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A 20-Year Perspective

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and

Reply to Levy and to Zaidel

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Right Hemisphere Language Following Brain Bisection

A 20-Year Perspective

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ABSTRACT: A review of studies of right hemisphere language in split-brain patients suggests that it occurs infrequently. When present in these patients, right hemisphere linguistic competence ranges from simple comprehensive skills to a system that can both recognize written and spoken language and produce speech. Such patients also prove extremely valuable for the study of global mechanisms of mind, such as those underlying the sense of conscious unity.

In the early 1960s at the California Institute of Technology, Sperry and I initiated a long series of studies on the psychological and neurological consequences of brain bisection in humans (see Gazzaniga, 1970; Sperry, 1968). The patients were a small, select group of epileptics who suffered intractable seizures. Cerebral commissurotomy including both the corpus callosum and the anterior commissure was carried out in one operation to limit the interhemispheric spread of seizure activity (Bogen, Fisher, & Vogel, 1965). The early results contributed to a number of advances concerning the functional organization of the human brain, including findings concerning somatosensory representation (Gazzaniga, Bogen, & Sperry, 1963), visual function (Gazzaniga, Bogen, & Sperry, 1965), praxis (Gazzaniga, Bogen, & Sperry, 1967), language processes (Gazzaniga & Sperry, 1967), and nonverbal processes (Bogen & Gazzaniga, 1965). These findings also had philosophical implications with respect to generally accepted views on the unity of conscious experience (Gazzaniga, 1972; Sperry, 1968).

Research with the California Institute of Technology patients has been continued by a number of subsequent investigators under Sperry's direction, with much of the theoretical emphasis of this work arguing for the importance of differences in cognitive style between the hemispheres (Levy, Trevarthen, & Sperry, 1972) and the special properties of right hemisphere language (Levy & Trevarthen, 1977; Zaidel, 1978a). More traditional neuropsychological tests of auditory function (Zaidel, 1976), memory skills (Zaidel & Sperry, 1974), and other general observations concerning behavior as assessed on a battery of psychological tests have also been conducted (Zaidel & Sperry, 1973).

In the early 1970s I was invited to test another group of patients undergoing similar surgery by Donald Wilson (Wilson, Reeves, Gazzaniga, & Culver, 1977) at Dartmouth Medical School. The surgical approach, as well as the structures sectioned and the staging of the operation itself, provided an opportunity to confirm, modify, and extend the earlier findings. The new series also provided a small group of patients with a range of right hemisphere language skills.

In addition, we have been testing another split-brain patient operated on by Mark Rayport of the Medical College of Ohio. This patient has also proved to be linguistically sophisticated in each hemisphere. What follows is a review of studies of these three series of patients focusing on issues concerning right hemisphere language. In general, the data collected so far show that (a) most split-brain patients do not possess right hemisphere language of any kind and (b) when right hemisphere language does occur, it varies widely in its organization and extent of sophistication.

General Background and Critical Review

Traditionally, the clinical neurological literature has shown that language processes in the adult brain are largely a property of the left cerebral hemisphere (Geschwind, 1965). In recent years this view has been enhanced by new neuroanatomical correlations (Geschwind, 1965; Galaburda, LeMay, Kemper, & Geschwind, 1978) as well as by behavioral measures of language lateralization, including event-related potentials (Hillyard & Woods, 1979; Kutas & Hillyard, 1980), blood-flow measures (Lassen, Ingvar, & Skinhojie, 1978), dichotic listening procedures (Milner, Taylor, & Sperry, 1968), and unilateral sodium amytal tests (Milner, Branch, & Rasmussen, 1966).

As a consequence of the early testing of the California split-brain patients, however, there was the suggestion that the extent of right hemisphere involvement in language processing had been underestimated. With separate testing of each hemisphere, we found that two of the three commissurotomy patients tested (N.G. and L.B.) possessed some right hemisphere language capacity (Gazzaniga & Sperry, 1967). In general, what was meant by "language capacity" in these patients was the ability to understand written or spoken words. Other than the observation that bimorphemic "er" nouns derived from verbs could not be processed by the right hemisphere, we did not further delineate the semantic capacity of the right hemisphere.

It is important to note a major methodological constraint of split-brain testing: One can only be assured that the right hemisphere is performing a task if either the question or the mode of response is strictly lateralized to the right hemisphere. The only modality that allows for this is vision (Figure 1). Any conclusions concerning right hemisphere language capacity based on auditory or tactile stimulation are therefore somewhat suspect. For example, if the experimenter asks a blindfolded patient to retrieve a particular object with the left hand, a correct response cannot be interpreted as evidence for right hemisphere language. Although stereognostic information from the left hand is primarily projected to the right hemisphere, it has been shown that if the left hemisphere also knows what is being sought, it can use ipsilateral somatosensory cues to make the correct match. This fact brings into question several early conclusions concerning auditory comprehension in the right hemisphere (Gazzaniga & Sperry, 1967).

A somewhat anecdotal argument for the existence of right hemisphere language capacity commonly advanced is that the right hemisphere is capable of following verbal instructions and, therefore, must possess some language skills. It seems fallacious, however, to argue that right hemisphere competence to carry out a nonverbal task implies a language capacity because successful completion of the task signifies an understanding of the experimenter's verbal instructions. Tasks given to a split-brain patient are not only described verbally, they are also demonstrated. Just as no one would claim that a chimp understands a human's instructions when it learns how to perform a complicated association (see Premack, 1976), such a claim should not be made for the right hemisphere of humans (Gazzaniga, 1970).

With these points clearly in mind, we obtained further evidence that the right hemisphere language capacity of N.G. and L.B. was limited (Gazzaniga & Hillyard, 1971). A series of tests measuring syntactic competence as well as linguistic function suggested that these two patients had only a limited language capacity. Still, at the time, these studies implied that a reassessment of the frequency with which right hemisphere language occurs in normal adults was necessary. We stated:

> The language capacity of the minor hemisphere in Case 1 proved to be almost negligible and was decidedly inferior to that of the other two subjects. Also, Case 1, unlike the others, had sustained considerable brain damage, especially in the minor hemisphere prior to surgery. For these

Guide and Glossary to Split-Brain Research

The so-called *split-brain operation* was initially carried out by Joseph E. Bogen and P. J. Vogel in an effort to control otherwise intractable epilepsy. The operation was further developed by the late Donald H. Wilson of the Dartmouth Medical School and has now been put to use at a number of medical centers.

In brief, the brain is bilaterally organized with the left and the right half connected by the corpus callosum. This is the brain fiber system that is responsible for the exchange of information between the two hemispheres. During the surgery, this structure is sectioned by the neurosurgeons. The medical consequence of this procedure is that generalized convulsions are markedly reduced, or eliminated completely.

The neuropsychological analyses of the separate functions of each half-brain are made possible by simple lateralized testing techniques that capitalize on the normal organization of the human visual and tactile sensory systems. In brief, when a point is fixated in space, all visual information to the right of the point is exclusively projected to the left half-brain. Information presented to the left of fixation is projected to the right half-brain. This makes easily possible the separate testing of each hemisphere.

Touch information is also lateralized to a large extent. Information related to object recognition coming from the right hand is projected to the left hemisphere; the opposite is true for the left hand. More details on basic testing techniques and the simple brain anatomy that is associated with these studies can be found in Gazzaniga (1970).

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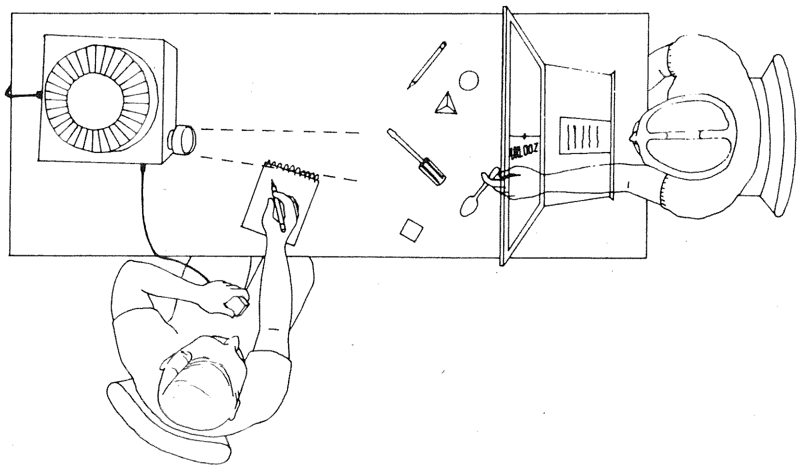
Figure 1
General Purpose Testing System



Visual information is presented tachistoscopically in either visual half field, thereby assuring lateralized testing of each separate cerebral hemisphere. Unimanual presentation of objects for somesthetic exploration favors contralateral identification. The ipsilateral hemisphere, however, can also be accurate at identifying the object if the total response set is known to the subject.

reasons it was assumed that findings in Cases 2 and 3 could be relied upon to reflect more accurately the typical effects of cerebral disconnection per se, whereas Case 1 is more representive of the kinds of disconnecxion syndrome seen in cases of brain tumor, vascular accidents, or other cerebral pathology. (Gazzaniga & Sperry, 1967)

We concluded:

> Though based on only two cases and clearly at variance with many reports in a literature filled with contradictions, there nevertheless are reasons at this time for thinking that the general picture seen in these two individuals may represent, by and large, a common and perhaps the typical picture. (Gazzaniga & Sperry, 1967)

In this light, we initiated studies on another clinical population with the aim of demonstrating more language competence in the right hemisphere (Glass, Gazzaniga, & Premack, 1973). In a study of a group of patients who were globally aphasic due to left hemisphere strokes, no natural language facility was observed other than the ability to recognize an occasional noun and a curious ability to carry out word versus nonword judgments. These observations discouraged the view that right hemisphere language was common to the general population.

As more cases were added to the split-brain series, it became clear that our early reports and conclusions were based on an unrepresentative set of split-brain patients and that the generality of our findings to normal brain organization was suspect. Work with these additional cases also suggested that perhaps we had overestimated the amount of auditory comprehension present in the two cases, N.G. and L.B. As noted above, several of the tests reported were flawed because auditory comprehension of words was assessed by the ability to retrieve the correct object with the left hand.

In the new East Coast series (see below), we have now seen evidence for right hemisphere language of varying degrees in only 3 of 28 patients. Taken together, our findings imply that right hemisphere language is not common. When present, it can be attributable in almost every case to the presence of early left hemisphere brain damage. At the same time, the relative incidence of right hemisphere language in these patients is consistent with other clinical data on the frequency of right hemisphere language as assessed by unilateral injection of amytal (Milner, et al., 1966).

Nonetheless, the claim persists that not only is right hemisphere language common, it is of a different quality and kind than the normal system coexisting in the left half-brain. For example:

> It is argued that right hemisphere language represents the experience-reinforced linguistic capacity of a special purpose cognitive apparatus as opposed to the innate language mechanisms in the left hemisphere which specializes in syntactic and phonetic analysis. (Zaidel, 1978a)

and

> Results of the Rhyming Objects Test strongly suggest that the right hemisphere lacks a phonetic analyzer that can also generate phonetic images and that its verbal capacities depend on special right hemisphere processes which although adequate for understanding simple written and spoken language are probably quite deficient for complex linguistic tasks and are certainly incapable of integrating

all but the simplest articulation. The articulations of which the right hemisphere may be capable are probably formed as motor Gestalts and are not constructed analytically from phoneme-elicited articulemes as many linguists would claim to be necessary for speaking. (Levy & Trevarthen, 1977)

Zaidel's hypotheses are based on observations of two split-brain patients, N.G. and L.B., the same patients studied earlier, plus one patient who had undergone a left hemispherectomy. There are 6 frequently studied patients in the California series and approximately 15 patients altogether (Bogen & Vogel, 1975). Levy and Trevarthen (1977) also base their conclusions on observations of these 6 patients. Yet, 4 of the 6 have not been independently assessed for language using lateralized visual techniques. In initial testing of these 6 patients by the present author, only N.G. and L.B. evidenced clear right hemisphere language function. Unless there has been a dramatic change in the language skills of the other 4 patients in the interim, all of the evidence for right hemisphere language in the West Coast group is derived solely from cases L.B. and N.G., and there are no published data to date to suggest that such a change has occurred.

Although these two patients are not characteristic of split-brain patients as a whole, they alone have led to several general hypotheses concerning the role of the right hemisphere in recovery from stroke (Zaidel, 1976) and its possible involvement in deep dyslexia (Coltheart, 1980). They have even been used as a rationale for why aphasics might be able to regain language skills (Hécaen, 1978). These claims are made despite the fact that most patients who have suffered left hemisphere strokes show little or no recovery of language beyond that which immediately follows the acute phase of illness (e.g., Luria, 1970; Sarno & Levita, 1971; Woods & Carey, 1979).

In this context, it is of interest to identify the specific claims that have been made for the special nature of right hemisphere language and to examine in some detail the underlying data base.

Phonetic Processing and the Right Hemisphere

Levy and Trevarthen (1977) were the first to observe that N.G. and L.B. were unable to carry out rhyming tasks in the right hemisphere. Zaidel (1978b) extended these observations by including a word-to-sound matching test and also found that N.G. and L.B. were unable to demonstrate evidence for phonetic processing. Comparable results were obtained in our laboratory for Case J.W. (Sidtis, Volpe, Rayport, Wilson, & Gazzaniga, 1981).

At the same time, we have also shown that the right hemispheres of two other patients are capable of rhyming, even when tested before the right hemisphere developed access to speech (Gazzaniga, LeDoux, & Wilson, 1977; Sidtis et al., 1981). Thus, the inability to perform rhyming tasks is not an absolute property of right hemisphere language. This inability also raises the question of whether performance on a rhyming task is a true index of phonetic processing in general. In follow-up studies on Case J.W., who showed no phonetic processing using the tests just described, phonological capacity was demonstrated in a semantic priming paradigm (Sidtis & Gazzaniga, in press).

In this light, it would seem premature to interpret rhyming deficits as a general phonological deficit and to conclude that, therefore, the auditory processing strategy of the right hemisphere differs from that of the left.

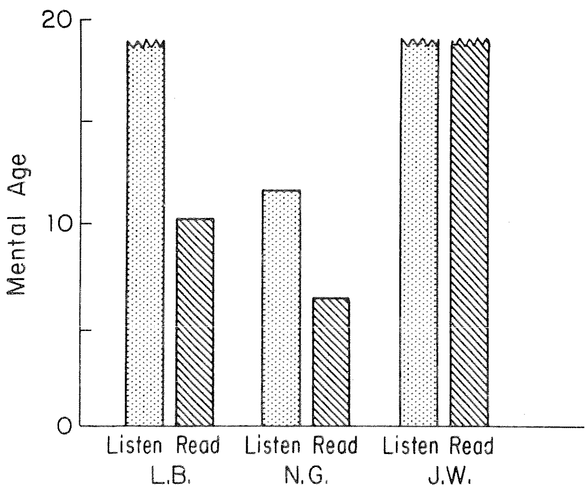
Language Comprehension in the Right Hemisphere With Prolonged Lateralized Assessment Procedures

Several other studies have reinforced the notion that the right hemisphere processes linguistic information in a unique fashion (Zaidel, 1976, 1978c). In one instance the use of a special system of stimulus presentation was combined with the administration of standardized tests of auditory and visual language comprehension. Based on these studies, Zaidel concluded that (a) auditory comprehension is superior to visual comprehension in N.G. and L.B., (b) syntactic competence is generally poor, and (c) if word frequency is taken into account, there is no difference between the comprehension of nouns and verbs. Each of these conclusions is considered in detail below.

Auditory versus visual comprehension. The claim for the superior auditory comprehension of the right hemisphere of N.G. and L.B. is based largely on the results of the Peabody Picture Vocabulary Test. N.G. has a raw score of 82; L.B. scores 103. Mental age equivalents are then determined using the established norms for the test. The mental ages for auditory stimuli were 11 and 16, respectively. The visual version of the test produced mental ages of 6.5 and 10.5, respectively. Since the highest chronological age category is 18, the values of N.G. must be considered an approximation. L.B., on the other hand, was at approximately the correct age for the mental age determination.

We administered the same test to J.W.—the patient in the Wilson series who possesses right hemisphere language that is comparable in sophistication to that found in N.G. and L.B. Lateralized presentation of the picture choices for the test were easily managed tachistoscopically (Gazzaniga, Smylie, Baynes, Hirst, & McCleary, Note 1). The testing procedures differed only in whether the test word was spoken or written. We found no difference between the visual and auditory verbal processing skills of J.W. (Figure 2). Additionally, the overall scores for the left hemisphere were higher (133) than those for the right hemisphere (109). An error analysis suggested that both hemispheres tended to miss the same words.

Figure 2
Combined Raw Scores of Three Split-Brain Cases



Shows differences in overall capabilities of the left and right hemisphere as well as differences in auditory versus visual processes for Cases N.G. and L.B. but not J.W. (Adapted from Zaidel [1978a] and Gazzaniga et al. [Note 2].)

The difference between these results and those for N.G. and L.B. may merely reflect yet another different profile of right hemisphere language. Yet, Zaidel (1978a, 1978c) argues that the difference between visual and auditory verbal processing is a real property of all right hemispheres and that the auditory processing capacity of the left hemisphere of a split-brain patient can appear to be subnormal. This conclusion is based on the left hemisphere score of a new patient, R.Y., who is a "representative commissurotomy patient" and who was actually tested under free-field conditions. The patient's subnormal performance, he concluded, was due to the fact that the right hemisphere did not contribute its normal input for auditory language functions.

This analysis raises serious questions. R.Y., a bilingual Mexican-American, is a patient who has never demonstrated right hemisphere language under any condition. This makes it questionable to argue that poor left hemisphere performance is a result of commissural section. For the claims made about the right hemisphere's normal contribution to auditory comprehension, the left hemisphere auditory comprehension of L.B. and N.G. also should be considered. In fact, these data exist (Zaidel, 1978c), and the language performance appears to be normal.

Syntactic capacity of the right hemisphere. Both patients in the California series (N.G. and L.B.) exhibited little if any syntactic capacity in the right hemisphere (Gazzaniga & Hillyard, 1971; Zaidel, 1978c). These results are also consistent with results on J.W. from the Wilson series. This is not the case, however, for patients with both language and speech in the right hemisphere (see below).

Noun versus verb understanding in the right hemisphere. Early reports on N.G. and L.B. suggested that whereas the right hemisphere could comprehend nouns, it was unable to carry out lateralized written commands (Gazzaniga & Sperry, 1967). This has been reconfirmed for N.G. and L.B. by myself (Gazzaniga, 1970) and has been noted for patient J.W. (Sidtis et al., 1981). Zaidel (1978a) reported that in N.G. and L.B. these findings were not due to a failure of the right hemisphere to comprehend action verbs: When word frequency was taken into account, the right hemisphere could define action verbs and nouns equally well. Sidtis et al. (1981) obtained comparable results for patient J.W. It should be stressed, however, that verb comprehension should not be confused with the capacity to generate a behavior. One would not necessarily predict that a patient who could correctly select a picture of a runner when the word *running* is lateralized to the right hemisphere would also be capable of carrying out the lateralized command *run.* It is this difference in generative capacity that distinguishes the left and right hemispheres of these patients, not a differential capacity to comprehend nouns and verbs. It should be pointed out, however, that both P.S. and V.P. were able to carry out commands lateralized to their right hemispheres even prior to the emergence of right hemisphere access to speech (Figure 3).

In sum, the foregoing results support the notion that the right hemisphere language skills of the few cases studied to date exhibit a wide range of sophistication. The variability of right hemisphere language comprehension is even more apparent for the recent split-brain cases. Two of these patients (P.S. and V.P.) demonstrate extensive and more complex right hemisphere language capacities than previously noted, which ultimately has included the ability to generate speech. Additional data collected from these patients are discussed below.

Language Competence of the Wilson and Rayport Series

Commissural surgery of the three patients described below differed in two respects from that performed on the California patients (see Figure 4). First, in

Figure 3
Lateralized Commands Given to the Mute Right Hemisphere

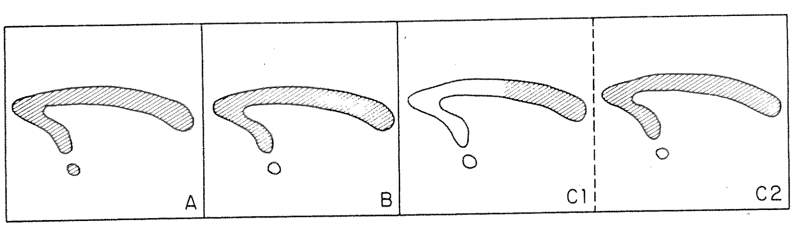
These tests were possible only in Cases P.S. and V.P. These same tests were not possible for J.W. and L.B. and N.G.

all of these cases, the anterior commissure was left intact; in the California series, commissural section included the anterior commissure. Second, in two instances (J.W. and V.P.), commissurotomy was performed in two stages, with a several-month interoperative period. The posterior portion of the callosum was initially transected in J.W.; the anterior portion was initially transected in V.P.

One might argue that because of these differences, behavioral measures of the California patients are not comparable to those of the East Coast patients. For example, it could be asserted that differences in performance between the two patient groups are accountable in terms of the functional role of the anterior commissure. This interpretation is implausible for several reasons. For one, in general, the performance of the East Coast and West Coast patients in right hemisphere language tasks is very similar. Of the 28 East Coast patients, only 3 have demonstrated evidence of right hemisphere language, a ratio consistent with the California series. Second, the right hemisphere language profile of patient J.W. is very similar to that obtained for the two West Coast patients with right hemisphere language, despite an intact anterior commissure in this patient. J.W. was also one of the patients who underwent the staged surgical procedure. It therefore seems unlikely that the manner in which the callosum is sectioned has an impact on the quality of right hemisphere language.

It should be pointed out that two of the patients discussed below (V.P. and P.S.) have developed right

Figure 4
The Variable Method and Extent of Cerebral Commissurotomy



As shown in A, Bogen et al. (1965) sectioned the corpus callosum and anterior commissure in one operation without the aid of an operating microscope; in B, Wilson et al. (1977) cut only the callosum; and in C, Wilson and Rayport cut the callosum in two stages.

hemisphere speech, whereas none of the West Coast patients have done so. It remains an as yet unsubstantiated possibility that the anterior commissure provides a means of access to the speech system from the right hemisphere. It should be emphasized that if this is the case, it cannot be argued that this invariably takes place; J.W. has shown no sign of right hemisphere access to speech in the four years following surgery.

In sum, it would appear that the quality of right hemisphere language does not depend on the presence of the anterior commissure nor does it depend on the manner in which commissural section is performed.

Language comprehension. A summary of the language comprehension skills of the 3 patients who possess some right hemisphere language in the Wilson and Rayport series, along with those of the Bogen and Vogel series, is presented in Table 1. Of the 44 split-brain patients living in the United States, only these 5 have shown clear evidence of language processes in the right hemisphere, the quality and extent of which ranges from rudimentary naming skills to language skills essentially identical to left hemisphere processes.

When several aspects of language processes are considered, two levels of language competence emerge. For example, J.W., N.G., and L.B. demonstrate clear evidence of right hemisphere semantics. Further analysis of J.W. revealed that within his right hemisphere semantic network, superordination, synonyms, antonyms, and other semantic relationships were all present. It might be expected that similar results would be found in L.B. and N.G., but despite the ability of each to comprehend verbs, neither could carry out simple verbal commands.

For P.S. and V.P., on the other hand, language comprehension in the right hemisphere appears essentially normal (Gazzaniga & LeDoux, 1978; Sidtis, 1981). In addition, the ability to carry out verbal commands for both axial and distal movement was unimpaired. Both were able to detect semantic incongruity in sentences lateralized to the right hemisphere as assessed by the N400 event-related potential (Kutas & Hillyard, in press), in a series of studies carried out by Kutas, Hillyard, and ourselves. Cases N.G., L.B., and J.W. showed much smaller N400 responses. In other behavioral tests, P.S. was able to perform well in each hemisphere on the token test, which examined a variety of syntactic skills.

The results for P.S. and V.P. indicate that, by a number of criteria, right hemisphere language is essentially normal; it is not frozen into an intermediate stage of competence as in L.B., N.G., and J.W.

Speech and writing. Case P.S. was the first split-brain patient to develop expressive speech controlled by the right hemisphere (Gazzaniga, Volpe, Smylie, Wilson, & LeDoux, 1979). Approximately 26 months after callosal section, P.S. began to provide verbal descriptions of stimuli appearing in either visual field. This was the case for both pictorial and verbal stimuli. Our first assumption was that remaining interhemispheric connections had "opened up" and that the sensory information presented to the right hemisphere was being transferred to the left. This did not prove to be the case. For example, P.S. was able to compare two stimuli only if they both appeared in the same visual half-field. If half of the information was presented to the left hemisphere and half to the right, P.S.'s performance did not exceed chance. Additional paradigms involved brief presentation of complex scenes to the

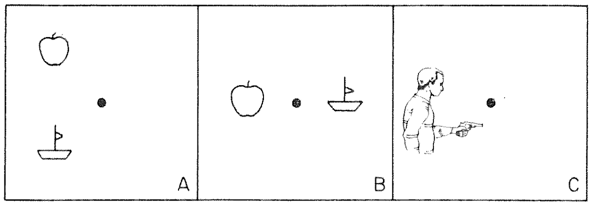
Table 1
Right Hemisphere Language Comprehension: Summary of Skills in Five Patients

	Patient				
Skill	P.S.	V.P.	J.W.	N.G.	L.B.
Phonetic					
Rhyming (visual)	+	+	−	−	−
Rhyming (priming task)	n.a.	n.a.	+	n.a.	n.a.
CV discrimination (auditory)	n.a.	+	−	−	−
Semantic					
Picture/word–word/picture	+	+	+	+	+
Synonym	+	+	+	+	+
Antonym	+	+	+	n.a.	n.a.
Function	+	+	+	n.a.	n.a.
Class membership:					
Superordinate	+	+	+	+	+
Subordinate	+	+	+	+	+
Verbal commands	+	+	−	−	−
Action verbs	+	+	+	+	+
Electrophysiological response to semantic violation (N400)	+	+	−	−	−
Syntax					
Active/passive sentences	n.a.	+	−	−	−
Token test	+	n.a.	+/−	+/−	+/−

Note. + = capable, − = incapable, +/− = intermediate, *n.a.* = not available.

left visual field. A picture of a man holding a gun, for example, prompted the exclamation "holdup." Yet, when the patient was questioned as to the details of the stimulus, an erroneous account of its actual nature was provided. Most likely, this account was generated by the left hemisphere, which remained in charge of extended dialogue (Figure 5).

Figure 5
A Variety of Tests Demonstrated That the Right Hemisphere Had Gained Access to Speech



In a within-field condition (A), same/different judgments were easily carried out, whereas across-field judgments (B) were not. In C, complex scenes were apprehended by the right in a short verbal description such as "holdup" only to then be explained away in erroneous detail by the more talkative left half-brain (from Gazzaniga et al., 1979).

The surprising development of right hemisphere speech in P.S., which is described in more detail below, was also noted in Case V.P. In early postoperative testing, it was clear that her right hemisphere language system was evolving in a manner much like that of P.S. (Sidtis et al., 1981). Shortly after surgery, her right hemisphere was able to generate responses to verbal commands and showed signs of syntactic competence. Approximately nine months postoperatively, V.P.'s right hemisphere began to generate speech. As with P.S., at first she could only name single-field stimuli presented to either the left or right half-brains. Subsequently, her naming of double-field stimuli improved.

For both P.S. and V.P., shortly after surgery the right hemisphere was able to generate written responses to questions put to it. J.W., on the other hand, was unable to do so. At the same time, however, J.W., a skilled artist, was able to draw the picture corresponding to words presented to the right hemisphere. The writing and drawing skills of N.G. and L.B. are not extensive (Gazzaniga & Sperry, 1967).

Paracallosal Integration of Phonetic Information

Just as P.S. was the first to demonstrate right hemisphere speech, he also was the first to demonstrate interhemispheric communication between the two language-competent hemispheres without overt voicing movements (Gazzaniga et al., 1982). In a series of tests, a target word was flashed to one hemisphere, and P.S. was instructed not to report the word but to call it something else. For example, if the word *apple* was flashed to the right hemisphere, the right hemisphere would be taught to respond *petunia.* Once the *apple/petunia* association was established in the right hemisphere, a series of other words was presented to either the left or right hemisphere. They were all named normally. During the series, if the word *apple* was presented to the trained hemisphere, P.S. promptly responded *petunia.* To our surprise, however, when the word *apple* was presented to the left hemisphere, P.S. also responded *petunia.* In other words, a hemisphere that had never been perceptually exposed to the word *apple* was able to associate it with the word taught only to the opposite hemisphere. This would be expected only if a transfer of information between the hemispheres had occurred. In follow-up studies, the results of a control test revealed that interhemispheric transfer in P.S. did not include the figural properties of the stimulus. These findings suggested that phonetic encoding of a stimulus is required before interhemispheric communication can occur. It is not yet clear whether such transfer relies on midbrain and brain stem systems or afferent information provided by the speech musculature.

This skill appeared in P.S. approximately one year after the right hemisphere began to initiate speech. In V.P., although she has developed right hemisphere speech, she has not, at this writing, demonstrated evidence of interhemispheric transfer. We predict that she will.

Right Hemisphere Language and Speech: An Overview

It is clear from the foregoing that language and speech in the right hemisphere can exist at either a sophisticated or rudimentary level. It is present in a small subset of the split-brain patients and in almost every case can be attributed to brain pathology occurring prior to commissural section.

It would also appear that in language systems that possess generative skills such as writing and the ability to carry out verbal commands, the probability that speech will develop is high—even in a maturational state beyond the period commonly believed to allow for such brain plasticity.

With two separate but coexisting language systems in one cranium competing for a single vocal apparatus, it might be predicted that with continual practice, interactions between the two systems would develop. This in fact has occurred in P.S. Through some as yet poorly understood language-processing mechanism, the phonetic activities of one hemisphere are known to the other.

Interhemispheric Interactions

Still more recently, we have demonstrated other, more subtle indications of interhemispheric interactions. In a series of experiments on split-brain patients (Holtzman, Sidtis, Volpe, Wilson, & Gazzaniga, 1981; Sidtis & Gazzaniga, in press), it has been demonstrated that both attentional and semantic interactions occur not only within the two cerebral hemispheres but also between the separated hemispheres (Figure 6A). These are the first studies to demonstrate that cognitively based information activated in one half-brain can influence specific processes in the other. Prior to this work, interhemispheric interactions were linked to emotional aspects of stimuli, and the spreading of emotional tone helped the speaking hemisphere narrow down possible responses (Gazzaniga, 1970; LeDoux, Wilson, & Gazzaniga, 1977; Sperry, Zaidel, & Zaidel, 1979).

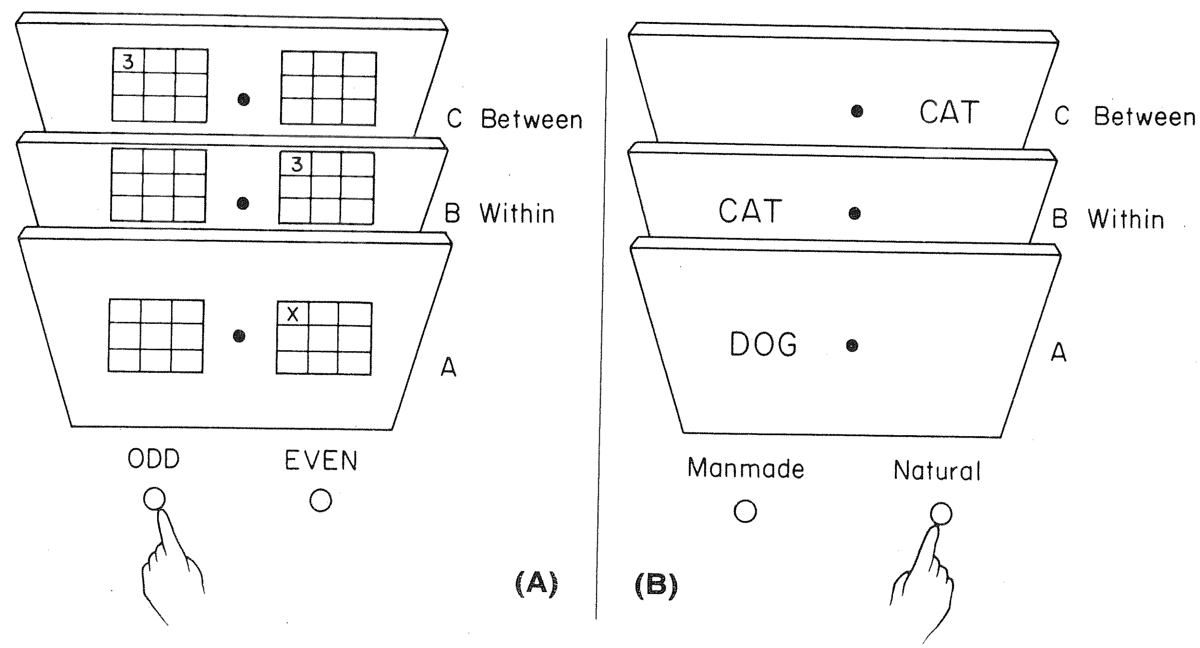
In brief, attentional interactions were demonstrated in a spatial priming task. Here, a 3 × 3 cell grid appeared in each visual field on either side of a central fixation dot. On each trial an X appeared in one of the cells followed by a digit, either in the same cell or a different cell of the same or different grid. The subject then made an odd/even judgment, and response latencies were recorded. Performance in the within- and between-field conditions was compared. Split-brain subjects showed normal facilitation of response under both conditions. Despite this outcome, patients performed at chance when asked to provide a same/different judgment of the relative location of two Xs, each appearing in a different visual field.

In an analogous fashion, semantic interactions were discovered on a priming task that required one hemisphere to judge whether or not a word designated something "natural" or fabricated. Prior to this judgment, a related or unrelated word was presented to either the same or opposite hemisphere. Priming was observed under both the within- and between-field conditions (see Figure 6B).

These results suggest that subcortical structures may play a significant role in relaying information to both hemispheres. Yet, it must be stressed that these kinds of results only obtain in patients with bilateral language. Does this mean that such observations are only of limited interest since they describe what is clearly a set of idiosyncratic patients?

On the contrary, their results provide provocative dissociates that require consideration for models of normal cognition. In the case of the semantic priming results, it has always been of interest where in the informational processing system priming effects occur. Our results suggest that priming effects

Figure 6
Attentional Interactions



Demonstrated by showing a facilitation on an RT measure to the judgment of whether a flashed number was odd or even. If the prime appeared in the same cell as the number, facilitation was seen both within and between visual fields. Semantic priming was observed for related items on a natural versus fabricated discrimination.

do not occur at the perceptual level or the phonological level since these loci for interaction are not available to patients such as Case J.W. The data appear to support the view that priming effects occur at the level of the semantic representation.

Language and Personal Awareness

One intriguing aspect of patients who have developed right hemisphere speech is that the right hemisphere becomes an assertive agent. It must be remembered that most split-brain patients have little or no right hemisphere language, resulting in extremely passive mental systems capable of performing, at best, simple match-to-sample nonverbal perceptual tasks. With a mental system that can perform transformations on stimuli, can carry out commands with ease, and can write, draw, and even talk, new questions emerge. Principally, how does the dominant left hemisphere cope with actions and even statements generated by a mental system that exists separately and initiates actions for its own discrete reasons?

One question that has concerned psychologists and philosophers for years can be tested directly in new split-brain paradigms. The effect of what traditionally has been called unconscious processes can be approached directly by observing how the verbal left hemisphere copes with overt behaviors produced by the newly verbal right hemisphere.

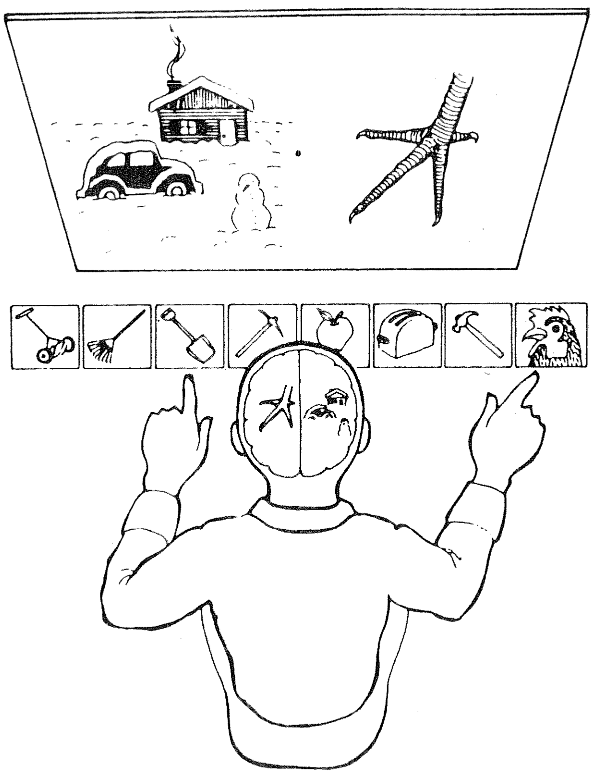
It should be noted that these studies were conducted at two points along the postoperative course of patients with right hemisphere speech: In Phase 1, the observations were made prior to the emergence of right hemisphere speech; Phase 2 took place subsequent to the emergence of right hemisphere speech.

Even during Phase 1, the left hemisphere's language system interpreted actions taken by the right hemisphere as meaningful (Gazzaniga & LeDoux, 1978). For example, in one study a single stimulus was lateralized to each hemisphere on each trial, and the subject was required to select related items from pairs of flashed stimuli. Thus, if a cherry was one of the stimuli flashed, the correct answer might have been an apple as opposed to a toaster, chicken, or glass, with the superordinate concept being, of course, fruit.

Each hemisphere could perform this task under conditions of both unilateral and bilateral stimulation. Only rarely did the response of one hemisphere inhibit a response by the other hemisphere. Of particular interest was the manner in which the subject verbally interpreted double-field responses. When a snow scene was presented to the right hemisphere and a chicken claw was presented to the left, P.S. responded correctly by selecting pictures of a shovel and a chicken from among a series of pictures before him. He was then asked, "What did you see?" He responded, "I saw a claw and I picked the chicken, and you have to clean out the chicken shed with a shovel" (Figure 7).

A similar example of creative fabrication was observed in patient V.P. In this case, a simple line drawing of a Christmas tree was lateralized to her right hemisphere. When asked to describe the picture, her left verbal hemisphere, knowing that something had been presented, responded, "A house . . . with smoke . . . coming out of a chimney." She was then asked to close her eyes and with her

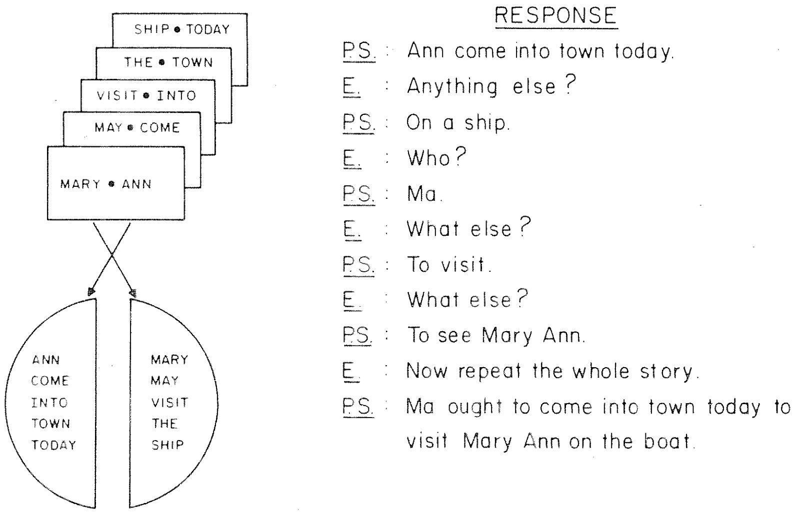
Figure 7
Method for Presenting Different Cognitive Tasks Simultaneously to Each Hemisphere



The left hemisphere was required to process the answer to the chicken claw, and the right dealt with the implications of being presented with a snow scene. After each hemisphere responded, the left hemisphere was asked to explain its choices (from Gazzaniga & LeDoux, 1978).

left hand write the name of the person usually associated with the picture. The right hemisphere, knowing very well that it saw a Christmas tree, wrote, "Sata Mein." When asked what she had written, her verbal system said, "fireman," which is consistent with her earlier left-hemisphere-generated

Figure 8
A Series of Slides Presented to the Subject



Normals read them from left to right, resulting in Story 1. Split-brain subjects read the words on the right in series, making Story 2, and the words on the left in series, making Story 3.

description. Next, using her left hand and with her eyes closed, she was asked to write the date usually associated with the picture. The right hemisphere wrote, "Dec 25." After the left hemisphere saw this response, she exclaimed, "Oh . . . Christmas! The picture must have something to do with Christmas." Asked once more to describe the picture, she replied, "Oh, you guys are going to think I'm crazy, but it was a house with smoke coming out of the chimney and a Christmas tree."

These results imply that the right hemisphere knows exactly what the picture is and can abstract information about it but cannot directly express this information to the left verbal hemisphere. The left hemisphere, on the other hand, when confronted with the fact that it wrote something totally unrelated to its initial verbal response, chooses to integrate the written message into its description.

In the case of P.S., a different experimental approach could be taken. Having developed right hemisphere speech, problems proposed to it could be remarked upon, which leads us to Phase 2. We now see in P.S. an interesting interweaving of spoken reports, one from each hemisphere (Figure 8).

In this study, P.S. was shown a series of slides with two words on each slide. Read normally from left to right, the series of slides told a logical story (Story 1: Mary + Ann, May + Come, Visit + Into, The + Town, Ship + Today). P.S., of course, cannot read the story from left to right, but rather, each hemisphere on a given trial receives a single word. The left hemisphere proceeds to read only the words on the right side of the screen, which by design also make up a story (Story 2: + Ann, + Come, + Into, + Town, + Today), and the right hemisphere reads only the words on the left side of the screen (Story 3: Mary +, May +, Visit +, The +, Ship +).

Following presentation of the entire story, P.S. was asked to recall it. He immediately responded, "Ann come into town today." This was the more robust left hemisphere expressing what it had perceived. Then, P.S. was asked if that was the full story. He paused briefly and blurted out, "on a ship . . . to visit . . . to visit Ma." When asked to repeat the whole story, he replied, "Ann came into town today to visit Ma on the ship."

Once again we see the integration of disparate behaviors into a coherent framework. With the development of bilateral access to speech, behaviors generated by the right hemisphere, which now initiates the spoken word, are incorporated into the conscious stream of the left hemisphere.

Conclusions

My intention has been to review the relevant split-brain studies to date that concern aspects of right hemisphere language and speech. I would now like to consider how these observations contribute to our understanding of the role of language in our conscious awareness.

The emerging picture is that our cognitive system is not a unified network with a single purpose and train of thought. A more accurate metaphor is that our sense of subjective awareness arises out of our dominant left hemisphere's unrelenting need to explain actions taken from any one of a multitude of mental systems that dwell within us (Gazzaniga & LeDoux, 1978). These systems, which coexist with the language system, are not necessarily in touch with language processes prior to a behavior. Once actions are taken, the left, observing these behaviors, constructs a story as to the meaning, and this in turn becomes part of the language system's understanding of the person.

Many problems, of course, remain. It is too simple to say language is identical with "consciousness" or "subjective awareness." Language can exist in virtually perfect repair in an otherwise demented or cognitively deficient neurologic patient who is incapable of solving the simplest kind of perceptual or conceptual task. As a result, it would seem more prudent to think that the left language system is intimately linked to a cognitive system that strives for consistency and order in the buzzing chaos of behaviors that are constantly being produced by the total organism.

Second, a half-brain system does not seem to be cognitively sophisticated without language despite certain visual-spatial skills. In testing right hemispheres without language skills, simple perceptual matching tests are frequently not possible (Gazzaniga, Bogen, & Sperry, 1962). Indeed, it could well be argued that the cognitive skills of a normal disconnected right hemisphere without language are vastly inferior to the cognitive skills of a chimpanzee. This raises intriguing ontogenetic questions. Since the right hemisphere during normal development most likely goes through a phase of being able to become language competent, the subsequent consolidation of language processes in the usually dominant left hemisphere seems to lead to a freezing of the overall cognitive competence of the right. Of course, this fact only emerges in these special split-brain cases and in left-hemisphere-damaged patients. It would appear, nonetheless, that the price of lateral specialization for language on the left is a state of rudimentary cognition for the right hemisphere, which is revealed only if the latter has to serve alone following brain bisection or left-brain damage.

Finally, the fresh awareness that the two separate cognitive systems do interact at important levels in the realms of both attentional process and semantics suggests that any of a variety of subcallosal brain mechanisms may be involved in these functions. It has been suggested, for example, that specific pathways involving pulvinar/parietal systems may integrate the visual half-fields for the control of attention (Holtzman et al., 1981). Possible linking systems for semantic processes are less definite.

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Reply to Levy and to Zaidel

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The foregoing review of split-brain data (Gazzaniga, this issue) was intended, first, to argue that the incidence of right hemisphere language in commissurotomy patients is relatively rare and when present varies in its level of competency; second, to elucidate several interesting hemispheric interactions that occur in these patients in the attentional, semantic, and emotional domains; and third, to argue that the left-speaking hemisphere constructs theories about the assertive behavior emanating from the mute right hemisphere. I will present my response to the two critiques separately.

Levy (this issue) concurs that the incidence of right hemisphere language is rare and chooses not to address the other issues. Instead, her reply is almost exclusively concerned with the implications of my assertion that "most split-brain patients have little or no right hemisphere language, resulting in extremely passive mental systems capable of performing, at best, simple match-to-sample nonverbal perceptual tasks" (p. 534). Although this point is tangential to the main argument of the article, it is worthwhile to consider the bases of the disagreement.

1. Levy claims that the two patient populations (California and East Coast) differ in their neurologic histories and argues that early neurological damage is peculiar to the East Coast patients. In fact, California patient L.B.'s seizures were first noted at the age of 3½, whereas N.G.'s seizures were first noted at the age of 18 (Bogen & Vogel, 1975). In a more recent review, it is claimed that both of these patients may have experienced birth trauma (Campbell, Bogen, & Smith, 1981). Of the East Coast patients, P.S. had early signs of neurologic abnormalities (age 2), J.W. was considered normal until age 19, and V.P. had her first seizures at age 9. Thus, both series of patients show evidence of early and late neurologic injury, and it is unlikely, therefore, that any behavioral differences between the two patient groups are due to differences in the onset of their epilepsy.

2. Levy states that the capacity of the right hemispheres of L.B. and N.G. to associate pictures and words (Gazzaniga & Sperry, 1967) does not imply "linguistic" competence, nor, for the same reason, can it be argued that linguistic competence exists in a left hemispherectomy patient studied by Zaidel (1978). In the context of the variability of right hemisphere language competence seen in commissurotomy patients, I would argue that the presence of a naming skill represents the rudiments of a minor hemisphere language system. The presence of right hemisphere syntactic ability, phonetic processing, and other language skills in V.P. and P.S., of course, clearly represents some kind of linguistic competence. My point was simply to describe the demonstrably broad range of minor hemisphere language competence that is found in commissurotomy patients. The implications of this linguistic competence for general cognition is quite another matter (Gazzaniga & Smylie, 1983b).

3. Levy is most concerned with the issue of right hemisphere passivity. Here, important qualifiers were ignored. My contention was that the performance of right hemispheres with little or no language is limited to simple match-to-sample tasks, whereas right hemispheres with language are more capable, since among other things, they are free to respond to linguistic input.

Empirical support for right hemisphere responsiveness is based on a study in which a different half-picture was simultaneously presented to each hemisphere. Each hemisphere's ability to carry out a physical ("appearance") and a functional match-to-sample was subsequently assessed. It was found that if the task demanded an appearance match, the right hemisphere stimulus was frequently chosen. That is, in a competitive situation in which visual tasks that can be carried out by both hemispheres are presented simultaneously, the right hemisphere often dominates the response. In this instance, the right hemisphere performed a physical match-to-sample that presumably requires minimal cognitive skill. Using the same stimuli, we also have noted that each hemisphere is capable of responding (Gazzaniga & LeDoux, 1978).

4. Finally, Levy claims that it is my belief that the human right hemisphere is incapable of processing information in uniquely human ways. I make no such contention and, in fact, have argued to the contrary (Gazzaniga, Bogen, & Sperry, 1965; Gazzaniga and Smylie, 1983b). The right hemisphere does appear uniquely capable of certain kinds of visual, tactile, and auditory processing, and it is of interest to elucidate the nature of such specialization.

After the first observation on the disconnected right hemisphere of W.J., N.G., and L.B., it was clear that there were dramatic differences between the two half-brains in their capacity to process certain kinds of visual-spatial information. Subsequent studies by Levy, Trevarthen, Nebes, Milner, and others advanced the view that the right hemisphere was perceptually superior to the left and processed information in a different cognitive style, the left being more analytic, the right more holistic, and so on.

Levy asserts that the definitive demonstration of right hemisphere reasoning was performed by Franco and Sperry (1977). In this study, an array of five visual stimuli was placed in full view of the subject. The stimuli in each array were interrelated based on a specific geometric relationship. It was asserted that this relationship could only be abstracted by considering the complete set of stimuli. Although the results suggest that the right hemisphere could perform this task, a critical problem with this study is that a correct solution may have been feasible by considering only *one* of the five stimuli, with the choice made on a simple physical match-to-sample.

As for the test of unfolding patterns, the data are not compelling. Here, only L.B. performed this task better with the left hand—a patient with right hemisphere language who, I would therefore predict, should be most capable of doing so. Yet, this is the patient who rarely shows any of the right hemisphere superior performance effects on the various other tests such as those of Nebes.

On the whole, Levy's concerns are issue oriented. As neuropsychology moves toward a more complete understanding of brain laterality, the contribution of each hemisphere to the expression of specialized skills and the role language plays in such expression will continue to be clarified through future research.

Zaidel's (this issue) claims on the other hand seem to me to run contrary to the first-hand experience of all those who have studied these patients. They are also inconsistent with his own prior claims and, furthermore, are internally inconsistent. I will deal only with the major inaccuracies.

1. Zaidel leads the reader to conclude that patients N.G. and L.B. were selected for study because of their sex, IQs, and clinical histories and that their neurological histories would suggest that they should have less than normal right hemisphere language. That is a perception that is shared by no one else involved with the patients (e.g., see Levy, this issue). If we accept Zaidel's claims, it is puzzling why someone who is interested in establishing the "upper limits of right hemisphere language," as Zaidel appears to be, would initially select patients in whom impoverished right hemisphere language would be anticipated. When Zaidel's studies began in the early 1970s, patients L.B. and N.G. were the only patients who demonstrated any right hemisphere language. It is most likely that Zaidel, like myself and others, chose to study these patients for this reason.

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2. Zaidel's current claim that 5 of the 11 California patients demonstrate right hemisphere language competence comparable to that observed in L.B. and N.G. is nowhere substantiated in the existing literature. We look forward to examining the data finally acquired from patients in whom the existence of right hemisphere language resisted empirical demonstration for over 15 years. We are also awaiting an explanation as to why a lexical decision task revealed a competence that could not be demonstrated by such simple tasks as determining whether or not the right hemisphere could point to a word, in free field, that best described a lateralized picture such as an "apple." We also look forward to the explanation of why tachistoscopic techniques can now accurately portray the linguistic capacity of the right hemisphere when Zaidel has been arguing for several years that the upper capacities can only be determined with the "Z lens."

3. The veritable bottom line is, of course, Is there a right hemisphere profile for natural language? The answer, demonstrably and clearly, is no. Every patient studied and reported in the literature has a different profile. Does Zaidel (1978) argue for a normal contribution from the right hemisphere for normal language activities? I quote:

> Probably the most common characterization of hemispheric specialization is the material-specific description of the LH as linguistic and or the RH as nonlinguistic or visuo-spatial . . . But even the assumption that the LH is uniformly adult-like on any psycholinguistic test is incorrect. For example, Figure 5 shows the mental age profile of a representative commissurotomy patient, R.Y., in standard, free-field testing . . . On the assumption that (especially verbal) responses in the free-field testing situation are typically controlled by the patient's LH, it follows that the psycholinguistic ability of this LH is not uniform and, indeed, that it is subnormal . . . But the low psycholinguistic profile is representative of more or less subtle linguistic and related deficits (e.g., in reading speed, or richness of spoken vocabulary) which may be partly attributable to the lack of normal RH contributions. (p. 270)

4. Finally, is there a common neurologic event that could explain these rare occurrences? It would appear not, and even my suggestion that early left hemisphere damage created the neural climate for such a state has come into question, a point not so clearly established 3 years ago when I first submitted this article to this journal (Woods, 1981).

Zaidel's position reminds me of an incident involving the great Cuban chess champion, Capablanca. He was called on to analyze how "black" could make the best of a decidedly disadvantageous position on the board. After a masterful analysis of what "white" and "black" had done and why, he sighed, "The only real solution to this problem was not to have gotten into this situation in the first place."

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