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Article abstract

The linguistic capacity of each separate cerebral hemisphere was examined in a 15-year-old, callosally sectioned, normally right-handed male. The results demonstrated that while the right hemisphere was not capable of expressive speech, it could comprehend nouns and verbs, and also possessed the motor engrams necessary to carry out verbal and pictorial commands. In addition, the mute hemisphere was found to be capable of spelling the names of visually presented items by arranging letters as well as by writing with the left hand. Finally, the manner in which the left hemisphere dealt with the overt bodily response to commands presented to the right hemisphere suggested clues to what we feel are mechanisms by which a personal sense of conscious reality is created in the normal brain.

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Language, praxis, and the right hemisphere: Clues to some mechanisms of consciousness

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Studies assessing the neurologic and psychologic functioning of the separated hemispheres in brain-bisected humans have stimulated speculation concerning the role of the mute right hemisphere in language processing. While early reports questioned the ability of the mute hemisphere of split-brain patients to process verbs, adjectives, and syntax,[1-3] more recent studies have suggested that with prolonged stimulus lateralization, a rich and somewhat unique language representation is found in the right half-brain.[4,5]

Closely tied to the linguistic issues of place and process are questions associated with the nature of voluntary movement. It has been suggested recently that the mnemonic information necessary for executing and controlling skilled movement is stored primarily in the hemisphere contralateral to the preferred hand.[6,7] While this view is largely consistent with the early split-brain findings that suggested that verbal commands could not be processed by the right hemisphere,[1-3] it is at odds with the data suggesting that each hemisphere of split-brain patients can control the distal musculature of the contralateral, but not the ipsilateral, hand.[2]

We describe our observations of language and praxis, with particular reference to the right hemisphere, in a recent callosal-sectioned patient.

Case report. P.S. is a right-handed, 15-year-old boy who experienced a severe series of epileptic attacks around the age of 2, with a left temporal seizure focus. Subsequently, he apparently developed normally until age 10, when the seizures recurred spontaneously, and became intractable. In January 1976, he underwent complete surgical section of the corpus callosum. A more complete medical history has been published elsewhere.[8]

Method. All tasks involved the lateralized presentation of visual stimuli.[9] In brief, the subject was seated 2 to 3 feet from an opaque screen and instructed to fixate on a dot in the center of the screen. Using a standard Kodak Carousel 650 slide projector fitted with an electronic shutter, stimuli were presented to the right or left of the fixation point for 100 to 150 msec. This brief exposure was necessary to be certain that the subject did not deviate gaze during exposure and bring the stimulus into view in the opposite visual field. Stimulation of a single hemisphere was further controlled by the random

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presentation of stimuli in either field, as well as by close observation of eye movements.

Naming. Five common objects were visually presented to each hemisphere, and the subject was required to name the object on each trial. If an object could not be named, the subject was presented with three choices and required to select one. This control was used to determine if failure to name was attributable to inability to name or failure to perceive the lateralized stimulus.

Spelling. Line drawings or pictures of seven common objects (safety pin, apple, tire, playing card, bicycle, light bulb, leaf, sheep) were flashed to the right hemisphere. The subject, after seeing each item, was asked to spell the name of the item by arranging the letters in front of him. At least two (and usually three to five) irrelevant letters were included on each trial.

Writing. Line drawings or pictures of common items (key, cup, pen) were flashed to the right hemisphere. The subject was required, after seeing the item, to write the name of the object, using his left hand.

Word-object matching. Seven words, each naming a common object, were presented to each hemisphere. On each trial, after seeing the lateralized word, the subject was required to point to the object that matched the word. In addition to the matching objects, three irrelevant objects were presented as choices. The left hemisphere words included hose, knife, penny, pipe, plug, razor, and wire. The right hemisphere words included cigar, cube, eraser, medal, pill, phone, and thread.

Opposite matching. Four words were presented to each hemisphere. On each trial, the subject was required to select from three choices the word that suggested a meaning opposite to the lateralized word. The matches included the following: circle-square; army-navy; cat-dog; bride-groom; girl-boy; doctor-patient; angel-devil; child-adult.

Conceptual matching. Six words were presented to each hemisphere. On each trial, the subject was required to select from three choices the word that was most associated with the lateralized word. The matches included the following: clock-time; porch-house; devil-hell; crowd-people; shell-turtle; chair-table; phone-talk; check-bank; nurse-hospital; court-judge; shore-beach; floor-tile.

Rhyming. Six words were lateralized to each hemisphere and the subject was required to select from three choices the word that rhymed with the lateralized word. The rhyming matches included the following: canoe-new; sky-hi; corn-barn; brook-shook; beet-heat; hall-maul; tie-buy; rose-knows; fur-her; knee-pea; stair-care; hoe-dough.

Action verbs. Action verbs (sleeping, laughing, crying, eating, writing, falling, running, drinking, dripping, and smoking) were visually lateralized to each hemisphere. The subject was required to point to the picture depicting the action specified by the lateralized word.

Verbal commands. Fifty-seven verbal commands were presented to each hemisphere. Several different types of instructions were used for this test. The subject was told to either "do what the word says," or was given a special set of instructions. For example, on some trials, he was told to "touch your thumb to this finger," or to "touch your index finger to this finger." On other trials, he was told to "stand like a ____." On still other trials, he was told to move his head in a particular manner or direction, to touch a particular point on his body, or to "do this with your hand." Finally, he was occasionally asked "how would you use this item?"

Finger postures. Six line drawings of finger postures[2,9] were lateralized to each hemisphere. The subject was required to mimic the six postures with each hand. All combinations of postures, hands, and visual lateralization were tested.

Results. The subject correctly named all right-field (left hemisphere) stimuli and failed to name all left-field (right hemisphere) stimuli. However, he correctly pointed to the object that matched each unnamed left-field stimulus. In addition, the subject correctly spelled, by arranging letters, as well as by writing with the non-preferred left hand (figure), the name of all items presented to the right hemisphere. These observations suggest that while the expressive speech mechanism is lateralized in the left hemisphere of this patient, other forms of linguistic expression are represented, at least in part, in both half-brains.

The various items were correctly matched to their common noun names on all seven trials by both hemispheres on the word-object match test. Opposite words were correctly matched on all four trials by both hemispheres. Each hemisphere performed correctly on five of the six conceptual matches. The left hemisphere correctly matched the rhyming words on four of six trials, while the right was correct on all six trials.

On the action verb tests, the right hemisphere matched the verb to the appropriate action picture on 10 of 10 trials, and the left was correct on nine of 10 trials. The hemispheres also performed at similar levels on the verbal commands test. This was true for the total score (left: 26/53; right: 27/53), and subtest scores (hand and finger praxis—left: 7/17; right: 8/17; whole body and head praxis—left: 13/28; right: 16/28; engrams for object

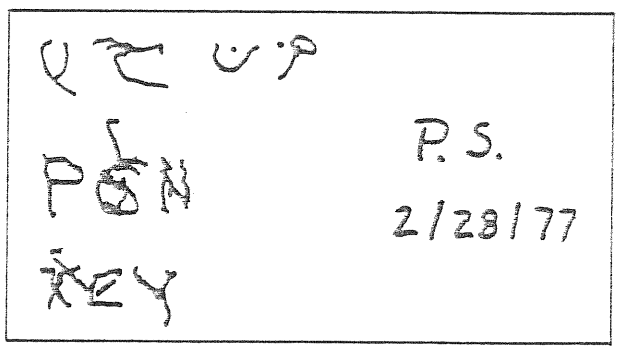

Figure. Right hemisphere writing. On separate trials, line drawings of a coffee cup, a ball point pen, and a key were lateralized to the right hemisphere. Using his left, nonpreferred hand, P.S. was able to write clumsily the name of the object seen.

use—left: 3/8; right: 6/8). The only indication of a hemispheric difference was seen on the "object use" trials. However, the small number of trials precludes any conclusion on this point. Furthermore, it should be noted that the low overall response rate is accounted for by "no response" trials and "incorrect response" trials, both of which may reflect active inhibition or even interference from the nonseeing hemisphere,[10] as well as failure to comprehend the command and failure to perceive the word flashed. Finally, on some trials, a correct response by the left hemisphere did not come until he named the stimulus out loud. It is possible that the right hemisphere carried out the correct activity after being cued by the left on these trials. As such, the overall left hemisphere total score may be slightly (but not substantially) inflated.

On the finger postures test, each hemisphere proved capable of accurately mimicking the postures with the contralateral hand (right hemisphere, five of six correct; left hemisphere, six of six). In contrast, performance was poor ipsilaterally (left hemisphere, one of six correct; right hemisphere, one of six correct). The only posture correctly mimicked ipsilaterally was the pointing posture.

The last set of results involved the manner in which the verbal system of the left hemisphere dealt with the examiner's queries as to why the subject was acting in a certain way on the verbal commands trials. When P.S. was asked, "Why are you doing that?", the verbal system of the left hemisphere was faced with the cognitive problem of explaining a discrete overt movement carried out for reasons truly unknown to it. In trial after trial, when queried, the left hemisphere proved extremely adept at immediately attributing cause to the action. When "laugh," for example, was flashed to the right hemisphere, the subject commenced laughing, and when asked why, said, "Oh, you guys are too much." When the command "rub" was flashed, the subject rubbed the back of his head with the left hand. When asked what the command was, he said "itch." Here again the response was observed by the left hemisphere, and the subject immediately characterized it. Yet, that he said "itch" instead of "rub" shows that he was guessing. In the same way, he could be seemingly quite accurate when the command had less leeway for multiple description, such as in the case of the word "boxer." The test instruction was to "assume the position of ___." Here the subject correctly assumed the pugilistic position, and when asked what the word was, said "boxer." Yet on subsequent trials, when the subject was restrained, and the word "boxer" was flashed, the left hemisphere said it saw nothing. Moments later, however, when released, he assumed the position, and said, "O.K., it was "boxer."

Similarly, on the spelling test, if the subject was asked to name the word being spelled, the left hemisphere's verbal response was consistent with the available information, but inconsistent with the true state of affairs known only by the right hemisphere. For example, after the picture of a playing card was flashed to the subject's right hemisphere and he began to select the letters, he was asked what the word was. Looking down at the letters c, a, and r, he replied "car." However, as this response was being emitted by the left hemisphere, the left hand and right hemisphere completed the word by adding the final letter, d. The left hemisphere then said, "Oh, it was card," and P.S. smiled.

Discussion. *Language.* In P.S., each half-brain has a rich representation of linguistic skills. Both hemispheres can process nouns and verbs, as well as rhymes, antonyms, and superordinate concepts. Most striking, however, is the capacity of the right hemisphere to produce verbal responses, by writing, as well as by selecting and arranging letters.

The extent of linguistic representation in the mute hemisphere of P.S. is greater than that previously noted in split-brain patients. In all, only four split-brain patients have been systematically tested for language skills. Earlier reports on the Bogen patients suggested that while W.J. had little or no linguistic representation in the right hemisphere, N.G. and L.B. could process nouns, but not adjectives and verbs.[1-3] More recently, Zaidel has suggested that under special testing conditions that allow prolonged stimulus exposure, more extensive language skills were found in the right half-brain of both N.G. and L.B.[4,5]

These observations on commissure-sectioned patients, however, are of limited value in suggesting "where" language is processed in the normal brain. We feel that the split-brain results probably reflect neuroplasticity during early development. It is generally believed that language develops in both cerebral hemispheres, to some unknown extent, with the process eventually consolidating in the left for most right-handers.[11] It would appear that the early pathology in the left temporal region of P.S. may have influenced cerebral dynamics to the extent that language remained active in the right hemisphere. In addition, both N.G. and L.B. experienced birth problems, and both have been shown to have left temporal seizure foci, with L.B. also showing right temporal foci.[12] In contrast, W.J., who apparently developed normally until age 30, shows no sign of right hemispheric language under standard testing conditions.[13]

The variable existence of some linguistic skills in the absence of other linguistic skills in the right hemisphere of split-brain patients demonstrates that different linguistic functions can develop and exist independent of the other functions. Written expression can exist independently of the capacity to produce speech, and neither speech nor writing is a necessary prerequisite for the various comprehensive skills, which may exist together or separately. These observations suggest that the classic dichotomy of expressive and receptive language functions may be an oversimplification of the complex neural relationships that underlie the development and maintenance of the various facets of linguistic processing.

In summary, we feel that the observations to date on split-brain patients are at best inconclusive concerning the location of language skills in the human cerebrum. In contrast, these cases are potentially a rich source of information concerning the more interesting questions of process and plasticity, particularly when the unique neurologic history of the individual patient is considered.

Praxis. The demonstration that verbal commands can be processed and carried out by the mute hemisphere of P.S. addresses the neurologic basis of praxis. What is of particular interest is the clear absence of evidence that the information needed to orchestrate complex movements is stored primarily in the left hemisphere of this right-handed patient. This contrasts with the recent view suggesting that the hemisphere contralateral to the preferred hand is the primary locus of storage of motor engrams.[6,7]

While P.S. is clearly unique in his capacity for processing and executing verbal commands in his right hemisphere, we feel that the motor skills involved are normally present, and that the rich linguistic representation in this case merely allows verbal access to these motor skills. This view is supported by the finding that each half-brain in P.S., as in other split-brain patients,[2] exercises good control over the contralateral distal musculature, but has minimal control over the ipsilateral distal musculature.

Thus, whatever advantage the left hemisphere may possess relative to the right in sequencing and controlling skilled movement, the split-brain data suggest that each hemisphere exercises primary control over the contralateral distal extremities. In addition, the observations on P.S. show that each hemisphere can have its own store of information for executing and controlling most nondistal motor activities, save for the important exception of speech, for which one half-brain, usually the right, falls short.

Clues to mechanisms of consciousness. The existence of two major, yet independent language systems allows for an examination of how we normally go about constructing a personal sense of conscious reality. In particular, on trials requiring that the right hemisphere initiate motor acts, the left half-brain was forced into a position of observing responses of unknown origin. Yet, trial after trial, the left hemisphere proved particularly adept at providing a reasonable explanation for the response (see Results). The verbal system, in short, attributed cause to the behavior produced.

This process of attribution by the verbal system seems to be a major mechanism of consciousness. The verbal system is not always privy to the origins of our actions. It attributes cause to behavior as if it knew, but, in fact, it doesn't. One's belief system could arise as a consequence of this attribution process. We may build our sense of reality by considering what we do. It is as if self-consciousness involves verbal consideration of our actual sensorimotor activities.

A final observation on this case sheds some light on the nature of emotional mechanisms. When the subject was instructed to "do what the word says," and the word in question was "kiss," although the word was flashed to the right half-brain, the left hemisphere blurted out, "Hey, no way, you've got to be kidding." "What was the word flashed?" asked the examiner. A look of puzzlement came over the subject's face, and he shot back, "Oh, 'nurse,' I guess." When "kiss" was flashed to the left hemisphere, he adopted the same tone, saying "No way. I'm not going to kiss you guys."

These observations stand in marked contrast to the predominant cognitive theory of emotion, which states that the bodily arousal in emotional reactions is nonspecific. The tone or coloring given the arousal is a function of the cognitive state of the person experiencing the arousal.[14] Here the left hemisphere was in no particular mood, yet it immediately and correctly read the proper tone of the emotional reaction to the word "kiss," which proved to be particularly volatile to this adolescent. It would appear, therefore, that the verbal system can assess brain or body states, or both, to determine the emotional tone of an event or real-life situation.

Taken together, we believe that these results allow us to understand where and how language processes can be organized and reorganized in the brain. They also allow us to observe how the split-brain patient tries to reintegrate the conscious processes that have been fragmented by the surgeon. It is this phenomenon that we think gives a major clue to the mechanisms of consciousness. Specifically, behaviors are being continually exhibited, the origins of which may come from coherent, independent mental subsystems,[15,16] and these actions have to be and are immediately interpreted by the verbal system. As a consequence, a large part of our sense of conscious reality, we believe, comes from the verbal system attributing cause to exhibited behavior.

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