# Chapter 2
# The Neural Substrate for Language

## 2.1 *Issues*

One of the most striking findings in the study of the relation between the structure of the human brain and behavioral functioning is cerebral dominance. Abundant evidence indicates that language processing is generally a left-hemisphere function, whereas the processing of visuospatial relations is generally a right-hemisphere function. Of course, this evidence was obtained with hearing subjects, whose language is a spoken one. In ASL, unlike spoken language, the signal is spatially organized. Let us recapitulate here briefly how in ASL spatial patterning figures in highly significant ways in the grammar of the language. The rich inflectional and derivational devices of ASL make structured use of space and movement, embedding signs in specific planes of space and spatial arrays. ASL conveys its syntax and discourse in large part by manipulation of space. Nominals introduced into the discourse may be associated with specific points in a plane of signing space; verb signs move between these points to specify subjects and objects of the verb. Pointing to a specific locus later in the discourse clearly "refers back" to a specific nominal, even after many intervening signs. Different subsystems of the language (pronominal reference, nominal establishment, verb agreement, and coreferentiality) thus rely on space and spatial representation (Klima and Bellugi 1979; Bellugi and Klima 1982b; Bellugi 1980).

Because ASL incorporates both complex language structure and complex spatial relations, it exhibits properties for which each of the hemispheres of hearing people shows specialization. Deaf people who have been deprived of auditory experience and who rely on a sign language for their principal mode of communication throughout their lives thus provide a privileged testing ground for investigating how the brain is organized for language, how that organization depends on language modality, and how modifiable that organization may be.

A great deal of evidence on brain organization for language has come from studies of speakers with brain lesions. We present here results of our studies of lifelong signers who have experienced brain damage. Because there is scarcely any previous research on sign language impairment in deaf signers, we have tested various hypotheses about the overall organization of the brain for sign. We wondered whether sign language is strictly unilaterally represented, as speech is, or bilaterally represented in congenitally deaf signers to a degree not characteristic of speech in hearing people. Alternatively, we wondered whether the left or the right hemisphere would be dominant for sign. Furthermore, when sign language breakdown occurs, would impairments be selective with respect to the structural components of the language? And, if we were to find left-hemisphere dominance for sign, would damage to the classical speech areas disrupt sign in the same manner as it affects speech? Because grammatical and spatial relations are so intimately interwoven in ASL, we consider it especially important to investigate not only how sign language breaks down but also how visuospatial functions break down; that is, we want to explore whether or not spatial functions are represented in the brain differently in deaf signers and to what degree spatial processing deficits affect sign performance.

Patterns of ASL impairments resulting from localized lesions in deaf signers can help illuminate the nature of neural organization for language. However, the brains of deaf people do not evolve independently of those of hearing people, and language mechanisms have certainly evolved in part to meet the needs of spoken communication. The neural organization for a visual-gestural language in deaf signers may therefore be determined in part by the evolutionary history of language development in the oral-auditory transmission modality. To the extent that specialized language structures developed for speech govern the representation and processing of ASL, neural mechanisms in deaf ASL signers will be similar to those found for hearing speakers. To the extent that the modality in which a language develops shapes the structure and processing of the language, modality-relevant neural structures may be implicated in its representation. The study of brain organization in deaf ASL signers allows us to address such fundamental questions regarding neural mechanisms for language.

### 2.1.1 *Specialization for a Language in a Visual Modality*

Besides its specialization for language, the left hemisphere seems better adapted than the right for processing sequential signals. As we pointed out in chapter 1, a major difference in form between ASL and most spoken languages is that ASL tends to transmit structural information in co-occurring layers rather than in sequence. The concurrent display of *linguistic* structure in ASL therefore allows study of the interplay of these (opposing) attributes: Will separate linguistic levels in ASL break down independently of one another, much as they do in spoken languages, despite the radical differences in the way in which the linguistic information is packaged in the signed signal? Will there be substitutions and transpositions involving sublexical components of signs? Will the syntax of ASL be disturbed independently of the lexicon?

Undoubtedly, the most distinguishing characteristic of ASL as a language is its reliance on spatial mechanisms to convey syntactic structure. Does right-hemisphere damage disrupt the processing of this linguistic signal? Are left-hemisphere mechanisms, some of which clearly involve sequential analysis, called into play for a language that preferentially packages its linguistic information in such a spatial, concurrent manner? Or is the underlying basis of left-hemisphere specialization for language tied to *function* rather than to *form*?

### 2.1.2 *Apraxia and Aphasia: Motor versus Linguistic Impairment*

The use of aphasias to reveal brain organization for sign language presents special problems. An important question involves the dissociability of sign aphasias from apraxias, neural disorders of movement not traceable to any motor weakness or lack of coordination. Because apraxias frequently co-occur with aphasias, some investigators have proposed that the two share a common underlying basis, namely, an underlying deficit in the control of movement or gesture. We use a number of tests, described in detail later in this chapter, to distinguish among impairments in linguistic, symbolic, and motor functions and to evaluate each separately. Results of these tests can illuminate the relation between aphasia and apraxia in both hearing and deaf individuals in a strong way by determining the dissociability of the breakdown of nonlinguistic gestural behavior and of gestural *language*.

### 2.1.3 *Specialization for Visuospatial Capacity*

The right hemisphere has long been considered a poor relation to the left; the left has been said to be dominant for language, skilled motor control (praxis), fine temporal processing, analytic analysis, and feature extraction, whereas the right has been considered to lack any significant specialization of its own. This view is still reflected occasionally. However, the work of Roger Sperry and his associates with split-brain patients and mounting case reports of patients with unilateral lesions to the right hemisphere converge to indicate that the right hemisphere has its own specialized abilities (Ratcliff and Newcombe 1973; Ratcliff 1982; Levy 1982). Rather than extracting features, the right hemisphere organizes parts into complex configurations, and rather than being dominant for speech, it is dominant for processing visuospatial relations. Its function with respect to processing spatial relations might be especially important in sign language, because many of the grammatical processes crucially involve spatial relations and the manipulation of space. What, then, are the consequences for brain organization when space functions linguistically?

To our knowledge, this is the first investigation of brain organization for nonlinguistic visuospatial processing in brain-damaged deaf signers. Our objective is to determine whether this organization is the same as or different from that in hearing-speaking individuals. We administered a battery of tests for nonlinguistic processing to deaf patients with brain lesions (and to matched deaf controls). The tests have proved in hearing patients to distinguish maximally the performance of those with lesions in the left hemisphere from those with lesions in the right. We investigate (1) whether lack of auditory experience and use of a spatial language affect the functional organization of the brain of deaf signers for nonlinguistic visuospatial processing, and (2) the degree to which impairments in nonlinguistic visuospatial processing affect sign performance.

Before describing the methods used in our investigations, we review previous studies of the effects of brain damage on deaf signers, including the limitations of these studies. At the end of the chapter we introduce the six patients with unilateral lesions (three with left-hemisphere lesions and three with right-hemisphere lesions), whose cases form the major focus of this book.

## 2.2 *Background and Previous Studies*

Until recently, little has been known about brain organization for sign language. Two lines of evidence have been used, one with normal deaf signers and the other with brain-damaged signers. Neither of these lines has proved definitive.

Experiments with non-brain-damaged deaf signers have generally employed tachistoscopic presentation of signs, following the paradigms developed for the differential presentation of visual material to the two cerebral hemispheres. In order to stimulate one hemisphere exclusively, in these paradigms it is necessary to present visual stimuli rapidly. But an important attribute of ASL lexicon and grammar is movement, and it is extremely difficult to capture movement in the brief exposure necessary to stimulate one hemisphere exclusively. This difficulty has meant that most investigators presented only static line drawings or photographs of signs tachistoscopically to the visual hemifields of signers (see Poizner and Battison (1980) for a review). These studies found more right- than left-hemisphere involvement. One study, however, presented signs in motion, as well as ones presented statically (Poizner, Battison, and Lane 1979), and found a shift from right-hemisphere dominance to a more balanced hemispheric involvement with the change from static to moving representations. A new experiment has, in fact, shown significant left-hemisphere dominance in normal deaf signers for the identification of computer-synthesized moving ASL signs (Poizner and Bellugi 1984). Nonetheless, it is impossible to capture much of the movement of sign language in the brief exposure durations available; only lexical signs have been presented, and no analysis of hemispheric specialization for grammatical processing or for language production has been possible. Furthermore, the weight of the evidence from the tachistoscopic studies shows greater right-hemisphere than left-hemisphere involvement, possibly because of greater right-hemisphere preprocessing of signs presented statically. In any case, these studies have not proved definitive.

The study of the breakdown of sign language following localized brain lesions in deaf signers can resolve these and many other issues. In the study of brain-damaged signers, there is no limitation on the presentation of movement; grammatical processing as well as lexical processing can be studied, language production as well as language comprehension can be studied, and analyses of brain function can be made not only in terms of left-hemisphere and right-hemisphere functioning but also in terms of the roles of specific anatomical structures within the hemispheres. Furthermore, the study of language breakdown under conditions of brain damage can reveal in a robust way the nature of brain organization for language. We first mention some historical aspects of the study of the breakdown of spoken language resulting from brain damage in hearing individuals and then review previous studies of brain-damaged signers.

As early as the time of Hippocrates in the fourth century B.C. in Greece, it was reported that injury to the brain could result in impairment of language capacities. In fact, even the ancient Egyptians knew that certain head injuries could result in loss of speech. Thus the recognition of the disturbance we now call aphasia has a long history.

Of more recent vintage are the aspects of aphasia most relevant to our concerns in this book: brain organization for language and its relation to modality.

It was in 1865 that Paul Broca, a French neurologist, made the seminal discovery that a lesion in a part of the *left* hemisphere resulted in sudden and long-lasting language disturbance in a previously normal individual and led to his statement that "we speak with the left hemisphere." Lesions to the corresponding regions of the *right* hemisphere were not accompanied by any observable language impairment.

A decade after Broca's work, the Viennese neurologist Carl Wernicke noted that lesions to different parts of the left hemisphere are accompanied by radically different patterns of language problems. Specifically, the lesion site that Broca had studied (the posterior regions of the frontal lobe) most noticeably involved language production: reduced output, slow and effortful articulation with articulatory errors, and omission of grammatical formatives. Comprehension did not appear to be affected. This constellation of symptoms came to be known as Broca's aphasia. By contrast, the lesion site that Wernicke had identified most noticeably involved problems in comprehension. Production showed fluent, rapid output and preserved syntactic markers, but the output was often irregular in the frequency of lexical and sublexical substitutions. In the most extreme cases, it constituted a sort of "word salad." This syndrome came to be known as Wernicke's aphasia.

One of the earliest researchers to address the issue of modality of language and brain organization was the British neurologist Hughlings Jackson. In an 1878 article Jackson predicted that, because of injury to some part of the brain, a deaf signer might lose his natural system of signs, that is, his sign language. This prediction remained purely speculative for a long time. The reason was that no relevant cases had been reported in the literature. Gradually, however, pertinent, if not decisive, cases did appear, and these few clinical reports of sign aphasia do show left-hemisphere involvement. Most of these reports, however, are not especially revealing because the linguistic impairments of these patients were usually extremely underreported and because testing procedures were insensitive to critical linguistic, psycholinguistic, and sociolinguistic issues of sign languages. Furthermore, most of these studies were carried out before the advent of computer-assisted tomography (CT scans), which has provided an extremely important means of localizing the site of brain damage. Without autopsy information, therefore, such studies had no way of specifying exactly where the brain damage occurred. As we turn to these earlier case studies, let us remind the reader that aphasia is to be understood as a language disorder that results from brain damage and cannot be accounted for by peripheral sensory or motor dysfunction or by general cognitive deterioration in attention or motivation. (More detailed reviews of the early case studies are in Poizner and Battison (1980) and Kimura (1981).)

Grasset (1896) provides the first report of a deaf man who experienced a left-hemisphere lesion. The patient was French. His right-handedness is implied but not specifically reported. Unfortunately, only his fingerspelling in French was evaluated, and not his use of French Sign Language. The patient had mild paralysis of the right arm and could not fingerspell with that hand; however, he showed no impairment in fingerspelling with his left hand and showed no comprehension loss. This patient's impaired right-handed fingerspelling apparently resulted from peripheral motor impairments of his right hand, rather than from a central language deficit. Thus Grasset's patient is not a case of aphasia. It is neither a true "fingerspelling" aphasia, in which case fingerspelling production in the nonparalyzed left hand would also have been impaired, nor presumably a case of sign aphasia. At any rate, no mention is made of the patient's use of sign language.

Burr (1905) likewise sheds little light on brain organization for sign language. The patient in this study became deaf early in childhood and learned to sign. She never learned to talk, but she did learn to read and write. She later suffered massive left-hemisphere damage that left her fairly unresponsive and with general intellectual deterioration that included loss of language. This case also does not demonstrate sign aphasia, for it lacks the appropriate selectivity of impairment.

Critchley (1938) provides a report of a right-handed deaf British man who experienced a left-hemisphere stroke. The patient could hear until the age of 7, at which time his hearing gradually diminished. By the age of 14 years, he was deaf. He communicated by means of sign language. Critchley reports that the patient's natural sign language was unaffected but no information on the testing of sign language is given. The patient's fingerspelling, however, was impaired. The patient was reported to have an initial paralysis of the right hand, which improved considerably with time. This case is difficult to interpret. Because the patient did not become completely deaf until the age of 14, hemispheric specialization might have been established on the basis of hearing and speech, before his learning of sign language. Furthermore, it is unclear how skilled the patient was in fingerspelling and in the sign language he used (presumably some form of British Sign Language) before his stroke, and no details are given of the testing of his reportedly unimpaired sign language.

Reider (1941) introduces a case of a hearing patient from the American Midwest who learned sign language from his deaf mother, possibly as a first language. Although few details of testing were presented, the patient reportedly was severely aphasic for speech but less impaired in sign, although he tended to perseverate in his signing. Autopsy revealed effects of diffuse encephalitis throughout the entire brain, without any focal lesions. This case also provides little resolution of the issues, because the patient did not have unilateral brain damage and because few test details are given.

Leischner (1943) presents an important and well-documented case of a congenitally deaf, apparently right-handed man from a deaf family who learned Czech Sign Language as a first language. Language testing was extensive. The patient was bilingual in written Czech and German but could speak neither well. The testing was carried out primarily in Czech Sign Language. The patient showed both difficulty in expressing himself in his sign language and loss of sign comprehension. He produced nonsense signs, perseverated in his signs, incorrectly named objects and pictures, and reportedly produced a superfluous number of signs, more than was necessary to communicate. He had difficulty signing automatic sequences; for example, when asked to sign the days of the week, he once signed SUNDAY, SATURDAY, FRIDAY, SEPTEMBER, APRIL. As mentioned, his comprehension of sign language was also impaired. In these respects his signing resembled the speech of a hearing Wernicke's aphasic. A strength in this study is that the brain was autopsied, so the precise areas of damage could be determined. There was damage to the left parietal lobe, including the supramarginal and angular gyri, and to portions of the temporal lobe. Unfortunately, there was also an older lesion to the basal ganglia of the right hemisphere, which prevents any conclusive interpretation of how sign language might be represented in the brain.

Tureen, Smolik, and Tritt (1951) present a case of a congenitally deaf right-handed man who lost his ability to fingerspell after sustaining an injury to the left hemisphere. A hemorrhaging tumor in the left frontal lobe was surgically removed. Posterior portions of the second and third frontal convolutions were excised. Tureen and his colleagues held common misconceptions of their time about sign languages, viewing them as a universal primitive system of gestures. They report that the patient lost and recovered his use of sign language, although no testing of sign language was performed because the interpreter knew only fingerspelling.

Douglass and Richardson (1959) present a case of 21-year-old congenitally deaf right-handed woman who learned sign language from her two older deaf siblings. She had attended an oral school for deaf children and later married a deaf man. It appears from reports of her clergyman, relatives, and friends that sign language was not her primary mode of communication; rather, fingerspelling seemed her superior skill. During an abortion, the patient experienced a stroke that caused extensive damage to her left hemisphere, with associated paralysis of the right arm. Clinical signs led the authors to infer that the greatest damage was to the posterior frontal region, with lesser damage to the parietal and temporal areas. Both the production and comprehension of signing and fingerspelling were impaired, but signing was the more affected. Reportedly, the patient could carry out nonlanguage movements with the left hand without difficulty. Although descriptions of fingerspelling errors were given, those for sign were not.

Sarno, Swisher, and Sarno (1969) present the case of a 69-year-old right-handed congenitally deaf man who apparently learned sign language and fingerspelling at the age of 7 at a school for deaf children. He had two sisters who were also deaf. Before his stroke he was reported to have intermixed speaking and mouthing with signing and fingerspelling. His stroke was to the left hemisphere, which left him with moderate paralysis of his right arm. After his stroke he was severely aphasic, with deficits in both production and comprehension. The patient's ability to express himself was apparently more impaired than was his comprehension. The authors report that his expressive impairment was worst in speaking, followed by fingerspelling and writing; he was least impaired in signing. Likewise, his comprehension of fingerspelling and lip movement was more impaired than his comprehension of print or signs. Although this case is fairly well documented, interpretations based on it are complicated by the mixed language system the patient apparently used before his stroke.

Meckler, Mack, and Bennett (1979) present the second case of a *hearing* signer who suffered brain damage. The patient was a 19-year-old man of deaf parents. He had learned sign language and speech concurrently. The patient was left-handed. An automobile accident left him with a dense paralysis of his right arm and a right-sided sensory deficit. He apparently had a generalized lesion to the left hemisphere. He was initially globally aphasic for both sign and speech; over time he showed improvement, but his comprehension in both modes improved considerably more than did his expressive capacities. Apparently, fingerspelling was more impaired than signing.

Battison and Padden (1974) and Battison (1979; discussed in Poizner and Battison (1980)) describe a 70-year-old right-handed man who became deaf at the age of 5. He learned sign language a few years later, after being enrolled in a school for deaf children in Canada. His brain damage was in the region of the left middle-cerebral artery. His signing, fingerspelling, and writing were all impaired. He showed hesitations, substitutions, formational errors, and perseverations in all three modes of expression.

Underwood and Paulson (1981) present the case of a left-handed signer, a 57-year-old congenitally deaf man. At the age of 7 he was enrolled in a school for deaf children, where he learned sign language. The patient reportedly was a skilled signer, although it is difficult to interpret Underwood and Paulson's statement that "in addition to American Sign Language, gestures were incorporated into his communication with deaf peers" (p. 286). The patient had a left-sided stroke with resulting right hemiplegia. No further information localizing the site of the brain lesion is given. The patient was severely aphasic for sign language, unable to express even his basic needs. His comprehension of sign was also impaired. Unfortunately, no description of his sign language errors is given, although errors in fingerspelling and writing are described.

Chiarello, Knight, and Mandel (1982) provide a well-documented case of a 65-year-old American woman who became deaf at 6 months of age after contracting scarlet fever. At the age of 5 years, she was enrolled in a residential school for deaf children, where she learned sign language. She had a stroke in the left hemisphere, with consequent paralysis of the right arm. A CT scan revealed a lesion to the left parietal region and some subcortical extension into the posterior portion of the middle frontal gyrus. Globally aphasic initially, her symptoms resolved somewhat to fluent signing with substitutions (paraphasias), difficulty in finding signs, and impaired sign comprehension and repetition.

There have been two reported cases of signers with damage to the right hemisphere. The first (Battison (1979); discussed in Poizner and Battison (1980)) involved a 68-year-old prelingually deaf man who was left-handed. He began signing in early childhood, either through contact with his older deaf sister or through his early entry into a school for deaf children. The patient experienced a right-hemisphere stroke with consequent paralysis of the left hand. He showed severe impairment in both production and comprehension of signs, fingerspelling, and writing.

Kimura, Davidson, and McCormick (1982) present the second case of a signer with right-hemisphere damage. This patient was a 52-year-old right-handed prelingually deaf woman from Canada. She learned to sign at age 7, when she entered a school for deaf children. She had mild neurological deficits, consisting of a slight weakness of the left arm and hand and a slight neglect of left hemispace. She apparently had no sign language deficits, as assessed primarily by family reports and conversations with a skilled sign language interpreter.

It is clear from this review of existing case reports that previous research has failed to assess the linguistic competence of signers with respect to such central aspects of language as syntax and morphology. Because it has only been in the last decade that the grammatical system of ASL has been elucidated, the shortcomings of these studies are to be expected. With sign language regarded as "primitive" or a "form of pantomime" instead of as a complex language system, many of these studies can supply little usable information about the nature of sign language breakdown following brain damage. It becomes difficult, after all, to assess a patient's skills in ASL when the interpreter for the testing knows only fingerspelled English. Most of the case reports, in fact, do not even provide a single description of any sign language error. Without any linguistic description of the signing behavior of these patients, it is impossible to reach any conclusions about the nature of aphasia for sign language. Furthermore, previous studies have not compared performance of left-lesioned patients and right-lesioned patients across a given array of tests. In this manner left- and right-lesioned patients can be directly compared. With our current understanding of the nature of ASL, we have been able to develop a battery of tests with which to analyze a signer's strengths and weaknesses. These tests are described in detail in the next section.

## 2.3 *Methods*

We have four basic groups of tests. (1) To begin to investigate sign aphasia, we adapted the Boston Diagnostic Aphasia Examination (BDAE; Goodglass and Kaplan 1972) to ASL in order to see whether the pattern of impairment following brain damage in deaf signers is at all comparable to that found in brain-damaged hearing individuals. (2) We also developed a series of tests directed toward production and comprehension of particular grammatical structures of ASL.

Specifically, we tested for the capacity to process sublexical structure, morphology, and spatialized syntax. (3) To determine the relationship between apraxia and aphasia in a user of a gestural language, we assessed the capacity for representational and nonrepresentational movements of the hands and arms. (4) Finally, we used an array of nonlanguage visuospatial tests that have been shown in hearing people to differentiate the effects of damage to the left as opposed to the right hemisphere.

The entire battery of tests was administered to six brain-damaged signers, who are our focus here, and to deaf controls matched in age, age of onset of deafness, and language background. A native ASL signer administered all tests (in order to make the subject feel at ease in using ASL), with responses videotaped for later analysis.

### 2.3.1 *Evaluation of Sign Aphasia*

We adapted a standardized assessment of language skills, the BDAE (Goodglass and Kaplan 1972), for use with deaf, signing patients. We first translated the BDAE into ASL, with necessary modifications. Edgar Zurif and Harold Goodglass, pioneering investigators of aphasia in hearing people, helped us adapt the test to a visual-gestural language. As an example of a modification, note first that the right-sided paralysis of many aphasics requires that they take the sign examination with their left hand only. We therefore built this constraint into our adaptation of the BDAE by using only one-handed signs. The fact that a deaf signing patient may have use of only one hand does not in itself produce a language impairment. In ASL there are no lexical contrasts based on the use of one versus two hands, and, indeed, left-handed signers have mirror image signing of those who are right-handed. Signers often have one or the other hand occupied and sign well nonetheless. We have, in fact, asked native signers to sign lists, stories, and passages with only the left or the right hand; not only have they found this to be an easy task, but other signers, when tested, can comprehend their signing without trouble. Linguistic ability and effective communication are not hampered by using only one hand instead of two (Vaid, Bellugi, and Poizner 1985).

Another change in adapting the BDAE was motivated because hearing patients had to make rapid repetitions of items ranging from easy (*mama*) to difficult (*huckleberry*). In our test the items were not direct translations into ASL but were chosen to range correspondingly from formationally simple (UNDERSTAND, MOTHER) to formationally complex (BEE, RESEMBLE, FOREVER). Certain linguistic facts obliged us to modify some test items, as is usual in translating a test from one language to another. In the responsive naming task, for example, the question, "What do you do with a razor?" calls for the answer, "Shave." The signs RAZOR and SHAVE, however, share the same root, so the question in ASL contains an obvious clue to the answer. We changed the item to WHAT DO YOU DO WITH A BOOK? because the answer, READ, is formationally unrelated to any sign in the question itself.

The BDAE yields more than an index of a patient's general communication or language capacity; it also provides a profile of language impairments. The first part of the BDAE consists of standardized tests assessing various aspects of language production and comprehension; the second part yields ratings of attributes of conversational and expository signing. We discuss results of the BDAE in chapters 3, 4, and 5.

*Standardized Tests of the Boston Diagnostic Aphasia Examination*
The BDAE, as adapted by us for deaf patients, consists of five tests having to do with sign language: sign fluency, sign comprehension, naming, repetition, and paraphasia. We describe each separately.

Sign fluency is based on three subtests: a rating of ease of sign articulation, a measure of the length of sign phrases in spontaneous signing, and a test of sign agility requiring rapid serial repetitions of single signs that vary in formational complexity.

Sign comprehension consists of four subtests. The first is sign discrimination, a multiple-choice test of sign recognition in which the examiner produces a single sign and the patient points to a picture of the sign's referent. In the second subtest, body part identification, the patient points to the appropriate body parts in response to their names designated by the examiner. The third subtest requires the patient to carry out sign commands, varying from one to five significant informational units (such as "Put the pencil on the card, then put it back"). The final comprehension subtest, complex ideational material, requires yes/no answers to simple factual material and brief questions that explore the patient's comprehension of short, signed stories.

There are four naming subtests for evaluating word-finding ability. Responsive naming requires the patient to answer a signed question (such as "What color is grass?"). In visual confrontation naming the patient names pictures. In body part naming the examiner points to his or her own body parts, and the patient is asked to name the parts. The animal naming subtest measures patients' facility in controlled association by having them produce as many names of animals as they can in 60 seconds.

In the repetition test the patient is asked to repeat single signs and to repeat sentences of either low or high probability, that is, referring to likely as opposed to unlikely situations.

Types of paraphasia (linguistic substitution) are tabulated in specific BDAE subtests. These substitutions include what is commonly referred to as "slips of the tongue" as well as substitutions of elements from outside the immediate string. These transpositions and substitutions can take several forms. In phonemic paraphasias there is transposition or introduction of extraneous phonemes in a spoken word. Phonemic paraphasias in sign arise from substitutions of one sublexical element for another (a change in Handshape, Location, or Movement). In speech, for example, the error might be the word "bindow" for "window." Verbal paraphasias involve the substitution of one sign for another, and neologistic distortions are substitutions or introductions of extraneous sublexical elements such that most of the intended word or sign is not recognizable as a unit.

*Rating-scale Profiles of the Boston Diagnostic Aphasia Examination*
The second part of the BDAE provides a rating scale for assessing certain aspects of spontaneous language production. To obtain a database for the rating-scale profiles, we transcribed and tabulated various characteristics from a 10-minute sample of each patient's conversation and expository signing. We measured the length of sign phrases, noted paraphasias, and classified and counted all grammatical and lexical morphemes.

We obtained ratings for six aspects of sign production: melodic line, phrase length, sign agility, grammatical form, paraphasia, and sign finding. In the BDAE for hearing individuals, what is termed the melodic line refers to the number of words within an intonational contour. Strictly, melodic line is not a property of signing or of gesturing. What is comparable, however, is the rhythmic flow of signing (as distinguished from simply unfaltering, fluent output). Rhythmicity is important as a measure because it provides evidence that a string of signs, whether fluently outputted or not, represents phrasal/sentential structure rather than merely a string of signs linked together associatively as opposed to syntactically. In the ASL adaptation the rating reflects the number of signs within a single rhythmic grouping. Phrase length is the maximum recurring number of signs in an uninterrupted run, bounded by pauses or sentence markers; the scale reflects the average of the longest number of runs of signs for every ten starts. Sign agility is the patient's ease of articulating signs and sign sequences. Grammatical form reflects the variety of grammatical constructions a patient uses. Paraphasias focus on substitutions or insertions of semantically inappropriate signs or neologisms. Sign finding reflects the informational content of the patient's signing with respect to the patient's level of motoric fluency; measurement is based on the proportion of substantives and specific action signs relative to the number of low-information signs (such as pronouns and other closed-class morphemes and indefinite signs, for example, THING). A seventh scale, sign comprehension, is based not on ratings but on test scores from the four BDAE comprehension subtests.

Five of the six rating scales are 7-point scales, in which 7 stands for normal and 1 for maximally abnormal language characteristics. For the sixth scale, sign-finding ability, both extremes reflect deviant language production, with normal performance in the middle. Our ratings closely follow the principles specified for hearing patients, outlined in Goodglass and Kaplan (1972), but adjusted for characteristics of ASL.

The Cookie Theft picture of the BDAE (figure 2.1) is typically used to elicit speech from aphasic patients; we used it to elicit signing. On the right-hand side the picture shows a woman standing beside an overflowing kitchen sink; the woman, drying a plate, appears oblivi-

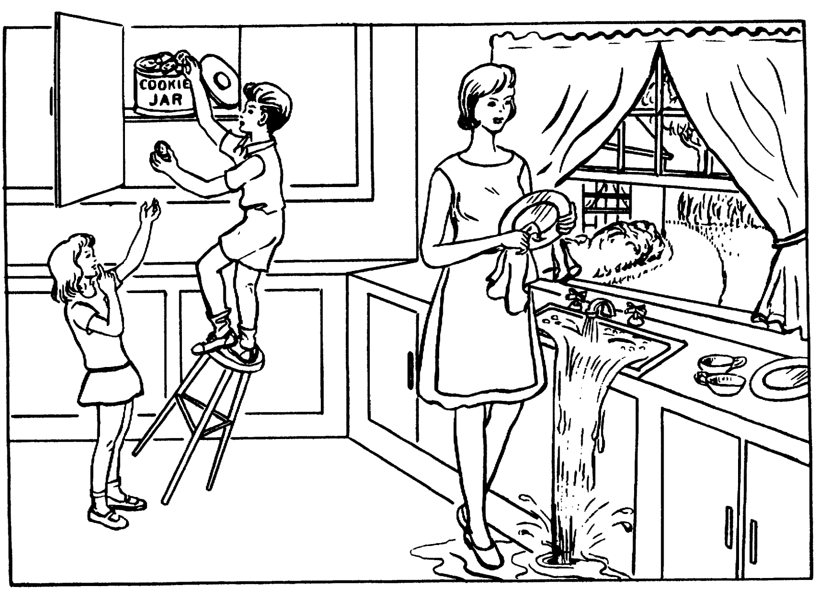



Figure 2.1
The Cookie Theft elicitation card from the Boston Diagnostic Aphasia Examination. Copyright © 1972 by Lea and Febiger. Reprinted with permission.

ous. On the left-hand side of the picture a boy stands on a stool, attempting to reach a jar of cookies on a shelf above his head. The stool is tipping over and is about to fall. Also on the left-hand side is a girl reaching up to the boy, presumably for a cookie.

### 2.3.2 *Tests for Processing the Structural Levels of American Sign Language*

We designed the following battery of tests of language comprehension and processing for the levels of structure in ASL:

1. tests for processing ASL "phonology": the Rhyming Test and the Test for Decomposition of Signs;
2. tests for processing ASL morphology: the Comprehension and the Elicitation of Noun/Verb Distinction;
3. tests for processing spatial syntax in ASL: the Nominal Establishment Test, the Test of Verb Agreement with Fixed Framework, and the Test of Verb Agreement with Shifting Reference.

Our studies focus on morphological and syntactic processes because in these processes sign language makes the most widespread and distinctive use of the properties of the visuospatial modality. Some of these studies are outlined in what follows. (These processes and their measurement are also discussed in chapters 4, 5, and 6.) In the tests described in the following discussion we found that normal, deaf young adults and control subjects matched in age and background to the brain-damaged signers perform quite well. In addition, we gathered data on young deaf children and found that they have the requisite capacities early on.

*Sublexical Tasks*

The two tests for evaluating ASL "phonology" are Rhyming and Decomposition.

It has been argued that for hearing people phonological processing is one aspect of linguistic processing that is mediated primarily and preferentially by the left hemisphere. But is this left-hemisphere specialization based on the linear, temporal sequencing of phonemes in the words of spoken languages, or is it based on sublexical processing in general? Given the difference between the sublexical structure of English words and that of ASL signs (linear temporal contrasts versus co-occurring components in space), it becomes important to determine the nature of the errors that brain-damaged deaf patients make at this level and to assess their abilities to decompose signs into their component elements. In our test for impairment in phonological processing, the subject looks at three pictures of objects and identifies the two objects whose signs "rhyme" (that is, signs that differ in only one of the three major parameters of signing: Hand Configuration, Place of Articulation, and Movement).

In developing a test of the ability to decompose signs into their sublexical components, we used familiar signs that can be represented by pictorial objects. First, we assess the patient's ability to name the pictures. For each of the major formational parameters of ASL (Hand Configuration, Place of Articulation, Movement), there are five sets of items. The subject sees a sign and then a set of four pictures. He or she is asked to pick out the picture that represents a sign with the same Hand Configuration (or Place of Articulation or Movement; see figure 2.2). The arrays include a semantic distractor and a formational distractor (picture of an object representing a sign similar in another component to the target sign). The central question of interest is whether left-lesioned signers, but not right-lesioned signers, are impaired with respect to these phonological processing tasks.

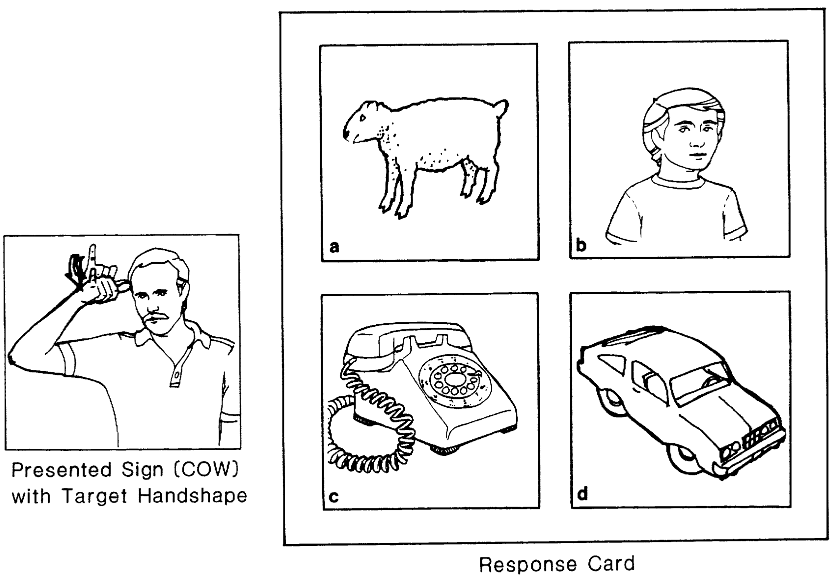



Figure 2.2
Test for processing ASL "phonology": Decomposition of Signs. The subject is asked to select the picture whose sign has the same Hand Configuration as the target. The correct choice is (c), because the ASL sign TELEPHONE has the same Hand Configuration as COW.

*Morphological Tasks*

Two tests are used to evaluate the morphological processing of signs. The tests examine comprehension and elicitation of noun/verb distinction.

In ASL the formal distinction between the action-instrument noun-verb pairs, discussed in chapter 1, is marked by the patterns of movement. This derivational process relates semantically associated noun-verb pairs, such as SIT and CHAIR, FLY and AIRPLANE, and CUT and SCISSORS. In such pairs the members share the same Handshape, Place of Articulation, and Movement Shape (for example, back and forth, closing, and nodding) but are differentiated by movement features, such as frequency, end manner, and tension. Some verb signs have repeated movement, others single movement; but the related noun movement is always repeated, restrained, and small (Supalla and Newport 1978). Thus the morphological marker that distinguishes nouns from verbs involves manner, size, and repetition. The linguistic structure of these forms in the adult language has been well analyzed, as has its acquisition in deaf children (Lillo-Martin et al., "Acquisition," 1985; Launer 1982). We have developed tests to assess knowledge of this derivationally related distinction.

In the test for Comprehension of Noun/Verb Distinction, the examiner makes a single sign—a noun or a verb from a related pair—and the subject designates which one of four pictures illustrates the sign. The four pictures include the object referred to by the noun, the activity referred to by the verb, a sign distractor (something whose sign is similar to the target sign), and a semantic distractor (something similar to the thing referred to by the target sign). Figure 2.3 presents an example.

The second test, Elicitation of Noun/Verb Distinction, is designed to elicit the production of a noun/verb distinction. The subject sees a picture of an object or of an activity corresponding to the noun or verb, respectively, of a related pair. The examiner then prompts the production of the noun or verb, asking, "What is that?" or "What is she (or he) doing?"

*Spatialized Syntax*

Three tests examine the processing of spatialized syntax: the Nominal Establishment Test and two tests of Verb Agreement, one in a fixed framework and the other with a shifting reference.

The verb agreement tests we have developed provide a means for assessing selective impairment of the structural components of ASL. As described in chapter 1, for a large class of inflecting verbs in ASL, subject and object are signaled by reference to loci in the plane of

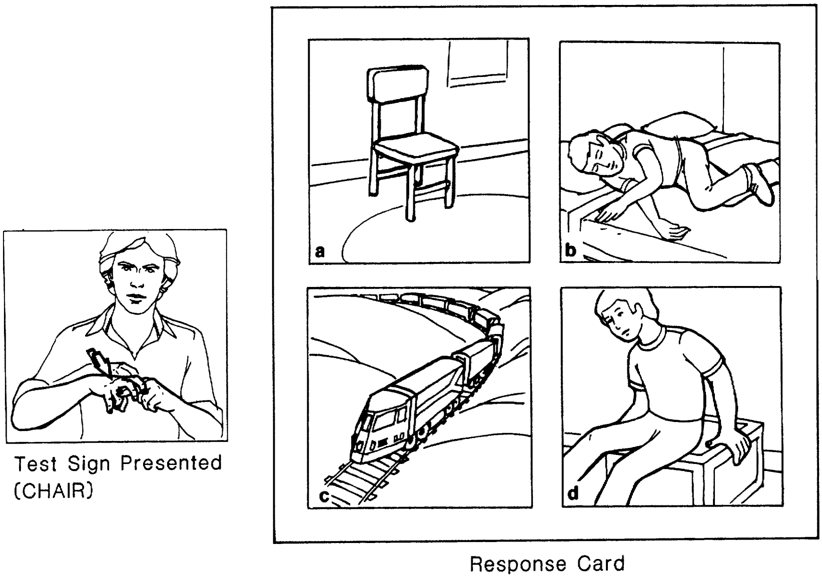



Figure 2.3
Test for processing ASL morphology: comprehension of the formal distinction between nouns and related verbs. The correct choice is (a). The sign for (d), SIT, is morphologically related to the sign CHAIR, differing only in features of movement (for example, repetition and restrained manner). The sign for (c), TRAIN, is a formationally related distractor.

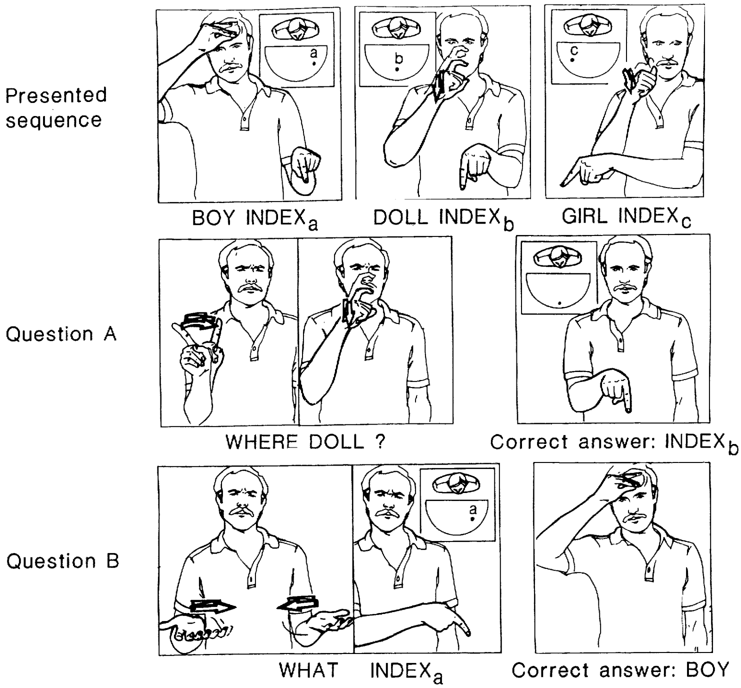
signing space. Noun phrase referents are assigned arbitrary places in space (their spatial loci); verb signs, for which these nominals function as arguments, move between spatial endpoints that correspond to the loci. The movement of the verb proceeds either from the locus of the subject to the locus of the object (for example, GIVE) or in the opposite direction (for example, INVITE), depending on the verb class. In discourse referent identity is maintained through consistent indexing to established referential loci in space. Index maintenance and shifting is grammatically determined. Sentence structure in ASL can therefore be specified by the way in which verbs, nominals, and pronominal indexes are related to one another in space. Spatial contrasts play a central role in specifying grammatical relations in ASL. The tests we have developed for the processing of such spatial mechanisms have been given to normal deaf adults and to deaf children of deaf parents as additional normative data to that obtained from the elderly deaf control subjects (Bellugi, in press; Lillo-Martin et al., "Acquisition," 1985).

The test for Nominal Establishment probes perception and memory for spatial loci associated with specific nominals. The examiner signs a test item and asks two kinds of question (figure 2.4): (A) where a certain nominal has been established (to which the subject answers by pointing to a specific locus in signing space), and (B) what nominal has been established at a certain locus (which the subject answers by signing the nominal). Half of this test has two nominals on each list, and the other half has three. In associating loci with their nominal reference, this test assesses perception and memory for the assignment of loci to their nominal reference, a key aspect of coreference structure in ASL syntax and discourse. The graph in figure 2.4 presents results of testing young deaf children of deaf parents on the Nominal Establishment Test. As the figure shows, children of 2 years of age are unable to handle the test. When asked question A, for example, they look around the room for the real objects; they are unable to answer question B at all. By age 3, however, young deaf children can perform well the task of comprehending the association of nouns with arbitrary spatial loci.

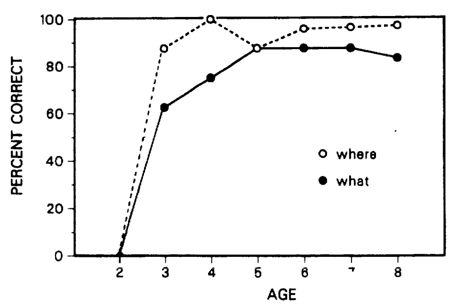
There are two tests for verb agreement; they investigate the memory and processing of verb agreement markers in ASL. In the Verb Agreement with Fixed Framework test the experimenter signs a sentence describing an event with two participants, either of which semantically could be the subject or the object of the verb. Figure 2.5 shows two sample items selected from the test (presented at different times in the test administration), one of which shows a picture of a cat biting a dog and the other of a dog biting a cat. Sentence A, for example, is notated as DOG $\text{INDEX}_a$ CAT $\text{INDEX}_b$ $_a\text{BITE}_b$; for example, 'The dog bit the cat.' Note that the same signs presented in the same order but with different spatial endpoints of the verb (sentence B) means 'The cat bit the dog.' The spatial pronominal indexes and order of signs are maintained; thus the movement of the verb between spatial points is the only indicator of grammatical relations. The subject's task is to point to the picture described by the examiner's sentence.

A correct response involves processing and remembering the nominals and their associated spatial loci as well as the direction of movement of the verb between the spatial loci. Furthermore, so that subjects cannot use surface cues and therefore must grammatically decode the sentence, the spatial arrangement of items in the picture does not necessarily match the spatial arrangement set up in the experimenter's sentence.

The second test, Verb Agreement with Shifting Reference, again involves describing events with two participants, either of which semantically could be the subject or object of the verb, for example, the




a




b

Figure 2.4
Association of nominals with spatial loci. (a) Two sample items from the Nominal Establishment Test in which three nouns, BOY, DOLL, and GIRL, are established at different points in signing space. In question A the experimenter asks for the locus of a specific noun sign. In question B the experimenter asks the subject to name the noun associated with a particular locus. (b) Results of the Nominal Establishment Test for sixty-eight young deaf children of deaf parents.

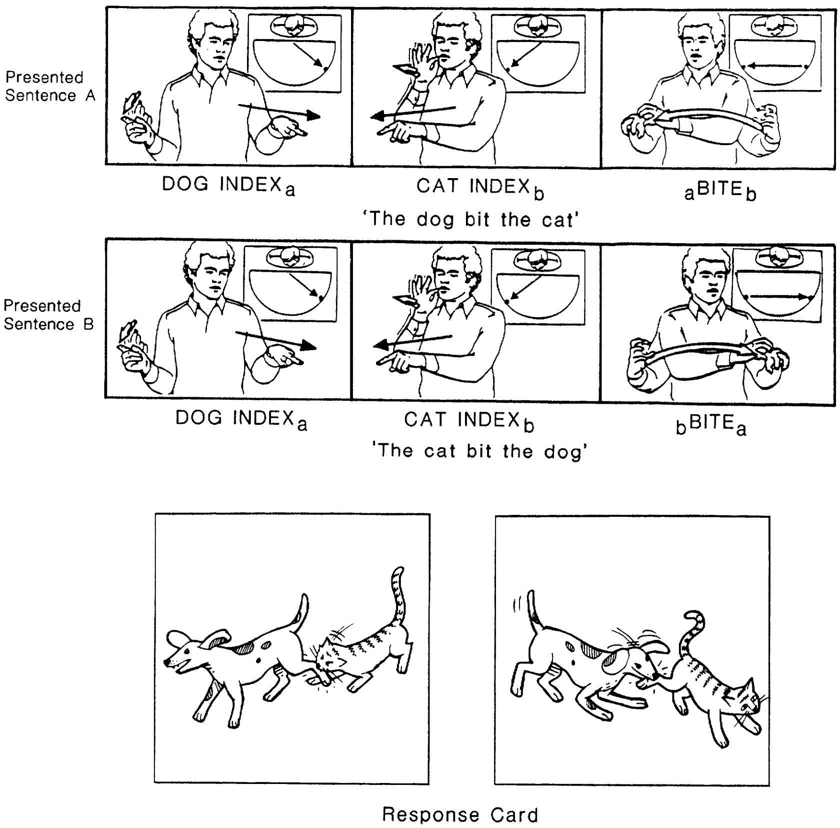



Figure 2.5
Verb Agreement with Fixed Framework to test spatialized syntax. Grammatical relations are signaled by the spatial endpoints of the verb. We show here two sample items from the test and the corresponding response-choice card. The subject is asked to select the picture on the card that corresponds to the sentence signed. Note that the spatial arrangement of the nouns in the sentence need not match the spatial arrangement of the objects in the picture.

verb HIT and the two arguments BOY and GIRL. In this test the experimenter first signs a sentence involving nominals, each with an associated spatial pronominal index and an action verb whose spatial endpoints mark subject and object by means of the associated spatial loci, as in

(2.1) GIRL $INDEX_a$, BOY $INDEX_b$, $_aHIT_b$.
'The girl hit the boy.'

(2.2) GIRL $INDEX_a$, BOY $INDEX_b$, $_bHIT_a$.
'The boy hit the girl.'

The experimenter then asks the subject two questions in random order about the sentence (figure 2.6). These questions are equivalent to asking: (A) Who was the recipient of the action (that is, who got hit)? and (B) Who was the agent of the action (that is, who did the hitting)? Note that the only difference in form between sentence (2.1) and sentence (2.2), which differs from it in meaning, is in the movement of the verb between the spatial loci established for the nominals. In ASL answers to such questions involve the processing of nominals, the loci associated with them, and the direction of movement of the verb between spatial endpoints. In addition, the test question requires processing a shift of spatial reference, because there is no identity between the spatial loci of the presented sentence with those of the test question.

The tests for processing spatial syntax and coreference in ASL, the Verb Agreement Tests, thus require not only intact syntactic processing but also the intact spatial cognitive abilities that underlie these linguistic functions. Such spatial cognitive functions include perception and memory for spatial locations, for spatial relations, and for higher-order spatial transformations.

*Linguistic Analysis*

One of the main methods we used to analyze language capacity is the in-depth analysis of language samples of brain-damaged signers. Up to now, with almost no exceptions, previous studies of brain-damaged signers have not analyzed signing in terms of breakdown within the individual structural levels of the sign language.

We have used several sources of data for analyzing free conversation in brain-damaged signers: free interchange, eliciting commonly known stories or having patients retell stories from brief videotaped versions or from stories from books without words, having patients describe their apartments or rooms, and eliciting anaphoric reference in ASL. From this language material we have performed a detailed analysis of language capacity, language use, and language break-

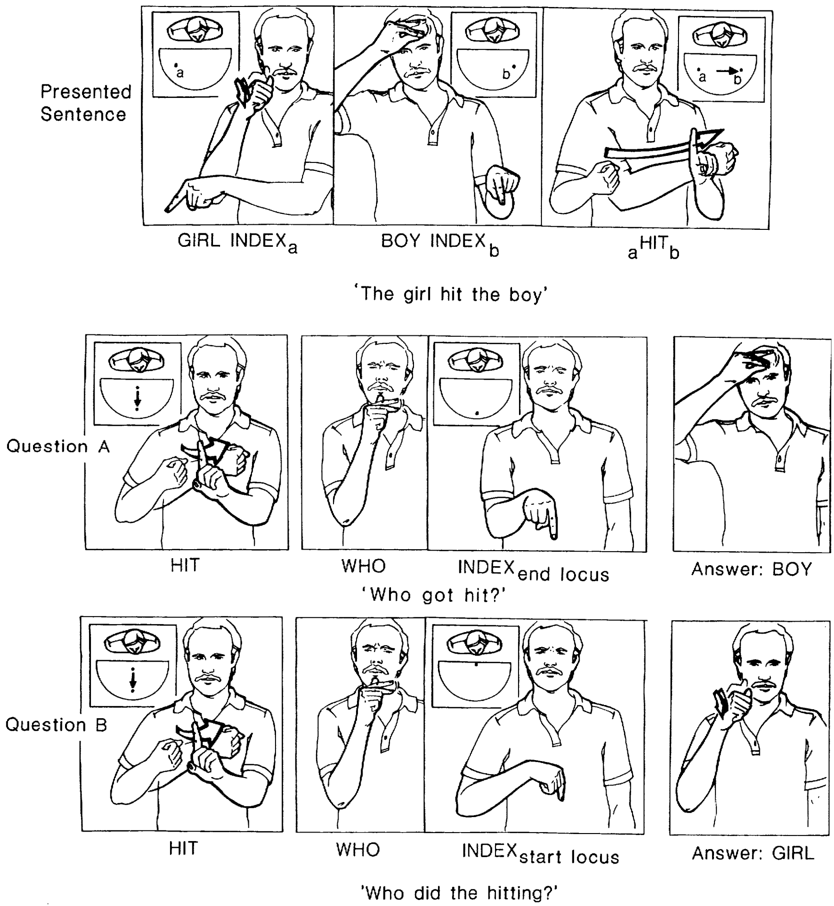



Figure 2.6
Verb Agreement with Shifting Reference to test spatialized syntax. We give a sample test sentence and two questions together with their appropriate responses. Note that the questions involve a shift in the spatial frame of reference relative to the test sentence.

down. We have used the array of techniques at our disposal to understand language structure, function, and breakdown.

### 2.3.3 *Apraxia Tests*

In order to investigate apraxias and their possible relation to sign aphasias we administered the following tests, which examine nonrepresentational movements (the Kimura Movement Copying Test), representational movements (ideomotor apraxia tests of the BDAE), and pantomime recognition.

We administered a slightly abbreviated form of the Kimura and Archibald Movement Copying Test (Kimura 1982). In this test of nonrepresentational movement, the subject imitates unfamiliar, meaningless sequences of hand and arm movements.

For symbolic (that is, representational) movements we used the ideomotor apraxia tests of the BDAE, adapted for signers. As in the BDAE our adaptation divides tests of apraxia into three sections: buccofacial movements, intransitive limb movements (for example, "Wave goodbye"), and transitive limb movements (for example, "Throw a ball"). When subjects are unable to carry out a commanded movement ("Show me how you would . . ."), the examiner demonstrates the movement and asks the subject to copy it.

Varney and Benton's (1978) Pantomime Recognition Test was used to assess the ability of our patients to understand meaningful nonlinguistic gestural communication. The test consists of a series of videotapes of a person miming the use of common objects, such as a spoon, pen, or saw. The patient must point to a drawing depicting the object pantomimed from a test booklet containing four response choices per item.

These issues are developed further in chapter 6.

### 2.3.4 *Nonlanguage Visual Processing Tests*

We selected the following tests, which maximally distinguish the performance of right- from left-brain-damaged hearing individuals: visuoconstructive tests, visuoperceptual tasks, and visuospatial tasks. Again, our questions deal with the possible special interactions between the use of a visuospatial language and the processing of nonlanguage spatial relations.

*Visuoconstructive Tests*

In all four of the tests described in what follows (WAIS-R block design, drawing without a model, drawing to copy, and Rey-Osterreith complex figure), hearing patients with right-hemisphere damage are more severely impaired than patients with left-hemisphere damage and show different types of error.

The *block design* subtest of the Wechsler Adult Intelligence Scale (WAIS-R) has proved to be a sensitive means of distinguishing left- from right-brain damage in hearing patients. The subject assembles four or nine three-dimensional blocks with red, white, or half-red and half-white surfaces to match a two-dimensional model of the top surface. In the *drawing without a model* test, the patient draws from memory a clock with numbers and two hands, a daisy, an elephant, a box with three sides visible, and the front and sides of a house (Boston Diagnostic Aphasia Examination, Goodglass and Kaplan 1972). In the *drawing to copy* test the patient copies pictures of a daisy, an elephant, a cross, a box, and a house from models. And finally, in the *Rey-Osterreith complex figure* test the patient copies a drawing of the Rey-Osterreith complex figure (Osterreith 1944), a figure with much internal complexity.

*Visuoperceptual Task: Benton Facial Recognition*

In hearing people it is mainly the right hemisphere that mediates the discrimination of unfamiliar faces (Benton 1980; Rizzolati, Umilta, and Berlucchi 1971). There are several parts in the test of facial recognition (Benton et al. 1978). In one part the patient matches identical front-view photographs. The subject is shown one photograph of a face and an array of six different front-view photographs below it; the patient must pick the one of the six photographs that is the same as the sample. In the second part of the test the patient matches a front-view photograph with three-quarter-view photographs. He or she picks the three three-quarter-view faces that match from an array of six. In the third part the patient matches front-view photographs taken under different lighting conditions.

*Visuospatial Tasks: Hemispatial Neglect and Line Orientation*

Certain patients, primarily those with right-hemisphere lesions, have attentional deficits that result in their neglecting one half of the surrounding world, so-called hemispatial neglect. This neglect can extend to patients' ignoring one half of their own bodies. We use two tests of hemispatial neglect. In one test the patient marks the apparent midpoints of horizontal lines of different length. Patients with hemispatial neglect tend to put the mark off center, away from the neglected side, as if they were bisecting just the portion of the "unneglected" line (Benton 1979). In the second test, Albert's (1973) test of hemispatial neglect, the patient crosses out forty lines arranged pseudorandomly on a page. Patients with neglect tend to omit lines on the neglected side.

The perceptual capacity to judge the spatial orientation of lines is primarily mediated by the right hemisphere in hearing individuals. In the Benton Judgment of Line Orientation test, the patient matches the angular orientation of a pair of lines to a response-choice display of eleven lines. Five practice items consist of pairs of lines from the response-choice display that are shown in full length. The thirty test items consist of pairs of lines of partial length. Each partial line of the pair corresponds to the orientation of one of the lines appearing in the response-choice display below it. The partial lines represent either the upper, middle, or lower segments of the response-choice lines. The subject responds by pointing to or giving the numbers of the appropriate response-choice lines.

## 2.4 *Summary Characteristics of Patients*

The program of study just outlined is designed to investigate the effects of either left-hemisphere damage or right-hemisphere damage in deaf signers. All tests were administered entirely in ASL by deaf researchers from our laboratory. We videotaped all sessions for later analysis. We generally tested patients well after their cerebral injuries, so the deficits we encountered are likely to be stable ones. Testing requires several sessions, and with some patients we have been able to perform the entire battery more than once, although there are occasional gaps in our data. Because brain-damaged deaf signers are so rare, the patients we studied are scattered across the country. In selecting subjects, we studied only patients who were right-handed before their cerebral injury and who have unilateral damage. (Damage is assessed by CT scans whenever possible.) Subjects are preferentially prelingually deaf, have been signing throughout their lives, have deaf spouses, and are members of the deaf community.

In this book we report in depth on six deaf, brain-damaged signers, three with damage to the left cerebral hemisphere and three with damage to the right cerebral hemisphere. All were given the same range of tests, with occasional omissions. Furthermore, the entire battery was administered to matched deaf controls. (In chapter 8 we also provide results from some other cases of signers with right- or left-hemisphere damage to provide converging evidence for our first findings.)

Table 2.1 presents a summary of the characteristics of the six deaf signers who form the focus of this book. In order to protect the anonymity of the patients, we do not use their real names or initials,

Table 2.1
Summary characteristics of three left-lesioned and three right-lesioned deaf signers

| | | | | | Language environment | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Patient | Age at testing | Sex | Age at onset of deafness | Handedness | Parents and siblings | School | Spouse | Cultural group | Primary communication | Hemiplegia | Lesion |
| **Left-hemisphere-damaged signers** | | | | | | | | | | | |
| Paul D. | 81 | M | 5 yrs. | Right | Hearing | Residential deaf | Deaf | Deaf | Sign | — | Left subcortical; deep to Broca's area extending posteriorly beneath parietal lobe. |
| Karen L. | 67 | F | 6 mos. | Right | Hearing | Residential deaf | Hard of hearing | Deaf | Sign | Right hemiplegic | Left parietal; supramarginal and angular gyri; extending subcortically into middle frontal gyrus. |
| Gail D. | 38 | F | Birth | Right | Older deaf siblings | Residential deaf | Deaf | Deaf | Sign | Right hemiplegic | Most of convexity of left frontal lobe; Broca's area damaged. |
| **Right-hemisphere-damaged signers** | | | | | | | | | | | |
| Brenda I. | 75 | F | Birth | Right | Hearing | Residential deaf | Deaf | Deaf | Sign | Left hemiplegic | Right hemisphere |
| Sarah M. | 71 | F | Birth | Right | Hearing | Residential deaf | Deaf | Deaf | Sign | Left hemiplegic | Right temporoparietal area; most of territory of right middle cerebral artery damaged |
| Gilbert G. | 81 | M | 5 yrs. | Right | Hearing | Residential deaf | Deaf | Deaf | Sign | — | Right superior temporal and middle temporal gyri extending into the angular gyrus. |

and we have changed identifying information, including appearance, in the illustrations. As table 2.1 shows, all the patients were right-handed before their brain damage; all received their entire education at residential schools for the deaf; all had deaf or hard-of-hearing spouses; all used sign language as a primary mode of communication with family and friends throughout all or most of their lives; and all were culturally members of deaf communities.

We first present individual case studies of the three left-lesioned signers, focusing on their language functioning in chapter 3. In chapter 4 we compare visuospatial language capacities across the three deaf signers and present results from the formal language testing. In chapter 5 we present case studies of the three right-hemisphere-damaged signers and contrast the effects of left- and right-hemisphere damage on sign language functioning. In chapter 6 we examine the relationship between apraxia and aphasia for sign language, and in chapter 7 we address the effects of left- and right-hemisphere damage on nonlanguage visuospatial capacities. Finally, in chapter 8 we provide results from a larger group of brain-damaged subjects and address broader questions about what the hands reveal about the brain.