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The Two Sides of Perception

1 Introduction and Historical Overview

The asymmetric function of the mammalian brain took hundreds of years to discover. Anatomically, the central nervous system appears remarkably symmetrical. It looks much the same on each side with only minor and inconsistent differences in overall size and orientation of different areas. This symmetry is manifest at all levels of the nervous system, from the relatively simple structures of the spinal cord to the complex and extensively convoluted folds of the cerebral hemispheres (figure 1.1).

Correspondingly, the early writings on the biological basis of behavior tended to assume that function was symmetrically organized (see Finger, 1994; Harrington, 1995). The last 100 years of neurological study, however, have made it clear that the two hemispheres are not identical in function. The consequences of injury to one side of the brain or to the other are not the same: Patients with left hemisphere damage in a particular location can show vastly different symptoms than those shown by patients with right hemisphere damage in an analogous location.

The clinical observations of asymmetric function motivated researchers to ask whether evidence for this asymmetry could also be found in the neurologically intact brain; that is, in the behavior of healthy humans. The results of these investigations have consistently supported the hypothesis that cerebral functions can be represented asymmetrically. Indeed, the lay population has accepted the notion of hemispheric specialization with a passion. Popular books proselytize new techniques that are supposed to allow us to discover and strengthen our unique hemispheric preferences. It is claimed that we can learn how to improve drawing or cooking skills, for example, by releasing the capabilities of the right side of the brain or heighten our analytic abilities by tapping into the left side of the brain.

Scientific arguments are expected to be more conservative. The differences in hemispheric function appear quite subtle, at least when studied by behavioral methods in normal human beings. This means that understanding hemispheric specialization requires that we both acknowledge the similarities between hemispheres and continue to search for more appropriate descriptions of the functional differences between the two

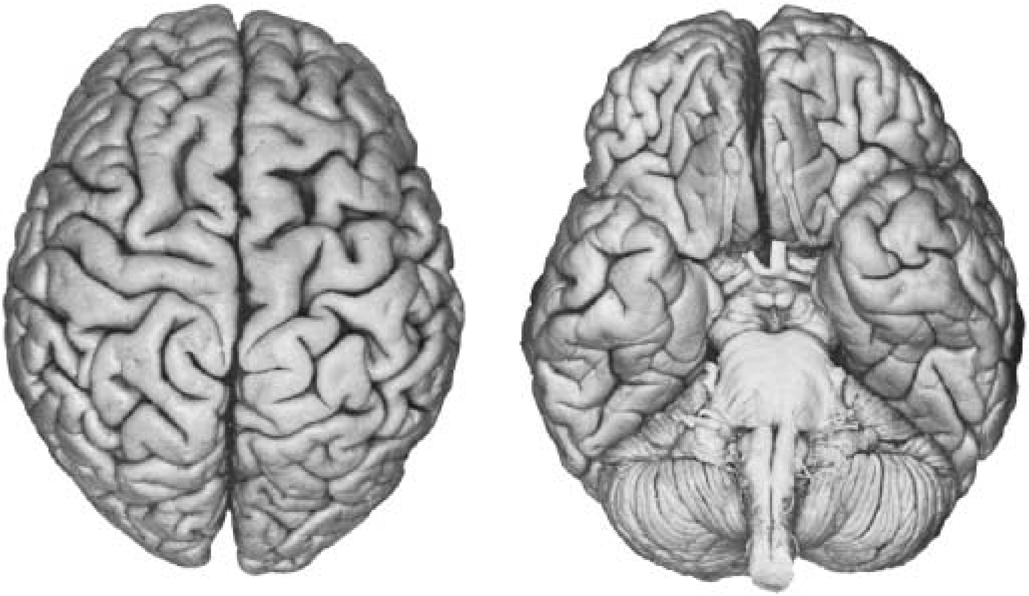

Figure 1.1 Viewed from the top or the bottom, a human brain looks symmetrical. (From DeArmond et al., 1989).

hemispheres. The theory presented in this book is intended to begin to offer such a balance. This work centers on a hypothesis concerning functional asymmetry across perceptual modalities in perceptual processing; the proposed asymmetry, however, begins with an overall similarity between the hemispheres in how information is initially represented and processed. We argue that perceptual asymmetries in performance reflect a difference in strength rather than in kind. There are small but important differences in relatively early stages of information processing. As these small but asymmetric differences interact with higher-order systems, the results may appear as if the hemispheres are qualitatively different, but this may be the result of basic and more subtle asymmetries early in information processing.

Much of the initial work in neuropsychology focused on delineating basic dichotomies that could capture the functional differences between the left and right hemispheres. For example, the right brain has been described as holistic and spatial, the left brain as analytic and verbal. These dichotomies continue to resonate in some current reports, although the focus has shifted to the development of detailed cognitive theories that tend to focus on specific phenomena. Advances in sophistication and detail, however, have also entailed a cost in generalizability and integration.

We introduce this book with a brief history of the study of hemispheric specialization and development in other areas that influenced its popularity. First, we review some of the major clinical findings in the neurological literature that provided the most obvious demonstrations of functional asymmetry in humans. We then discuss how behavioral scientists historically have attempted to incorporate these abnormal patterns of behavior into their general understanding of the human mind. This work has been guided by a strong reliance on methods and concepts derived from cognitive psychology, a field in which the ability to parse component processes and elucidate interactive computations of cognition has been fundamental in developments within neuropsychology and neuroscience.

APHASIA: THE ORIGINAL CASE FOR HEMISPHERIC SPECIALIZATION

The thought of losing the ability to speak is a terrifying prospect. Our social world revolves around verbal communication. Language skills are acquired with seemingly minimal effort and in today's technological world we spend little time without hearing or engaging in some form of linguistic interaction. Yet there are neurological disorders that can transport a normal, communicating person into a world of isolation in which the patient is at a loss to understand speech and is unable to generate spoken or written language. These deficits, classified as aphasias, are typically associated with damage to the left cerebral hemisphere.

It was the dramatic effects of left hemisphere damage on language abilities that first awakened the scientific community to the possibility that the brain could appear to be physically symmetric but function asymmetrically. The evidence for left hemisphere contributions to language has been steadily catalogued in the neurological literature for more than a century. Such insights preceded the advent of modern neuroimaging tools such as computerized tomography (CT) and magnetic resonance imaging (MRI) that have made it possible to more precisely localize brain damage. Indeed, behavioral analysis coupled with crude localization techniques proved sufficient for quite some time. It had long been known that head trauma, perhaps the result of blows to the head or penetration from sharp projectiles, could produce sensory and motor problems on the opposite side of the body (contralateral). This effect on sensory-motor function could also provide a correlational basis for problems in other domains. For instance, language deficits accompany right-sided paralysis more than left-sided paralysis.

In retrospect it seems surprising that it took so long for the scientific community to note the high correlation between right-sided motor or sensory deficits and problems in language. A visit to any neurology ward or rehabilitation center will provide easy confirmation. Nonetheless, it was not until the nineteenth century that the study of human disorders began to firmly adopt the requisite tools to objectively investigate these correlations.

Even as members of the neurological community began to share their observations about the relationship between brain and behavior, the idea of brain localization met with resistance. The late eighteenth century had been a heyday for those favoring a localizationist position. Following Franz Gall's description of the numerous faculties of the human mind, the idea that different functions were associated with localized brain regions gained wide acceptance (figure 1.2). These crude ideas floundered, however, in the face of experimental work by researchers such as Pierre Flourens and others. Lesions of so-called centers of function rarely produced their predicted effects. The zietgeist of localization was replaced by a view of brain function as a holistic process. The brain was seen to be equipotential, with each behavior requiring the interactions of the entire structure.

A telling example of the dominance of this view is given by the reaction, or lack thereof, of the scientific community to an 1836 report linking language deficits and the left hemisphere. Springer and Deutsch describe the scene in terms that are hard to improve upon (1981, p. 1).

> Marc Dax, an obscure country doctor, read a short paper at a medical society meeting in Montpellier, France. . . . [He] was struck with what appeared to be an association between the loss of speech and the side of the brain where the damage had occurred. In more than 40 patients with aphasia Dax noticed signs of damage to the left half, or hemisphere, of the brain. He was unable to find a single case that involved damage to the right hemisphere alone. In his paper to the medical society, he sum-

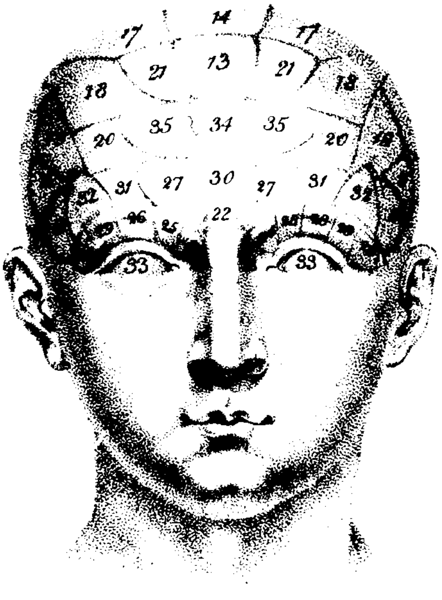

Figure 1.2 An example of phrenology. Each number represents a different proposed brain function. (From Finger, 1994.)

marized these observations and presented his conclusions: each half of the brain controls different functions; speech is controlled by the left half.

The paper was an unqualified flop. It aroused virtually no interest among those who heard it, perhaps because it ran contrary to the dominant view of equipotentiality. Dax died the following year and the paper was soon forgotten.

The possibility of language localization did not resurface for nearly 25 years. At a scientific medical meeting in 1861, Paul Broca, a respected anatomist (as opposed to an obscure country doctor), displayed the brain of a patient who had suffered inarticulate speech following a lesion to his left frontal lobe. Broca reported (1861) that the patient had been able to comprehend what was said to him before his death, but that when he attempted to speak all that could be heard was the nonsensical syllable "tan" repeated over and over. Broca subsequently described a second patient with a milder yet similar speech problem, and from this concluded that articulation deficits in language resulted from damage in the frontal lobe in the area of the third convolution.

It is somewhat ironic that even in this seminal report the emphasis was not on hemispheric specialization. Rather than focus on the left-right dimension, Broca emphasized an anterior-posterior distinction. Initially, he did not appear to be very interested in the significance of his findings for hemispheric differences. In the spirit of the debate of the time, Broca argued that his findings provided strong evidence for localization, and in his early description he placed less importance on the left-sided position of the lesions than on their effects on a specific function.

The significance of Broca's findings for hemispheric specialization began to grow as more reports accumulated ascribing to the left hemisphere a dominant role in language (see De Renzi, 1982). Within a few years, the German neurologist Karl Wernicke (1874) provided another case report enlarging the spectrum of language deficits that could be linked to left hemisphere damage. Whereas Broca had addressed the inarticulate speech that was associated with lesions of the anterior hemisphere (and, as it turned out, on the left), Wernicke described a different language disorder associated with lesions to the posterior regions of the left hemisphere. These lesions created problems in language comprehension. The patients either failed to understand what was said to them or responded in a manner indicating that they had not accurately perceived what was said. Surprising at the time was the fact that the spontaneous speech for patients with Wernicke's aphasia was fluent and articulate. It also tended to be devoid of meaning or semantic consistency, however. These findings led Wernicke to propose a taxonomy of aphasic disorders that were linked to lesions of different parts of the left hemisphere (figure 1.3).

These neuropsychological reports triggered a general excitement concerning the role of the left hemisphere in language, and in particular concerning a division of function within the left hemisphere for different

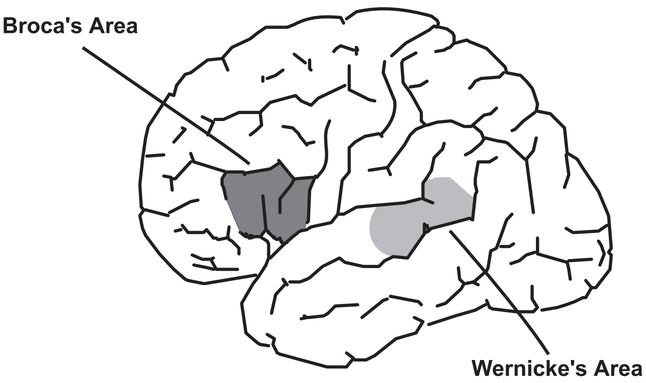

Figure 1.3 Classical Wernicke's and Broca's areas of the left hemisphere.

linguistic processes (for additional historical details, see Harrington, 1995; Springer & Deutsch, 1981). By the end of the nineteenth century the left hemisphere began to be frequently described as the "dominant" or "major" hemisphere, a designation still prevalent in some scientific journals today. These designations are increasingly challenged by the explosion of data from contemporary cognitive neuroscience investigations.

Early accounts treated the right hemisphere like a poor stepsister to the left. The right hemisphere was called the "minor" hemisphere, and there was a general lack of interest in its functions. Researchers who may have wanted their work to meet a better fate than Dax's focused on the left hemisphere and its capabilities. Indeed, hemispheric specialization in these early days was almost exclusively domain driven.

Of course, there were exceptions to this pattern. Hughlings Jackson in 1876 and Jules Badal in 1888 described disorders of spatial representation in patients with right hemisphere lesions. The patients retained their visual capabilities, but they had difficulty navigating in well-known environments. In 1909 Russo Balint described a patient who appeared to see only a single object at a time and who had great difficulty reaching for the object he did see or tracking its position if it moved. In a classic study of head injury patients from World War I, Holmes (1918; Holmes & Horrax, 1919) observed a similar syndrome in a number of patients and named the behavioral constellation "Balint's syndrome."

This syndrome did not bear directly on the issue of hemispheric specialization because the patients almost invariably had bilateral lesions. As other disturbances of spatial representation were reported during this period, however, it became clear that visual-spatial deficits could occur without any accompanying disturbance of language and that they were more often associated with right hemisphere damage. This dissociation provided the foundation for what would become the dominant theme for many decades: that language and spatial processing represented two fundamental cognitive capabilities. Language was associated with the left hemisphere, and visual-spatial representation with the right hemisphere.

UNILATERAL NEGLECT: THE CASE FOR HEMISPHERIC DIFFERENCES IN SPATIAL COGNITION

How might a visual-spatial problem be experienced? Suppose you were to awaken one morning and the left half of the world had disappeared from your awareness. Of course you would not notice because, by definition, you would not be aware that part of the world had disappeared. At first, you might think that things looked normal. You might notice a bird sitting on a branch on the right side of the tree outside your window. You may try to get up but fail, yet you may not care. One of your family members may be the first to notice that the situation is very serious. If this person approaches you from the left, you may not notice. Quite likely you lapse back into unconsciousness. When you wake up sometime later in the emergency room of your local hospital, you may feel that there has been some mistake and fail to appreciate the concerns of the people around you. In other words, not only are you failing to orient to anything on your left side, because you are unaware of its existence, but you may even deny that you are in trouble at all. Such denial is a symptom known as anosognosia that sometimes accompanies the symptoms of unilateral neglect just described.

Scenarios such as this one can occur even following a relatively small stroke in the right hemisphere, if the stroke is located in a strategic place. Surprisingly, not all stroke patients are aware that they have experienced a serious cardiovascular accident. The patients may ignore a paralyzed limb, or if the limp state of their arm is pointed out by an observer, the patient may attribute it to an old war wound or prior surgery. The disappearance of a part of contralesional space from conscious awareness, known as unilateral neglect, is sometimes although not always accompanied by anosognosia. Unilateral neglect is more likely during the first few days after an insult such as a stroke. These symptoms are most often found following right hemisphere damage.

Patients with unilateral neglect either do not respond to objects located in the contralateral side of space or do so only after long pauses or coaxing. When approached from the neglected side, they may not orient appropriately. In severe cases, the patients may ignore their own body, pushing away a contralateral hand or leg as if it were an intruder. These problems can be separated from those associated with a simple sensory deficit. For example, patients with neglect typically detect a bright light flashed in an otherwise dark field regardless of whether the stimulus is shown in a location ipsilateral to the lesion (e.g., on the right side in right hemisphere stroke patients) or contralateral to the lesion (e.g., on the left side in a right hemisphere stroke) (figure 1.4). They may be able to detect the presence or absence of a simple feature such as motion or color on their neglected side. However, they may report that these features are located on the ipsilesional, or good, side rather than on the neglected side. Furthermore, individuals with blindness on the side contralateral to their

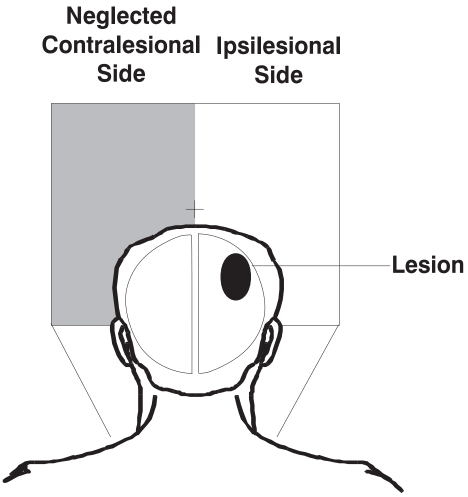

Figure 1.4 A patient with right hemisphere damage may neglect items in the contralesional side of space (represented by the shadowed area).

lesions who do not suffer neglect will compensate by turning into the direction of their scotoma. Individuals with neglect will not.

As one can imagine, it is nearly impossible to function in everyday situations following the onset of unilateral neglect. Most patients cannot move around a room because they consistently bump into things. Often their eyes and head deviate toward the ipsilesional side. In the acute phase, the patients are confused and lethargic. As days go by, patients with neglect typically become less confused and fatigued, and those who in the acute phase had twisted their body and eyes to one side usually show less and less of these behaviors. Yet they continue to ignore the neglected side, although they often orient to it if told to do so. When attempting to perform simple everyday acts such as dressing or eating they may fail to place their left arm in a shirt sleeve, may comb only one side of their hair, and may restrict their eating to food on the unneglected side of their plate. As noted above, they can be completely undisturbed by the disappearance from their consciousness of one side of a scene. It is as if the world had never appeared any different.

A female patient was seen by one of us in the acute stage of her illness. She was seen at her hospital bed about 5 days after she suffered a right hemisphere stroke. She was alert and friendly. She told us that a visitor had dropped by and put a box of candy in the drawer of her bed stand. The bed stand was located on her left, and she remarked that she couldn't find it. When she was told to look to her left, she followed instructions readily and spotted the table and its drawer. After opening the drawer, she took a piece of candy from the box, politely offering some to us as well. She then turned back toward her right side and shortly thereafter wanted another piece of candy. Again, she couldn't find the bed stand. After a long time spent searching the room (on her right), she said that someone must have stolen the candy. She had not forgotten about the candy or that she had eaten a piece from the box located in the bed stand, but she seemed unable to imagine that there was a part of the room where it was still located.

This patient had suffered a middle cerebral artery infarct (stroke), producing a large lesion in the right hemisphere similar to that shown in figure 1.5. It is unlikely that a comparable lesion in the left hemisphere would produce the same behavioral deficits. Such a lesion would likely produce an aphasia. While it has been argued that neglect in left hemisphere patients is often overlooked because language problems make it difficult to test these patients, large-scale studies have shown that profound neglect is more frequent and more severe than lesions of the right than left hemisphere (Ogden, 1987).

Constructional Apraxia: The Case for Qualitative Hemispheric Differences in Spatial Cognition

Unilateral neglect can be considered one of the more extreme forms of a unilateral deficit in spatial cognition. If we were to just consider the occurrence of this syndrome in assessing the brain mechanisms involved

Figure 1.5 CT scan of a patient whose infarct resulted in unilateral visual neglect. Standard coordinates are used in the image—the right hemisphere appears on the left.

in spatial abilities, we would conclude that these processes are related more to the right hemisphere. When we consider more subtle types of spatial deficits, however, it becomes clear that both hemispheres play a role in constructing a representation of spatial information and in moving attention to locations within that space. Indeed, these deficits reveal important insights into the bases of hemispheric specialization.

A standard neuropsychological test that has been used for decades to assess perceptual disturbances is the Rey-Osterrieth test. Patients are presented with the figure shown at the top of figure 1.6 and, after studying it, they attempt to copy the complex drawing while it is present in front of them. After they complete this drawing, the figure is taken away and the patient is asked to make a second production, this time from memory. Representative drawings from two patients are shown at the bottom of figure 1.6. The patient with left hemisphere damage accurately drew the overall shape, but failed to fill in the finer details. In contrast, the patient with right hemisphere damage failed to reproduce the overall pattern, yet was able to draw the individual parts. Thus, both patients demonstrated problems in reproducing accurate spatial relations, but of different sorts.

Historically, this dissociation has been discussed in terms of the representation of parts and wholes for motor planning. Within this framework, the left hemisphere patient was said to have difficulty in reproducing the parts; the right hemisphere patient had difficulty in reproducing the whole because the proper motor plans could not be carried out.

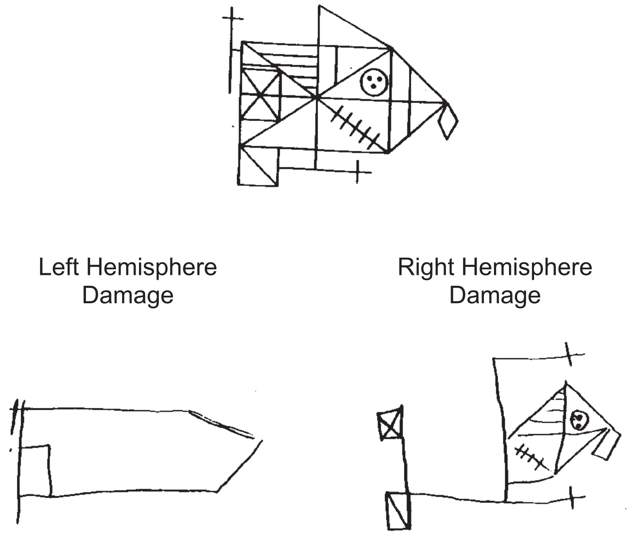

Figure 1.6 The standard Rey-Osterrieth figure used in neuropsychological examinations (top). The patient with left hemisphere damage drew the overall form with little detail (lower left). The patient with right hemisphere damage drew many local details but organized them incorrectly (lower right). (Adapted from Robertson & Lamb, 1991.)

Yet findings such as these suggested that both hemispheres might contribute to processing spatial information. On the basis of the Rey-Osterrieth test only, it is not clear whether the problems exhibited in patients' drawings should be considered perceptual or motoric. Early work in this area indicated a motor problem. The patients were described as having constructional apraxia, a label that emphasized that the drawing problem stemmed from distorted motor representations. According to this theory patients with left hemisphere damage had trouble generating the motor programs required to fill in details, whereas those with right hemisphere damage had trouble generating large-scale motor plans. This view downplayed possible perceptual contributions, but this may have been because techniques to properly address the question had not yet been developed.

The original studies of constructional apraxia for parts and wholes were reported by McFie and his colleagues (McFie, Piercy, & Zangwill, 1950; McFie & Zangwill, 1960). Others soon supported their findings that this constructional apraxia for wholes was linked more to right than to left hemisphere damage (Black & Strub, 1976; Costa & Vaughan, 1962; Gainotti & Tiacci, 1972; Piercy, Hacean, & Ajuriaguerra, 1960; Piercy & Smyth, 1962). It remained for future research to demonstrate that visual input contributed to these effects.

Balint's Syndrome: Further Evidence for Bilateral Representation of Spatial Cognition

One of the most debilitating visual-spatial problems occurs when both parietal lobes are damaged, resulting in Balint's syndrome or what has been called dorsal simultanagnosia in cognitive neuropsychology (Farah, 1990). These patients report seeing only one object or one part of an object at a time. Again, it is hard to imagine what this would be like.

We take it for granted when we awaken each morning that we will see several objects in the room. There is the hateful alarm clock with bright numbers on its digital screen. The dog yawns and stretches where she lies at the foot of the bed. There are bedposts and windows behind her, and a robin outside sings. The leaves on the trees sway in the wind.

Suppose that you awaken one morning and all you can see is the bird outside your bedroom window. You cannot stop gazing at that one bird. Your attention appears to be captured by the object. Your dog is within fixation, but you do not see her nor do you know where she is. You do not see the window or the bedpost, and you have difficulty moving your attention from the bird. You may know there must be other objects in the room, but you have no idea where they are. You are not even sure where the bird you see is located. You have lost the spatial layout of your bedroom entirely, and you do not know where to reach for the alarm clock, nor can you move from your bed to the door. You are not paralyzed. You just do not know where things are, and perhaps because you do not know where they are, you cannot move your attention to them and away from the bird you now see. In time, the bird may vanish as the object of your attention to be replaced by the perception of your dog. One thing abruptly and rather randomly is replaced by another without your control, and this is how it would be all day and perhaps for the rest of your life.

Obviously, this would be a terrifying experience. You would be a prisoner in the space of your own body except for one bizarre link to a single object. You would not be blind, although your problems might be mistaken for blindness. Blindness does not cause people to lose a sense of space or attentional control. Blind people know where to reach for the alarm clock. They can attend to spatial locations. They know where things are even though they cannot see them.

A person with these symptoms would be classified as having Balint's syndrome. Fortunately, the symptoms are rare in this pure form, although they can be observed in conjunction with degenerative diseases such as Alzheimer's dementia. Pure cases began to be reported in the literature in the late nineteenth century. Although only a few cases have been thoroughly studied there is a common thread among their problems that has been discussed as a deficit in spatial awareness (see Friedman-Hill, Robertson, & Treisman, 1995; Robertson, Treisman, Friedman-Hill, & Grabowecky, 1997).

These patients generally exhibit fixation of gaze with no primary motor deficit (oculomotor apraxia). They do not track moving objects well, losing sight of the target as it moves away from fixation. It is as if the patients do not know how to move their eyes to see objects that they want to see. Their spatial deficits can result in a complete inability to correctly report the location of objects or to even crudely locate an object near the upper or lower boundary of a large computer screen. They may have difficulty saying whether an object is moved away or toward them and they exhibit no startle response when a hand moves rapidly toward their face and stops only inches from their eyes. They cannot reach accurately for the one object that they can see and are often at chance when reporting its location (although locations on their own bodies are correctly reported, demonstrating a lack of primary spatial confusion). Not surprisingly, these patients have great difficulty in activities of everyday life and require constant care.

Given the infrequent occurrence of relatively pure cases of bilateral parietal damage resulting in Balint's syndrome, only a few cases have been reported (Balint, 1909; Baylis, Driver, Baylis, & Rafal, 1994; Coslett & Saffran, 1991; Michel & Henaff, 1996; Friedman-Hill et al., 1995; Robertson et al., 1997; Holmes, 1918; Holmes & Horrax, 1919; Humphreys & Riddoch, 1993; Tyler, 1968; also, see reviews by De Renzi, 1996 & Rafal, 1996). To our knowledge, all of these cases have had bilateral damage in occipital-parietal cortex. These deficits may therefore seem irrelevant in a book about functional differences between the hemispheres. It is somewhat surprising, however, that no one emphasized the increased severity of the spatial and attentional deficits in these patients compared to patients with unilateral right hemisphere damage and neglect. If spatial abilities were lateralized to the right hemisphere, then additional damage to the left hemisphere should not increase the visual-spatial problems to the extent that they do when bilateral damage occurs. It is clear, however, that it does.

The representation of space must be a combined effort by the two hemispheres. The computations that contribute to this representation appear to be divided in such a way that right hemisphere damage produces more severe overt visual-spatial problems than does left hemisphere damage. Damage to both parietal regions, however, produces profound loss in visual and spatial abilities accompanied by a loss in spatial awareness.

Data collected with these types of patients play a large role in theoretical development today and will be discussed in detail in subsequent chapters of this book. Our emphasis will be on perception and encoding in areas of the cortex that are assumed to be involved in relatively early stages of analysis. This is not to say that motor planning and performance are not lateralized as well, but theories based on later stages of lateralization should first rule out explanations that can be accounted for by perceptual differences.

Spatial Deficits: Summary

Studies of deficits in spatial cognition have added at least three important aspects to the study of hemispheric specialization. First, such studies pointed to the folly of describing functional hemispheric asymmetries in terms of a "major" and "minor" hemisphere, a nomenclature that suggests the right hemisphere either plays a back-up role to the left hemisphere or is somehow subservient to it. On certain types of tasks, lesions of the right hemisphere are more devastating than lesions of the left hemisphere. Not only are disorders of spatial attention more likely to be observed following right hemisphere lesions, but the long-term problems experienced by these patients in everyday life can be considerably greater than those experienced by patients with left hemisphere lesions.

Second, the detailed study of disorders of spatial cognition emphasized the need for a more sophisticated approach to the study of spatial processing and its link to neural systems. The same criticism that was leveled at Gall and the adherents of phrenology could also be applied to the early work of the neuropsychological diagram makers. Complex cognitive domains such as language and spatial cognition could not be linked simply to brain locations. Rather, these processes involve numerous component operations distributed over a number of different areas. Spatial deficits may occur because of a problem in analyzing the parts of an object or scene or in integrating these parts into a coherent whole or for a myriad of other reasons. Spatial problems may also arise because of an inability to orient to a region of space or an inability to maintain an internal representation of part of the external world (see Rafal & Robertson, 1995). As in the study of language, the early taxonomies were crude, providing only the roughest partitions. More detailed analyses were required to reveal that a complex task such as spatial reasoning requires both the contribution of a large number of component processes associated with many different brain areas and a great deal of computational power.

A third, related conclusion is that it is too simplistic to assume that hemispheric specialization occurs at the level of tasks such as language or spatial cognition. As described throughout this chapter, spatial deficits can arise from lesions of either the right or left hemisphere. As will be discussed in chapter 6, the same holds for language. The right hemisphere has also been linked to certain paralinguistic and linguistic processes. Thus, if we take language and spatial cognition as two representative cases, both hemispheres provide contributions to each task domain. By making this claim (by no means a new one), we do not wish to suggest that each hemisphere contributes equally to all tasks or that they process information identically. But we should not expect that a theory of hemispheric specialization can be articulated in terms of task-defined goals such as speech decoding or the construction of representational space. We will need to consider the computations required to achieve the task-defined goals.

THE HISTORICAL IMPACT OF SPLIT-BRAIN RESEARCH

One of the most important historical events for the investigation of hemispheric specialization in neuropsychology occurred as a by-product of the search for new medical procedures to treat intractable epilepsy. One of the more radical interventions involved a procedure in which surgeons isolated the two halves of the brain from one another by severing the corpus callosum, the massive bundle of fibers that connects the left and right cerebral hemispheres. This procedure renders what is often called the “split brain.”

Epilepsy is a common neurological disorder that affects a large segment of the population. The defining feature of epilepsy is recurrent electrographic seizure—the high-frequency bursting of millions of neurons in close synchrony. The causes of these seizures are many. In some cases seizures are preceded by a traumatic event such as a stroke, car accident, or high fever. In others, the seizure activity is idiopathic and occurs in the absence of any detectable anatomical abnormality. Seizures may originate consistently from a given brain region such as the temporal lobes or limbic structures, or they may have a widespread origin. In all cases the seizure activity tends to spread quickly, disrupting consciousness as the brain is sent into a wild oscillation of overactivity.

Many treatments have been developed for controlling epilepsy. The most common are drug treatments that use medication to inhibit excessive neural activity. In a small percentage of cases, however, these medications are insufficient. Patients may have several seizures per day, resulting in severe disruption of function. It is for the treatment of these patients that invasive surgical interventions have been developed. The strategy typically takes one of two forms. In one case the goal is to resect the neural tissue that is the source of seizure activity. In the other case the goal is to eliminate the means by which the seizure activity is propagated over the brain. It is in these latter instances that the split-brain operation, or commissurotomy, is employed. The procedure is often effective. Seizure activity can be greatly retarded, and many patients show relatively mild behavioral changes following recovery from the procedure. This does not mean that there are no persistent neurological deficits. In most cases candidates for this operation are severely impaired prior to the operation.

The fact that postsurgical behavior may appear only slightly abnormal in patients who undergo this operation is puzzling, given that the split-brain procedure essentially disables the transfer of information across the two cerebral hemispheres. It seems unfathomable that the 200 million fibers of the corpus callosum serve such a small functional purpose. Indeed, a closer examination of these patients has provided strong evidence for hemispheric specialization and has yielded important insights into how the two hemispheres may integrate information in normal processing.

Much of the early work was conducted by a research team composed of Joseph Bogen, Roger Sperry, and Michael Gazzaniga. These researchers performed extensive cognitive testing of a group of approximately 25 patients. Their studies have now become classics in the field (Bogen & Gazzaniga, 1965; Gazzaniga, 1970; Gazzaniga, Bogen, & Sperry, 1962, 1965; Sperry, 1968).

The fibers of the corpus callosum have widespread projections. Most common are those projections linking together homologous areas in the right and left cerebral hemispheres. These connections are reciprocal. In general, an area not only is innervated by a comparable area in the opposite hemisphere, but sends fibers back to that same region. When the callosum is split these transcortical connections are lost. The two sides of the brain are disconnected from one another. If the surgical procedure also includes the anterior and posterior commissures as well as the massa intermedia, several subcortical structures are also segregated from their homologous partners.

The cortex of the two hemispheres is anatomically independent after commissurotomy. In normal subjects we can lateralize the presentation of

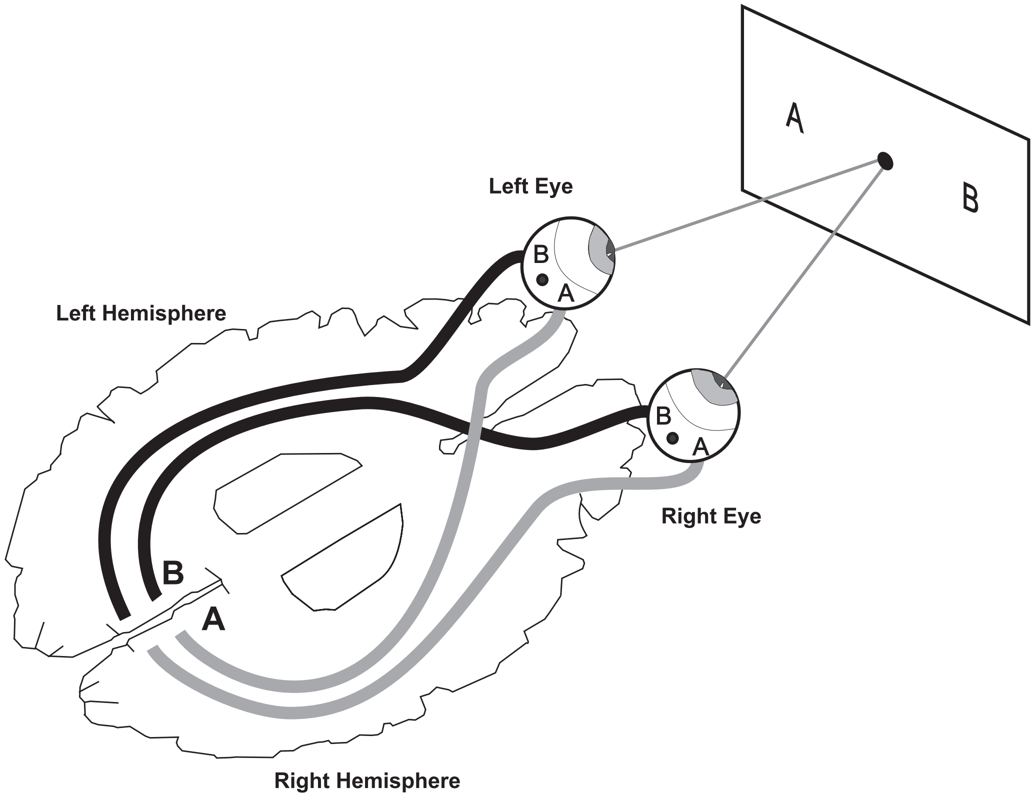

Figure 1.7 Drawing of visual system organization that results in stimuli presented in the left visual field (A) being projected to the right visual cortex and stimuli presented in the right visual field (B) being projected to the left visual cortex. Eyes are fixated on the central dot.

a stimulus to project the input to one hemisphere. For example, if a visual stimulus is flashed on the left side of space from foveal fixation, input will be into the right visual cortex. From the anatomical projections from the eye to the brain we know that the stimulus will first arrive in the right hemisphere, the side contralateral to the stimulus (figure 1.7). But it would be naive to assume that this information is processed solely in that hemisphere. Transcortical transfer occurs very rapidly. For example, responding with the right hand (controlled primarily by the left hemisphere) to a stimulus in the left visual field is slower by a few milliseconds than responding with the left hand to the same stimulus.

Thus, with healthy people there is no way of knowing whether a response to a lateralized stimulus is driven by processing within the contralateral hemisphere or whether the response reflects the joint effects of both hemispheres after transcallosal interaction. In the split-brain patient the possibility for interhemispheric transfer through the corpus callosum is eliminated. Stimuli presented in the right visual field are projected to the left hemisphere and have no cortical-cortical connection over which to engage the right hemisphere (although subcortical pathways exist).

Disconnection of function can be seen in the patient's motor behavior, especially right after the operation. During recovery the two hemispheres often act to achieve different and conflicting goals (Springer & Deutsch, 1981). One side may want to wear a red dress, the other side, a blue dress. The right hand may pull the red dress off a hanger, only to have the left hand hang it back up.

Such dramatic examples are rare in the behavior of these patients after a certain recovery period. The patients develop strategies to make their lives as normal as possible. It would be unusual for information to remain isolated in one hemisphere or the other without being affected by experience. For instance, most people quickly move their eyes around the visual field. For commissurotomy patients, this would allow the stimulus to be projected to both hemispheres (also, the central region of space appears to have a bilateral representation). The patients also develop specialized strategies to cope with their predicament, such as reaching for objects with both hands to ensure that somatosensory information is projected bilaterally (see Gazzaniga and Hillyard, 1971).

Given the presence of these strategies, it has required carefully controlled experiments to explore the segregated processing of the cerebral hemispheres in the split-brain population (Zaidel, 1975). The study of these patients provided powerful converging evidence to the patient studies for the dominant role of the left hemisphere in language. In one early study (Gazzaniga, 1970), the patients' ability to read lateralized words was tested. The subjects were required to fixate a central fixation point, and a stimulus was flashed in either the left or right visual field. Words that were flashed in the right visual field were nearly always reported correctly. In contrast, when words were presented in the left visual field and projected directly to the right hemisphere the patients were rarely able to report the stimulus.

The problem for the right hemisphere does not appear to be related to a general lack of knowledge. Rather it seems to be one of accessing and/or producing verbal labels. To observe this it was necessary to use nonverbal stimuli such as pictures of common objects. Split-brain patients were able to name the objects only when the stimulus was presented to the left hemisphere. If the task was changed so that the response was also nonlinguistic, however, they performed comparably regardless of whether the stimulus was projected to the left or right visual field. For example, when shown a picture of a ball in the left visual field, they could then select this object when allowed to touch several unseen objects with their left hand (Gazzaniga, 1970). Further evidence of the separation of processing came from the fact that they failed on matching tasks if the input and output channels depended on different hemispheres. Objects seen in the left visual field could not be matched with objects felt with the right hand.

A conclusion that emerged from these early studies was that the two hemispheres were of roughly comparable competence in their perceptual capabilities. Perceptual processes were segregated in the split-brain patients but there was no specialization of perceptual function. Either hemisphere could perform the requisite operations so long as the tasks did not require the linguistic functions of the left hemisphere.

It was not clear how this apparent equipotentiality could be reconciled with the data from the study of patients with spatial disorders like unilateral neglect. One argument was that the split-brain patient was abnormal, not only because of the commissurotomy, but also because these patients had suffered countless seizures over an extended period of time. Given their histories, it would be imprudent to expect similar patterns of hemispheric specialization in split-brain patients, as were seen in other types of patients, such as those with stroke. It might also be concluded that compensatory strategies used to deal with impairments were different for patients who underwent commissurotomy and for patients who suffered cortical lesions of either the right or left hemispheres.

Although these caveats are important, subsequent investigations demonstrated striking similarities between the drawings of patients with right hemisphere damage and drawings directed by the left hemisphere of split-brain patients (Gazzaniga et al., 1965). For the commissurotomy patients right-handed drawings (controlled by the left hemisphere) necessarily reflect processes limited to the left hemisphere because no callosal transfer was possible. For the patients with unilateral right hemisphere damage the drawings are assumed to be dominated by the intact left hemisphere. In both cases, the drawings were disorganized and often unrecognizable, despite the fact that many relatively obscure details were included.

Paralleling the findings for patients with unilateral left hemisphere strokes (intact right hemisphere), the results for the split-brain patients showed that they were able to produce properly organized and recognizable drawings with their left hands (right hemispheres). These results were obtained even when the patients were right-handed. Right-handed drawings did include more details than left-handed drawings, but the overall structure was still disorganized. The right-handed split-brain patients were also much more proficient in reproducing complex geometric designs when using their nondominant, left hands (figure 1.8).

It was not clear how these qualitative differences were to be interpreted in these early findings. If the percept was intact in each hemisphere, one might conclude that the drawings reflected differences in response selection. In motor production hand differences have been described in terms of the spatial scale at which movements occur (Guiard, 1987; Previc, 1991). For right-handers the dominant hand is usually required to make

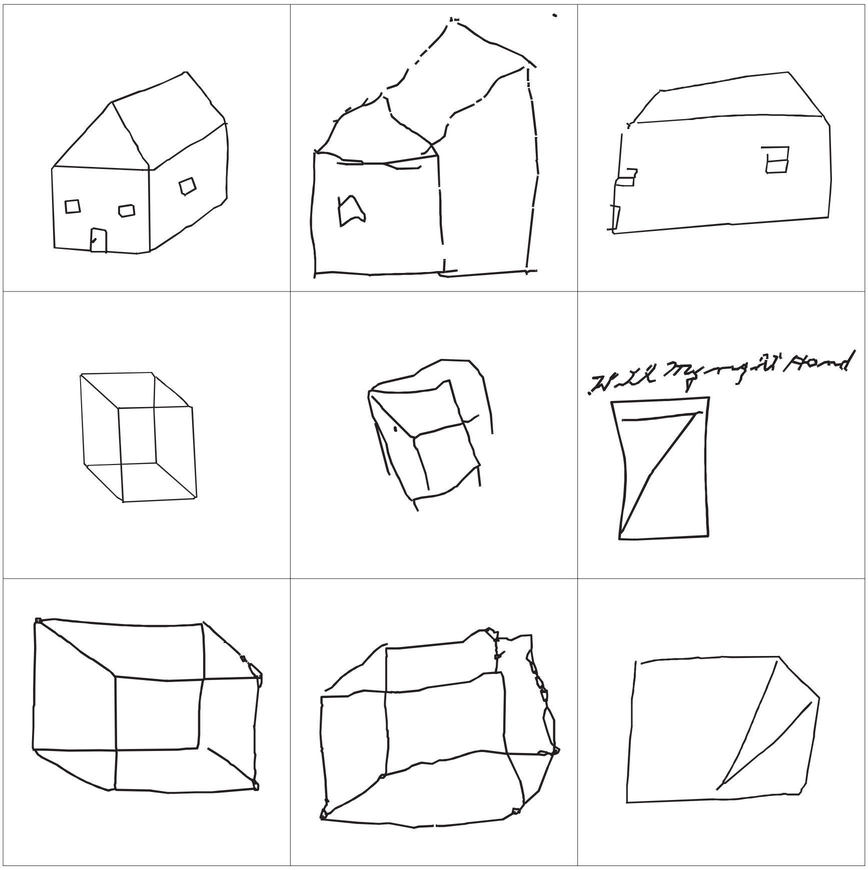

Figure 1.8 Standard (left-most column) and drawings by a commissurotomy patient. The drawings in the middle column were made with his left hand (controlled by his right hemisphere), and those in the right column were made with his right hand (controlled by his left hemisphere). Although the patient was right-handed, drawings with his left hand more closely captured the overall configuration. (From Gazzaniga, 1967.)

fine movements that require precise detail. The left hand is used for maintaining stability. The left hand holds a bowl while the right hand stirs the spoon. The left hand holds the matchbook steady while the right hand is used to strike the match. Perhaps these asymmetries in motor performance produced similar biases in drawings, an argument reminiscent of those made for constructional apraxia.

Over the last two decades, however, a great deal of evidence has begun to accumulate suggesting that similar differences can be found on perceptual tasks, although ascertaining these differences required more sensitive measures. The earlier evidence suggesting perceptual equipotentiality likely resulted from the use of crude measures such as overall error rates or patient drawings. Reaction-time measures indicate that this equivalence is illusory. For example, a recent study (Robertson, Lamb, &

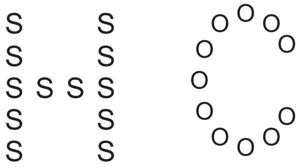

Figure 1.9 Examples of hierarchical letter patterns: a global *H* created from local *S*s and a global *C* created from local *O*s. (Adapted from Navon, 1977.)

Zaidel, 1993) with split-brain patients employed hierarchical letter stimuli (figure 1.9). Because all stimuli were shown in peripheral vision, where acuity is decreased, global targets were responded to more rapidly than local targets. The stimuli were also presented briefly in the right or left visual field. For the split-brain patients the normal reaction-time advantage for global targets was enhanced relative to that of control subjects when the stimuli were presented in the left visual field and reduced when the stimuli were presented in the right visual field.

As had been found in earlier studies, both hemispheres were capable of making discriminations whether the targets were global or local. The differences were only in terms of milliseconds in reaction-time measures. Although the two hemispheres are similar in their overall perceptual functions when using gross measures, there are subtle differences in how they process features of the stimulus.

THE IMPACT OF COGNITIVE PSYCHOLOGY

Developments in cognitive psychology question the assumption of a simple correspondence between complex tasks and brain areas. Cognitive psychologists have sought to develop detailed theories of how we process information in order to accomplish particular tasks. As the theories mature they become more complex. For example, what had been lumped into a single box labeled “reading” became elaborated into a theory that includes letter identification, whole word recognition, and semantic activation (Coltheart, 1985). As time progresses these component operations can be expected to be further fractionalized.

Similar trends can be found in the literature on object recognition. For example, a recent computer model elaborates seven essential stages that are required for recognizing an object (Hummel & Biederman, 1992). The initial processing stages are devoted to decomposing the image into component parts, the latter stages to linking the parts into a coherent whole. Although this decomposition and then reconstitution may seem inefficient it offers a number of computational advantages. For example, by enumerating the parts and their relations recognition can occur even when the object is viewed from novel or unusual positions.

The part/whole distinction, which shows reliable hemispheric differences, has a long history in the study of cognition and perception. A central question has focused on the dynamics of perception: Does perception begin by processing individual parts and then put the parts together to form wholes, or does it begin with an analysis of the whole followed by subsequent parsing into parts? Introspection would seem to favor the latter interpretation. We do not have a sense that we recognize a telephone by carefully examining the stimulus to determine whether there is a receiver, a number pad, and a cord. But this introspection contradicts reason. How could we derive a global representation that was not created out of an assemblage of component parts?

Indeed, when we build an object in the physical world, construction of the whole requires that we produce all of the parts and then put them together. We build a wall by placing a series of boards in a row, one after the other. If the arrangement of the parts is altered, the wall too is altered. If building a house can serve as a metaphor for building a perceptual representation of an object, then we might expect processing to occur in a piecewise, cumulative manner (e.g., from lines and edges to shapes). The associative view of cognition motivated by behaviorism and prevailing during the middle of this century would be an example of an approach that would embrace this view.

Max Wertheimer, the patriarch of the Gestalt school of psychology, was one of the first to disagree with the behavioristic approach. He presented several demonstrations showing that the percept of the whole could not always be predicated on the basis of its perceptual parts (Wertheimer, 1938). The sum of the parts was different from the whole. A melodic sequence of notes will be perceived as the same melody whether played in the vicinity of middle C or in a higher or lower key. The tune can quickly be recognized even though each of the parts has been substantially altered. It is the *relationship* between the parts that is important and not their exact identity. In vision, the percept of a diamond standing on its tip can be changed to the percept of a square when the shape is surrounded by a rectangle (Koffka, 1935) (figure 1.10). The part has not changed in the figure, but its percept is changed by the addition of a more global figure. The identity of one part is affected by the orientation of the other. Again, the key factor is the relationship between the parts.

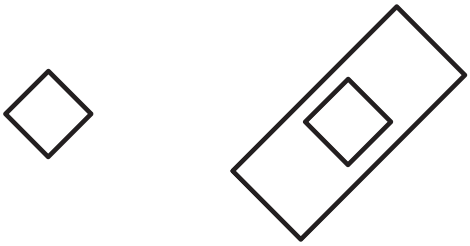

Figure 1.10 The diamond (left) is perceived as a square (right) when the tilted global rectangle defines a tilted "object-centered" orientation. (Adapted from Koffka, 1935.)

The influence of the gestaltists was widespread during the early part of this century, and they continue to have an influence on current cognitive theory (see Robertson, 1986). In the 1930s neurologists like Kurt Goldstein were quick to incorporate Gestalt ideas, including those of perceptual function, into clinical assessments (Goldstein, 1995). Gestalt thinking also played a major role in loosening the hold of behaviorism on experimental psychology. Behaviorism sought to account for complex behavior as the end result of the successive chaining of individual stimulus-response pairs independently formed by appropriate reinforcement. The Gestalt approach offered an alternative. In contrast to the behaviorists' devotion to the parts, early cognitive theorists like Edward Tolman and David Krech redirected psychological investigation to the molar aspects of behavior—the overall goals that constrain an animal's learning processes. When learning a maze, rats first demonstrate knowledge of the general layout of the maze and only later exhibit learning of individual turns and alleys (Krechevsky, 1938). Later studies with humans (Krech & Calvin, 1953) revealed similar effects with perceptual learning tasks. When people were given a series of visual problems and then were tested on what they had learned, they learned the wholes faster than the parts.

With the advent of cognitive psychology in the late 1960s, the focus of study changed. Psychologists felt less compelled to restrict their theories to observable behaviors. Instead, they sought methods to develop theories that emphasized the internal representation and transformation of information that supports observable patterns of behavior. For visual perception the questions about parts and wholes again became central. What defines a set of sensations as a whole versus a part? Do wholes or parts or both direct further processing of the scene? What sorts of interactions occur between these different levels of representation? How does attention affect the perception of wholes and parts?

Investigations into these questions were aided by the development of methodologies and paradigms that allowed fine-grained analysis of the operation of mental behavior. Of key importance was the refinement of chronometric methods (Posner, 1978), or the use of temporal measures and manipulations. Psychologists had long been interested in the speed with which people responded to stimuli, but researchers such as Michael Posner and Saul Sternberg were instrumental in showing how theoretical issues could be addressed by comparing response times in well-controlled experiments.

Implicit in their work was the recognition that neural processing takes time. The human brain cannot keep pace with the speed of a modern computer, at least not in terms of the time it takes to transmit information from one unit (neuron or bit) to another. It takes time for sensory transducers to send their signals through the central nervous system, and each synapse within the brain adds additional processing time before a response can be made. When a given percept results from the interactions between millions and millions of neurons, each firing hundreds of times, measurable differences can be observed as the experimenter manipulates the type of information that is available or the task the subject is required to perform.

Chronometric methods allow us to test theories of how perceptual recognition arises. They serve as a useful tool in identifying functional components of a cognitive task and their interactions in a distributed system. In the area of part/whole perception, a classic example is a study conducted by Navon (1977). This study is especially important because it has had a large impact in neuropsychology. Navon presented his subjects with patterns with a large global form made from several smaller local forms (see figure 1.9). Because the patterns contained information at different levels or at different spatial scales these patterns are referred to as hierarchical stimuli.

Navon used larger letters and forms created from the repetition of smaller letters and forms. Subjects were asked to press a key to identify the larger global form in one block of trials and the smaller local forms in another block of trials. Some experiments measured reaction time to perform this task and others measured the display time needed for a person to accurately perform the task. To avoid large acuity differences between foveal and peripheral vision the stimuli were presented in either the right or left visual field for just a few milliseconds before the subject responded. Navon measured the speed at which subjects were able to identify targets at different levels of stimulus structure. He reasoned that representations that were derived with the most speed would be associated with faster response times.

The results showed that subjects were much faster at identifying the global forms than the local forms, and that the global form interfered with the speed at which local forms could be identified but not vice versa. For example, during a response to a local target *H*, a global *S* (also a possible target) slowed reaction time, but during a response to a global target *H*, a local *S* had no effect. On the basis of these two effects Navon proposed a theory of global precedence. Perception begins with a derivation of the representation of the overall form and then proceeds to an analysis of the local elements.

Together, the faster response times and differences in interference were interpreted as revealing several aspects of part/whole perception. Consistent with the arguments of the Gestalt school, the global shape had precedence in perception. Perception of the whole did not require perceptual identification of the parts. Moreover, part perception was affected by the perception of the whole. Global information interfered with the speed of a local response, whereas local information had no effect on the speed of a global response.

Broadbent (1977) was the first to suggest that global precedence was due to attention being pulled to the global form by the lower spatial frequency content (roughly lower spatial resolution) at the global level (see chapter 2 for descriptions of spatial frequencies and how they relate to these types of patterns). Others proposed parallel processing models in which local features (although not necessarily identity) influenced the perception of a global form and vice versa (Palmer, 1980, 1982). Kimchi and Palmer (1982) demonstrated that global precedence was limited to cases in which the local forms were not perceived as texture, in a study reminiscent of those performed by Eric Goldmeier, an investigator from the early Gestalt school of psychology (Goldmeier, 1972).

More recent research with hierarchical figures has led to a softening of Navon's strong claims. As one might expect, global precedence is limited. If the global shape is too large, subjects will become faster at identifying the local elements (Kinchla & Wolfe, 1979). The patterns of interference have also been found to be more complex and subtle than was first suspected. For instance, Lamb & Robertson (1990) found that the speed required to identify a global or local form was not simply a function of stimulus size on the screen, but was also calibrated to sizes of stimuli presented throughout a block of trials. When the stimulus set contained stimuli between 1.5 and 6 degrees visual angle, global precedence was present at 3 degrees. When the set contained stimuli between 3 and 12 degrees visual angle, however, local precedence was present at 3 degrees. Global precedence then appeared at 6 degrees. In a later study, Robertson, Lamb, & Zaidel (1993) found no relationship between interference from the global form and the speed at which local forms could be identified. Still others found that response speed was affected by the ratio and density of global to local size (Martin, 1979a) as well as by where the stimulus was presented on the fovea (Lamb & Robertson, 1989).

In retrospect, these findings were predictable. When looking out over a landscape, we quickly recognize the trees scattered along a hillside. The ability to identify the species, however, may depend on a number of factors. In some cases the global shape may be sufficient: the overall shape of a fir is seldom confused with that of a drooping willow. In other instances, at least for the naive naturalist, species identification may depend on an analysis of individual leaves. There are many factors that will influence this process. Not only must we be standing at a reasonable distance to resolve the leaves' individual shape, but our perception will further depend on leaf density as well as other properties. Nevertheless, under many circumstances perception can begin with the parts. When we are napping at the base of a tree, its global shape is obscured, but identification is still possible as we examine the leaves in view.

Wertheimer was correct, in that the whole could be different than the sum of its parts. Furthermore, he was correct in maintaining that parts could predict the percept of the whole under some but not all situations. It took developments within cognitive psychology, however, to support the priority of the whole over the part in terms of time; temporal priority is reflected in subtle ways such as reaction-time differences of tens of milliseconds. As cognitive science has developed, computational models of part/whole perception have had to account for these effects, focusing on factors such as global and local symmetry (Palmer, 1982), levels of spatial resolution (Watt, 1988), or grouping processes (Enns & Kingstone, 1995). The chronometric method was critical in opening the door to more sophisticated theories of object recognition and in prompting researchers to acknowledge that perception involves a series of representational states that can extract the hierarchical spatial structure of the world.

STUDIES OF LATERALITY IN HEALTHY INDIVIDUALS

The marriage of hemisphere specialization and cognitive psychology began with split-brain research but evolved most rapidly with studies of young, normal college-aged subjects. One of the seminal studies using auditory stimuli was reported by Doreen Kimura (1961). As did the studies of patients with focal brain injuries and the early split-brain research, Kimura's research tested whether the left hemisphere has a distinct advantage over the right in processing linguistic information. Kimura adopted the dichotic-listening task, which had proven useful in the study of selective attention.

This task was developed to mimic processing demands in the natural world, where sensory overload is common. Consider the cocktail party or, more appropriate for today, the wine-tasting party. We may attempt to speak with one individual, but the speaker's voice is intermixed with a multitude of incoming auditory signals: conversations going on about us, music from the compact disc player, the clatter of plates being filled at the buffet table, the children watching a video in the next room. Despite this cacophony of sound, we are quite proficient at focusing on the relevant signal—the words being spoken by our conversational partner.

To explore this ability, dichotic-listening tasks were used. They involve the presentation of two simultaneous messages, one to each ear. In the early studies of attention, subjects had been instructed to attend to one message while ignoring the other. The goal was to assess the fate of the unattended message (Broadbent, 1954; Treisman, 1969). Kimura modified this task by asking subjects to report the information from both ears. Her objective was to determine whether subjects were more likely to report information presented to one ear at the cost of information presented to the other ear.

In the initial studies the stimuli were digits, presented so that one digit was heard in the left ear at the same time as a second digit was heard in the right ear. Kimura found that people were much more likely to report the stimuli presented to the right ear. This effect was dubbed the right ear advantage. It has been interpreted as reflecting an underlying advantage for the contralateral left hemisphere for processing linguistic stimuli.

Without the observations from neurological patient data, this ear bias would probably not have had much impact. It converged, however, with the neurological observations of language deficits produced by left hemisphere damage.

Kimura (1961b) went on to show that patients with left temporal lobe lesions performed worse at the task than did patients with right temporal lobe lesions. In addition, split-brain patients showed a huge right ear advantage in a study using words as stimuli. They succeeded in recognizing words presented to the right ear, but were at chance for words presented to the left ear (Milner, Taylor, & Sperry, 1968; Sparks & Geschwind, 1968).

Subsequent research showed that the right ear advantage could not be attributed to a generic advantage for the left hemisphere (or the right ear). When the stimuli were melodies, the advantage shifted to the left ear (Kimura, 1964; also, see chapter 5). Thus, the side of the ear advantage was dependent on the type of stimulus material being processed.

At the time, these results were surprising since other work had found no ear advantage with monaural stimuli. It was well known that visual information was lateralized. Information from each visual field was projected initially to the contralateral hemisphere. But this segregation of information does not hold as strictly for audition. In addition to the dominant contralateral projection from each ear, there are ipsilateral projections as well (Rosenzweig, 1951). Yet Kimura's work indicated that functional asymmetries could be revealed when the system was taxed. The dichotic procedure put the two hemispheres into competition with each other. This competition allowed the right ear advantage for linguistic stimuli to surface. A corollary of this interpretation is that each hemisphere is primarily driven by stimuli from the contralateral ear.

Some of Kimura's conclusions have been challenged over the years. Ear differences can be obtained with monaural presentation if precise chronometric measures are used (Catlin & Neville, 1976). In addition, it is now believed that, as with vision, auditory information is lateralized, not in terms of ears, but in terms of the side of space from which the signal originates. Thus, each ear may project to both hemispheres, but auditory inputs from one side of space will be projected to the contralateral hemisphere. Thus, a sound coming from a person's left will be projected to the right hemisphere, following the contralateral pathway from the left ear and the ipsilateral pathway from the right ear (Morais & Bertelson, 1975).

Nonetheless, it would be difficult to overestimate the impact of Kimura's work. Her research introduced a methodology that seemed to make it possible to explore laterality effects in people with intact, fully functioning brains. It was hoped that questions of hemispheric specialization no longer required the researcher to have access to neurological populations. Studies could now be conducted on the experimental psychologist's favorite research subject: the undergraduate college student. Armed with the tools of cognitive psychology and with the belief that lateralized stimuli produce asymmetric activation of the two hemispheres, these researchers generated an explosion of articles on hemispheric specialization that has continued unabated to the present time (unfortunately not always to the benefit of the field).

These studies have explored a wide range of tasks involving the modalities of vision, audition, and somatosensation. Two basic approaches have been employed. Most prevalent has been the use of lateralized stimuli. For vision, this involves the brief presentation of stimuli in either the left or right visual field (see figure 1.7). For audition, stimuli are presented either dichotically, as in the early Kimura studies, or monaurally. A smaller literature has emerged that explores differences in somatosensory perception (e.g., Bradshaw, 1986).

Another approach has been to combine tasks in such a way as to tax one hemisphere more than the other. These studies involve the dual-task methodology. Subjects are asked to perform two concurrent tasks to examine patterns of interference between the tasks. For example, suppose we were to accept that language selectively activates the left hemisphere. One could then compare what happens when a language task is combined with a motor task that involves either the right or left hand. The simplest dual-task prediction is that the language task will produce more interference for right-handed performance since both of these tasks would be expected to require left hemisphere processing resources (Kinsbourne & Cook, 1971).

A basic premise underlying this approach is that the degree of interference will be related to the cerebral distance between the component operations required for the two tasks (see Kinsbourne, 1975). Of course, if the two tasks do not use any common resources, no interference should emerge, regardless of the side of hemispheric involvement. Nonetheless, the dual-task paradigm has added another methodology for exploring functional hemispheric asymmetries in normal individuals.

These methods, of course, have their limitations. A critical assumption has been that differences in performance with lateralized stimuli nearly always reflect functional differences between the cerebral hemispheres. This is an extremely strong assumption. Researchers have tended to ignore or downplay the fact that asymmetries in brain function cannot be directly observed with these methods. It requires a leap of faith to assume that there is a straightforward mapping between lateralizing a stimulus and producing disproportionate activation throughout the contralateral hemisphere. Normal subjects have an intact corpus callosum, which provides for the rapid transfer of information from one hemisphere to the other. Many cells in areas outside early visual cortex respond to stimulation on both sides of the fovea (see Gattass, Sousa, & Covey, 1985).