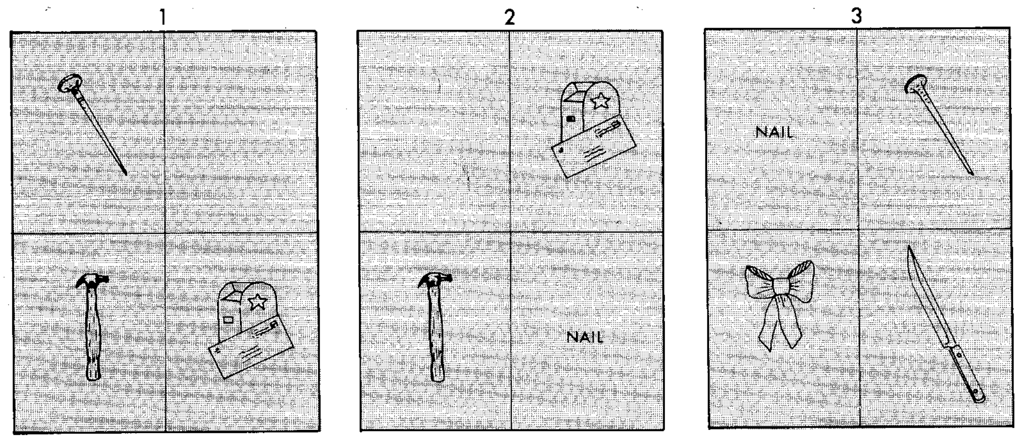


Sample item from the homonym test: "Find two that sound alike but mean different kinds of things."

developed by Ann Peters, from the University of Hawaii, and myself. The task is this: "Find two that sound alike but mean different kinds of things." The answer is a (finger) nail and a (steel) nail. Notice that the two decoys were not chosen randomly; one of them is a

continued on page 29

The Elusive Right Hemisphere of the Brain . . . continued from page 19



Find two pictures where the names rhyme.

Find a picture that rhymes with the printed word.

Control test: Which picture illustrates the printed word?

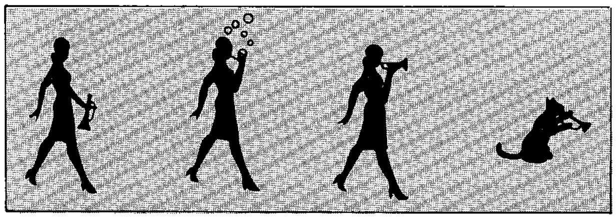
semantic associate of the nail (hammer) and one rhymes with it (mail). The left hemispheres can do this task very well but not the right. One patient, NG, could not do it at all with her right hemisphere. The other patient, LB, could do it above chance but not as well as with his left hemisphere. So we say that connection #4 is possible, but not necessary. This is especially interesting in the case of LB because there the connection occurs without speech. (We know that right hemisphere muteness is not due simply to lack of right hemisphere control over the vocal apparatus.) How can you evoke the sound image of a word without actually being able to say it? We are not sure!

What about the ability of the right hemisphere to go directly from the printed form to the auditory form? This process is very important and is called grapheme-to-phoneme correspondence rules. It is what every beginning reader is supposed to be taught in school—how to associate sound with the printed word. He sounds the word out first and then, since he knows its meaning when it is spoken, he can learn to recognize its meaning when it is printed. Psycholinguists still debate the question whether in fact the mature reader has to go through this stage when he reads efficiently. Do we, in fact, sound out the words when we read silently? Well, we don't sound them out overtly, but maybe we do it sub-vocally or unconsciously. So it's interesting to find a neurological model where this may not happen.

Does it happen in the right hemisphere? Above are three tests again. On the left is a rhyming version of the homonym test. You have seen the homonym test before. But here the task is to find two pictures where the names rhyme with each other. In fact, we used the same stimuli as for the homonym test but the picture of one of the homonyms is removed. There are many stimuli, of course, and this is just one of them—nail and mail. The second test is the crucial one. Here you have to find a picture that rhymes with a printed word. Finally, we have a control test, to see if the right hemisphere can read what "nail" means in the first place. If the right hemisphere cannot read the word, then we have a rather uninteresting reason for its failure to do the rhyming task. To rule that out we require the right hemisphere to match the printed form with the actual picture that goes with it rather than with a rhyme.

The patient who couldn't do the homonym test with her right hemisphere cannot do this either. She can do it only with her left hemisphere. What about the patient LB who could do the homonym test with his right hemisphere? Again, on the rhyming test his left hemisphere is perfect, but his right hemisphere is also very good—just as it was in the homonym test. On the reading version, however, although the left hemisphere is still perfect, the right hemisphere is at chance level. It can't do it, and this is not because the right hemisphere cannot read the word. When you just give the control test of matching the printed word with the picture, the right hemisphere is very good, almost perfect. So we say that the right hemisphere does not have connection #5. It does not do phonetic recoding. This shows that we can read without phonetic recoding; it's neurologically possible to do so, though this is not necessarily the way we actually do it, of course.

Now this is very interesting. Notice what we have here. The same right hemisphere of the same patient can match the printed form with the picture of a word, and, separately, the picture with the sound of the same word, but it cannot spontaneously go directly from the picture to the sound. Formally, this is to say that the lexical transformation



Test sentence: "Lady blowing the horn." Which is the correct picture?

relation is not transitive. By one of the tests I've shown you before where the right hemisphere had to match a spoken word with one of the four spellings of it and from other error patterns in reading, we can show that the right hemisphere does seem to have the ability to go from the auditory to the visual form (connection #6). So we can go in one direction from auditory representation to orthography but not from orthography to sound in the other direction. That means that the lexical transformation relation is not reversible. So Einstein may have been right when he said that God does not play dice with the universe—but He doesn't seem to be playing a simple formal game either. At least not when He made up the right hemisphere.

What about the reading of sentences? Above is a sentence that can be either spoken or printed, and the pictures that go with it. Notice that there are three critical items on this example: lady, blowing, and horn. Unless you get all three, you cannot point to the correct picture reliably. First let's look at the ability of the left and the right hemisphere to perform the auditory version, to listen to the sentence and point to the correct picture. The left hemispheres are normal. They can always decode sentences regardless of how long they are, up to and beyond 4 and 5 elements. The right hemisphere begins to fail if the sentence is longer than 3 items. So for those of you familiar with George Miller's magical No. 7, we may say that the left hemisphere has a short-term verbal memory of 7 plus or minus 2 items. The right hemisphere, on the other hand, may well have a short-term verbal memory of 3 plus or minus 1 items.

What about the reading version of the same test? The left hemisphere can do this still, of course, perfectly well. But the performances of the right hemispheres are definitely lower than they were on the auditory version. This is a bit surprising. I was hoping that because the printed version is always in front of the subject, the right hemisphere will be able to recover here what it had lost in the auditory version; that it can refresh its memory by reference to the print. In the auditory version, once the sentence has been said, it's no longer available, of course. But it turns out that the printed form doesn't help at all. Apparently what you need to decode a longer message is to keep the sentence in some *internal* representation. The printed form out there in the real world helps you not at all.

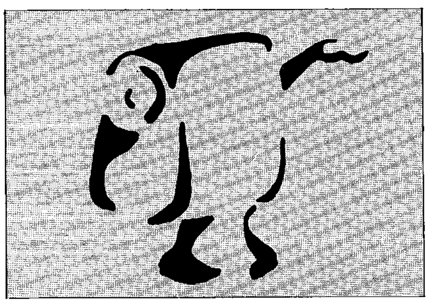
It remains to be answered by further research, what is really the special role of the right hemisphere in reading, if any. Is the right hemisphere especially important in beginning reading—that is, in assigning meaning to new and unfamiliar linguistic symbols? Or, on the contrary, is it especially important for efficient speed reading through the quick recognition of recurring visual patterns, such as the suffix "ing" or common phrases like "in the" and so on?

How does all this fit within a more general theory of human intelligence? We now know that we cannot characterize the differences between the two hemispheres in terms of sensory modality. It is not simply the case that everything visual is done better by the right hemisphere, anything auditory better by the left hemisphere. It's not the material that counts, either. Language in the left, space in the right doesn't work either. What is it then? It's the information-processing style. What are those styles?

One way to try to find out is to look at the psychometricians' concept of human intelligence. You know what the psychometrician, the factorial analyst, does; he makes up many tests. He gives them to many subjects—normal subjects—and using statistical techniques he observes which results cluster together. These he defines as primary and perhaps secondary factors or mental abilities. Most factorial theories of human intelligence, like Spearman's in England, Thurstone's in the United States, and Guilford's, not far from here at USC, recognize many factors and always at least the following three: a spatial factor, a verbal factor, and a numerical factor.

Well, spatial and verbal abilities sound like good candidates for right and left hemisphere factors, respectively, until you look more carefully. It turns out that the verbal factor is indexed, among others, by the size of the vocabulary that a subject has, but this is precisely what does not distinguish well the right hemisphere from the left—the size of the auditory vocabulary of the right hemisphere is very large. What about space? It turns out that the spatial factor is indexed among others by what is called "embedded figure tasks," the ability to extract a figure from the surrounding background. You will see in a minute that that is not a very good right-hemisphere ability. Rather, it is highly specialized in the left hemisphere. There is more promise when we look at what Thurstone called "the two visual closure factors."

The first visual closure factor is defined as the ability to perceive an apparently disorganized or unrelated group of parts as a meaningful whole; that is, the capacity to construct a whole picture from incomplete or limited material. Here is an example from a test developed by Thurstone himself to measure this ability. The question is this: If you fill in the missing parts, what do you see here? (The



Fill in the missing parts—and what do you see?

answer appears at the end of the article.) If you see a penguin, you're wrong but in good company. Those of you who don't see what this is can argue that their right hemisphere has a lower level of tolerance and has gone to sleep by now. This is presumably a very right-hemisphere type of task, as has been shown both on the split-brain patients, normal subjects, and especially with patients who have had unilateral brain damage. There is often a severe disability on this task after parietal right-hemispheric damage.

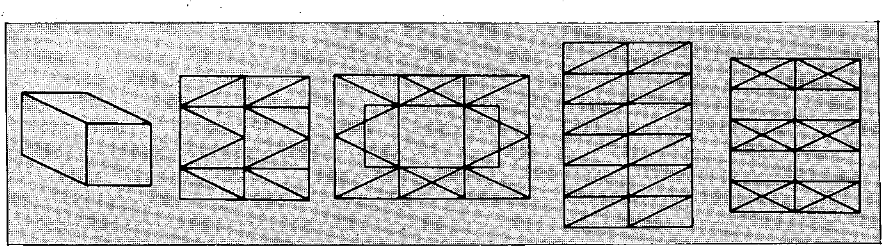
The second visual closure factor is the ability to hold a configuration in mind despite distraction; that is, the capacity to see a given configuration that is hidden or embedded in a larger, more complex pattern. Below is an item from a commonly used test for this ability—Thurston's Embedded Figures Test. It turns out that people fall into one of two groups. They are either field-dependent or field-independent, depending on whether they are poor or good on this test, and this goes with a certain personality type as well. The task is simple. Can you trace the design on the left within the more complex pattern on the right, in the same size and orientation? (The answers are shown at the end of the article.) I've given this kind of test to the two hemispheres, and it turns out to be a very heavily left-hemisphere factor. The right hemisphere is very poor in this test—even though to outside appearances it's a spatial task, the kind that the right hemisphere may be good at.

My point is not simply that these two visual closure factors describe the specialization of the two hemispheres in the visual-spatial domain, but rather that they apply equally well to the linguistic domain. The analogy is that the right hemisphere recognizes verbal units—for example, spoken or printed words—as whole patterns, as gestalts, without being able to divide and analyze them into their components. The left hemisphere, on the other hand, decodes words and sentences by feature analysis.

What are some of the prospects of this kind of work? I think that the main advances we will see in the next 10 or 20 years will be technological. We will have techniques to create benign and reversible lesions, so that any one of us could feel what it is like to operate with only part of the brain. One part of the brain could be taken out of commission for a short time by cooling or some other electrical or chemical technique and then restored to its normal operation. Then, for example, we could experience what it means to be a split-brain patient.

Undoubtedly we will have methods for interhuman communication that involve no language at all. We may have some electrodes implanted in the brain or some other means of sampling cortical neuronal activity, and we will then be able to communicate directly in terms of states of consciousness rather than with words. Here the right hemisphere may become increasingly important for the communication process. But meanwhile, until this happens, the thing I am going to do next is to try to apply the technique of the contact lens to a more general technique that enables us to present information to one half of the visual field of any person without any attachments to the eye, i.e., without the contact lens itself. And this promises to be very exciting because there is even the possibility that we will be able to rehabilitate aphasics using this technique. By getting information only to the good half of the brain, we are perhaps going to remove some pathological inhibitions from the diseased part and encourage the residual structures to take over the language functions. It also promises to be of some value for the diagnosis and remediation of certain forms of specific developmental language disability, where, presumably, hemispheric dominance is never established. Perhaps we can "encourage" and induce dominance by getting information to only one half of the brain.

You may want some more practical implication of this research, and here is my personal advice, not too serious.



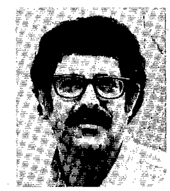
Are you field-dependent or field independent? Trace the design on the left within the more complex patterns on the right, in the same size and orientation.

The Elusive Right Hemisphere

If you are worried about incurring some brain damage, and want to minimize its consequences, choose to have it when you are very young. If this is not possible, at least be a female or a left-hander, preferably both. If everything else fails, use the following rule of my friend and colleague Rita Rudel: When you see a bullet coming, turn your right cheek.

Let me conclude with an epilogue. It is a common condemnation these days of our Western educational system that it discriminates against the right hemisphere. There is no doubt that our educational system is half-brained, but is it left-brained? To be sure, there are important differences in the learning styles of the two cerebral hemispheres; the left is constructive, algorithmic, stepwise, and logical. It benefits from narrow examples and from trial and error; it can learn by rule. The right hemisphere, on the other hand, does not seem to learn by exposure to specific rules and examples. Our studies show that it does not benefit from error correction, perhaps because it does not have an internal model of its own solution processes, which it can then interrogate and update. It needs exposure to rich and associative patterns, which it tends to grasp as wholes. Programmed instruction is certainly not for the right hemisphere, but I am not sure what is the proper method of instruction for our silent half. It is part of the elusiveness of the right hemisphere that we find it easier to say what it is not than what it is.

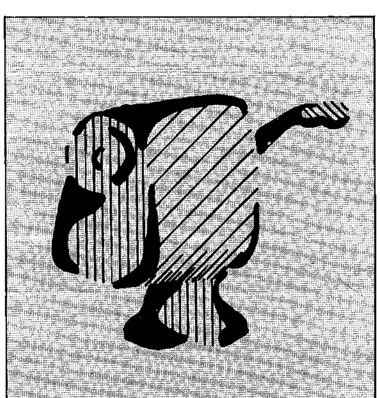
Meanwhile, rather than lament the cultural disadvantages of the right hemisphere, I ask you to take a second look at its moral fiber, lest it lead us all into temptation. I am referring to a news item in one of the issues of *Mind and Brain Bulletin*. It reads as follows: "A team at Rutgers Medical School reported that the brain's right hemisphere has a more pronounced involvement in sexual climax than the left." So I ask you, "Doesn't the right hemisphere have more fun?" □



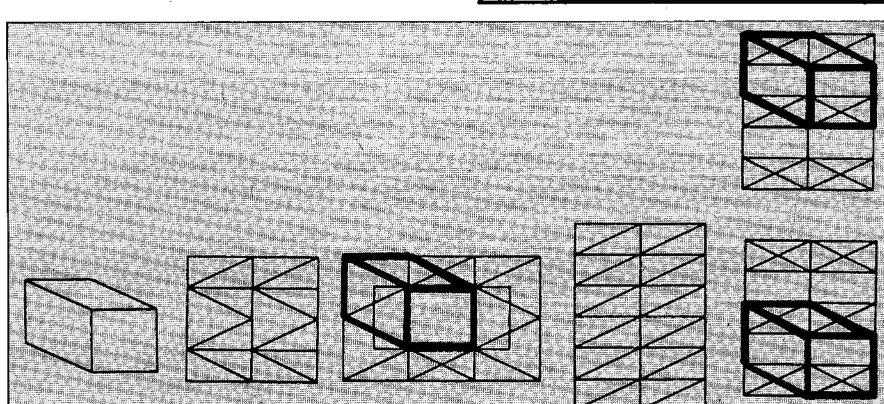
Eran Zaidel received his MS from Caltech in 1968 and his PhD in 1973 in engineering science. He became a research fellow in biology in 1973, and since 1976 he has been a senior research fellow. His article, "The Elusive Right Hemisphere of the Brain," has been adapted from a Watson Lecture given at Caltech on April 12. As a graduate student, according to his colleague Derek Fender (professor of biology and applied science), Zaidel "masqueraded as an expert in mathematical linguistics, working with Fred Thompson (professor of applied philosophy and computer science) on the problems of communication between man and the computer.

"Essentially it was his plan to teach the computer to understand English instead of its normal gobbledygook. But, as he worked on this problem, his interests swung strongly to the human side of the communication link. He transferred his allegiance from Fred Thompson to Roger Sperry (Hixon Professor of Psychobiology) and he began working on the functional capacity of the human brain. Now, his interest is condensed still further—he is only interested in *half* a brain."

ANSWERS to problems on page 31



Of course—it's a pencil sharpener.



Configuration on left is repeated three times in the larger patterns.