85 Split Decisions

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ABSTRACT Split-brain patients provide a fascinating look at some of the issues surrounding consciousness. We briefly review past findings and insights gained from studying these patients. We discuss in more detail some of the more interesting (to us) findings since the last edition of this volume. We conclude by suggesting a modified version of signal detection theory that may shed some light on aspects of consciousness in these patients.

Consciousness in the split brain

Split-brain patients offer a unique perspective on some aspects of conscious experience, and perhaps on the nature of consciousness itself. Roger Sperry once referred to the patients as "two separate realms of conscious awareness; two separate perceiving, thinking and remembering systems." There were early fears that severing the callosum was a bad idea and would lead to dire consequences. The operation might create a person with the ultimate split personality, just like having two persons inside the same body. One of the big early surprises was the seemingly complete absence of any splitness in the consciousness or personality of these patients (Akelaitis, 1941; Gazzaniga, Bogen, and Sperry, 1962). Most of the patients seemed blithely unaware that anything had changed in their mental processes, with the pleasant exception that their seizures had lessened or even stopped. Why don't split-brain patients experience dual consciousness? Possibly consciousness is housed in neural tissue that is completely lateralized to one hemisphere or the other. Perhaps consciousness is completely tied to language, and since language is generally lateralized, consciousness is as well. Perhaps the two hemispheres have worked out a division of labor such that consciousness follows the task or materials and that different hemispheres are consciously aware at different times. We will explore that final possibility later in this chapter.

The split-brain operation

Split-brain surgery is a treatment for certain types of intractable epilepsy. Seizures in epilepsy are caused by an abnormal electrical discharge that leads to a reverberating or rhythmic discharge. In some individuals, the rhythmic discharges recruit tissue in both hemispheres. The split surgery involves severing all or part of the corpus callosum, the major fiber tract connecting the two cerebral hemispheres, and on occasion other forebrain commisures as well. The corpus callosum is the largest fiber tract in the brain. The human corpus callosum contains about 200 million axons, originating from layer 2/3 pyramidal neurons (Aboitiz et al., 1992). The first reported use of splitting the corpus callosum to control epilepsy was by Van Wagenen and Herren (1940). Van Wagenen got the idea for the surgery by observing that one of his patients with severe seizures experienced considerable relief after developing a tumor in his corpus callosum. Based on that observation, he and his colleague severed part or all of the callosi in 10 patients and reported considerable relief from seizures. They performed the surgery on a second set of 14 patients as well. After a hiatus of a couple of decades, the procedure was tried in a new set of patients in California (Bogen and Vogel, 1962). The behavior of these patients was studied extensively by Gazzaniga and his colleagues (Gazzaniga, Bogen, and Sperry, 1962, 1963, 1965). The treatment was effective in reducing seizures in these patients. Overall there was about a 60%–70% seizure reduction in 80% of the patients. However, there were serious complications in many of these earlier cases. More than 50% of the early patients experienced aseptic meningitis or hydrocephalus, often resulting in death. Among other difficulties, the wall separating the bottom of the corpus callosum from the ventricles is only four cells thick in places and is easily punctured. D. H. Wilson at Dartmouth perfected the use of microsurgery in splitting the corpus callosum and revived the use of the procedure in controlling seizures (Wilson et al., 1977). Split-brain surgery was never performed at a high rate and was considered a treatment of last resort. The procedure is less common today, with the availability of newer and better pharmacological treatments coupled with advances in neurolocation and more focused neurosurgery. Further, a higher percentage of recent split-brain operations have involved

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only a portion of the corpus callosum. In theory, patients who have undergone a complete callosotomy form an ideal population for studying the independent functioning of the two hemispheres. In practice, only a relatively small percentage of these patients are appropriate for behavioral studies. All of the patients have had a long history of severe epileptic seizures, and many suffer from other cognitive deficits. Although relatively rare, there are more split-brain patients than there are patients for many of the other interesting brain anomalies.

Hemispheric asymmetries

Since at least the time of Broca, we have believed that some behavioral functions such as language are lateralized in the brain. Broca studied a patient who was paralyzed on the right side and had lost the ability to speak. The man died shortly thereafter, and his brain was preserved. Most of our knowledge about hemispheric asymmetries over the next century came from studying people with various types of brain injuries. Researchers also examined hemispheric differences in people without brain damage, using tachistoscopic presentation to one visual field or the other. The research on neurologically intact subjects confirmed much of the patient work, but interpretation of the results obtained in such subjects is always clouded by the fact that any information presented to a specific hemisphere can cross to the other hemisphere at will, and that crossing takes only a few milliseconds (Berlucchi et al., 1971).

Split-brain patients provided an ideal environment for studying these hemispheric asymmetries, because information presented to a specific hemisphere more or less had to stay there. Early studies with split-brain patients confirmed that language was usually lateralized to the left hemisphere and confirmed advantages in the right hemisphere for spatial processing. There has been interesting evidence that processing in the right hemisphere is relatively more literal, while processing in the left is more constructive (Metcalfe, Funnell, and Gazzaniga, 1995). Several studies over the last few years have helped clarify those asymmetries. In this chapter, we will focus on several new developments concerning the role of the two hemispheres in attention and memory, and we will present some intriguing studies aimed at clarifying the precise advantages of the right hemisphere in spatial processing.

Perceptual Processing It has been known at least since the time of John Hughlings Jackson (1874/1915), a contemporary of Broca, that many perceptual processes are lateralized to the right hemisphere. Current research has shown that not all perceptual processing is superior in the right hemisphere. The presence of asymmetries is quite specific to both the particular stimuli and the particular task. For example, Corballis, Funnell, and Gazzaniga (2000a) found that both hemispheres of two split-brain patients (one with a complete split, the other a partial split) could discriminate two objects with different identities equally well, but that the right hemisphere performed better than the left hemisphere in discriminating two identical objects with different spatial locations. In subsequent studies they found that the right hemisphere was better at line orientation and vernier acuity, but that both hemispheres performed equally well in size comparisons and luminance discrimination (Corballis, Funnell, and Gazzaniga, 1999, 2000a).

Furthermore, Corballis and colleagues have suggested that these hemispheric asymmetries in visuospatial processing are not entirely due to hemispheric specializations for particular types of sensory input but involve lateralization of specific types of processing, such as visual grouping. One piece of evidence for this idea involves the line motion effect. This occurs when a line is presented briefly between two squares. Just prior to the appearance of the line, one of the squares flashes. To observers, it appears that the line is propagating from the flashing square. Hikosaka, Miyauchi, and Shimojo (1993) proposed a low-level visual process to explain the effect in which the flashing square draws attention to the location prior to the onset of the line. However, subsequent researchers have demonstrated that changing the properties of the stimuli can create quite different illusions (von Grünau and Faubert, 1994; Tse, Cavanagh, and Nakayama, 1998). For example, using a red line between a red and green square will create the illusion that the red line is propagating from the red square. In this case, the effect of apparent motion must rely on visual grouping after the onset of the line. Corballis and colleagues found that the left hemisphere in a split-brain patient was indifferent to the color manipulation but that the right hemisphere almost always perceived the line as moving away from the square with the matching color (Corballis, Funnell, and Gazzaniga, 2000b; Corballis, Barnett, and Corballis, 2004).

Corballis and colleagues reached similar conclusions using paradigms involving the perception of subjective figures by modal and amodal boundary completion (Corballis et al., 1999). Modal completion can be solved by relying solely on low-level visual processing. Two split-brain patients were found to perform modal completion equally well in both hemispheres. Amodal completion relies on visual grouping to resolve the spatial ambiguity, since there are no subjective contours, and, in this case, the right hemisphere was superior to the left. Corballis refers to this lateralization of visual grouping in the right hemisphere as the "right hemisphere interpreter" (Corballis, in press).

A recent study that is consistent with the idea of a right hemisphere interpreter involves the perception of causality using the Michotte task. Short movies were shown to patient J.W., who had a complete split. Each movie showed one disk moving toward a second disk and coming to a standstill when it touched the second disk. The second disk then moved away from the first disk. To most observers, it would appear that the movement of the second disk is caused by the first disk. However, if a large enough gap, either spatial or temporal, is inserted between the two circles, the motion of the disks does not appear causally related. The left hemisphere of a split-brain patient, J.W., was indifferent to the manipulation of the magnitude of the gap, but the right hemisphere responses were affected by the magnitude of the gaps in an appropriate fashion (Roser et al., in press).

Despite the right hemisphere advantage for some forms of visuospatial processing and evidence for a right hemisphere interpreter, there are some visual processes in which the left hemisphere has an advantage. For example, recent neuroimaging studies have shown that mentally rotating an object activates parietal and frontal regions in both hemispheres, but that imagining yourself in a different spatial perspective relative to an object may involve different parietal and frontal regions located primarily in the left hemisphere (Wraga, Church, and Badre, 2002; Zacks et al., 2002). Funnell and colleagues have tested this distinction in a split-brain patient using a paradigm in which an identical stimulus can be mentally rotated or imagined from a different perspective. They found that while the right hemisphere appeared to be better at mental rotation, the left hemisphere appeared to be better at perspective taking (Funnell, Johnson, and Gazzaniga, 2001).

For these relatively low-level perceptual paradigms, the hemispheric asymmetries appear to be driven by top-down processes. In contrast, many hemispheric differences with higher-order cognitive processes, such as attention and memory, appear to be driven by specialization for stimulus properties. Kingstone, Friesen, and Gazzaniga (2000) performed several fascinating studies on reflexive attention using eye gaze direction in split-brain patients. As in the Posner cuing paradigm, a schematic face was presented as the cue. The direction of the eyes may point to a target, or it may not. In the case of primary interest, the direction of eye gaze was not predictive of the target location. Yet in the right hemisphere, but not the left, the patient was faster to respond to a target in the path of the eye gaze. This effect was obtained with schematic faces and with eyes alone, but not when the schematic faces were presented upside down (figure 85.1). When the face was actually predictive of target location or when the stimulus was a nonpredictive arrow, both hemispheres showed a similar effect. These finding suggest that reflexive joint attention is mediated by cortical processes that are lateralized to the hemisphere responsible for face processing, which in these two patients is the right hemisphere. Parenthetically, this work with split-brain patients led to the surprising finding that nonpredictive arrows did orient attention in normal subjects, a finding that runs counter to a basic assumption (and never explicitly tested) in the field of attention since the start of the Posner cuing paradigm in the 1970s (Kingstone et al., in press).

MEMORY Hemispheric specialization in particular low-level cognitive processes can affect episodic memory formation, the memory for real-world events, as well. Retrieving episodic memories often involves decision processes that are affected by a variety of influences, just like any other decision process, and the underlying brain regions engaged during retrieval can vary greatly from subject to subject, depending on individual strategies (Miller et al., 2001; Miller, Kingstone, and Gazzaniga, 2002; Windmann, Urbach, and Kutas, 2002). The encoding of episodic memories, as opposed to retrieval, appears to be elicit more consistent neural activations across subjects (for review, see Cabeza and Nyberg, 2000). Hemispheric asymmetries play a role in memory formation, as evidenced by neuropsychological studies (Milner, Corkin, and Tueber, 1968; Milner, 1972) and more recently by neuroimaging studies (Tulving et al., 1994; Kelley et al., 1998; Nyberg, Cabeza, and Tulving, 1998; Wagner et al., 1998; Nyberg et al., 2000). However, many memory researchers debate the nature of those asymmetries. Some investigators have argued that episodic encoding is predominantly a left prefrontal function and that episodic retrieval is predominantly a right prefrontal function (Tulving et al., 1994). Typically these neuroimaging studies rely on the encoding and retrieval of familiar verbal material (Cabeza and Nyberg, 2000). Other researchers have suggested that hemispheric asymmetries, particularly episodic encoding, are material-specific rather than process-specific. For example, recent neuroimaging research has found predominantly right hemisphere activations in the prefrontal cortex during the encoding of unfamiliar faces (Kelley et al., 1998) and textures (Wagner et al., 1998). Nevertheless, proponents of a lateralized episodic encoding region argue that the bulk of neuroimaging research, including some studies using nonverbal material, is consistent with episodic encoding being predominantly a left hemisphere process (Nyberg, Cabeza, and Tulving, 1998; Nyberg et al., 2000).

The testing of split-brain patients can play a role in resolving this debate. If encoding and retrieval are predominantly lateralized processes in opposite hemispheres, then split-brain patients should have major memory impairment, because the information is encoded in one hemisphere and retrieved by the other and the two hemispheres are disconnected. Yet these patients demonstrate only minor deficits in episodic memory (Zaidel and Sperry, 1974; LeDoux et al., 1977; Phelps, Hirst, and Gazzaniga, 1991; Metcalfe, Funnell, and Gazzaniga, 1995; see Viskontas, Zaidel, Knowlton, 2003, for a recent case of a patient with more severe impairments in autobiographical memory). Split-brain patients perform normally on most recognition tests yet often have slight impairments on free recall tasks that

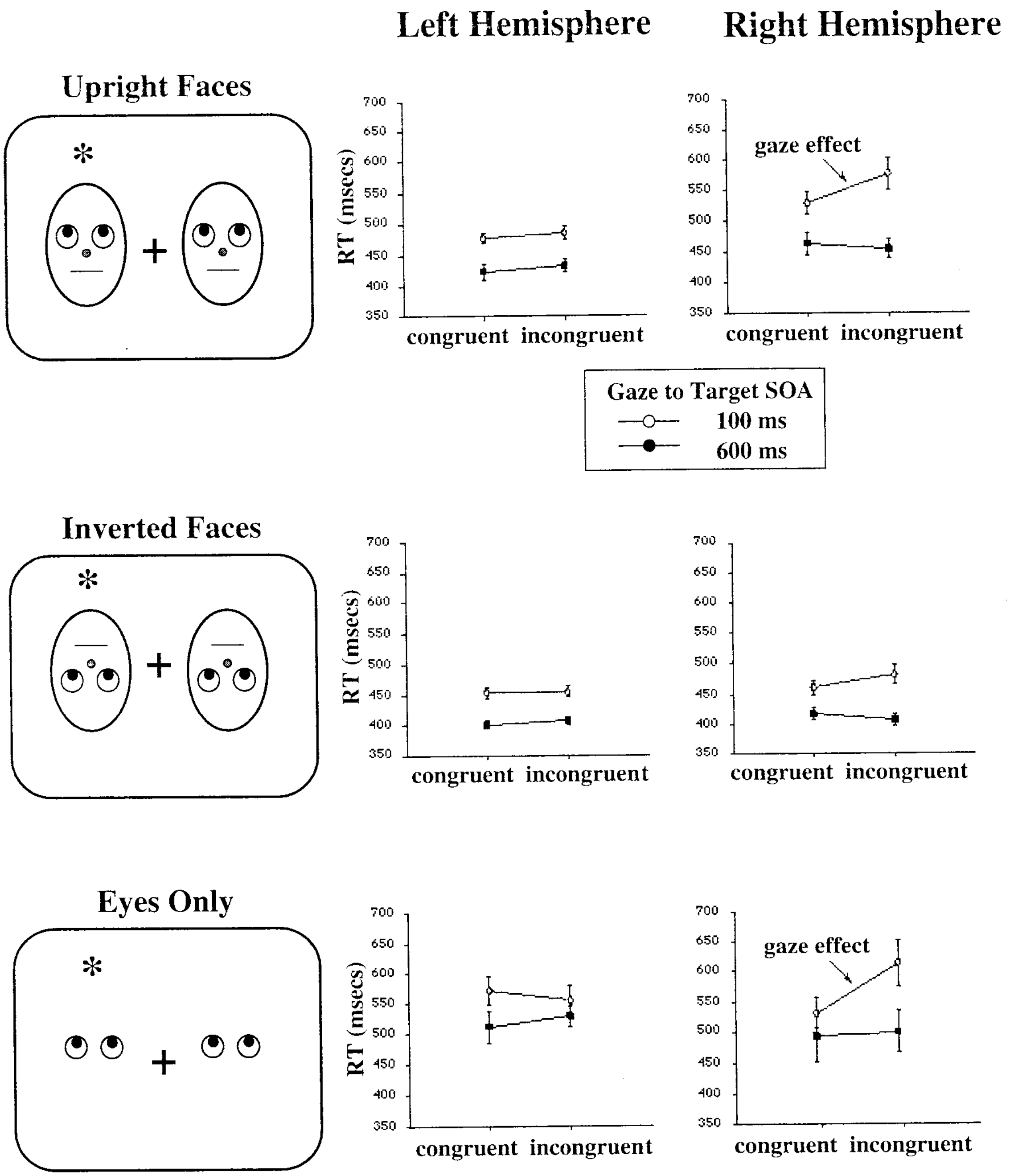

FIGURE 85.1 The graphs represent split-brain patient J.W.'s performance. Two faces (upright or inverted) or two pairs of eyes were presented concurrently to the left of a central fixation cross and to the right of the cross. The task was to maintain central fixation and to press a left-hand key when the target asterisk was presented to the left visual field (right hemisphere) and a right-hand key when the target was in the right visual field (left hemisphere). Gaze direction did not predict target location. The gaze effect (responding significantly faster to a congruency between target location and gaze direction than to an incongruency) was evident only in the right hemisphere, and only for upright faces and eyes. Patient V.P. had similar results (Kingstone, Friesen, and Gazzaniga, 2000).

require additional recruitment of strategic resources (Phelps, Hirst, and Gazzaniga, 1991). These findings in split-brain patients suggest that activations seen on neuroimaging studies may indeed be material-specific rather than process-specific, as suggested by Kelley and colleagues (1998) and Wagner and colleagues (1998).

We directly tested this hypothesis by manipulating the encoding of words and faces in each hemisphere of two split-brain patients, one with a complete split and the other with a partial split (Miller, Kingstone, and Gazzaniga, 2002). If episodic encoding is predominantly a left hemisphere function independent of material type, then only the left hemisphere in these patients should benefit from more elaborate encoding of words and faces. However, because language is preferentially lateralized to the left hemisphere and face processing is lateralized to the right hemisphere in these patients (Gazzaniga, 2000), we hypothesized that the left hemisphere, but not the right, would benefit from the deeper encoding of familiar words, and that the right hemisphere, but not the left, would benefit from the deeper encoding of unfamiliar faces. Our hypothesis would work only if encoding processes were available in both hemispheres.

As shown in figure 85.2, we found in both patients a significant difference in recognition performance after deep processing during encoding of words versus shallow processing during encoding of words in the left hemisphere, but no difference as a function of depth of encoding in the right hemisphere. Unfamiliar faces yielded the opposite result. There was a significant difference in recognition performance after deep encoding of faces versus shallow encoding of faces in the right hemisphere, but no difference in the left hemisphere. Our results clearly indicated that manipulations of episodic encoding differentially affect the performance of the hemispheres, depending on the type of material being processed. Each hemisphere seems to be fully capable of supporting episodic memory, and some asymmetries seem to be based on the type of material being processed. A more recent fMRI study of normal subjects regarding hemispheric asymmetries during encoding of faces (Wig et al., in press), along with previous patient studies (Milner, 1972) and sodium amytal studies (Kelley et al., 2002), demonstrate functionally separable routes to memory within prefrontal cortex that depend on both the intrinsic properties of the to-be-remembered materials and on the specific cognitive operations required by the task.

Wig and colleagues (in press) also suggest that memorization of namable objects (materials with fluent access to both verbal and pictorial codes) engages both hemispheres, and that these materials are remembered better than materials that have access to single codes—the "picture superiority" effect (Paivio and Csapo, 1973).

We conducted a study (Cooney et al., 2002) with a split-brain patient using a simple full-field, nonlateralized

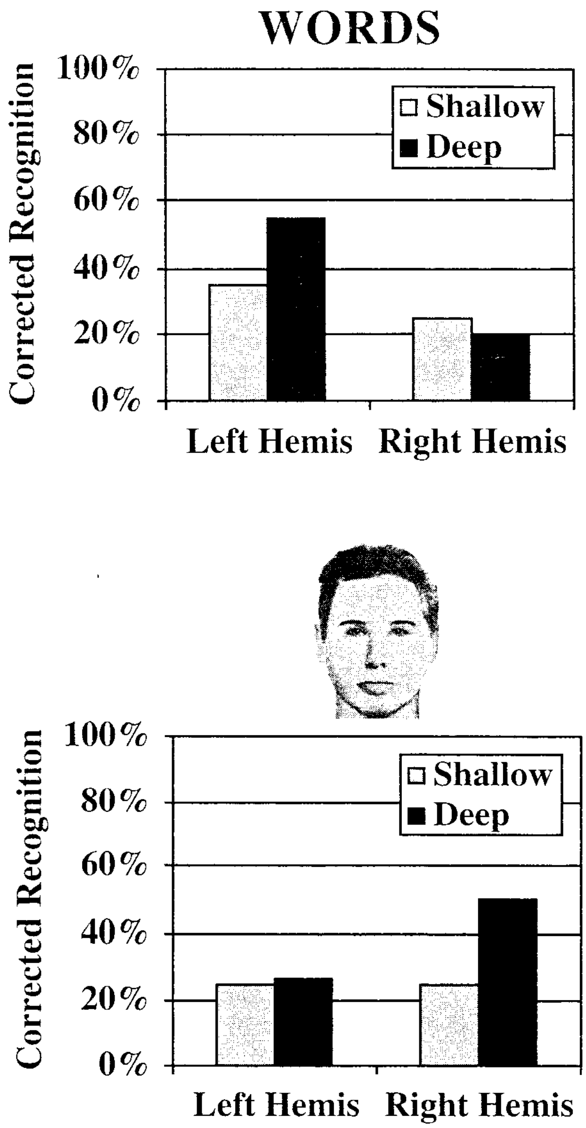

FIGURE 85.2 The top graph represents recognition performance using words for the left and right hemispheres of split-brain patient J.W., while the bottom graph represents recognition performance using unfamiliar faces. Gray bars represent a shallow level of processing during encoding (for words: does the word contain the letter *a*? for faces: is the face female?), and black bars represent a deep level of processing (for words: does the word represent a living object? for faces: is the face the face of a healthy person?). Both the study and the test sessions were lateralized to one hemisphere. The left hemisphere's recognition performance improved significantly after deep processing of words compared to shallow processing, while the right hemisphere showed no improvement. In contrast to word processing, the right hemisphere's recognition performance improved significantly after deep processing compared to shallow processing, but the left hemisphere's recognition performance did not. Patient V.P. had similar results (Miller, Kingstone, and Gazzaniga, 2002).

presentation with responses collected separately for the right and left hands. In three separate conditions, the patient memorized words, namable objects, and unfamiliar faces. Following the presentation of each stimulus set, the patient was given a recognition memory test with responses for each hand. Consistent with dual-coding predictions, when the subject used the right hand, memory for namable objects was no better than for words, and when the subject used the left hand, memory for namable objects was no better than for faces. These findings suggest that the picture superiority effect results from the collective contribution of left and right hemisphere brain regions during memorization.

Looking for patterns

Gazzaniga and his colleagues have long argued for the existence of a structure in the left hemisphere referred to as the interpreter. The interpreter was the process that tried to make sense out of incomplete or ambiguous information. The existence of such an interpreter has been demonstrated in several experiments in which the left hemisphere apparently "felt" the need to explain responses made by the left hand under control of the right hemisphere (Gazzaniga, 2000). We recently developed a new technique for examining the existence and characteristics of the interpreter in the left hemisphere (Wolford, Miller, and Gazzaniga, 2000). The technique is quite simple and involves having the participant guess which of two events will happen on the next trial. This paradigm, referred to as probability guessing, was examined extensively in the middle of the twentieth century. One curious and easily replicable finding is that humans tend to frequency match in this paradigm. Frequency matching means that humans tend to guess the alternatives in the proportion at which they have been presented in the past. So, if the two alternatives are "left" and "right," and left occurs on 70% of the trials, participants will tend to guess "left" about 70% of the time. Frequency matching is curious because it is nonoptimal and because animals from almost every other species maximize the optimal strategy (Hinson and Staddon, 1983). Maximizing is always guessing the most frequent alternative.

The likely reason that humans frequency match is that they believe there is a deterministic pattern, and they are determined to find that pattern even when told there isn't one. Yellott (1969) provided a striking demonstration that people were looking for patterns in these experiments. In his experiment, a stimulus appeared either on the left or on the right, on each trial, and subjects had to predict which light would appear. The probability of the lights was varied across blocks. Subjects matched the frequency of the actual presentations (frequency matching), changing when the frequency changed. In the last block of 50 trials, the light appeared wherever the subject predicted it would, regardless of the subjects' guesses. Subjects continued to frequency match during these last 50 trials. When Yellott stopped the experiment and asked subjects for their impressions, they overwhelmingly responded that there was a fixed pattern to the light sequences and that they had finally figured it out. They proceeded to describe elaborate and complex sequences of right and left choices that resulted in their responses always being correct. These verbal reports support the contention that subjects had been searching for fixed sequences all along and were fooled into thinking they had succeeded.

We reasoned that if frequency matching results from searching for patterns even when there are none, and if the left hemisphere interpreter postulated by Gazzaniga is a neural structure that tries to make sense of the world around it, then there might be an intimate relationship between frequency matching and the left hemisphere. To test this hypothesis, we lateralized the probability guessing paradigm, presenting the stimuli to either the right or left visual field of two split-brain patients and collecting the predictions from the appropriate contralateral hand. We reasoned that if the interpreter were responsible for frequency matching, then we should see frequency matching with left hemisphere presentation and maximizing with right hemisphere presentation.

That is what we found. We replicated the paradigm using patients with unilateral frontal brain damage, reasoning that a patient with unilateral but widespread damage to the right frontal cortex would perform similar to the left hemisphere of a split-brain patient, and vice versa for a patient with unilateral damage to the left hemisphere. As predicted, the patient with unilateral left frontal damage maximized, but the patients with unilateral right frontal damage frequency matched. Figure 85.3 shows the data averaged across the two split-brain patients and the patients with frontal lesions (see original article for individual graphs).

Recognition of self

Various researchers have argued that the concept of self is intimately related to consciousness (Kihlstrom and Klein 1997; Turk et al., in press). Leaving aside the notion of consciousness during visual perception as portrayed by Crick and Koch (see Crick and Koch, this volume), the self as agent seems to be a major part of much conscious experience. Is processing or awareness of self really different from other forms of semantic processing? Are there neural circuits specifically related to self processing? Could there be a connection between the left hemisphere interpreter and the self? There have been interesting findings related to all three of these questions over the last few years.

Many investigators, following the level-of-processing tradition, have shown that self-relevant processing leads to

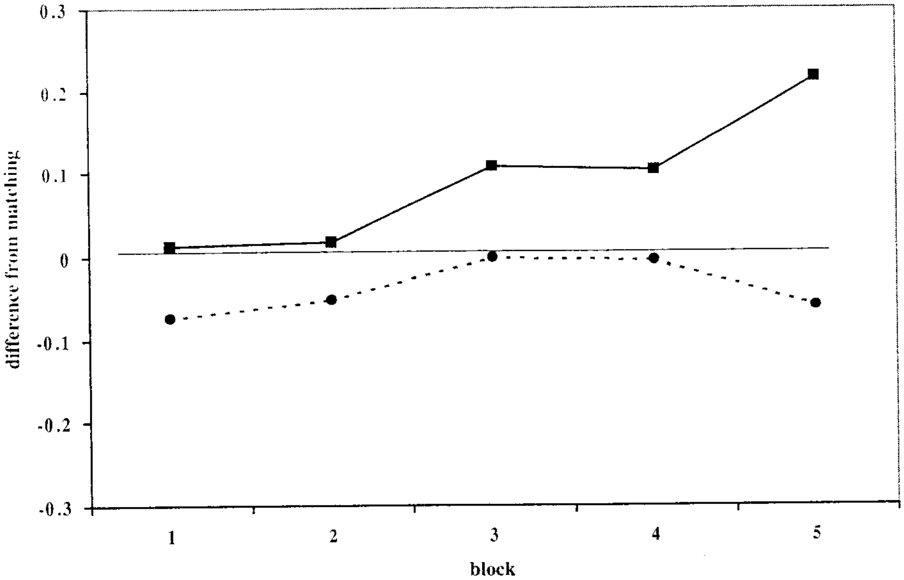

FIGURE [illegible]5.3 The graph represents the probability of guessing the most frequent stimulus as a function of hemisphere for each block of trials. The data are averaged over two split-brain patients and two patients with unilateral frontal damage. The most frequent stimulus appeared 70% of the time in all cases, and the horizontal line in the middle of the graph represents frequency matching or guessing the most frequent stimulus 70% of the time. Left hemisphere presentations yielded frequency matching, but right hemisphere presentations yielded maximizing or guessing the most frequent stimulus most of the time. (The data, broken down by individuals, are presented in Wolford, Miller, and Gazzaniga, 2000.)

better subsequent memory than even deep semantic processing (see review by Lockhart and Craik, 1990). Some investigators have argued that self-relevant processing is not qualitatively different from other forms of semantic processing (Kihlstrom and Klein, 1997). They argue that its advantage comes from increased familiarity with self and the broader array of associations that are available. Kelley and colleagues (2002) compared self-relevant processing to other-relevant processing and to upper- and lowercase judgments. They found that both self-relevant and other-relevant processing produced greater activation in the left inferior frontal cortex and in the anterior cingulate when compared to case judgments, but there was no difference between self and other in these regions. They did find one area, the medial prefrontal cortex, in which self processing was substantially higher in activation level than either other or case processing. Taken together, these findings suggest that self processing is similar in some ways but qualitatively different in other ways from deep semantic processing.

What about the possible relationship between the left hemisphere interpreter and the processing of self? The findings from Kelley and colleagues (2002) were ambiguous as to laterality, and the medial prefrontal activation straddled the midline. Given the smoothing algorithms used, the activation might have been bilateral or might have been lateralized to one of the two sides. The previous literature has been mixed with respect to the laterality of self processing. Using WADA tests, Keenan argued that the right hemisphere was more apt to remember having seen one's self following presentation of morphed photographs in which the self was part of the morph (Keenan et al., 2001). Of necessity, perception and memory are confounded in a WADA paradigm. Generally, face processing is better in the right hemisphere (Kanwisher, McDermott, and Chun, 1997), but not necessarily processing of one's own face. Other studies have shown a left hemisphere advantage for autobiographical memory and for pictures of one's face (Conway and Pleydell-Pearce, 2000).

In a recent study, Turk and colleagues (2002) examined the perceptual recognition of self in a split-brain patient. They presented morphs of the patient and one of three familiar others to the patient, varying the percentage of self in the morph. They went through each sequence of morphs from 0% self to 100% self twice. On some sequences the patient was asked to respond "yes" if he saw himself. On other sequences, he was asked if he saw a particular familiar other. They found a strong dissociation in that the patient was more likely to identify the other familiar person in right hemisphere presentations but substantially more likely to identify himself in left hemisphere presentations. These data do not necessarily resolve the ambiguity in the previous literature, but they do suggest that the left hemisphere may be biased to perceive one's self. Such was not the case in the right hemisphere.

The foregoing data do not necessarily speak to the involvement of the interpreter, but the link between a structure that tries to make sense of the world and the perception of self is compelling. Both appear to reside in the left hemisphere, and a large part of making sense of the world seems to involve thoughts about one's self. Continuing in the speculative vein, it is possible that consciousness, the self, and the left hemisphere interpreter are intimately connected. As compelling as these relationships seem to us, we are going to do our best in the next couple of sections to complicate the picture.

A two-stage signal detection model

We noticed an interesting aspect to the data on self perception presented by Turk and colleagues (2002) that was not discussed by the authors. A reanalysis of the data confirmed our impression and meshed with previous observations of working with split-brain patients. The split-brain patient went through each of the morphed sequences several times using one of two response options. On one-half of the trials the patient was instructed to respond "yes" if he saw himself in the picture. On the other half of the trials he responded "yes" if he saw the familiar other in the photograph. We reanalyzed the data by adding together the number of yes responses for a given morph stimulus across the two different response formats. For example, on one morph sequence for the stimulus that contained 90% of the patient's face, the patient responded "yes" a sum of 110% of the time (100% of the time when asked about self and 10% when asked about the familiar other) when the morph was presented to the left hemisphere, but only 75% of the time (60% and 15%) when the morph was presented to the right hemisphere. The average rate of yes responses across the different morph fractions is presented in figure 85.4.

As the figure shows, presentations to the left hemisphere were more likely to yield a yes response, regardless of morph fraction or response required. We concluded that presentations to the left hemisphere are biased to yield a perception of "self," but they are also more likely to yield a yes response in general (92% yes responses in left hemisphere vs. 72% in the right). Treating different morphs as replications, this difference was significant ($t(10) = 2.82$, $P = 0.018$).

We are suggesting that willingness to respond and bias for a particular response given that a response is made are separable parameters. This separability is not observable in most paradigms, as the subject is forced to respond in most paradigms. The separation between willingness to respond and bias for a particular response seems well captured by a two-stage signal detection model. Subjects first decide to respond, and once they have decided to respond, the traditional signal detection model would apply. In order to avoid this possible confound, one would have to use a paradigm that allowed a nonresponse on each trial. However, even in paradigms that do not permit a nonresponse, we believe that in some conditions, the subjects may essentially decide not to respond, even though they hit a button. In those cases, the subjects would choose responses with little or no thought.

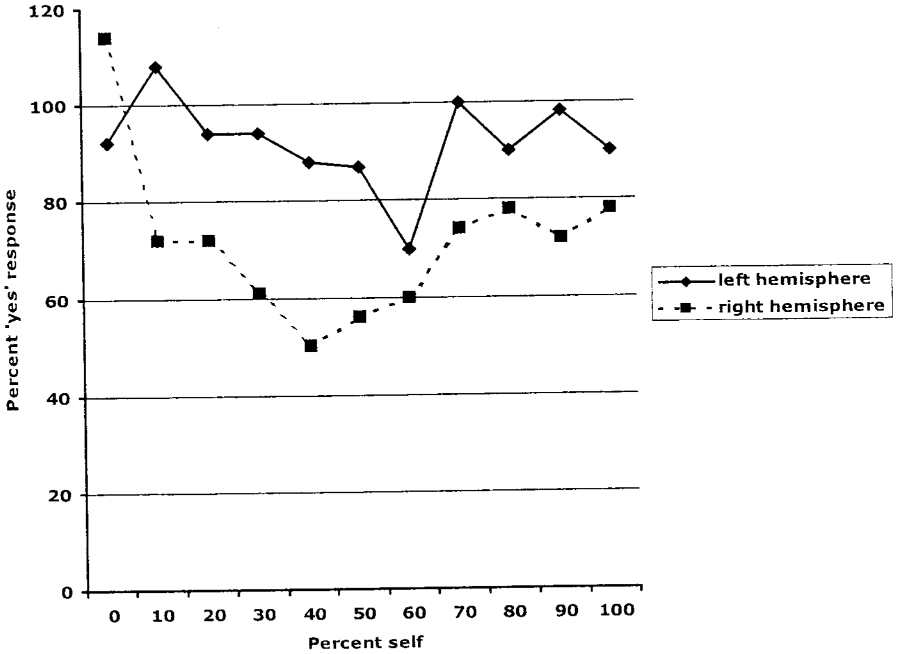

FIGURE 85.4 The graph represents the percentage of yes responses summed over trials on which patient was asked to say "yes" if he saw himself and on trials in which he was asked to say "yes" if he saw a familiar other as a function of percentage of self in the morphed image. If the patient always said yes in both response categories, the measure would sum to 200%. The graph shows that yes responses are significantly more common in the left hemisphere.

We present a rough idea of this model in the context of a recognition memory experiment requiring an old/new response in which the test is presented to different hemispheres on some schedule. The first stage would be a decision about whether to bother trying. The subject might decide that the task was too difficult in the right hemisphere and would not even to try to decide whether the item was old or new. The subject would make that decision with probability g. If the subject chose not to try, then he or she would make some response that required little thought or effort. Such a response might be pure guessing (50/50), perseveration on a single response, and so on. If the subject chose to try (say on tests in the left hemisphere), then he would assess the position of the item on some dimension of strength and respond "old" if that strength exceeded a criterion value and "no" otherwise. The decision to bother trying would be based on several factors such as the strength and quality of the available information, the context, the subject's a priori confidence in being able to perform the task, and so on.

In most standard tasks, it is difficult or impossible to disentangle the two processes with the usual data as collected. A decision not to try in some conditions of a standard recognition or judgment paradigm would show up as a reduced d' and an altered criterion, depending on the exact type of low-effort response that the subject chose to use. The paradigm of Turk and colleagues was unusual as it consisted of what could be described as two separate go/no-go tasks, one for each response option. By combining them, one obtains an estimate of the willingness to respond, the first stage, and in addition an estimate of the bias for or against the "self" response in the two hemispheres once a decision to try is made. To test the model systematically, one would need to run a standard recognition or signal detection paradigm and add the response option "don't know" on each trial. The "don't know" responses would be excluded from the estimation of the traditional signal detection parameters.

Our sense from testing split-brain patients in a number of diverse paradigms is that it seems that in many cases one hemisphere defers to the other hemisphere. The responses from the unfavored hemisphere look random and yield low estimates of d', but we have the sense that the low sensitivity often reflects an unwillingness to try. For example, the patient may believe that face recognition is the responsibility of the right hemisphere and may not try very hard on faces presented to the left.

We replicated our probability guessing paradigm with numerous variations on one of the split-brain patients. The typical result was frequency matching in the left hemisphere, but the behavior of the right hemisphere was quite inconsistent. We observed maximizing, minimizing (both forms of single-response perseveration), 50/50 responding, and simple alternation. As a group, we would characterize these responses as not trying with that hemisphere.

One of those probability guessing paradigms was particularly revealing. In addition to exploring new variables, one reason we kept varying the paradigm was to keep our subject from the depths of boredom. On one occasion we used facial hair as the event to predict. So the split-brain patient, J.W., was asked to predict on each trial whether the face that would appear had facial hair or not. For the only time in our lengthy series, the patient frequency matched with the right hemisphere and responded randomly with the left hemisphere. Our interpretation was as above. Faces were seen as the purview of the right hemisphere, so only that hemisphere took the task seriously.

The asymmetries discussed in this and in the preceding sections have implications for the nature and location of consciousness. There are undoubtedly specific modules in the brain both for different types of processing and for different types of stimuli. At least to some extent, these individual modules seem to be related to conscious experience (Cooney and Gazzaniga, 2003). The modular specificity of consciousness is further indicated by awareness of one's deficits or the lack thereof. With certain types of brain damage, the patient is fully aware of problems and bothered by them. With other types of brain damage, there is little or no awareness. A passage from Stuss and Alexander (2000) illustrates this specificity: "This domain specificity is the reason why impaired disorders of awareness within a specific module can exist. For example, a lesion in the left posterior temporal lobe typically results in Wernicke's aphasia (Benson, 1979) . . . the patient is unaware of the comprehension failure or the abnormal speech. If damage occurs to the right parietal lobe, the patient may neglect the left side with total unawareness of this neglect (Heilman et al., 1985)." We suggested earlier that for some tasks, a part of the brain assumes that it is its job to handle that task. We now suggest that when that occurs, that part of the brain is also responsible for any awareness that accompanies the task.

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