A VIEW OF THE WORLD FROM A SPLIT-BRAIN PERSPECTIVE

by

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Outline

Introduction

This chapter is not an account of dramatic personality changes following brain surgery. Instead, most of the changes are subtle and require special laboratory tests to emerge. But it is true that the daily lives of 'split-brain' patients stand in sharp contrast with their performance in laboratory tests and defy some simple, unitary understanding of how the mind is organized in the brain. These patients are cases with complete commissurotomy in the Bogen-Vogel, Caltech series. As a group, their behavior represents some of the most fascinating phenomena in neurology and understanding them has provided a challenge to students of neuropsychology and neuroscience as well as philosophy.

The contrast creates a paradox for the following reasons: The left and right hemispheres of the brain (the neocortex) are normally connected to each other via several different bundles of fibers but here these rich fiber systems were sectioned surgically, separating the hemispheres. The result is two halves of the brain, originally designed by millions of years of evolution to be anatomically connected, now processing information nearly independently from each other while having different functional specializations. The different hemispheric functions have come to be considered complementary and as such to represent the ideal for normal human behavior. And yet, in daily life, the patients appear to behave as if there was no evolutionary purpose to this major forebrain neuronal connection between the hemispheres. Certain functions considered by some to be specialized in the right hemisphere such as voice modulation or prosody appear unimpaired. Left hemisphere functions such as speech and language comprehension also appear unimpaired. Previously learned functions that require bilateral interaction such as, cooking, cycling, swimming, or piano playing appear unchanged, and have remained so until now, as long as 30 years post-surgery in some cases. Neither have there been major changes in personality or mannerisms, or in general intelligence. There are no psychiatric symptoms such as hallucinations, dellusions, fugue states, or multiple personalities. Each patient behaves as one with a single personality and unified consciousness. Thus, we must look at what is amiss in order to distinguish between the apparent and the real. Clues to the paradox were revealed in laboratory studies and those are discussed in the following sections of this chapter.

Boundaries of reality and conscious awareness

Boundaries of consciousness and of reality are recognized through deviation from that which is accepted and considered normal. What is normal in the split-brain patients' behavior will be described first.

Some of the many dimensions of conscious awareness include orientation to space and time, knowledge of human biological and sociological context, intentionality, and so on. In split-brain patientsas a group, all these dimensions of awareness seem intact. Orientation with respect to where they are located at any given moment is fully acknowledged and known as is time of day, month, or year. Memory for past personal events that occurred before surgery appears intact and knowledge of national or international historical events is at a level that would be expected given their educational background. Knowledge of current events is faulty and is most likely due to their poor recent memory and the lack of interest in reading following surgery. Knowledge of sociological good or evil and, depending on the personality and intelligence level of the patient, "taking sides", all appear normal. Moreover, intentions are executed normally. Thus, if they want to touch a person or a table, they do so and they feel the difference in their sensation. If they wish to listen to music, they turn the radio on and respond appropriately to the sounds. These are only a few examples.

In laboratory tests where information is lateralized to only one hemisphere and a lateralized motor response is required, either hand can do so, even when the left hand response is controlled by the right, non-speaking hemisphere. This is demonstrated in specially- designed tests where the answer is hidden from view and the response is nevertheless provided by either hand. For instance, if the examiner requests, "after feeling all the choices behind the screen, decide on the correct answer, and tap on it with your finger" The patients can carry out the instructions effortlessly (see D. Zaidel, 1990a for examples). In daily life, either the left or the right hand reaches out to touch or to pick things appropriately. In other words, intentionality is not restricted to the dominant, speaking hemisphere and can be initiated/controlled by either hemisphere.

Unity of consciousness

Recently, Searle (1992) summarized the essense of unity of conscious experience in the following way: "It is characteristic of nonpathological conscious states that they come to us as part of a unified sequence. I do not just have an experience of a toothache and also a visual experience of the couch that is situated a few feet from me and of roses that are sticking out from the vase on my right, in the way that I happen to have on a striped shirt at the same time as I have on dark blue socks. The crucial difference is this: I have my experiences of the rose, the couch, and the toothache all as experiences that are part of one and the same conscious event. Unity exists in at least two dimensions, which, continuing the spatial metaphors, I will call "horizonal" and "vertical". Horizontal unity is the organization of conscious experiences through short stretches of time. For example, when I speak or think a sentence, even a long one, my awareness of the beginning of what I said or thought continues even when that part is no longer being thought or spoken. Iconic memory of this sort is essential to the unity of consciousness, and perhaps even short-term memory is essential. Vertical unity is a matter of the simultaneous awareness of all the diverse features of any conscious state, as illustrated by my example of the couch, the toothache , and the rose. We have litttle understanding of how the brain achieves this unity." (Searle, 1992, pp. 129 - 130)

As far as we can tell from ordinary behavior, there is little to indicate that the type of unity described above is absent or is disrupted in a serious way in split-brain patients, both in daily life or under special testing conditions that lateralize the information to one or the other hemisphere. However, the clue to what is involved in achieving such unity may yet be revealed in the study of these patients.

Some clinical background

The split-brain patients under discussion here suffered from frequent generalized epileptic convulsions which were life threatening and could not be controlled by drugs alone (Bogen & Vogel, 1962). Surgical intervention was a last resort procedure. The logic behind the procedure was that sectioning the forebrain commissures (hemisphere-connecting fibers) would limit or abolish transfer of abnormal epileptic discharges from one hemisphere to the other, restricting them to only one side, which would then make it possible to have greater pharmacological control over them. Indeed the surgery was successful in the majority of cases (Bogen, 1990; Bogen, 1992; Bogen,Schultz, & Vogel, 1988; Bogen & Vogel, 1975).

Anatomically, the forebrain commissures are made up of three distinct structures that connect matched and non-matched areas in the left and right hemispheres: The corpus callosum has received most attention in scientific investigations. It is assumed to have more than 200 million neuronal fibers, the largest tract of fibers in the brain. It is present only in mammals and reaches its largest size in humans. And it is in humans where we find hemispheric functional specialization, that is, the lateralization of certain aspects of perception, memory, cognition, or emotion to one or the other hemisphere. Consequently, it has been suggested that the growth in size of the corpus callosum is closely related to phylogenetic brain development leading eventually to human hemispheric functional separation and specialization. The purpose of this extensive callosal development is to maintain easy communication between the left and right hemispheres.

Basic facts about left and right in the central nervous system

Human sensory and motor pathways function on the basis of contralateral innervation. Thus, sensations from the left limbs are received and processed predominantly in the right hemisphere while sensations from the right limbs are received and processed predominantly in the left hemisphere. Similarly, motor control of the right limbs is in the left hemisphere and the opposite is true for left limbs. With vision, information falling in the left visual half-field of either eye is projected initially to the right hemisphere, and the information falling in the right visual half-field is projected initially to the left hemisphere. In order for humans to interact with the physical world, sensory information from both halves of the body must be completely available to both hemispheres, and this is achieved principally, though not exclusively, through the forebrain commissures. In laboratory conditions described here, information is restricted to only one hemisphere at a time based on the principle of contralateral innervation.

Neurological pathology and hemispheric specialization in split-brain patient

In the majority of right- and left-handers, the left hemisphere is the main language and speech processor while the right is the main processor of visuo-spatial functions such as topographical orientation, facial recognition, and spatial relations. This functional separation and hemispheric specialization in high mental functions is seen only in humans (although very special laboratory training procedures have shown the precursors of functional separation in the brains of monkeys). The present group of split-brain patients is right-handed and the normal pattern of hemispheric specialization for right-handers is observed.

It is important to stress that early onset of habitual epilepsy was present in only some of the patients in the Bogen-Vogel series. A few had a later onset (e.g., ages 17 or 18). One could have predicted that at least in those in whom there was an early onset, the pattern of hemispheric specialization would have changed due to 'plasticity' and functional reorganization. On empirical grounds, one could not make this prediction since there are no available data to support it. Any data that are availabe regarding epilepsy and functional development consists predominantely of cases suffering from temporal lobe epilepsy, and in those cases there is evidence that early onset of habitual epilepsy could lead to reorganization of speech and language (Milner, 1975). However, in the absence of convincing data on patients with generalized convulsions, the pattern of observed functional asymmetries and symmetries in split-brain patients must be assumed to be attributable to normal development.

At the same time, age at time of surgery did appear to affect the extent of interhemispheric communication that developed, possibly via subcortical centers (Johnson, 1984; Teng & Sperry, 1973; D. Zaidel, 1988). Patients operated on when young (ages 12 to 14) showed signs of such transfer to a greater extent than older patients (ages 25 to 40). However, even in young patients the pattern of hemispheric specialization remained the same with no convincing reasons to believe that new functions, language for instance, developed abnormally in the right hemisphere (D. Zaidel, 1988).

Elements of the paradox and some clues

Much of what is known now about functional complementarity in the left and right hemispheres came originally from studies of patients with unilateral focal brain-damage. Some of those findings received convergent evidence from split-brain studies. But not all. There are several examples of such discrepancies. We will focus on two that concern right hemisphere specialization, prosopagnosia and hemi-neglect. In prosopagnosia, a patients with unilateral damage in posterior regions of the right hemisphere loses the ability to recognize previously known people by their faces alone, including the patient's own face. Herein lies a piece of the puzzle: If the right hemisphere specializes in facial recognition, why does the disconnected left hemisphere not show symptoms of prosopagnosia? Similarly, a patient showing hemi-neglect most likely shows the neglect for the left-half of external or personal space (severe neglect of the right half is rarely seen clinically). The right hemisphere in its normal, intact state is said to be responsible for events or actions in the contralateral half space. By logical inference, then, the left half has more biological significance than the right half. Otherwise, damage to the left hemisphere would result in equally frequent right neglect of space. All of this would make sense if the right hemisphere were crucial for spatial orientation, on personal or extra-personal space.

Yet, in split-brain patients, the disconnected left hemisphere does not show hemi-neglect of contralateral space (Plourde & Sperry, 1984). Nor does the disconnected right hemisphere, for the right half of space. Each disconnected hemisphere has full knowledge and awareness of both left and right halves of space. (It might be interesting to add that in right hemispherectomy patients, prosopagnosia or hemi-neglect are rarely observed as well.) Thus, hemi-neglect or hemi-inattention may be only tangentially related to knowledge of spatial relations or of topographical orientation, for these two functions appear to be intact in the disconnected right hemisphere. Hemi-neglect, then, must be related to some other hard-to-define higher mental function.

In light of the above, should we conclude that data from hemisphere-damaged patients reflect the inhibiting effects of the diseased tissue over healthy tissue rather than of the effects of the hemispheric damage itself? Should we infer that hemi-neglect is but an epi-phenomenon resulting from an abnormal brain-behavior interaction rather than a hemispherically-specialized function? And here is the important clue to resolution of the paradox under discussion. Should we infer that the absence of such symptoms in split-brain patients reflects subcortical integration of sensory and motor information? Or, is there sufficient redundancy in functional representation for one hemisphere alone to control a wide range of behaviors? And, are the mechanisms involved in the Interhemispheric interaction normal and present in the intact brain?

<u>Relevant early animal work</u>

The functions of the corpus callosum and of the other forebrain commissures were initially gleaned from experimental work on cats and monkeys (Glickstein & Sperry, 1960; Myers & Sperry, 1958; Stamm & Sperry, 1957). Researchers found that an animal with intact commissures can perform a particular task which it was trained to do very well, with either hemisphere when each hemisphere was tested separately. On the other hand, if another animal with sectioned commissures, is trained to perform a particular task only with one hemisphere is then exposed to the same task with the untrained hemisphere, it shows initially no signs of knowing the task. This was taken to demonstrate absence of transfer of information between the hemispheres.

On the whole, the human studies provided convergent evidence regarding the role of the forebrain commissures in interhemispheric communication. However, in some isolated split-brain animal experiments, researches reported that animals learned the task with the untrained hemisphere faster than one would expect from the initial learning level of the originally trained hemisphere (see Hamilton, 1982, for review). How? The most plausible answer is that this occurred through certain sub-cortical structures which normally provide integration for direct or crossed connections to the left and right hemispheres. These sub-cortical relay stations could conceivably have allowed some minimal memory in the trained hemisphere to be tapped by the untrained hemisphere. Yet, they did not provide a perfect substitute for the forebrain commissures since the animal continued to behave as if it had essentially two separated hemispheres, and, in any case, savings by the untrained hemisphere was observed rarely. Nevertheless, subcortical relay stations were hypothesized to transmit only rudimentary information.

Indeed, subsequent work on the human split-brain patients by Trevarthen & Sperry (1973) revealed that, at least for vision, there are one or two subcortical relay stations which permit uncrossed information to be integrated and then transmitted to the ipsilateral hemisphere. It was hypothesized that a 'secondary visual system' in humans is a vestige of a phylogenetically older mammalian visual system and that it becomes functional when certain types of brain damage occur (possibly in 'blind-sight' cases as well). In the absence of direct communication via the forebrain commissures, the secondary visual system would provide some minimal visual integration.

One person despite a split-brain

As maintained, daily behavior of the Bogen-Vogel group of patients appears to show unified consciousness. Their walk is coordinated, their stride is purposeful, they perform old unilateral and bimanual skills, converse fluently and to the point, remember long-term events occurring before surgery, are friendly, kind, generous, and thoughtful to the people they know, have a sense of humor, and so on down a whole gamut of what it takes to be human. How is that possible given hemispheric disconnection? There are two logical possibilities: First, there is more subcortical integration of behavior than was realized, so that in the end both hemispheres receive much the same sensory input, and the output is somehow integrated sub-cortically as well. Second, only one hemisphere controls the observed behavior. Each of the possibilities pose problems to biological reality. If either possibility is true, why do we have the forebrain commissures, or two hemispheres for that matter? Is it that they are only important in the initial sorting of information, relegating it into left and right hemispheres but not afterwards?

1. One hemisphere in control

There are several sources of evidence that suggest that one hemisphere controls ordinary behavior in split-brain patients, namely, the left hemisphere. First, all verbal communication is produced by the left hemisphere since this is the hemisphere dominant for speech and language comprehension in these patients. There is some language comprehension in the disconnected right hemisphere, more for auditory than for written vocabulary, and more for single words than for phrases (E. Zaidel, 1976; E. Zaidel, 1985). But the mental age-level of the vocabulary is lower than the chronological age of the patient. Given hemispheric disconnection, it is unlikely that substantial right hemisphere linguistic contribution is made in the course of a normal conversation. Similarly, the contents of the conversation, including concepts, thinking, problem solving, memory -- short- and long-term, must all be controlled by the disconnected left hemisphere. Topographical orientation and memory are impaired and they represent nonverbal behavior, indicating that nonverbal aspects of behavior are not expressed. Indeed, what components are missing in verbal conversation or in nonverbal behavior are very likely those components which normally are contributed by the right hemisphere. The degree to which one disconnected hemisphere can support a wide range of behaviors may depend on individual differences including intelligence, sex, or genetic factors (see D. Zaidel and Sperry, 1974, for discussion).

2. The case for subcortical integration

In the following discussion I shall use motor control as an illustration of subcortical integration. (The case for vision was described above.) I start with the following question: How is it possible that the patients under discussion walk normally and have normal bimanual coordination for previously learned movements and skills if cortical motor control is contralaterally innervated and the major cortical fibers allowing interhemispheric communication regarding the control are cut? Some likely possibilities include unified cerebellar control in conjunction with other subcortical structures.

After disconnection, when patients try to learn new bimanual movements, certain kinds are learned with exceptional difficulty and never reach normal levels (Preilowski, 1972; D. Zaidel & Sperry, 1977). These are skills which consist of interdependent bimanual movements such as those involved in using a children's toy called etch-a-sketch. Other bimanual movements, such as those consisting of parallel or alternate control, are not impaired. How can we be sure that the observed manual coordination is not in fact controlled by only one hemisphere, namely the left? We can be reasonably sure for the following reasons: Separate tests for ideomotor apraxia (the ability to carry out spoken commands) were administered in free vision and hearing, first with the request to execute the commands with the left hand and later with the right hand (D. Zaidel & Sperry, 1977). The results showed some ideomotor apraxia on the left side only. If the left hemisphere were "in charge" of motor control on both sides, we would not have observed unilateral apraxia but rather no apraxia at all. Thus, judged from this perspective, we may infer that habitual ordinary behaviors are integrated in subcortical structures while certain types of newly learned skills depend crucially on normal interhemispheric communication.

Sense of humor

Based on informal observations, the split-brain patients appear to have a good sense of humor. They tell funny stories designed to make the listener laugh. They use appropriate and relevant punch lines as well as dramatic pauses. They themselves laugh appropriately upon hearing others' stories. Many jokes are spontaneous and original. Some are ideomatic or are tongue-in-cheek. Their humor appears to consist of wit, puns, and some metaphors and to include references to the self, and to others. One patient repeats, " I told my husband I am a lot smarter than him; I have two brains and he has only one."

Sex

This is a sensitive topic to raise with patients and not much is known about matters related to it. However, informal observations have revealed that their interest in the opposite sex is appropriate. Both the men and the women make socially appropriate remarks regarding physical attractiveness and flirtation. I have never heard interest expressed in the same sex. To the best of my knowledge, inappropriate touching or reference to the anatomy of experimenters have not occurred. Similarly, unlike some patients with frontal lobe pathology, lewd or sexually inappropriate remarks are not known to have been made. An interesting observation, however, is that some of the women patients enjoy telling "dirty" jokes. One in particular, wrote a few limericks with veiled, strong, albeit sexual undertones which she did show to men and women experimenters.

Telling personal stories and anecdotes

The patients relate personal anecdotes that occurred preoperatively with a beginning, a middle, and an end. They are always to the point and appear nearly always to be relevant in the conversational context. Their stories seem complete with many if not all of the facts included. Because of their poor recent memory, they repeat the same stories and anecdotes to the same audience several times in the course of a year (though rarely if ever in the course of one visit to the laboratory).

There has never been any indication that these patients confabulate in ordinary conversation. Confabulations and guessing do occur under special testing conditions in which stimuli are lateralized to the right hemisphere and the task is to name the stimuli. stimuli can not be named because the control for speech is in the left hemisphere and yet, since a request for a verbal answer was received in both hemispheres, the left, dominant hemisphere provides the verbal response. It is the wrong response because sensory and perceptual information of the stimulus is lateralized only to the right hemisphere. The confabulations or "guesses", then, reflect an attempt to "make sense" of the world, to "fill in", so to speak, by the left hemisphere. In sum, right hemisphere removal from conscious experiences of the left hemisphere leads to left hemispheric verbal attempts to minimize the removal.

What is not normal

Memory

Clues to hemispheric involvement in daily life might be gleaned from what is not quite normal in split-brain patients behavior. Generally, it is assumed that their verbal output reflects left hemisphere functioning and whatever is missing in the output to be the right hemisphere component or the normal interaction between left and right. Now, what appears to have suffered dramatically after surgery is recent memory (though the severity level is not comparable to anterograde amnesia) (Huppert, 1981; D. Zaidel & Sperry, 1974; D. Zaidel, 1990b). Indeed, the type of nonverbal memory usually associated with right hemisphere specialization, topographical memory, is particularly poor in everyday life. Thus, they have exceptional difficulties in relocating a parked car or in locating items around the house, or in finding their way in a highly-familiar laboratory. Some verbal memory, especially newly learned material, is also not up to the level preceding surgery, as determined by family members. This is confirmed in laboratory tests as well. Even in the case of verbal material, it is assumed that what is missing in the performance is the normal right hemisphere imaginal component.

Because memory is poor they have no interest in reading novels, newspapers, and so on. Similarly, watching TV or films poses apparently insurmountable integration problems that are likely due to poor memory.

Emotional Reactions

In daily life Events such as divorce or death of a close relative do not appear to produce typical reactions such as bitterness, sadness, hatred, anger, violence, or related negative emotions (Hoppe & Bogen, 1977). In over 25 years I have never heard them speak of revenge or of violent acts. In fact, reactions to such situations are, by and large, factual. A definite dissatisfaction is expressed but there is a touch of bemusement, the degree of which varies from patient to patient. Infidelity of a spouse (they themselves are not known to be disloyal) is related simply, in the absence of what might be considered deep insight. To the listener it appears that there is no sense that death or disloyalty or infidelity are forgiven or are understood benevolently. Instead, the listener gains the impression that an account is given of yet another daily event but this time one describing an injustice. Could this be a case of denial? Hardly, since the facts are always provided. All of this is not to say that they do not feel sadness, infidelity, loss, or anger. We simply do not know if they do since no formal assessment has been undertaken beyond informal conversation.

An example: A 50 year old patient complained after he moved his residence from one caretaker to another that he was repeatedly not offered the food he is used to eating. Instead he was offered food unique to the ethnic background of the caretaker and after meals he still felt some hunger. He voiced his complaint to the caretaker, he says, but to no avail. A family member subsequently intervened and the food situation changed. There was no anger or resentment as he related the story. His tone of voice merely reflected the opinion of someone treated unfairly.

Facial expressions . Their faces are generally expressive. Based on casual observations, these appear just as symmetrical or asymmetrical as in normal subjects. However, anecdotes about personal injustice do not often appear to be accompanied with what one would normally expect to see. Hardly ever, if at all, did I observe a sad facial expression, for instance. But I did observe facial expressions denoting disgust or dissatisfaction (with food, say, or with unusually long waiting periods).

On the whole, the general personality characteristic is 'positive' rather than 'negative', and this is expressed both verbally or through facial expressions.

In the laboratory: One young male patient was tested with the hemi-field tachistoscopic technique which allows visual presentation of stimuli to only one visual half-field at a time. With his gaze focused on a central fixation point on a the screen, different simple configurations were flashed quickly one at a time either to the left or to the right side of the point and the task was to name them. He had no difficulty in naming those flashed on the right side of the fixation point (the information was transmitted to the left, speaking hemisphere) but he was unable to name simple geometrical configurations on the left (information was transmitted only to the right, mute hemisphere). He attempted guesses or simply said he was unable to name the image. One of the configurations that was projected on the left was that of a swastika. Unlike any of the previous reactions in earlier trials, he immediately sat back in his chair exclaiming, "What was this that you just showed me!" What do you think it was, asked the experimenter. He replied, "A terrible thing, an awful thing." You did not like it, stated the experimenter. "No, I didn't", he replied, shaking his head. Was it a good thing or a bad one, probed the experimenter (who did not anticipate strong reactions to any of the items in the set). "Bad, very bad", replied the patient. He was never able to name it nor to guess what it was.

In a separate, extensive series of trials which used the Z-lens, a technique which allows prolonged presentations of visual stimuli to one hemisphere at a time, social awareness and historical knowledge in the disconnected left and right hemispheres were measured (Sperry, D. Zaidel, & E. Zaidel, 1979). Faces of well-known historical figures such as Churchill, John Kennedy, Stalin, and so on, as well as faces of the patients themselves, family members, or familiar situations, were presented. The task was to indicate "thumbs up" for good and "thumbs down" for bad. The results showed that the level of social awareness and historical knowledge was the same in both hemispheres. Thus, Churchill was "thumbs up" and Stalin, "thumbs down" in either the left or the right hemispheres.

Dreams

Before surgery patients reported dreaming at night. After surgery, most reported that they stopped dreaming. It has been difficult to verify their assertions without rigorous scientific observation and this project has never been undertaken. At the same time, there have never been reports by family members that patients wake up tired or that they have spent sleepless nights.

It is uncertain whether or not dreaming did not take place at all, or that dream content was inaccessible to verbal communication or that whatever was dreamed was forgotten. In the past, in some scientific circles, there was a controversy regarding the lateralization of dreaming in the brain. That is, does dreaming take place in the right hemisphere alone. The fact that split-brain patients were unable to report their dreams was taken as support for this hypothesis. Otherwise, given that speech is lateralized to their left hemisphere they should have been able to report their dreams. The bottom line is that there is no conclusive evidence as of now on what role hemispheric specialization plays in dreaming.

Attitude towards the left hand

Neither the left nor the right hands are paralyzed or deprived of sensations. Yet, in some cases, remarks that appeared to personify the left hand were noted soon after surgery, and in a few cases this attitude remained for some years. These verbally expressed attitudes may fall under the rubric of "the strange hand syndrome." In traditional neurology, the syndrome is usually observed following strokes in different parts of the cortex, including in parts of the corpus callosum. There is no easy or clear explanation for the phenomenon. With the split-brain cases, one would hear the left hand described as "she won't do what I tell it", "it has a mind of it's own", "my left hand takes my cigarette out of my mouth while I'm smoking", or "I turn the water tap with my right hand and the left comes and turns it off". Such remarks about the left hand were reported in the first few months after surgery but milder aspects of the motor conflict can last longer, in some cases as long as several years (Bogen, 1992). For example, under specific laboratory conditions, one patient often slapped her left hand lightly with her right hand when she could not come up with the correct name of a blindly palpated object, saying something such as, "Bad, bad hand this one." Since sensory input from the left hand reached only the right hemisphere, the patient was unable to name the object. In other words, she was frustrated with her left-hand anomia. Whether the 'frustration' was a manifestation of left or right hemisphere mental processes is hard to tell. However, since it was the right hand that slapped, we must assume that left hemisphere mental processes were dominant.

Quality of life

Most people would agree that 'normal' is a relative term. Similarly, a 'full life' could be considered relative. One could conceive of low quality of life if memory were a serious problem (although some would argue that having a poor memory is a blessing). Poor memory could pose a serious problem for the patients if they did not make notes of impending appointments or other specific schedules. In fact, they do take notes and since they are cared for by dedicated family members, their poor memory is probably not a serious handicap. Only one patient in this group has been gainfully employed for a substantial period of time, albeit in a specially funded civic program. What may be difficult or unusual in split-brain patients' lives is their secondary limitations, namely, inability to drive due to the epilepsy and/or medication as well as their lack of interest in reading or keeping up with the latest movies or TV shows. The stimulation of such activities is missing from their daily life, leaving them dependent to a certain extent on others. But since they are friendly and enjoy a good conversation they do receive some enrichment. Consequently, they are involved and aware of crucial events that could have impact on their lives.

We do not really know how often, if at all, they generate an intention, a desire, or a wish in the right hemisphere, but are unable to carry it out. Such hypothetical situations in daily life are difficult to assess, let alone judge how much they would interfere with 'quality of life'. There is no doubt that the surgery alleviated or eliminated the epilepsy and they all acknowledge that the fact that they gained freedom from recurrent, debilitating seizures is the best thing that has happened to them.

Conclusion: Resolution of the paradox

So much can be done without the forebrain commissures and yet other things are not quite normal. What conclusions can we then draw regarding the role that these commissures play in the organization of the mind in the brain, from cognition to personality to emotions? The likely answer is that they play a crucial role in learning new things, in the initial sorting of incoming information, and the relegation to specialized regions within or between the hemispheres. This would also explain why skills learned before surgery are retained and only a few have been learned afterwards, or acquired with difficulty. This might explain why personality traits and mannerisms which were all established before surgery, did not change afterwards. Indeed, learning involves memory and memory functions are impaired with damage to the forebrain commissures (even when the commissurotomy is only partial (D. Zaidel, 1990b)).

The extent to which observed behavior in the complete commissurotomy patients is supported by only one hemisphere would depend on individual differences interacting with a variety of factors such as genetics, intelligence, and so on. The lesson imparted here is that there is sufficient functional redundancy in the neocortex so that the capacity to maintain a wide range of abilities is within the control of one hemisphere. And, yet, as seen in what is missing in the patients' behavior, one hemisphere is not quite enough. Nature seems to have intended that the two hemispheres complement each other, that the full range of human behavior be best accomplished through interaction between the left and right hemispheres.

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