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Competence versus Performance after Callosal Section: Looks Can Be Deceiving

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The classic approach to relating sensory, perceptual, and cognitive functions to specific brain areas has been to characterize the behavioral deficits that accompany damage to the areas in question. Functional significance is thereby established by inference: areas in which damage causes profound or relatively permanent deficits are generally assumed to subserve a more important role in the impaired function than are areas in which damage causes a less severe or more transient loss. Although this approach is not foolproof (for example, general regulatory areas may be assigned the same functional importance as areas that perform specific operations) the analysis of cognitive deficits following focal brain damage has provided the foundations for neurological and neuropsychological understanding of the functions of the left and right cerebral hemispheres.

An unusual complement to the classical approach to the study of lateralized cerebral function became available with the advent of the neurosurgical procedure of callosal section for the control of otherwise intractable epilepsy. Certainly, the classic approach has been and continues to be used in studying the human split-brain syndrome. The analysis of deficits in interhemispheric transfer and integration after surgical lesions to this tract has established the role of the corpus callosum in interhemispheric communication. The commissurotomy population also provides a situation in which the functions of each hemisphere can be studied directly, without recourse to defectology. In this approach, the comparison between the performance

obtained from each callosally disconnected hemisphere allows subjects to serve as their own controls, since callosal section does not result in focal damage of either hemisphere. The interpretation of the results of such interactions must take into account each patient's neurological history as well as the epileptic focus. In commissurotomized patients with two relatively intact cerebral hemispheres, the absence of any gross neurological deficits due to disconnection is striking.

It is the apparently normal behavior of commissurotomy patients that led to the first of several paradoxical findings in the history of split-brain research, namely, the early claims that surgical section of the corpus callosum produced no behavioral changes. As is now known, the first look at the split-brain subject was deceiving. In this chapter, several areas will be discussed in which the performance of commissurotomy patients provides the strongest impetus to reconsider the traditional ways in which lateralized cognitive functions are conceptualized.

NORMAL BEHAVIOR WITHOUT A CORPUS CALLOSUM

In the face of nearly a century of clinical-neurological observations and descriptions that strongly demonstrated that the left and right hemispheres mediated very different mental functions, A.J. Akelaitis purported to show that surgical section of the corpus callosum, the major interconnection between the cerebral hemispheres, had very little effect on behavior. In a series of studies that included 26 patients with either a partial or complete section of the corpus callosum, Akelaitis and his colleagues concluded that the callosum had no significant role in functions such as vision, gnosis, praxis, or language (e.g., Akelaitis, 1941, 1944; Akelaitis, Risteen, Herren & Van Wagenen, 1942; Smith & Akelaitis, 1942).

The role of the callosum in interhemispheric information transfer began to be understood with the animal work of Myers and Sperry (1953). By sectioning the optic chiasm in cats, information could be lateralized to one of the hemispheres by using a monocular training procedure. Myers and Sperry demonstrated that, whereas monocularly trained animals could perform the learned discrimination with either the trained or the untrained eye when the callosum was intact, the training was not bilaterally available when the callosum was sectioned. Subsequent work confirmed the importance of the callosum in the transfer of visual information between the hemispheres (e.g., Myers, 1956, 1962). It was in this context that a new series of human commissurotomy studies was initiated.

When Akelaitis's approach was repeated on this new series of patients, operated on by Bogen and Vogel, the results were similar to those reported by Akelaitis in the 1940s. However, when the methodology was modified so that information was lateralized to a single hemisphere, when visual guidance of motor acts was eliminated where inappropriate, and when the opportunities for cross-cuing were restricted, the human split-brain syndrome became apparent. Contrary to the conclusions drawn by Akelaitis, the corpus callosum was shown to play a major role in the interhemispheric transfer of sensory information, as well as in ipsilateral cortical control of distal motor activities (e.g., Gazzaniga, 1970; Gazzaniga, Bogen, & Sperry, 1962, 1965, 1967).

The study of commissurotomized patients and of patients with callosal lesions of vascular and neoplastic etiologies has revealed some of the important functional properties of the corpus callosum. The posterior part of the callosum provides a sensory window through which information about a hemisphere's ipsilateral sensory field is transferred. The splenium, which is at the most posterior extent of the callosum, is responsible for the interhemispheric transfer of visual information (e.g., Gazzaniga & Freedman, 1973; Maspes, 1948; Sugishita, Iwata, Toyokura, et al., 1978; Trescher & Ford, 1937). Anterior to the splenium but within the posterior half are the areas responsible for the transfer of audition, touch, and motor control (e.g., Sidtis, Volpe, Holtzman, et al., 1981a; Springer & Gazzaniga, 1975; Volpe, Sidtis, Holtzman, et al., 1982). The patient who has undergone surgical section of the posterior half of the callosum, then, looks like the completely commissurotomized patient in many respects. Table 5-1 presents performance on naming stimuli presented to the left and right sensory fields prior to and following section of the posterior callosum.

Unlike the patient with a complete callosal section, however, the patient with the posterior callosal section may not verbally deny right hemisphere stimulation. In one such patient, J.W., the left hemisphere language system could not name right hemisphere stimuli because of the absence of sensory transfer, yet he did express a sense of knowing what the stimulus was. The interhemispherically transferred information that provided this sense of knowing enabled the patient's left hemisphere language system to interact with the examiner in a game of "20 questions" regarding the right hemisphere stimuli. By using this strategy, J.W. could name right hemisphere stimuli at levels significantly better than chance. During a ten-week interoperative period when only the anterior portion of the callosum was intact, the patient learned to describe his sense of right hemisphere stimuli in a form much like that of a mental image. His descriptions were rarely that of the stimulus itself, but were typically of a context or episode related to the stimulus. For example, the word *stove* elicited a description of his aunt's kitchen; the word ***onion*** elicited a description of a family garden. Following completion of his callosal section, the

TABLE 5-1.
Naming Accuracy (percentage correct) on Stimuli Presented to the Left and Right Sensory Fields Prior to and Following Surgical Section of the Posterior Half of the Corpus Callosum

	Left sensory field		Right sensory field	
Modality	Callosum intact	Posterior callosum sectioned	Callosum intact	Posterior callosum sectioned
Vision				
Pictures	93	28[a]	93	91
Words	63	13[b]	92	96
Tactile				
Objects	100	20[b]	100	90
Audition				
C-V syllables	67	23[b]	77	100

[a]Reflected patient's use of 20-question interaction (see text).
[b]Not significantly better than chance.

patient could no longer access this information for verbal description. In fact, like the classic split-brain patient, he verbally denied right hemisphere stimulation. The kinds of responses produced at each surgical stage are depicted in Figure 5-1. The observations of cognitive transfer in J.W. suggest that the anterior callosum was providing the left hemisphere with mnestic information activated by the right hemisphere. The left hemisphere then had to search the memory to retrieve the original referent.

The corpus callosum, then, provides interhemispheric communication at several levels. It plays an important role in supplying visual, auditory, and somatosensory information from the ipsilateral sensory fields, and it also mediates ipsilateral motor control of the distal extremities. This tract also provides higher-order information, transferring the results of cognitive processing in each hemisphere.

Although, in retrospect, there may be a temptation to summarily dismiss the work of Akelaitis, his reports make an important point about the human split-brain syndrome. When two intact cerebral hemispheres are separated, there is little discernible loss of function at a gross behavioral level, except the capacity to cross-integrate information from the left and right sensory fields. Even the cross-integration deficits are not obvious in unconstrained behavioral situations, as is evident from Akelaitis's extensive negative results and from

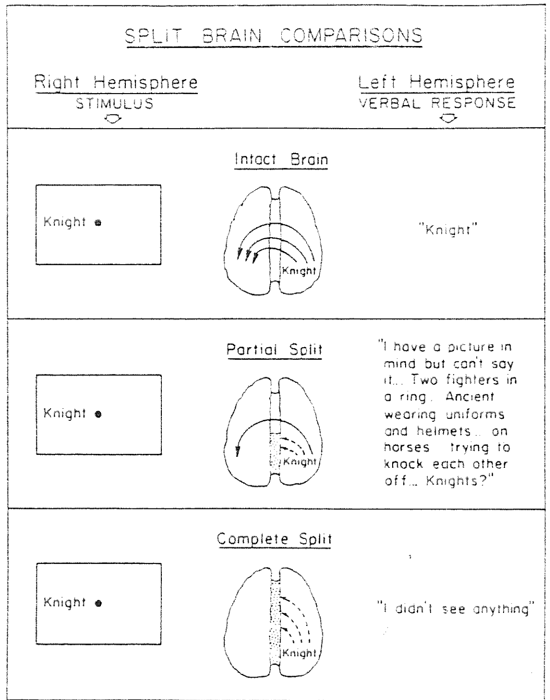

Figure 5-1. *Schematic representation of J.W.'s left-visual-field naming ability with the corpus callosum intact, with the posterior portion of the callosum sectioned, and with the entire callosum sectioned (after Sidtis et al., 1981a).*

simply observing commissurotomy patients' behaviors in normal situations. The comparative subtlety of the split-brain syndrome compared with other neurological syndromes emphasizes the enormous behavioral plasticity available to two intact hemispheres. To compensate for the absence of neural interhemispheric communication, split-brain patients attempt to ensure that communication by using any available information. Much of this information can be provided by behavioral means, such as eye movements, visual guidance of motor acts, and auditory cross-cuing. Moreover, since there is no apparent loss of specific cognitive function in either hemisphere, the subject has not one, but two brain systems contributing to the behavioral compensation for disconnection, without having to additionally compensate for cognitive gaps in mental function. The grossly normal performance of commissurotomy patients,

then, is not evidence of the competence of subcortical commissures in the normal interhemispheric integration of cortical sensory and motor activity. Rather, such performance demonstrates the competence of intact cognitive systems in using neural, perceptual, and behavioral information to integrate left and right hemisphere functions in the absence of the corpus callosum.

TWO KINDS OF VISUAL FUNCTION

The ability of split-brain patients to use behavioral cross-cuing strategies to compensate for callosal disconnection can account for some but not all aspects of their behavior. In general, each hemisphere receives direct sensory input largely from the contralateral sensory hemifield, with the ipsilateral hemifield supplied by the callosal window. Through the geniculostriatal projections, for example, occipital areas in each hemisphere receive information about the contralateral visual field, while the splenium of the corpus callosum supplies the ipsilateral visual fields. When the posterior portion of the callosum is cut, each hemisphere can subserve visual identification and recognition only for its contralateral hemifield, and the ability to integrate visual information from the two hemifields is lost (e.g., Sidtis et al., 1981a). In spite of this, visual-motor function in both the partial-posterior and complete commissurotomy patient is intact for a wide range of activities for which one might expect at least some dysfunction: running, throwing, catching a ball, swimming, and even riding a bicycle. Such goal-directed behaviors, which require integration of information across the visual midline, are somewhat paradoxical in light of the striking disconnection phenomena one can demonstrate in the laboratory.

Based upon the visual disconnection observed when commissurotomy subjects are required to identify stimuli, one might expect one or both of the following situations to occur during the execution of goal-directed visual-motor acts. If both hemispheres vied for the control of motor acts, one would observe a constant state of competition, likely to be marked by hesitancy, abrupt starts and stops, and misdirected movement. However, if a single hemisphere dominated the control of such acts, one might expect to observe some form of hemispatial neglect or inattention. Whereas both situations can be elicited under certain laboratory conditions, neither is common under normal conditions.

One possible explanation for this discrepancy is that the processes underlying visual identification and those underlying the control of visual attention are dissociable, both behaviorally and neurophysiologically. Whereas the processes underlying identification in each hemisphere have access only to information from the contralateral visual field after commissurotomy, the process underlying the control of attention in either or both hemispheres may retain bilateral access to visual information. The possible dissociation of the control of visual attention from explicit identification after commissurotomy was examined in a study that incorporated a spatial priming paradigm (Holtzman, Sidtis, Volpe et al., 1981).

The question in these studies was straightforward: although it was well known that visual information used for stimulus identification could not be integrated across the midline after commissurotomy, could the control of visual attention use information accessed from a source not restricted to a single hemifield? To examine the question of whether information used in the control of visual attention had a bilateral representation after commissurotomy, Holtzman et al. used a spatial priming paradigm, in which subjects had to judge whether a digit briefly presented at various spatial positions in one of the visual fields was odd or even. The spatial location of the digit was constrained to a cell in one of two three-by-three cell matrixes that were presented continuously, four degrees of visual angle to the left and right of fixation. Each presentation of a digit was preceded by a cue (the letter x); a valid cue would appear in the same cell as the digit, an invalid cue would appear in a different cell, and a neutral cue would appear at the fixation point between the two grids. These contingencies occurred under both within- and between-visual field conditions. In the between-field condition, the valid cue appeared in the cell homologous to the one in which the digit would appear in the opposite visual field. Likewise, the invalid cue in the between-field condition appeared in a cell other than the one in which the digit would appear, in the opposite visual field. The neutral cue was the same in both within- and between-field conditions. Figure 5-2, B, depicts a typical within-field valid trial, in which a cue appears in the right visual field, followed by the number 3 in the same spatial position in the same field. In Figure 5-2, C, a between-field trial, the number 3 appears in a homologous location in the opposite visual field. In both cases, the patient would respond appropriately by pressing the odd key.

The performance of normal subjects has been shown to benefit when an antecedent cue provides valid information about the spatial location of a subsequent target (e.g., Posner, Snyder, & Davidson, 1980; Shulman, Remmington, & McClean, 1979). As expected, the performance of two commissurotomy patients, P.S. and J.W., also showed such a benefit in the within-field condition. The critical data, however, are in the between-field condition, where performance was quite similar to that observed in the within-field condition. These results are presented in Figure 5-3. One can see that, in both the within- and between-field conditions, there was a significant effect of cue type: performance was best when the cue was valid and worst when the

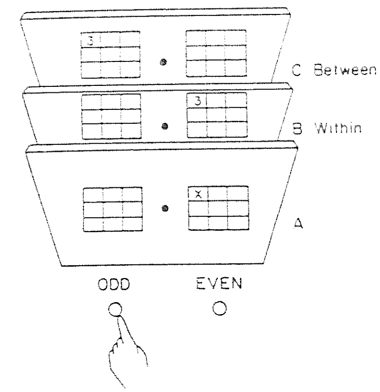

Figure 5-2. *Typical within-field (b) and between-field (c) trials in the spatial priming study.*

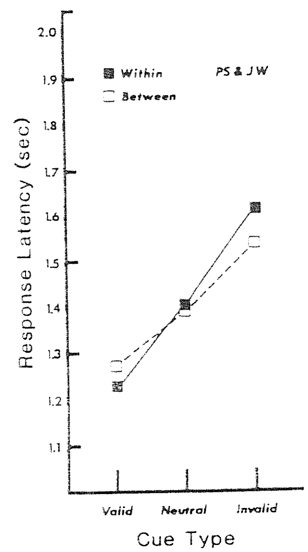

Figure 5-3. *Response latency as a function of spatial cue type. Data are presented separately for the within-field condition and the between-field condition. Each data point represents the average of two observers, with each given equal weight (after Holtzman et al., 1981).*

cue was invalid. Not only was spatial location information accessible within a visual field but also across fields.

A second experiment was carried out to determine whether or not spatial location information was bilaterally accessible for explicit interfield comparisons. As in the first experiment, three-by-three grids were presented continuously to the left and right of central fixation. In this study, however, the digit was replaced by the letter x, and the subject had to make a "same" response if the antecedent cue and the subsequent target appeared in the same or homologous cells or make a "different" response if the two stimuli appeared in different cells. Both patients showed good performance in the within-field conditions, but performance in the between-field condition was at or near chance. The spatial information that was bilaterally accessible for the control of attention was not accessible for explicit interfield comparisons.

The results of these two studies strongly suggest the operation of two dissociable cognitive components in visual information processing—one subserving identification and the other subserving the control of visual attention. Whereas the former is mediated by the primary geniculostriate pathways, which cortically represent the contralateral visual hemifield, and by the splenium of the corpus callosum, the latter probably reflects information processing in the parietal lobe, which appears to maintain access to both visual fields after callosal disconnection. It is probably the selective loss of one or the other of these two visual functions that is responsible for the clinical reports of blind-sight after occipital lesions (e.g., Perenin & Jeannerod, 1975; Weiskrantz, Warrington, Sanders, & Marshall, 1974), and of hemi-attentional deficits after parietal lesions (e.g., Friedland & Weinstein, 1977).

It should be emphasized, however, that the integration of visual information for attentional control is observed in the context of the classic split-brain syndrome. Although a cue appearing in the left visual field may either facilitate or interfere with the classification of a subsequent target, information appearing in this field cannot be accessed by the language systems in the left hemisphere. Commissurotomy patients cannot report left-visual field cues or targets and typically deny any experience after stimulation of that field. Thus, some of the information processing that contributes to the control of attention operates outside the sphere of verbal awareness.

Whereas the apparently normal performance of the commissurotomy patient under a wide range of conditions led Akelaitis to overestimate his subjects' competence in interhemispheric integration, there are other conditions for which the commissurotomy patient's poor performance under some conditions may lead to an underestimate or an inaccurate characterization of a hemisphere's competence. Two areas for which such conditions exist will be considered: the so-called visuospatial functions of the right hemisphere and the language functions of the right hemisphere.

VISUOSPATIAL VERSUS MANIPULOSPATIAL FUNCTION

In contrast with the role of the left hemisphere in language, the functional characteristics of the right hemisphere have been poorly understood. The descriptions of the cognitive strength of this side of the brain have emphasized its relative superiority over the left hemisphere for functions such as construction (Patterson & Zangwill, 1944; Piercy & Smyth, 1962), manipulation and spatial appreciation (e.g., DeRenzi, Faglioni, & Scotti, 1970; Weisenburg & McBride, 1935), synthesis (Denny-Brown & Banker, 1954), and holistic processing (Levy-Agresti & Sperry, 1968). Although none of the functional descriptions of the right hemisphere approached the detail provided by aphasiology for the left hemisphere, most of them shared an emphasis on visual and spatial abilities (see Meier & Thompson, this volume).

The so-called visuospatial dominance of the right hemisphere was also observed in early commissurotomy patients (Bogen & Gazzaniga, 1965). Prior to callosal section, both W.J. and N.G. could copy three-dimentional drawings better with their right hands than with their left hands. However, after surgery, better performance was produced by their left hands; for both patients, right-handed attempts at copying a cube produced drawings that failed to convey depth. A right hemisphere advantage was also observed on the block design subtest of the Wechsler Adult Intelligence Scale. Whereas the left hand of W.J. was able to accurately reproduce each of the seven designs tested, the right hand accurately reproduced two.

The right hemisphere advantage for visuospatial processing was reexamined in a patient, P.S., from the Wilson series (LeDoux, Wilson, & Gazzaniga, 1977). LeDoux et al. noted that, although many of the descriptions of right hemisphere function emphasized visual and spatial characteristics, most of the observations on which such descriptions were based were made in situations in which manual manipulation was required in the response. If, in fact, the right hemisphere's advantage was based upon a visual-perceptual superiority, they reasoned, it should be observed even when a manipulative response was not required.

Like W.J. and N.G., after complete callosal section, P.S. could only convey depth in the copy of a cube produced by his left hand, although prior to surgery this could be accomplished with either hand. Similarly, he accurately completed five out of six block designs with his left hand but only three out of six with his right hand. Two other tests of spatial processing were also used, and similar results were obtained. In the wire figures test (Milner & Taylor, 1972), a series of nonsense shapes fashioned out of wire were tactually presented, and after each figure was palpated, the subject was asked to manually select the figure from a set of four alternatives. P.S.'s left hand was errorless on this task, but his right hand performed at chance. A fragmented figures test was also administered (Nebes, 1972). In this test, the patient tactually explored three geometric shapes and was required to select the shape that corresponded to a visually presented "unfolded" version of the shape. Again, the right hand performed at chance, while the left hand's accuracy ranged between 75 and 90%.

When these tests were readministered without requiring a manual manipulative response, the previously observed right hemisphere advantage was eliminated or reduced. When the patterns from the block design test were visually lateralized to either hemisphere and the patient had to point to the correct design, the previously observed right hemisphere advantage was eliminated. Similarly, when the wire figure designs were presented visually, neither hemisphere erred, and when the fragmented figures task was presented in this fashion, left hemisphere performance improved to 85%, while the right hemisphere remained at 100%.

One of the important points of these results was, that for many of the spatial tests of right hemisphere function, the manipulative aspects of the response were more important than the demands of simply discriminating the test patterns visually. This is not to say that, under some circumstances, right hemisphere visual-perceptual advantages do not occur (e.g., Gazzaniga & Smylie, in press; Moscovitch & Klein, 1980), but rather that the right hemisphere's apparant advantage in spatial processes may be most salient when some form of pattern manipulation is required, either mentally or in terms of a manual response.

LANGUAGE FUNCTIONS OF THE RIGHT HEMISPHERE

Among the growing group of commissurotomy patients, at least 40 of whom have been studied, there are only five established cases of right hemisphere language in left hemisphere-dominant individuals. These few subjects have generated intense interest, since they provide a means by which a right hemisphere language system can be studied directly and with some degree of independence from the left hemisphere system. Inferring right hemisphere linguistic ability from the performance of such patients is even less straightforward than in the case of spatial tasks, however, since there is as yet only a crude understanding of the composition of right hemisphere language in cases of bilateral representation.

One of the most important points that can be made about the subgroup of commissurotomy patients with right hemisphere language is that the intersubject variability, in its extent, exceeds that observed for their left hemisphere language (Sidtis, Volpe, Rayport et al., 1981b). Whereas, in the least linguistically proficient right hemispheres, such capacity consists of little more than the ability to comprehend common words, the most linguistically proficient right hemispheres can gain access to the speech system. For the patients with only right hemisphere receptive language function, there has been a general agreement as to what this system can understand. Right hemisphere comprehension has been shown to be strongest for nouns (Gazzaniga & Hillyard, 1971), and although it has been suggested that the comprehension of verbs is similar to that found for nouns when word frequency is taken into account (Zaidel, 1976a), there is a marked deficiency for the execution of verbal commands by the nonexpressive right hemisphere (Gazzaniga & Hillyard, 1971; Sidtis et al., 1981b; Volpe et al., 1982). Further, there is little or no capacity for syntactic processing in the nonexpressive right hemisphere (Gazzaniga & Hillyard, 1971; Zaidel, 1977). In contrast, the two patients with expressive right hemisphere language not only comprehend but can also follow verbal commands, produce fluent writing, and generate speech from the right as well as the left hemispheres (Gazzaniga, Volpe, Smylie et al., 1979; Sidtis et al., 1981b). While different patients can perform different linguistic tasks with their right hemispheres, one function common to all such patients is the ability to comprehend the meaning of words. One may well ask what sort of linguistic competence this ability represents.

One way to begin to address this question is to examine the kinds of semantic relationships that the right hemisphere can recognize. Semantic judgments of visually presented words were obtained from two patients whose right hemisphere language capacities reflected the range of function found in the commissurotomy population. Patient J.W., from Wilson's surgical series, had a right hemisphere language capacity similar to that found in patients L.B. and N.G. in the earlier Bogen and Vogel surgical series (Gazzaniga & Sperry, 1967). These are the patients with some right hemisphere comprehension but no expression (see Zaidel, this volume). At the other end of the range, V.P., a patient in Rayport's surgical series, had both receptive and expressive abilities comparable to those of patient P.S. (also from Wilson's series). In both of these patients, the right hemisphere could follow commands, write using the left hand, and produce some speech (Sidtis et al., 1981b; Gazzaniga et al., 1979).

In order to test each hemisphere's performance in making various semantic judgments, a series of high-frequency words (rated A and AA on the Thorndike-Lorge word count) were briefly presented on a video monitor lateralized to the left or right of a center fixation point. Following the presentation of each word, the subject was presented with a response card in free vision, on which four words were printed. The subject was asked to select the word that best fit a specified semantic relationship, using the hand ipsilateral to the visual field in which the stimulus word was presented. Five tests were constructed to assess the recognition of the following semantic relationships: synonym (e.g., boat-ship), antonym (e.g., day-night), function e.g., clock-time), superordinate category membership (e.g., lake-water), and subordinate category membership (e.g., tree-oak).

The left and right hemisphere results obtained from J.W. and V.P. are presented in Table 5-2. Across all five tests, the left hemisphere accuracy of these two patients was nearly identical and, in both cases, consistently higher than right hemisphere accuracy. J.W.'s right hemisphere performance was consistently lower than that observed for V.P., suggesting that the intersubject differences found in right hemisphere expression were also present in word comprehension, albeit to a lesser extent. Also of note was the consistency of right hemisphere performance across semantic judgments: for V.P., accuracy on four of the five judgements was within 4 percentage points, while for J.W., accuracy on four of the five judgements was within 10 percentage points. For both subjects, the remaining test, on which right hemisphere performance was lowest, was also the test on which the left hemisphere produced the poorest performance. Thus, while the left hemisphere was consistently more accurate than the right hemisphere, there was no indication that a qualitative difference existed in the kinds of semantic judgments that each hemisphere made.

TABLE 5-2.
Left and Right Hemisphere Accuracy Scores (percentage correct) on Five Tests of Semantic Relationships Obtained from Two Subjects Who Have Undergone Complete Section of the Corpus Callosum

Semantic relationship	V.P. Hemisphere Left	V.P. Hemisphere Right	J.W. Hemisphere Left	J.W. Hemisphere Right
Synonym	96.0	80.0	87.0	43.5
Antonym	92.3	70.8	100.0	62.5
Function	100.0	84.0	100.0	66.7
Superordinate	96.0	80.0	96.0	68.0
Subordinate	95.8	80.8	100.0	72.0
Mean	96.0	79.2	96.7	62.8

Note: Each percentage is based on at least 23 trials.
Source: After Sidtis et al., 1981b.

The question of right hemisphere linguistic ability can be pursued further by determining the level at which the right hemisphere's disadvantage in recognizing semantic relationships occurs. Apart from a general difficulty in responding to verbal material (e.g., Sidtis et al., 1981b), the relatively poorer performance of the right hemisphere, compared with that of the left hemisphere on semantic judgments, may reflect left/right differences at either or both of two levels of function. The semantic system that is accessed by the right hemisphere may be uniformly less extensive than that accessed by the left hemisphere. Alternatively, the processes involved in reading and auditory comprehension that provide the right hemisphere with access to the semantic system may be less efficient than those available to the left hemisphere. A recent study of semantic activation after commissurotomy strongly suggests that the limiting factor in right hemisphere comprehension is not the extent of semantic representation available to it.

The previously described interhemispheric cognitive interaction that was observed after partial posterior-callosal section suggested a very close correspondence between the episodic and semantic memory representations activated by each hemisphere. Had there been qualitative differences in either the form or the substance of the memory representations accessed by each hemisphere, the observed cognitive interactions would have been unlikely. Although after complete callosal section, overt interhemispheric interaction no longer occurred, the possibility remained that the close correspondence between the semantic information available to the left and right hemispheres reflected each hemisphere's access to a functionally common semantic system. This possibility was examined by using the phenomenon known as semantic priming.

For normal subjects, processing the meaning of a word can have a significant effect on judgments made on subsequent words. Semantic relatedness, for example, can significantly facilitate word/nonword judgments (e.g., Meyer & Schvaneveldt, 1976; Schvaneveldt & McDonald, 1981) and semantic category judgments (e.g., Durso & Johnson, 1979) made on the second item of a related word pair. This facilitation, or so-called priming effect, is interpreted as reflecting both the organization of the semantic system and the process by which this system is activated. This effect was used to examine two questions for the commissurotomy patient with left and right hemisphere language: do both hemispheres benefit from processing a semantically related antecedent word, and is the benefit available to a hemisphere when the semantically related antecedent was processed by the other hemisphere? Whereas the first question addresses left/right differences in semantic activation, the second question addresses the independence of semantic processing in each hemisphere.

In one study, a commissurotomy patient, J.W., was presented with a series of high-frequency nouns that were flashed to the left or right of a central fixation point on a video screen. After each word was presented, the patient was asked to classify it as referring to something artificial or natural, by manually pressing one of two keys. Four conditions were tested in each hemisphere. Target words were preceded by either an unrelated word in the same category (e.g., ship-gate) or a related word in the same category (e.g., ship-boat), and the preceding word appeared in either the same visual field as the target (the within-hemisphere condition) or in the visual field opposite that in which the target appeared (the between-hemisphere condition). These contingencies are depicted in Figure 5-4.

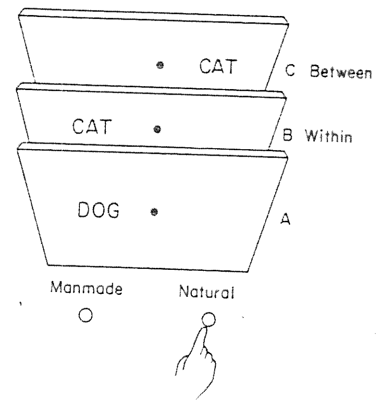

Figure 5-4. *Typical within-field (b) and between-field (c) semantically related trials in the study of semantic priming.*

Some of the results of this study are presented in Table 5-3 (Sidtis, Holtzman & Gazzaniga, 1981). As in the previously described study of semantic processing, left hemisphere performance (86%) was significantly better than right hemisphere performance (69%) across conditions (chi-square(1) = 10.899; $p<0.01$). Across hemispheres, there was a significant facilitation due to semantic relatedness, seen in both within-field accuracy (chi-square(1) = 10.790; $p<0.01$) and between-field accuracy (chi-square(1) = 7.752; $p<0.01$). A significant effect due to semantic relatedness was also found in latency of response ($F(1) = 11.028$; $p<0.001$). There was no significant difference between the within- and between-field conditions on either measure. For the present discussion, the important results are the presence of an interhemispheric facilitation effect and the absence of a difference in the within- and between-field conditions.

These data suggest that, after complete section of the corpus callosum, right and left hemisphere language systems maintain access to a functionally common semantic system. The language systems in each hemisphere, then, are not completely independent functional units, since they extract information from the same semantic store. This raises another paradox, however, because

TABLE 5-3.
Accuracy (percentage correct) and Latency (msec) of Semantic Categorization Judgments When the Preceding Word Was Either Semantically Related or Unrelated and Presented to Either the Same Hemisphere as the Subsequent Word or to the Opposite Hemisphere

Condition	Left hemisphere Related	Left hemisphere Unrelated	Right hemisphere Related	Right hemisphere Unrelated
	Percentage correct			
Within hemisphere	92.6	79.5	82.1	60.9
Between hemisphere	92.0	82.9	88.5	58.3
	Latency (SEM)			
Within hemisphere	1390 (64)	1469 (65)	1142 (62)	1493 (66)
Between hemisphere	1427 (76)	1604 (68)	1385 (77)	1723 (79)

Note: The standard errors of the means (SEM) for the latencies are presented in parentheses.

in spite of this interhemispheric semantic interaction, neither hemisphere in this patient can verbally name words presented to the right hemisphere. Like the interfield interaction in the control of visual attention, the semantic interaction occurs in the context of the classic split-brain syndrome: whereas semantic activation by one hemisphere can facilitate a subsequent judgment made by the other hemisphere, the activation alone does not provide the subject with sufficient information for explicit naming. Although the extent to which semantic activation alone can be used by an unstimulated hemisphere has yet to be fully determined, it does appear that, when provided with some context, such information is more useful to the left than to the right hemisphere (Sidtis, Holtzman, & Gazzaniga, 1981).

The bilaterality of language in these patients does not strictly imply the existence of two completely independent systems, even in the comprehension process. At least for high-frequency nouns, each hemisphere appears to have access to the same semantic information, although this common access provides neither a means of cross-cuing nor an avenue of paracallosal transfer (Gazzaniga, Sidtis, Volpe et al., 1982).

The limitations in right hemisphere word comprehension would appear to occur largely in the processes through which the semantic system is accessed. At least for the patients in whom there is only right hemisphere comprehension, there has been little consensus about how such access is gained. Based upon such patients' inability to recognize rhyming relationships with their right hemispheres (Levy & Trevarthen, 1977), some reports have suggested that language comprehension is mediated by qualitatively different processes in each hemisphere. According to such claims, the right hemisphere analyzes spoken language through some unspecified "acoustic-gestalt" process and written language through ideographic interpretation. Phonetic analysis is believed not to play a role in either hypothetical process, since the capacity for such process is supposed to be restricted to the left hemisphere (Levy & Trevarthen, 1977; Zaidel, 1976a). An examination of the range of right hemisphere linguistic capacities, however, suggests that, at least in some patients, the right hemisphere is indeed capable of phonetic processing.

One of the ways in which phonetic discrimination was assessed was by the use of dichotically presented consonant-vowel syllables. The test consisted of pairs of natural-speech syllables selected from among the following six: ba, da, ga, pa, ta, ka. Each member of a dichotic pair was aligned on a single channel of audio tape, using the pulse-code modulation system at the Haskins Laboratories, so that when played stereophonically, competing syllables had a simultaneous onset. Under the standard testing conditions, each dichotic pair was followed by a right-hand written response in which the subject was asked to report both items. In the discrimination form of the test, each pair was followed by a binaurally presented probe item, which matched the right ear stimulus 25% of the time, the left ear stimulus 25% of the time, and neither stimulus 50% of the time. After the probe item, the subject was asked to make a manual "yes" response if the probe matched the sound in either ear or a manual "no" response if it did not. As with this case, when there is sufficient stimulus competition, the dichotic technique functionally lateralizes stimuli to the hemisphere contralateral to the stimulated ear (Sidtis, 1978; Springer, Sidtis, Wilson, & Gazzaniga, 1978).

The results obtained from V.P., J.W., and a group of ten normal subjects on the standard form of the dichotic speech test are presented in Table 5-4. The left ear scores for both commissurotomy subjects were below those found in normal subjects, while their right ear scores were above the normal performance level. For J.W., preoperative testing was also performed, and both left (67%) and right (77%) ear accuracies were with the normal range. These results demonstrate the classic effects of callosal section on the auditory system; stimuli lateralized to the right hemisphere are not transferred to the responding left hemisphere and, hence, are not reported by the subject. The stimuli lateralized to the left hemisphere, however, are processed without interference from the competing information normally transferred through the callosum (Milner, Taylor, & Sperry, 1968; Sidtis, 1978; Sparks & Geschwind, 1968; Springer & Gazzaniga, 1975; Springer et al., 1978).

Although the standard form of the dichotic speech test assesses auditory disconnection, it does not provide a test of right hemisphere capacity, since a right hand response is used. Therefore, the standard test was readministered, using the left hand to provide a written response. When this was attempted out of vision so that the language-dominant left hemisphere could not visually guide the left hand by exerting ipsilateral control, V.P. performed at chance on both right (20%) and left (17%) ear stimuli, while J.W. refused to respond, claiming that he could not move his left hand.

TABLE 5-4.
Accuracy (percentage correct) of Identification of Consonant-Vowel Syllables Lateralized to the Left and Right Hemispheres in Two Commissurotomy Patients and Ten Normal Subjects

Patient	Hemisphere Left	Hemisphere Right
V.P.	100.0	8.0
J.W.	100.0	23.0
Normal subjects (N = 10)	78.0	65.0

Source: After Sidtis et al., 1981b.

In order to evaluate phonetic discrimination in the right hemisphere, independent of the capacity for linguistic expression, the discrimination form of the dichotic speech test was also administered to both patients. The results obtained for both left and right hand responses are presented in Figure 5-5. When the right hand was used to respond, the pattern was identical to that found with the standard test requiring a written response. For V.P., however, this pattern was reversed when the left hand was used to respond. Performance on left ear (right hemisphere) speech sounds rose to a nearly perfect level, while right ear (left hemisphere) performance fell to chance. No such reversal was observed for J.W.

Phonetic processing was also examined, using a visual rhyming test. High-frequency nouns were briefly presented to the left or right of a central fixation point on a video monitor. After each word was presented, the subject was asked to choose a word that rhymed with the stimulus (e.g., leg-egg, note-boat) from among four alternatives presented on a response card. Subjects used the hand homotopic to the visual field in which the stimulus word occurred. As with the auditory tests, V.P. and J.W. differed in their right hemisphere performance on the rhymes test. Whereas the left hemispheres of both subjects performed at 100% accuracy, J.W.'s right hemisphere performance (25%) was not significantly different than chance. Conversely, V.P.'s right hemisphere performance was well above chance, at 75% correct.

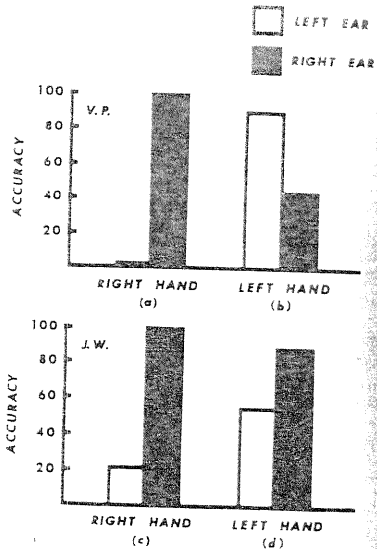

Figure 5-5. *Accuracy of discrimination (percentage correct) of consonant-vowel syllables as a function of ear of presentation and hand of response. CV syllables presented to the right ear are lateralized to the left hemisphere, while those presented to the left ear are lateralized to the right hemisphere.*

For both J.W. and V.P., the standard dichotic speech test demonstrated both the absence of interhemispheric auditory transfer and the ability of the left, but not the right, hemisphere to provide a written transcription following a dichotic trial. Although these results appeared to show that only the left hemispheres of both subjects were capable of phonetic processing, this picture was altered in V.P., when the task was changed to discrimination rather than identification and a nonlinguistic response was allowed. When each hemisphere's contralateral hand responses were compared under these conditions, V.P.'s right hemisphere performance was nearly as accurate as that of her left hemisphere. In contrast, J.W.'s right hemisphere showed no evidence of phonological processing on either the standard or the discrimination form of the dichotic speech test.

The presence of right hemisphere phonological capacity in V.P. and its apparent absence in J.W. was also demonstrated on the visual rhymes test. Although either hemisphere in V.P. could use phonological rules to generate rhyme, only the left hemisphere in J.W. could perform this task. Thus, the marked difference between these two patients in right hemisphere expressive capacity is also present in phonological processing, a function that plays a role in both auditory and visual comprehension.

At least for the commissurotomy patients with the most right hemisphere language, the capacity for phonological processing is present. For the commissurotomy patients with less extensive right hemisphere language, caution should be exercised in interpreting that system's phonological deficit. Phonological rules may be absent, or they may be present in a weak or incomplete fashion in the limited right hemisphere language system. In either case, the available data are beginning to identify the extent to which some linguistic functions can be bilaterally represented but, as of now, do not provide sufficient evidence that the left and right hemispheres subserve qualitatively different language systems.

As the language functions represented in some callosally disconnected right hemispheres have come under study, several things have become clear. There is significant intersubject variability in the representation of expressive and some receptive functions. Further, there is a paradoxical independence between the language functions in each hemisphere. Although both access a functionally common semantic system, the interhemispheric interactions that occur as a consequence of shared access are subtle and do not provide enough information for either explicit naming or even an awareness that any interaction is occurring. Finally, one of the receptive language functions that appears to limit the right hemisphere's capacity for comprehension is phonological processing, although it is inaccurate to say that such capacity is always restricted to the language-dominant hemisphere. Thus, it is reasonable to conclude that, at least in the commissurotomy population, there is no specific entity that could be reasonably termed right hemisphere language. In some of these patients, there is a bilateral representation of a greater number of language functions than in others, and for those functions that are represented bilaterally, there is considerable intersubject variability in the extent of their right hemisphere representation.

CONCLUSIONS

Although the preceding discussion has dealt with studies of cortical function in commissurotomy patients, a number of points can be made that are of general importance to the study of brain and cognition.

First, while it is obvious that cognitive systems process information from both internal and external sources, this fact takes on added importance when attempts are made to attribute cognitive function to specific areas of the brain. Even in the most general case of cortical localization, that is, ascribing particular functions to one hemisphere or the other, the corpus callosum is a significant source of information at cognitive as well as sensory levels of processing. The role of the callosum should not be understated, especially in studies of normal subjects. Whereas most stimulus lateralization procedures appear to provide the experimenter with a preferred channel of information flow into a hemisphere, caution should be exercised in the interpretation of lateral differences obtained with such techniques, since extensive interhemispheric communication exists in the normal, intact brain. Similarly, the extensive and sometimes sophisticated behavioral strategies employed by commissurotomy patients to ensure some degree of interhemispheric communication further suggest that lateralized cognitive systems actively use callosal information: when it is surgically removed, behavioral compensation is actively pursued.

The second point also pertains to sources of information for lateralized cognitive systems. The studies of visual attention and semantic activation after commissurotomy indicate that not every source of information available to a cognitive system is also necessarily available to consciousness, at least at the level of verbal report. However, the subtlety of these effects should not obscure their significance. For both spatial-location and semantic information, each hemisphere had access to common data, although such information was not interhemispherically transferred through the callosum. Some kinds of information, then, may also be available at other levels of the nervous system, albeit in a limited form, and restricted to specific operations in a cognitive system. The independence of cognitive function in either hemisphere is, therefore, limited not only by the degree to which callosal transfer is necessary but also by the degree to which such functions rely upon other common sources of information.

Finally, a point can be made about lateralized cognitive function and left/right differences. As was demonstrated in the examples of spatial processing and right hemisphere linguistic function, some of the general descriptions of these functions belie the extent of ignorance regarding their fundamental characteristics. Neither the spatial characteristics of right hemisphere perceptual and motor function nor the linguistic characteristics of right hemisphere word comprehension, when it exists, are understood. Caution is urged both in broadly characterizing lateralized functions and in invoking the presumed existence of poorly understood functions to account for either normal or pathological behaviors.

The study of split-brain subjects has provided a great deal of information about the functions of the left and right hemispheres. More generally, though, it has also provided a view of the relationships existing between the brain and cognition, which is different from that available from normals and other neurological populations. Through this view, a new picture of subtle interhemispheric interaction is beginning to emerge.

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6

Dichotic Listening To CVs: Method, Interpretation, and Application

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INTRODUCTION

Simultaneous presentation of different speech messages to the two ear does not result in a twofold gain in transmitted information. Instead, overa performance (relative to the 200% maximum) is only 125% to 150% Broadbent (1954),[1] suggested that this limitation reflects a "bottleneck" i speech information processing; that is, below a certain level, both channels ca be processed in parallel (or in a rapidly alternating, serial) fashion, but beyon a certain point, sensory/perceptual analysis is time and/or capacity limite and cannot process both signals together. As a result of the bottleneck, some (the information in one or both channels is lost.

The relative degree of information loss for each ear can be manipulate by varying the task. For example, asking the listeners to attend to sentences c digit sequences in one ear (while ignoring similar material in the other) ca reduce recall of the unattended ear's material to virtually zero (Cherry, 195: Norman, 1968). In addition, if the material in the two ears is semantically o syntactically related, and/or is spoken by the same voice, correctly attending t only one ear's message is especially difficult (Triesman, 1969). Such result suggest that the bottleneck occurs beyond basic sensory analysis, at a level o processing where perceptual, attentional, or cognitive mechanisms attempt tc focus on and abstract the messages conveyed by the two ears' signals.