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Proceedings of a Conference in Honor of Alvin M. Liberman.
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Chapter 7

Brain Function for Language: Perspectives from Another Modality

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Abstract

The left cerebral hemisphere provides the neural substrate for language in hearing-speaking individuals. The underlying basis of the specialization of the left hemisphere for language, however, has not been clearly understood. The study of sign languages of deaf individuals provides a unique opportunity for investigating brain function for language, because sign language displays complex linguistic structures by manipulating spatial relations. It, thus, exhibits properties for which each of the hemispheres of hearing individuals shows a differing specialization. Understanding brain organization for sign languages is allowing us to uncover basic principles underlying hemispheric specialization.

We have been investigating the language, visual-spatial, and motor abilities of profoundly deaf signers who have acquired lesions of either the left or the right cerebral hemisphere. Remarkably, the signers with right hemisphere lesions were not aphasic for sign language. This preserved signing stood in the face of marked deficits the right-hemisphere damaged signers showed in processing nonlanguage spatial relations. In contrast, the signers with left-hemisphere damage showed frank sign language aphasias (and relatively preserved nonlanguage spatial functions). Importantly, the sign language impairments were not uniform, but rather cleaved along lines of linguistically relevant components. Taken together, the data indicate that the left hemisphere has an innate predisposition for language.

Furthermore, the underlying basis of the specialization of the left hemisphere for language seems related to linguistic functions and the processing operations required, rather than to properties of the signal itself.

Al Liberman has pioneered investigations into many areas central to the relation of brain, mind, and language. Liberman's elegant experiments on the acoustic and physiological basis for speech perception, on the grammars of speech and language, and on the specializations of the human brain have provided challenges and inspiration for all interested in language and brain function (Liberman, 1974, 1979, 1982; Liberman & Mattingly, 1985; Mattingly & Liberman, 1988). Our own research has benefited greatly from his insightful thinking and clear focus on the biological foundations of language, for this is a topic which we too have pursued, but from the particular perspective of signed languages of the deaf.[1]

Over the past several years, we have been investigating the functional organization of the brain for language across language modalities. We are naturally led to the study of visual-gestural languages, because they present a truly unusual opportunity to delve into the human capacity for language and to uncover for language in general how the brain is organized for language, how modifiable that organization is, and how that organization develops. There clearly has been an evolution of language in conjunction with speech. The shape of the vocal tract and mechanisms of breath control have changed from nonhuman primates to man, shaping the vocal apparatus into a more efficient transmission system for the production of a variety of sounds (Lenneberg, 1967; Lieberman, 1975). Furthermore, no known hearing society has a sign language as a primary mode of communication, and there exists a tight neurological linkage between the primary language mediating areas of the brain and the speech channel. These facts make remarkable the discoveries that there exist natural, fully developed, autonomous sign languages that show the kinds of complexities of linguistic structure found in spoken languages (Bellugi, 1988; Klima & Bellugi, 1979; Lane & Grosjean, 1980; Liddell, 1980; Studdert-Kennedy & Lane, 1980; Wilbur, 1987). American Sign Language (ASL) is one of those autonomous linguistic systems.

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[1] Notational conventions used in this paper: Words in capital letters, e.g., SIGN represent English glosses for ASL signs. The gloss represents the meaning of the unmarked, unmodulated, basic form of a sign out of context. Morphological processes may be indicated by the specification of grammatical category of change or by the meaning of the inflected form: GIVE$^{[\text{Exhaustive}]}$ or GIVE$^{[\text{`to each'}]}$. As part of the spatialized syntax of ASL, a horizontal plane in signing space is used for abstract spatial loci. Nouns, indexible verbs, pronouns, classifiers, size and shape specifiers can be associated with abstract spatial loci, and these are indicated by subscripts. Subscripts from the beginning of the alphabet are used to indicate spatial loci. Nouns, pronouns, and verbs of location are marked with a subscript to indicate the locus at which they are signed (INDEX$_a$, BOY$_a$, AT–X$_a$) in planes of signing space. Inflected verbs are marked with an initial subscript to mark origin location and/or a final subscript indicate the endpoint location ($_a$GIVE$_b$). Subscripts from the middle of the alphabet are used to indicate abstract indices; reference as well as coreference, (e.g., $_i$SIGN$_j$).

Language in the Visuospatial Modality

ASL has been forged into an autonomous language with its own internal mechanisms for relating visual form with meaning. Like spoken languages, ASL exhibits formal structuring at two distinct levels, one involving internal structure to the lexical units and a second involving rules governing the relations between signs in sentences. The structure of ASL is likewise similar to that of spoken languages in terms of hierarchically organized rules, rules based on underlying forms, and recursive grammatical processes. ASL has evolved linguistic mechanisms that are not derived from those of English (or any spoken language), thus offering a new perspective on the determinants of language form. We have been specifying the extent to which the formal properties of languages are shaped by the modalities involved in their perception and production and have found that for the form of its grammatical devices, the modality in which a language develops makes a crucial difference.

The use of space is a unique resource afforded by the modality of signed languages. The inflectional and derivational devices of ASL, for example, make structured use of space and movement, nesting the basic sign stem in spatial patterns and complex dynamic contours of movement (Bellugi, Klima & Poizner, 1988). In ASL grammatical morphology, root, derivational patterns and inflectional patterns co-occur as layered in the final surface form, and forms can be spatially nested within one another (see Fig. 7.1a). Furthermore, many syntactic functions fulfilled in spoken languages by word order or case marking are expressed in ASL by essentially spatial mechanisms (see Fig. 7.1b). For example, nominals introduced into ASL discourse may be assigned to arbitrary loci in a plane of signing space. A pronominal sign directed to a specific locus clearly refers back to the previously mentioned nominal, even with many other signs intervening. The ASL system of verb agreement is also essentially spatialized. Verb signs for a large class of verbs move between the abstract loci in signing space, bearing obligatory markers for person (and number) via spatial indices, thereby specifying subject and object. This spatialized system, thus, allows explicit reference through pronominals and agreement markers to multiple distinct third-person referents (Lillo-Martin & Klima, in press). The use of spatial loci for referential indexing, verb agreement, and complex embedded structures is clearly a unique property of visual-gestural systems. ASL is, thus, markedly different in surface form from English and from spoken languages in general. Although ASL is the most thoroughly analyzed of the signed languages of the world to date, other signed languages examined suggest that these characteristics

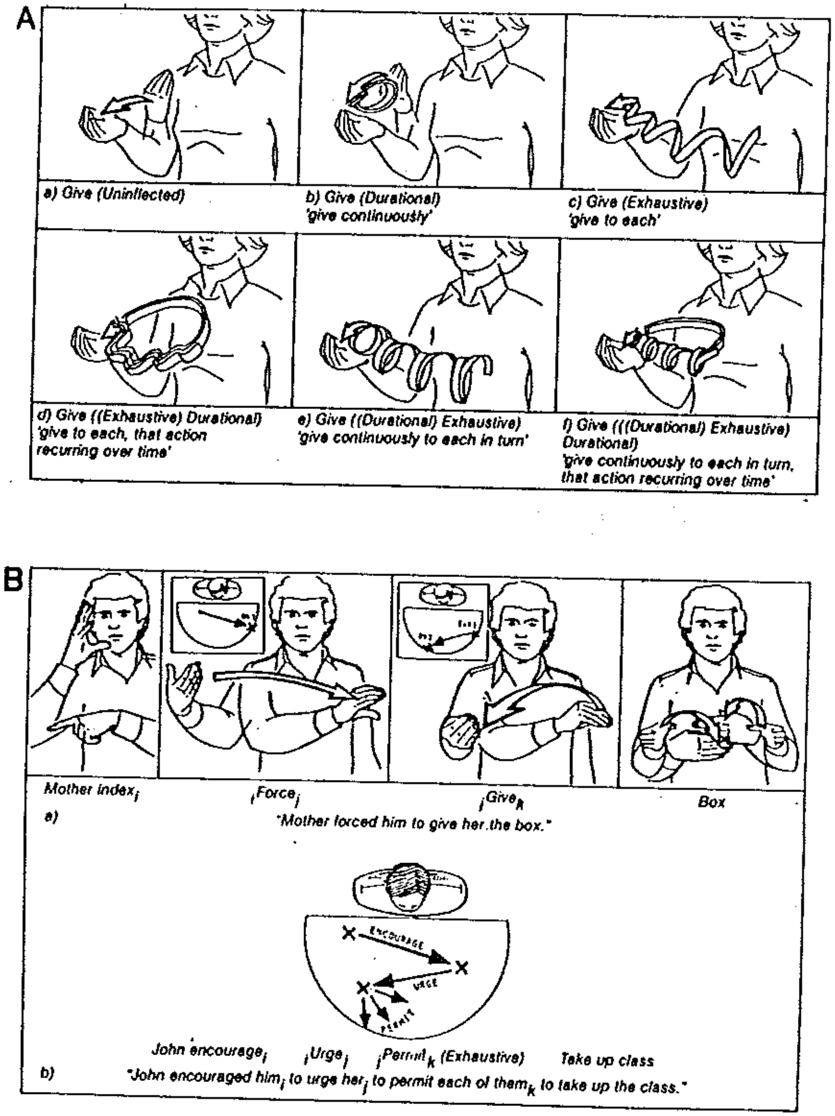


FIG. 7.1. Grammatical Processes in ASL.
(a) Recursive nesting of morphological processes.
(b) Syntactic spatial mechanisms.

may turn out to be general characteristics of primary signed languages (Fok, Bellugi, van Hoek, & Klima, 1988).

Three-Dimensional Computer Graphics and Linguistic Analysis

In many ways, the transmission system of sign languages (visual-gestural) is radically different from that of speech and offers remarkably different possibilities and constraints. In our studies, we take advantage of a basic difference between the signal properties of sign and speech. In sign languages, unlike spoken language, the movements of the articulators are directly observable and are, thus, susceptible to noninvasive measurement. To investigate the nature of grammatical processes in ASL, we have developed new systems that allow the realtime, three-dimensional tracking and computergraphic analysis of hand and arm movements (Poizner, Wooten, & Salot, 1986; Poizner, Klima, Bellugi, & Livingston, 1986; Jennings & Poizner, 1988). Two optoelectronic cameras directly sense the positions of infra-red emitting diodes that are attached to the hands and arms (see Fig. 7.2). A microcomputer synchronizes the sequential flashing of the diodes with the digitizing of the camera signals. The three-dimensional coordinates are then computed from the two sets of camera data. Finally, the movement is reconstructed in three dimensions on a computergraphic system for interactive analysis. Figure 7.3 presents three-dimensional reconstructions of the sequence of hand and arm positions for three grammatically inflected ASL signs.

Figure 7.3 illustrates the structured use of spatial contrasts within ASL's rich morphological system. The Apportionative Internal inflection contrasts minimally with the Seriated Internal inflection in trajectory shape: The former inflection is made with a circular path shape in the vertical plane of signing space, whereas the latter inflection is made with a linear path shape (these inflections and the Seriated External inflection convey different class membership distinctions, as described in Klima & Bellugi, 1979). The Seriated Internal inflection, however, contrasts minimally with the Seriated External inflection, not in trajectory shape but in planar locus. Variation in planar locus for a variety of ASL inflections for temporal aspect, number, and distributional aspect are presented in Fig. 7.4. These movements were digitized and the best fitting plane of the hand motion computed. Figure 7.4 shows several groupings of movements. Movements conveying temporal aspect distinctions (points H, J, and K) are grouped together in a sagittal plane, whereas those for number and distributional aspect (points A, B, C, D, E, and L) cluster in either the horizontal or vertical plane relative to the body. These clusterings based on the spatial properties of the movements markedly correspond to the independent linguistic classifications of these forms (Poizner, 1983).

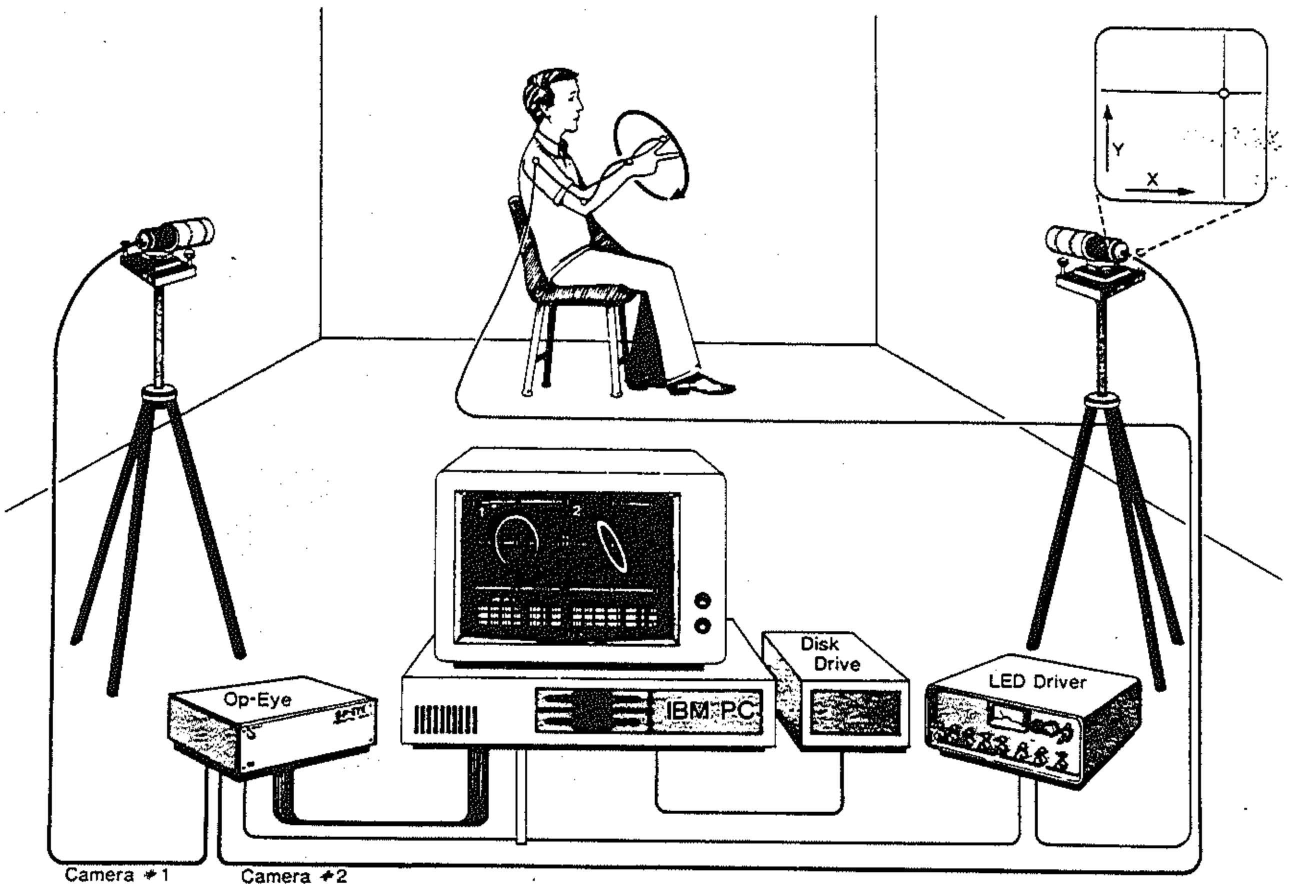


FIG. 7.2. Three-dimensional movement monitoring system. The main hardware components and the positioning of LED's on a subject are shown.

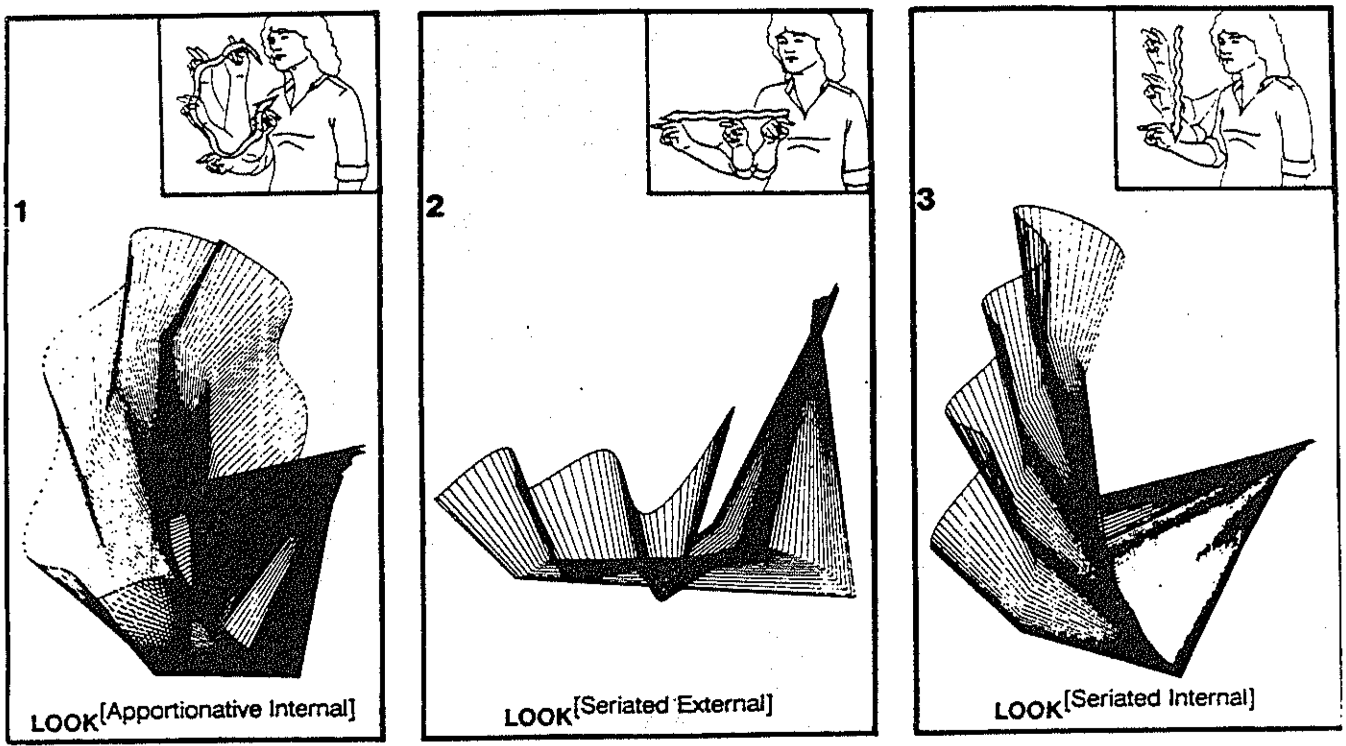


FIG. 7.3. Three-dimensional computergraphic reconstructions of the sequence of arm positions for three grammatically inflected ASL signs.

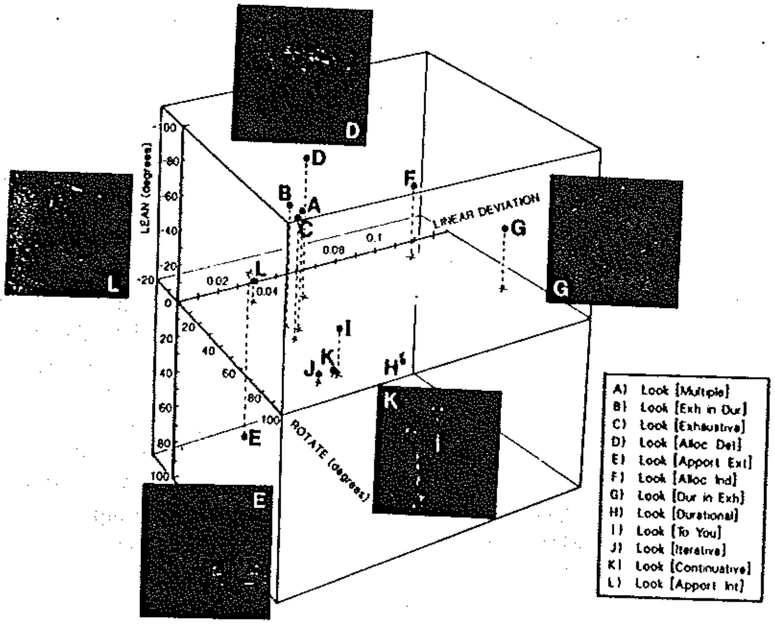
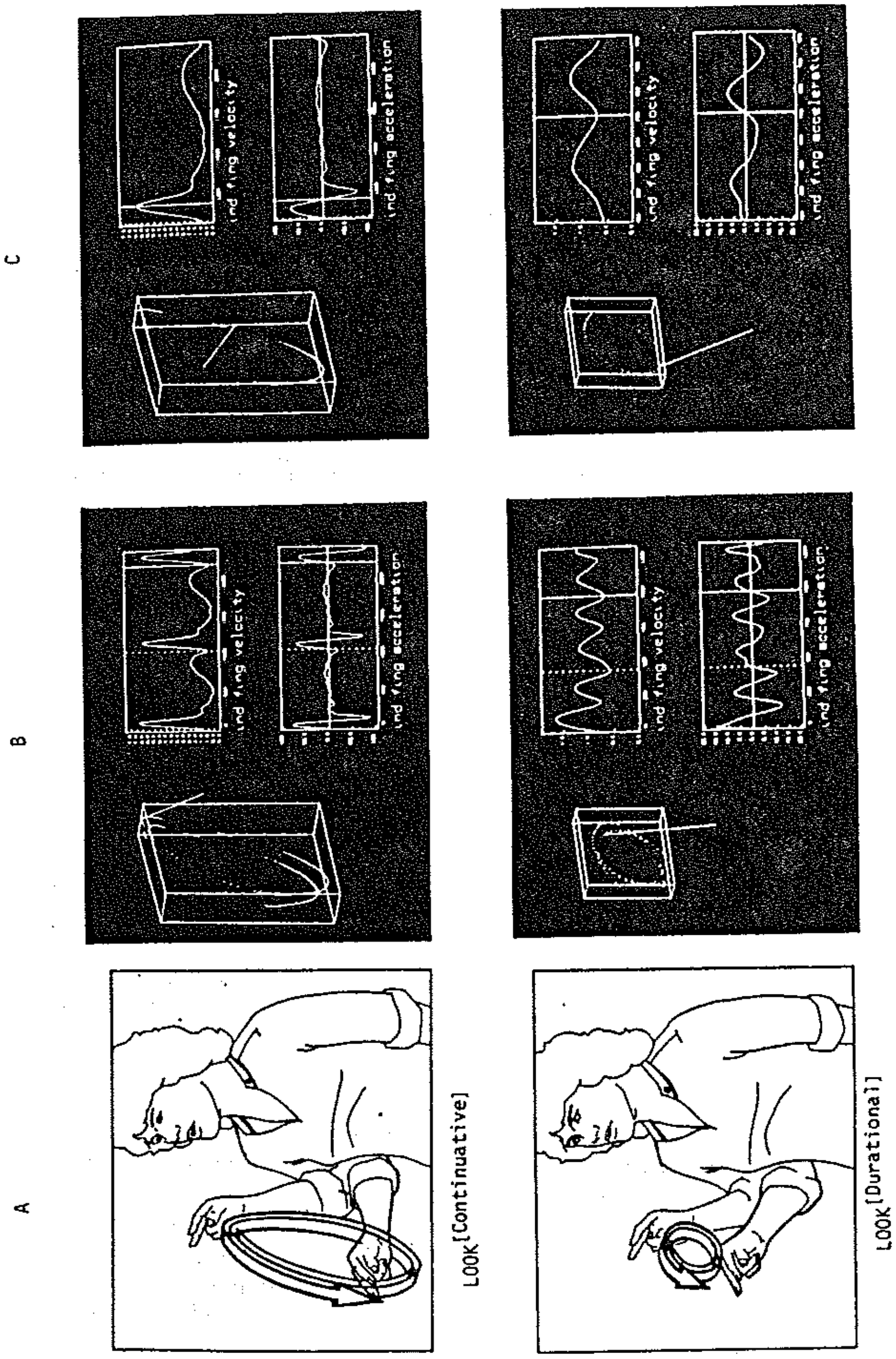


FIG. 7.4. Three-dimensional visual-phonetic analysis of the linguistic dimension Planar Locus. The two axes Lean and Rotate provide two angles (elevation and azimuth) that specify the particular plane of motion of the hand. The third axis, Linear Deviation, specifies how planar a motion was.

Thus, such spatial contrasts as trajectory shape and planar locus are key formational building blocks of ASL's morphology. Furthermore, as stated previously, space in ASL is actively manipulated for syntax and discourse. Nominals are assigned spatial loci in the horizontal plane of signing space, pronoun signs are directed toward those loci, and verb signs move among the spatial loci to convey grammatical subject and object. Because the left cerebral hemisphere in man has been considered specialized for linguistic functions, and the right, for visuospatial functions, ASL exhibits properties for which each of the hemispheres of hearing people shows a differing specialization.

FIG. 7.5. Three-dimensional reconstructions of two ASL inflections.
(a) Line drawings.
(b) The entire reconstructed movement of the hands with time pointers 'windowing' one movement cycle.
(c) Characteristics of one movement cycle. Tangential velocity is given in meters per second and acceleration in meters per second.[2]



The Nature of Hemispheric Specialization

Understanding how sign language is represented in the brain should allow us to uncover the basic principles underlying hemispheric specialization. In the first place, such data will allow us to test alternate theories of the nature of hemispheric specialization. The left cerebral hemisphere is closely connected with speech. A neuroanatomical difference between the hemispheres is in the planum temporale—a portion of *auditory* association cortex known to mediate language—which is, even at birth, larger in the left hemisphere than in the right. The finer auditory analysis that this area may allow has been suggested as a possible underlying basis for the left hemisphere's specialization for language. A related theory links the fact that the left hemisphere is specialized not only for language but also for rapid temporal analysis, which speech strongly requires. In this view, the left hemisphere's specialization for language is a secondary consequence of its more primary specialization for rapid temporal analysis. However, as we have seen, sign language relies heavily on spatial contrasts rather than on temporal contrasts. Furthermore, the temporal contrasts that do occur in ASL do not require the same degree of rapid temporal analysis as those of speech.

Figure 7.5 presents computer-graphic reconstructions for two grammatical inflections in ASL, the Continuative and Durational, which are minimally contrasted by their temporal qualities and serve to elucidate a difference in timing between signed and spoken language. The Continuative inflection, meaning "action for a long time," is made with a tense, rapid outward movement with an elliptical slow return to the starting point. The Durational inflection, meaning "continuous action," is made with a smooth, circular, even movement that is repeated. The panels of Fig. 7.5 present for each inflection the reconstructed movement of the hand along with the associated velocity and acceleration profiles both for the entire movement and for a single movement cycle. We find that the temporal contrasts underlying these inflections, as well as those for ASL in general, are typically stretched over much longer intervals than those found in speech. Sign language simply does not use the extremely rapid 40–50 msec temporal intervals found in spoken languages to contrast forms (Poizner, Klima, & Bellugi, 1987). Rather, temporal variation in sign language occurs over much longer intervals, and sign language heavily uses spatial contrasts. Thus, theories basing the specialization of the left hemisphere for language in all its aspects on superior capacities for auditory processing and rapid temporal analysis would not predict left hemisphere specialization for sign language. Sign language pits linguistic function against stimulus form in very strong way, because, in large part, it conveys grammatical relations through spatial relations.

Evidence from Brain-lesioned Signers

In a series of studies, we have been examining the effects of brain-damage on language and nonlanguage performance in deaf signers with left-hemisphere or

right-hemisphere damage. Our general program includes an array of probes: a) our adaptation, for ASL, of the Boston Diagnostic Aphasia Examination (BDAE) (Goodglass & Kaplan, 1983), b) linguistic tests we designed for processing the structural levels of ASL (sublexical, semantic, morphological, and syntactic), c) an analysis of production of ASL at all linguistic levels, and d) tests of nonlanguage spatial processing and motor control. The battery of language and nonlanguage tasks was administered to deaf brain-lesioned subjects and to matched deaf controls (Poizner et al., 1987; 1990; Bellugi et al., 1988; Klima, Bellugi, & Poizner, 1988; Poizner, Kaplan, Bellugi, & Padden, 1984; Poizner, Bellugi, & Iragui, 1984).

We report here on studies of six brain-lesioned signers: Three have left-hemisphere damage (Paul D., Gail D., and Karen L.); three have right-hemisphere damage (Brenda I., Sarah M., and Gilbert G.). All subjects were members of deaf communities, had been educated in residential schools for deaf

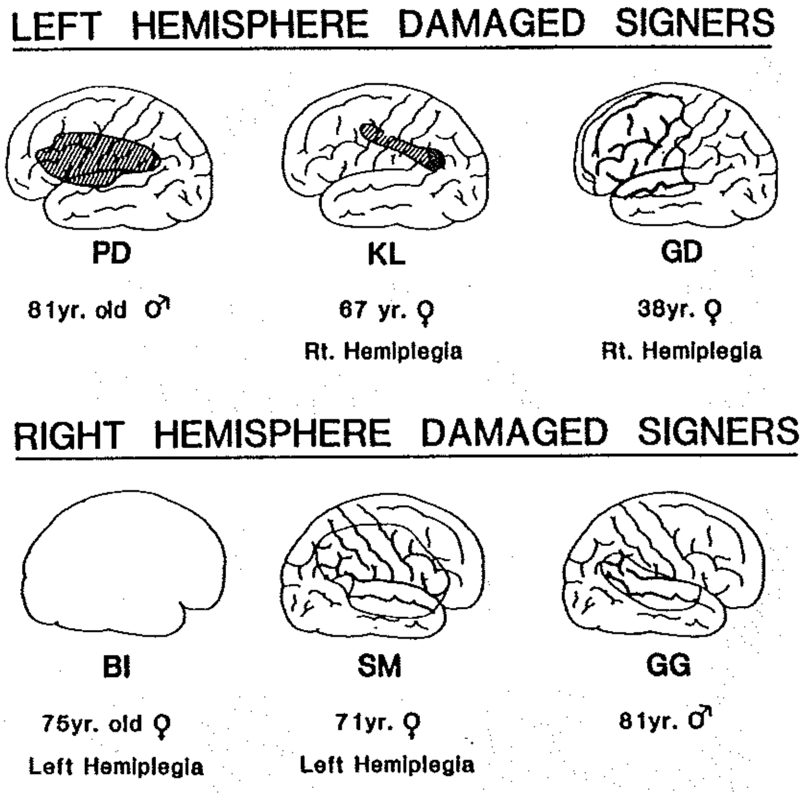


FIG. 7.6. Lateral reconstructions of brain lesions of the brain-damaged signers.

children, and had deaf or hard-of-hearing spouses. All were right-handed before their strokes. For each subject, the primary form of communication with family and friends was ASL.

Figure 7.6 presents lateral reconstructions of brain lesions and summary characteristics of the six deaf, brain-lesioned subjects. In brief, Paul D. has a subcortical lesion in his left hemisphere, with an anterior focus deep to Broca's area and including major portions of the basal ganglia. The lesion extends posteriorly into the white matter underlying the left supramarginal and, to a lesser extent, angular gyri. Gail D. has a large left-hemisphere lesion that involved most of the convexity of the frontal lobe, including Broca's area and the anterior portions of the superior and middle temporal gyri. This lesion is typical of those that produce agrammatic aphasia in hearing-speaking individuals. Finally, Karen L. has a circumscribed cortical lesion in the region of the left inferior parietal lobule that extended subcortically into the postcentral and precentral gyri, as well as into the posterior portion of the middle frontal gyrus. Both the traditional Broca's area and Wernicke's area were spared.

As for the right-lesioned signers, Sarah M. had a massive lesion involving most of the territory of the right middle cerebral artery. The lesion extends from the frontal operculum, the area of the right hemisphere homologous to Broca's area, involves premotor, motor, and somatosensory areas, to include the inferior parietal lobule, superior parietal lobule, and the middle and superior temporal gyri. Large critical areas of the right hemisphere were, thus, damaged. Gilbert G.'s lesion involves the cortex and underlying white matter in the superior temporal gyrus, extending inferiorly to partially involve the middle temporal gyrus. Posteriorly, the lesion extends into the lower portion of the inferior parietal lobule. Unfortunately, no CT scan was available for Brenda I., but, like Sarah M., she showed a dense paralysis of her left arm and hand (see Poizner et al., 1987 for more detailed neurological information on the six signers).

Preserved Language in Right-lesioned Signers

Quite remarkably, the signers with right-hemisphere damage were not aphasic for sign language. They exhibited fluent, grammatical, virtually error-free signing. Figure 7.7 (top) shows the rating-scale profiles from the ASL adaptation of the BDAE for the three left-lesioned signers. The middle part of the figure presents the rating scale profiles of three matched deaf control subjects, showing normal performance. Performance of the right-lesioned signers is shown in the bottom

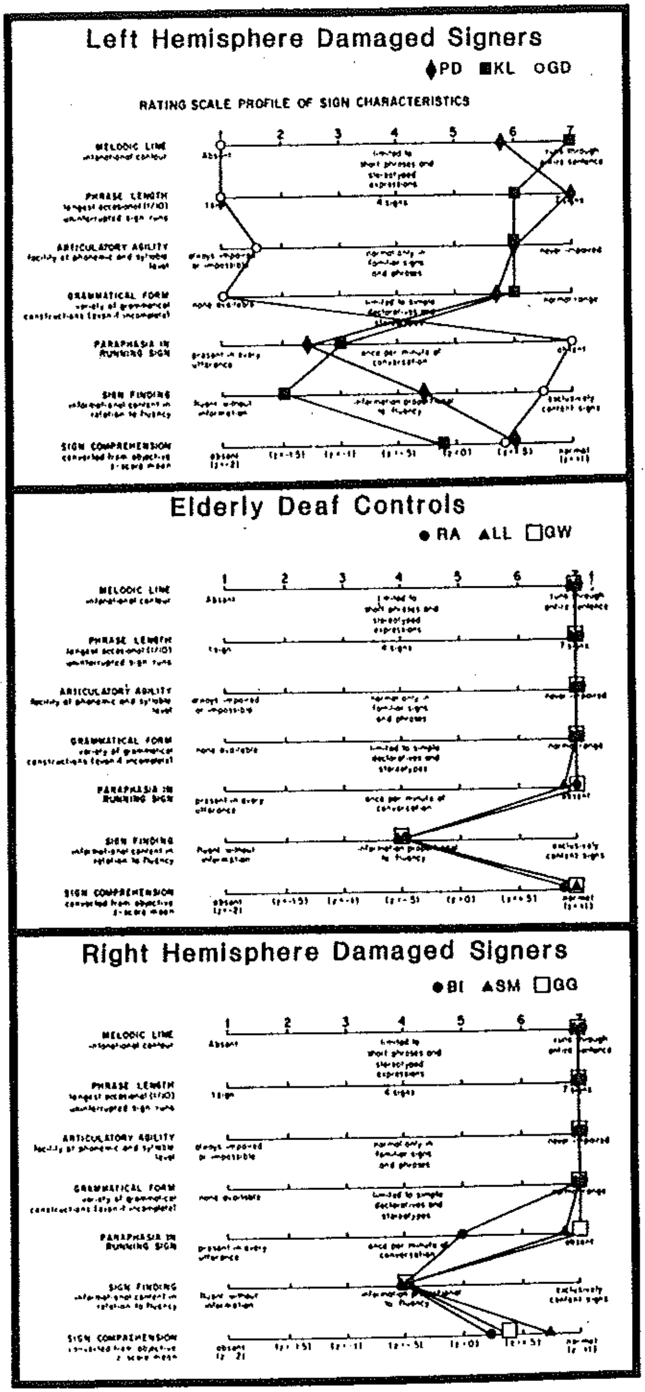


FIG. 7.7. Rating scale profiles form the ASL adaptation of the Boston Diagnostic Aphasia Examination for left- and right-lesioned signers and controls. Note that performance of the right-lesioned signers is similar to that of the controls.

panel of the figure. The rating scale profiles of their sign characteristics, shown in the lower portion of the figure, reflect their grammatical (nonaphasic) signing; in fact, their profiles are much like those of the control subjects. Furthermore, the right-lesioned signers, but not those with left-hemisphere damage, were unimpaired on our tests for processing the various levels of structure of ASL.

Importantly, this preserved signing was in the face of marked deficits the right-hemisphere damaged signers showed in processing nonlanguage spatial relations. Across a range of tests, including drawing, block design, attention to visual space, perception of line orientation, facial recognition, and visual closure, right-lesioned signers showed many of the classic visuospatial impairments seen in hearing patients with right-hemisphere damage. In contrast, left-lesioned signers showed relatively preserved nonlanguage spatial functioning. Figure 7.8 presents example performance on a block design test in which subjects must assemble either four or nine three-dimensional blocks to match a two-dimensional model of the top surface. The left-hemisphere damaged signers (upper row) produced correct constructions on the simple block designs and made only featural errors on the more complex designs; in contrast, the right-hemisphere damaged signers (lower row) produced erratic and incorrect constructions and tended to break the overall configurations of the designs: The severe spatial disorganization of the constructions of the right-lesioned signers provides one reflection of their severe spatial loss. These nonlanguage data show that the right hemisphere in deaf signers can develop cerebral specialization for nonlanguage visuospatial functions (Poizner, Kaplan, et al., 1984). However, despite their nonlanguage spatial deficits, the sign language (including spatially expressed syntax) of the right-lesioned signers was unimpaired. The correct use of the spatial mechanisms for syntax in right-lesioned signers points to the abstract nature of these mechanisms in ASL.

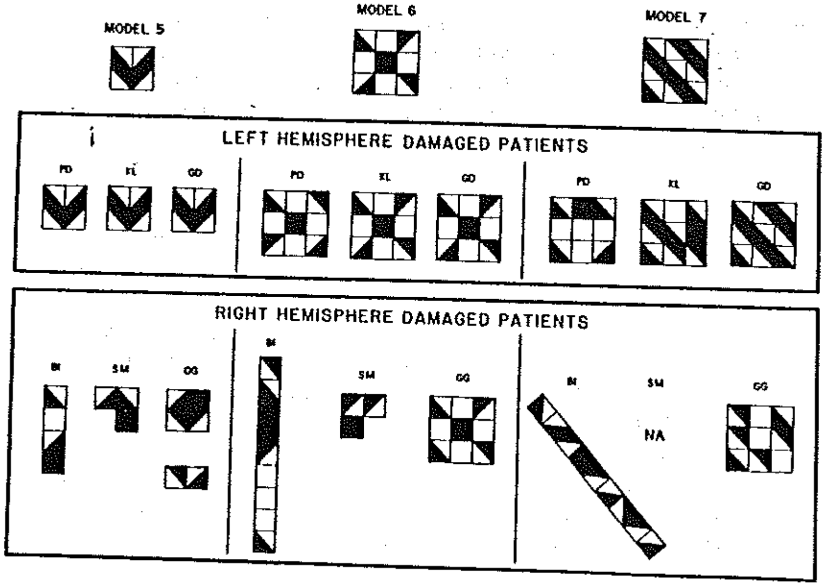


FIG. 7.8. Performance of left- and right-lesioned signers on the WAIS-R block design task, a nonlanguage visuospatial task. Note the broken configurations and severe spatial disorganization of the right-lesioned signers.

Sign Language Aphasias in Left-lesioned Signers

The three signers with left-hemisphere damage show clear sign language impairments, as indicated by their results on the sign language adaptation of the BDAE, on tests for processing the structural levels of ASL, and on a linguistic analysis of their signing. Figure 7.7 (middle) presents the rating scale profiles from the sign adaptation of the BDAE for the three left-lesioned signers, contrasted with right-lesioned signers and controls. On each scale, the scores of the left-lesioned signers are scattered, spanning virtually the entire range of values. These profiles reflect frank sign language aphasias. These aphasias contrast with the overall preserved nonlanguage spatial functions of the left-lesioned signers. Moreover, the sign language impairments are not uniform but rather diverge along lines of linguistically relevant components.

Gail D: Agrammatic Sign Aphasia

One left-lesioned signer, Gail D., is agrammatic for ASL. She is severely aphasic, with her signing faltering and often reduced to single-sign utterances. She uses hardly any indexic pronouns (the spatially indexed "pointing" sign forms that have pronominal function in ASL), and her verbs are without any spatial indices whatever. In fact, her signing is devoid of any of the syntactic and morphological marking required in ASL (i.e., her signing is what would be classified as *agrammatic* in speech-aphasics). Her language profile is very much like that of hearing patients classified as Broca's aphasics.

Gail D.'s description of the Cookie Theft picture from the BDAE (shown in Figure 7.9) is characteristic of her signing output and stands in marked contrast to the responses of the other two patients. Her complete description of the picture was the following:

> Gail D.: THREE...MOTHER...BROTHER...WHAT?...F-E-F-A-L-L...TURN-OFF.
> "Three...(Examiner prompts)...Mother...(E prompts)...Brother...(E prompts)... What?...(E prompts)...Fall...(E prompts)...Turn off."

Gail D.'s sparse description is not due to any reluctance to communicate on her part but to the extreme effort her signing seems to require; she is clearly frustrated in her attempts to communicate. She tried to produce not just signs but also gestures, mimes, fingerspelling, and the mouthing of English words: However, she is no better at producing these other means of communication than she is at signing. Gail D. can at times make single signs fluently and with little hesitation, for example, as single sign responses to comprehension tests. In expository conversation, however, she experiences great difficulty in expression. Her narratives are severely limited, effortfully produced, and without any of the grammatical apparatus of ASL.

The most salient characteristic of Gail D.'s signing is that it is agrammatic and effortful, composed of short utterances that consist largely of single, open-class items. She omits all grammatical formatives, including most pronouns, all inflectional and derivational processes, and all aspects of spatially organized syntax. Importantly, this nearly complete absence in Gail D.'s signing of any of ASL's inflectional morphology occurred, even although such inflectional morphology is not conveyed "horizontally" through a linear sequence of units, but rather "vertically" through the layering of form components. Gail G. was able to concatenate gestures, but few of her multisign utterances give any indication of having a sentence structure, whereby the meaning of the sentence as a whole is derived in a principled way from the meanings of the parts and their function in the sentence. Gail D.'s utterances lack any hierarchical combination of separate meaningful components. Thus, the basis for such combination, whether it is linear, as in many spoken languages, or layered, as in ASL, does not seem to be a crucial factor. Gail D.'s case shows the devastating effect that left-hemisphere damage can have on a visual-gestural language.

Karen L: Grammatical but Underspecified Signing and Impaired Sign Comprehension

Another left-hemisphere damaged patient (Karen L.) retained fluent output in signing after her stroke but shows impairment within sublexical structure (the equivalent of phonemic paraphasias in spoken language); however, she has relatively preserved grammar. In free conversation, Karen L. uses the spatialized syntactic mechanisms of ASL abundantly, including pronominal indices and verb indexing (the spatial device for indicating grammatical relations through verb agreement). Her language output is highly irregular, however, in that she characteristically fails to specify the nominals associated with these spatial indices; that is, the antecedents of the referentially functioning indices of her inflecting verbs and of her indexic pronouns are very often missing. These omissions give rise to an impression of vagueness and lack of content in her signing. Furthermore, Karen L. has a marked and lasting sign comprehension loss.

Karen L. communicates well and freely, carrying on a conversation (indeed, a monologue) with normal rate, flow, and with a wide range of grammatical structures. Karen L. signs freely without prompting. What follows is a sample of her signing that relates some incident in her past.

> Karen L: THERE$_a$ NOT-YET SEE. *THEY$_{b\text{-}c}$ SAY PRETTY *THERE$_a$. THIS$^{[+\text{to front}]}$ BETTER THAN *THAT$_d$. TROUBLE *THERE$_d$ THAN HERE. QUIET HERE, *THERE$_c$ TROUBLE. RIOTS$^{[\text{Allocative}]}$ DRINK$^{[\text{Habitual}]}$.

An English equivalent is:

> Karen L: I have not yet seen what's over there. They [unspecified] say it is pretty there [unspecified]. This is better than that [unspecified]. There was more trouble over there [unspecified] than here. It's quiet here. Over there [unspecified] was trouble—riots in different places and regular boozing.
> Examiner: Where was the trouble?
> [Examiner is lost in terms of the referents of the conversation.]

As this exchange indicates, it was often impossible to tell what Karen L. was talking about, because she used pronominal indexes so freely without specifying in any way their antecedents. Her signing, however, is grammatical with appropriate morphological inflections, including those for indexing, which she frequently used. Yet her signing shows two specific deficits: paraphasias in ongoing signing, involving substitutions within the parameters of signs, and failure to specify the nominals associated with her indexes. Furthermore, her comprehension of ASL is markedly impaired.

Paul D.: Paragrammatic Signing

A third left-hemisphere damaged patient (Paul D.), whose signing is also fluent and unfaltering in delivery after his stroke, shows a linguistic impairment with respect to the appropriate selection of lexical signs and also with respect to the selection and combination of the morphological operations that "modulate" the meaning of signs. His signing includes many substituted or added inflectional and derivational morphemes as well as lexical substitutions. Moreover, he fails to use the spatialized syntax of ASL (pronominal indexes and verb agreement markers). His signing is marked by an overabundance of nominals, a lack of pronominal indexes and the failure to mark verb agreement correctly at all. This appears to be an impairment of spatially organized syntax and discourse. Thus, two left-hemisphere lesioned patients have primary impairment at the *grammatical* level, the one agrammatic (Gail D.) and the other *paragrammatic* (Paul D.).

Paul D. presents a particularly interesting pattern of language breakdown. We have found that he shows parallel errors in ASL signing and in written English with respect to morphology. However, he appears to have a sign language specific breakdown in syntax. We asked Paul D. to describe the Cookie Theft picture in ASL and in written English. Figure 7.9 presents Paul D.'s written version of the story and an error from his signed version. His written description is:

> I see a kitchen where a girl washes *his dishes and a big cookie jar *jarring a boy in the kitchen and a young girl *outstretching her arms *at the cookie and *jar the cover and I notice the *award of the water washing toward the floor.

Paul D. was asked to describe the scene in ASL, and part of his response is:

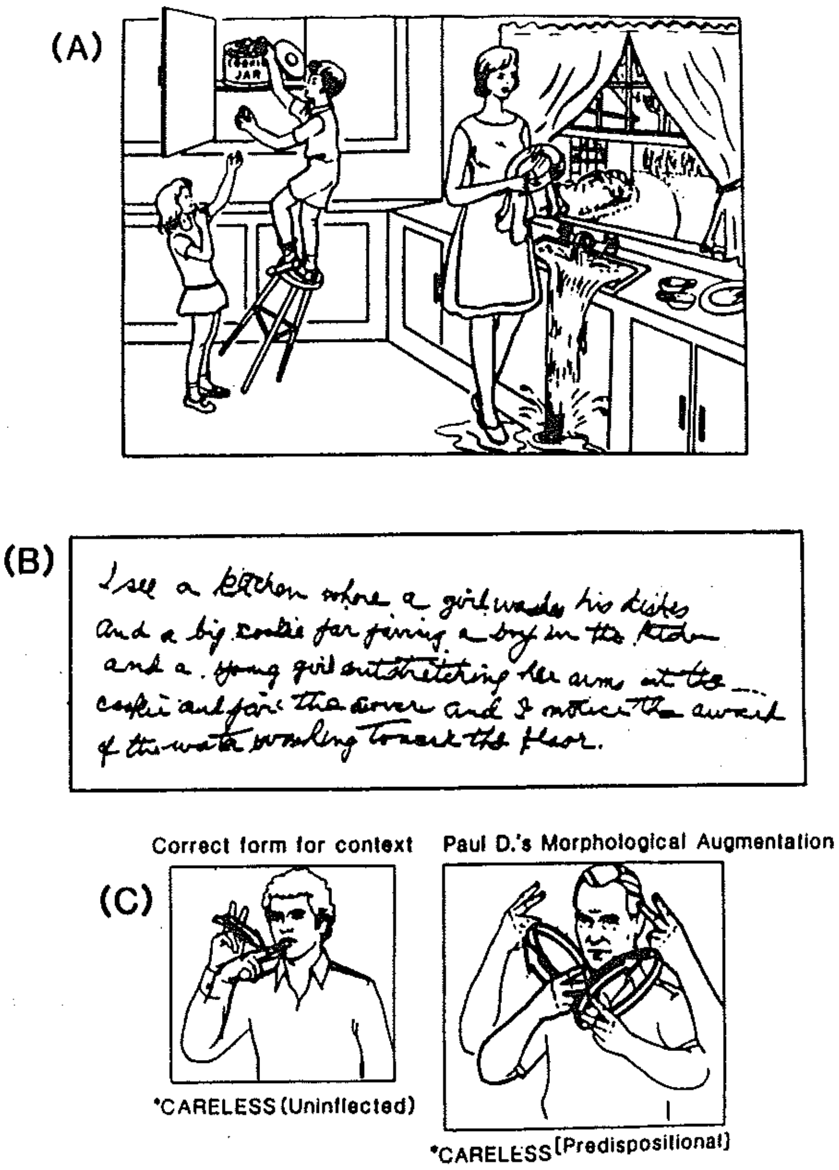
> Paul D.: GIRL SPILL (THERE) [points to woman in picture]. WATER OVERFLOW, WATER. (SHE)[points to woman] *CARELESS[Predispositional]. (HE) [points to boy] *FALL-LONG-DISTANCE-DOWN. (SHE)[points to woman] *GIGGLING. (SHE)[points to woman] WORK, THERE. (SHE)[points to woman] *SPILL-ALL-OVER-SELF.

Paragrammatisms in each passage are starred (*) and include a number of forms that are inappropriate or ungrammatical for the context. An English translation of Paul D.'s signing is:

> The girl spilled there [pointing to the woman]. The water overflowed, the water. She is always careless by nature. He [referring to the boy] fell in a double somersault to the ground. She [referring to the woman] is giggling. She [the woman] is working; she spilled water all over her dress.

Both Paul D.'s writing and his signing display errors of selection at the lexical and morphological levels. His written description contained inappropriate selections, such as "jar *jarring," "girl *outstretching her arms," and "*jar the cover," and "the *award of the water." Similarly, instead of a sign meaning "starting to fall," he used a form that means "fall a long distance;" instead of a sign form meaning "spill on the floor," he signed a form that means "spilled all over herself," and so forth. Figure 7.9 presents one error from his signed description. He used the morphologically complex form meaning "characteristically careless," when the sign form that would have been appropriate for the context is the uninflected form CARELESS. Thus, his signing, like his writing, showed paragrammatisms and inappropriate morphological augmentations.

Therefore, these data indicate a parallel breakdown at the morphological level in Paul D.'s signing and writing. This demonstrates that morphological breakdown in aphasia can be independent of language modality. Sign language, however, in a striking way shows its roots in the visual modality through the special



I see a kitchen where a girl washes his dishes
And a big cookie jar jarring a boy in the kitchen
and a young girl outstretching her arms at the
cookie and jar the cover and I notice the award
of the water washing toward the floor.

FIG. 7.9. Paul D.'s written English and ASL errors.
(a) The Cookie Theft elicitation card from the Boston Diagnostic Aphasia Examination. Copyright © 1972 by Lea and Febiger.
(b) Paul D.'s written description of the cookie theft picture.
(c) An error from Paul D.'s signed description. Note the morphological errors in both his writing and signing.

spatialized organization underlying its syntax. We have found that Paul D. has problems with the spatialized syntax of ASL that differ from his impairment in English syntax. This sign-specific syntactic breakdown may be intimately related to requirements of a syntax that is specifically spatially organized.

Although Paul D. makes many incorrect selections of lexical items, the syntactic structures of English are generally well preserved in his writing. In English, verbs are appropriately inflected for tense and number, and Paul D. makes few noticeable omissions. In contrast, Paul D.'s signing shows a pronounced irregularity in those aspects of syntax and discourse that are spatialized in ASL. Recall that pronominal reference in ASL is realized *spatially*—by means of "pointing" *indexic* pronoun forms; similarly, verb agreement (specifying grammatical relations on the basis of indexing) is a part of the spatialized system. An analysis of Paul D.'s signing suggests that he tends to avoid indexic pronouns (part of the spatialized system) and to overuse nouns—more than five times as many nouns as indexic pronouns in a stretch of discourse, which is highly irregular when compared to the noun/pronoun ratio in the signing of the age-matched, deaf controls. Moreover, he made errors in the spatially organized verb agreement system. For example, in signing the ASL equivalent of "We arrived (in Jerusalem) and stayed there," Paul D. produced a syntactically well-formed sentence consisting of the three signs: ARRIVE, STAY, THERE. However, each of the three signs was indexed to a different locus, when all three signs should have been indexed to the same locus. This is typical of Paul D.'s errors of indexic verb agreement in ASL's spatialized syntax.

Such problems may well be related to the organizational requirements of spatial planning and spatial memory involved in planning discourse. In ASL, the formal means for indicating pronominal reference is negotiated on-line and is spatialized. One aspect of this processing is that the signer has to negotiate the placement of points as he or she goes along, because there are no predefined points to choose from in sign. Furthermore, a signer must plan ahead to establish abstract loci so that they are suitably placed for subsequent reference. In addition, of course, a signer must remember where each locus exists in the signing plane. As we have seen, Paul D. has difficulty with the entire system of spatial indexes in ASL. He underuses the spatial indexes for purposes of pronominal reference and verb agreement, and he incorrectly indexes verbs. He also performed poorly on a test of the comprehension of nominals and their associated spatial loci and on a test of spatially organized syntax. Paul D.'s difficulties here may be due in part to the special requirements of spatially organized syntax in sign—spatial memory, spatial planning, and syntactic and discourse structure.

Brain, Language, and Modality

Patterns of language breakdown and preservation in left- as opposed to right-lesioned signers lead us to the following conclusions. Because the left-lesioned signers show frank sign language aphasias, and the right-lesioned signers show preserved language function, it appears that it is indeed the left cerebral hemisphere that is specialized for Sign language. This provides support for the proposition that the left cerebral hemisphere in humans has an innate predisposition for language. Thus, there appear to be anatomical structures within the left hemisphere that emerge as spacial-purpose linguistic processors in persons who have profound and lifelong auditory deprivation and who communicate with a linguistic system that uses radically different channels of reception and transmission from that of speech. In this crucial respect, brain organization for language in deaf signers parallels that in hearing, speaking individuals.

Furthermore, our data indicate that differential damage within the left hemisphere produces different forms of sign aphasia and suggest the possibility that those anatomical structures within the left hemisphere that subserve visual-gestural language differ in part from those that subserve auditory-vocal language. Gail D. has a massive lesion to the left hemisphere that in hearing persons is typically associated with a lasting agrammatic aphasia. Her lesion involves not only the traditional Broca's area but also much of the surrounding cortex of the frontal lobe. Gail D. has a severe agrammatic aphasia for sign language. Her case points to the fact that there is an anterior region of the left hemisphere that is important for sign language. Whether or not this will turn out to be the same as the anterior region for speech is not clear, because her lesion is so large that it includes not only Broca's area but also much of the surrounding cortex. Broca's area is adjacent to that part of motor cortex that controls movement of the vocal tract. An analogous area that controls movement of the hands is located just superior to Broca's area, and Gail D.'s broad lesion includes both of these areas. Whether or not the same sign symptomatology would appear, if one or the other were spared cannot be answered from this case. Gail D.'s case is an important one, however, because a comparable lesion in hearing people is typically associated with agrammatic aphasia. Indeed, she has a clearcut aphasia for sign language that is remarkably similar to that of hearing agrammatics.

The case of Karen L. points to a possible difference between those neural structures that may underlie spoken language and signed language. Her lesion is in the left parietal lobe (supramarginal and angular gyri) with a subcortical extension into the frontal lobe. Her lesion is well circumscribed and spares the traditional Broca's and Wernicke's areas. Although a hearing patient with this lesion might have some initial speech comprehension difficulties and suffer from word-finding difficulties, we would not expect a lasting speech comprehension deficit. Karen L., however, has such a pronounced and lasting deficit in the comprehension of sign language. It may well be that anatomical structures of the inferior parietal lobule of the left hemisphere play a greater role for sign language than for spoken language. These structures are intimately involved with higher order spatial analysis as well as with gestural control and may have been recruited in the service of sign language, because in sign language grammatical relations and spatial relations are so intertwined.

There is other evidence that indicates that brain structures are not indelibly and unalterably wired for particular functions but rather that the brain optimizes particular processing tasks. For example, Merzenich and his colleagues (Merzenich, Nelson, Stryker, Cynader, Schoppmann, & Zook, 1984; Merzenich, Kass, Wall, Sur, Nelson, & Felleman, 1983; Merzenich & Kaas, 1982) have studied the cortical reorganization that occurs in the central representation of the body's skin surface after peripheral nerve injury. These investigators cut the peripheral nerves of monkeys that provide the brain with sensory input from skin surfaces, and they found that the brain's map of these surfaces was dramatically reorganized. In that reorganization, the representation of skin surfaces in cortical areas adjacent to deprived areas expanded to occupy the deprived cortical zones. Furthermore, this reorganization (and optimization) of brain function occurred after only relatively brief periods of altered somatosensory input to the brain.

It is important to note that we are not implying that sign language (or sign language processing) is localized in the left parietal lobe (or in a left anterior region). There are a number of cortical and subcortical brain regions that are intimately involved with spoken language processing (Damasio & Geschwind, 1984), and there is undoubtedly a similarly large number of brain structures on whose integrated performance sign language functioning crucially depends on. The parietal (and frontal) lobes are heavily and reciprocally interconnected with many other cortical and subcortical structures, making them important nodes in a number of distributed systems (Mountcastle, Motter, Steinmetz, & Duffy, 1984). It may well be that the brain's execution of the complex linguistic functions of sign language are carried out by neuronal processing mechanisms of those distributed systems. It is important to note that our data lead to the view that those distributed brain systems that underlie visual-gestural languages differ in part from those that subserve language in the vocal-auditory mode.

Hemispheric Specialization

All six of our patients, before their strokes, were skilled signers who had used ASL as their primary mode of communication throughout their lives. Although the left-lesioned patients were able to process visuospatial relations well, and the although right-lesioned patients were extremely impaired, the language behavior of these patients was quite the opposite. An especially dramatic finding is the contrast between right-lesioned Sarah M. and left-lesioned Gail D. Gail D. suffered massive damage to the left frontal lobe and was the most severely aphasic of all the subjects. Her signing was reduced to very short effortful utterances that consisted largely of single, open-class items. She omitted all grammatical formatives, including most pronouns, all inflectional and derivational processes, and all aspects of spatially organized syntax. However, her capacity for nonlanguage visuospatial processing was the most intact of any of the six subjects. She had excellent performance on drawing and constructional tasks, and she scored in the normal range on tests of facial recognition, perception of line orientation, and judgement of dot localization. Gail D.'s case is striking, because it shows the separation that can occur in brain organization for linguistic and for visuospatial capacity, even for a visuospatial language.

The case of Sarah M. stands in marked contrast. Her case is a dramatic one, because she had been an accomplished artist before her stroke, with superior nonlanguage visuospatial capacities. After her stroke, Sarah M.'s visuospatial nonlanguage functioning showed profound impairment. Even when copying simple line drawings after her stroke, she showed profound impairment. Even when copying simple line drawings after her stroke, she showed spatial disorganization, massive left-hemispatial neglect, and failure to indicate perspective. Her performance on other constructional tasks was likewise extremely impoverished, although these tasks were ones she excelled at prior to her stroke. However, Sarah M. was not aphasic for sign language.

Sarah M.'s lesion was a massive one to the right hemisphere that included most of the territory of the right middle cerebral artery. The lesion included areas that would be crucial to language, if the lesion occurred in the left hemisphere of a hearing patient. In all likelihood, Sarah M. would be globally aphasic had this lesion been in the *left* hemisphere in a hearing person. Thus, there is more than ample possibility for aphasic symptomatology to occur following the particular lesion in this case due to its size and location. Yet astonishingly no aphasia for sign language resulted. Despite Sarah M.'s profound visuospatial impairment, her signing was virtually impeccable. This underscores the complete separation in function that can occur between the specializations of the right and the left cerebral hemispheres in congenitally deaf signers. This result is particularly revealing, because, in sign language, language and spatial relations participate in one and the same channel.

Conclusions

Patterns of breakdown of a visuospatial language in deaf signers, thus, allow new perspectives on the nature and determinants of cerebral specialization for language. First, these data show that hearing and speech are not necessary for the development of hemispheric specialization. Sound is *not* crucial. Second, the data show that the two cerebral hemispheres of congenitally deaf signers can develop separate functional specializations for nonlanguage spatial processing and for language processing, even though sign language is conveyed in large part via spatial manipulation. Furthermore, it is the left cerebral hemisphere that is dominant for sign language. Thus, the left cerebral hemisphere in man appears to have an innate predisposition for language, independent of language modality. It therefore appears that linguistic functions and the processing operations required, rather than the form of the signal, promotes left hemisphere specialization for language.

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