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BIOLOGICAL FOUNDATIONS OF LANGUAGE: Clues from Sign Language

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The general objective of the research reviewed here is to examine the biological foundations of human language. We report on language and its formal architecture, as well as its representation in the brain, through studying languages that have arisen outside of the mainstream of spoken languages; the visual gestural systems developed among deaf people. The study of sign languages offers a unique opportunity for insight into the nature of neural mechanisms for language, since sign languages utilize a transmission modality different from that of spoken languages. To understand the extent to which neural mechanisms for language are shaped by the modality of their implementation, we are naturally led to the study of sign language because we cannot solve the problem for language in general within the spoken-auditory modality. In these studies, one can make use of the difference in transmission modality between sign and speech to investigate the biological foundations of language. Manual communi-

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cation, with its very different motoric and perceptual substrate, offers a fresh opportunity to unravel the entwined strands of message structure and message performance. Recently developed linguistic analyses have been linked with three-dimensional computergraphic modeling and analysis in a major series of experiments, each bringing to bear a special property of the visual gestural modality on investigating language and brain relationships.

American Sign Language (ASL) displays complex *linguistic* structure, but unlike spoken languages, conveys much of its structure by manipulating *spatial* relations, thus exhibiting properties for which each of the hemispheres of hearing people shows a different predominant functioning. The study of deaf signers with left or right hemisphere damage offers a particularly revealing vantage point for understanding the organization of higher cognitive functions in the brain, and how modifiable that organization may be. We review a series of experimental studies of brain-damaged signers, each focusing on a special property of the visual gestural modality as it bears on the investigation of brain organization for language. By examining the nature of cerebral specialization for a visual-gestural language, we hope to shed light on theoretical questions concerning the determinants of brain organization for language in general.

STRUCTURE OF SIGNED LANGUAGE

The central issues addressed in this review arise from some new discoveries about the nature of language. Until recently, nearly all we had learned about language had come from the study of spoken languages, but now a lively field of research into signed languages has revealed that there are primary linguistic systems passed down from one generation of deaf people to the next that have become forged into autonomous languages, not derived from spoken languages (Bellugi 1983, 1988, Klima & Bellugi 1979, 1988, Bellugi et al 1983, 1989, Poizner et al 1987, Lane & Grosjean 1980, Stokoe et al 1965, Wilbur 1987). Thus one can examine properties of communication systems that have developed in an alternate transmission system, in the visual gestural channel. The existence of such fully expressive systems arising outside of the mainstream of spoken languages affords a striking new vantage point for investigating the nature of biological constraints on linguistic form.

Levels of Structure and Layers of Form in Sign Language

ASL shares underlying principles of organization with spoken languages, but the instantiation of those principles occurs in formal devices arising out of the very different possibilities of the visual-gestural mode (Bellugi

1980, Bellugi et al 1988, Poizner et al 1986b). We consider briefly the structure of ASL at different linguistic levels: the layered structure of phonology and morphology and the spatialized syntax of the language.

'PHONOLOGY' WITHOUT SOUND Research on the structure of lexical signs has shown that, like the words of spoken languages, signs are fractionated into sublexical elements. Recent analyses focus on segmented structure of signed languages, which suggest sequential structure analogous to features and syllables of spoken language (Liddell & Johnson, 1986, Perimutter 1988). Sign languages, however, differ in degree of simultaneity afforded by the articulators such that the elements that distinguish signs (handshapes, movements, places of articulation) are in contrasting spatial arrangements and co-occur throughout the sign.

VERTICALLY ARRAYED MORPHOLOGY The grammatical mechanisms of ASL exploit elaborately the spatial medium and the possibility of simultaneous and multidimensional articulation. Like spoken languages, ASL has developed grammatical markers that serve as inflectional and derivational morphemes. These markers involve regular changes in form across syntactic classes of lexical items associated with systematic changes in meaning. Some derivationally related forms are shown in Figure 1. In ASL, families of sign forms are related via an underlying stem: The forms share a handshape, a location, and a local movement shape. Inflectional and derivational processes represent the interaction of this stem with other features of movement in space (dynamics of movement, manner of movement, directions of movement, spatial array, and the like) all *layered* with the sign stem.

SPATIALLY ORGANIZED SYNTAX A major device for the specification of relations among ASL signs is the manipulation of sign forms in space; thus in sign language, space itself bears linguistic meaning. Nominals introduced into ASL discourse may be associated with specific points in a plane of signing space. Spatial indexing to these loci thus allows explicit coreference. The ASL system of verb agreement, like its pronominal system, is also in essence spatialized. Verb signs in one class of verbs may move between the abstract loci in signing space, bearing obligatory markers for person (and number) via spatial indices, thereby specifying subject and object of the verb, as shown in Figure 2a. This spatialized system thus allows explicit reference through pronominals and agreement markers to multiple distinct third person referents. Coreferential nominals are indexed to the same locus point, as is evident in complex embedded structures, such as shown in Figure 2b.

Different spaces may be used to contrast events, to indicate reference to

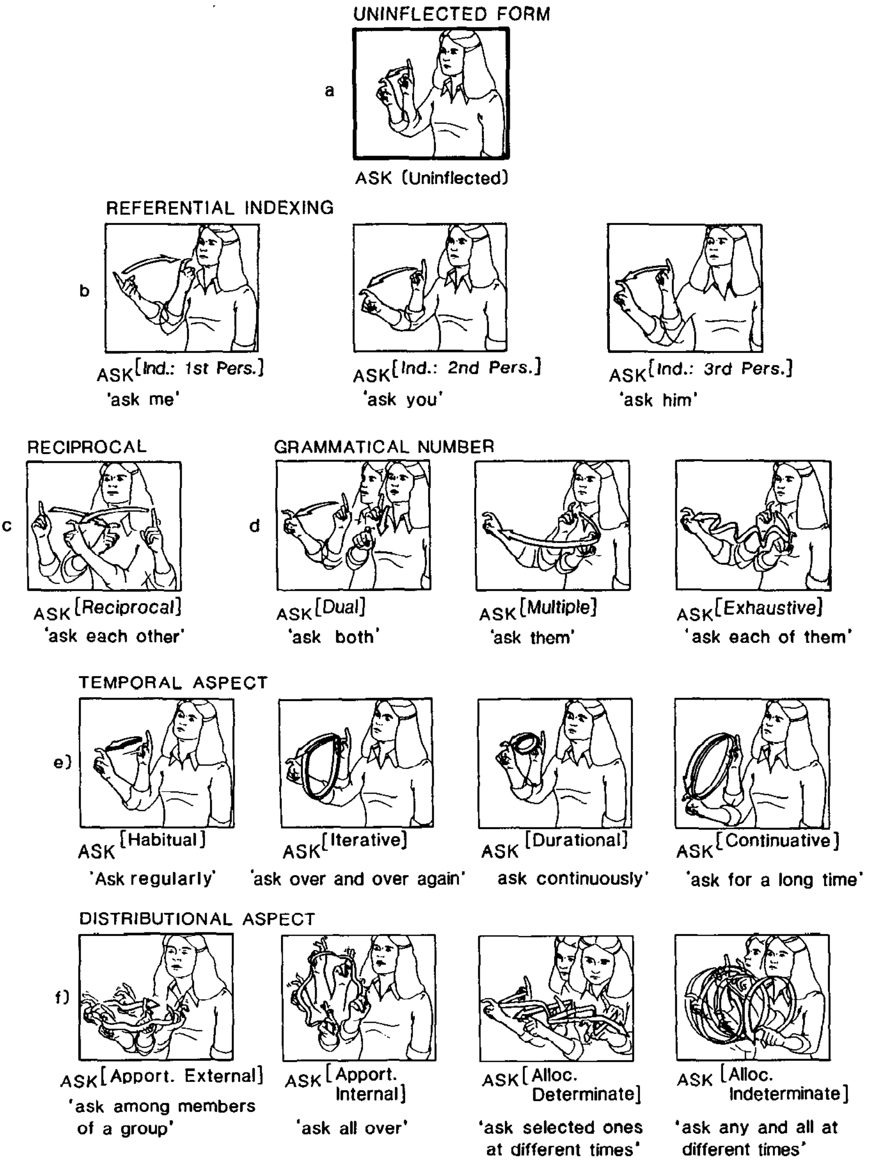


Figure 1 A variety of morphological processes in ASL layered on a single root.

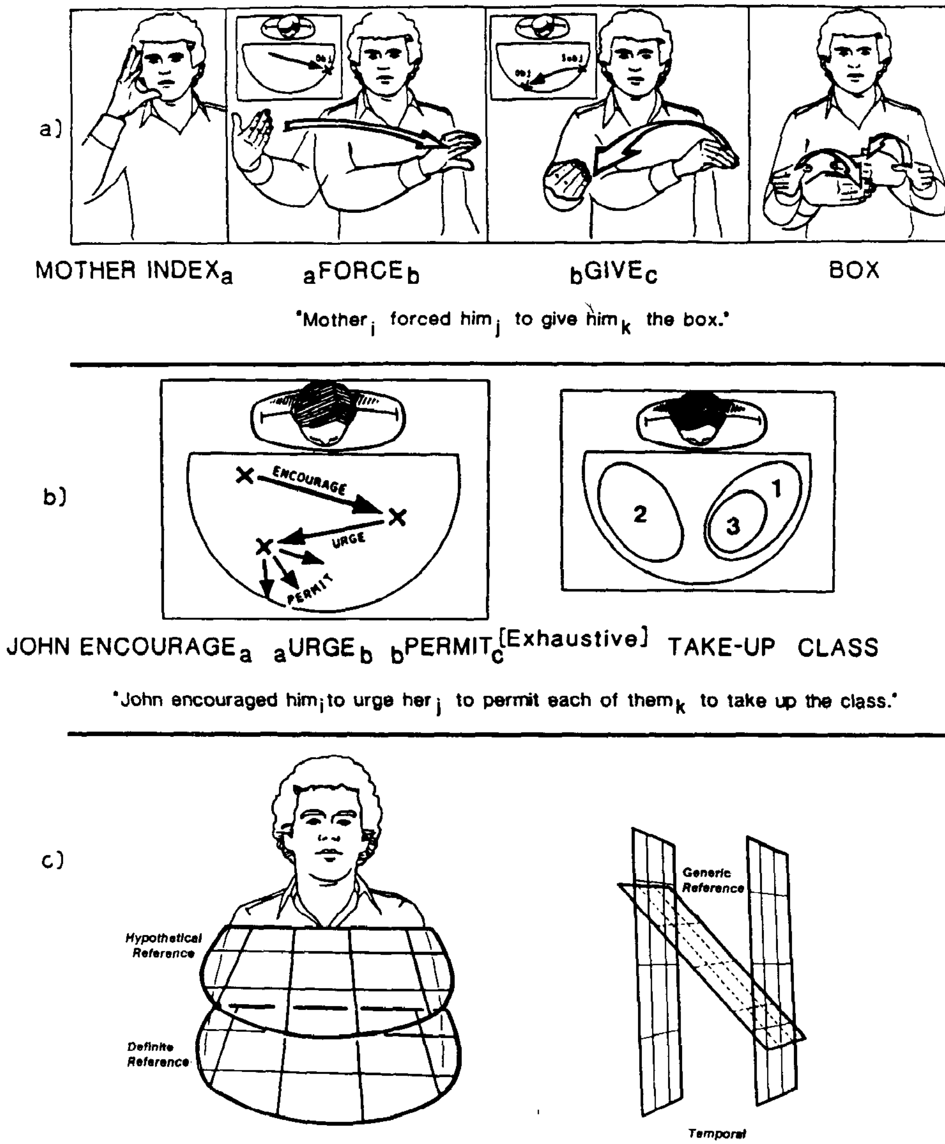


Figure 2 Spatialized syntactic mechanisms in ASL.

time preceding the utterance, or to express hypotheticals and counterfactuals (van Hoek 1988). As Figure 2c shows, the grammar of ASL divides sign space along several different axes, and utilizes each of the spatial dimensions for a particular semantic contrast: spatial, temporal, or realis. Contrasts in spatial location are marked by distinctions in the horizontal plane (i.e. left to right), which is the plane of definite reference; generic reference, instead, is marked on an oblique plane. Temporal contrasts may be marked by distinctions in the sagittal plane, thus differentiating events in time. Distinctions between real and hypothetical situations may be marked by the height of the signs, which represent another dimension of semantic contrast; conditionals (e.g. "if it rains") involve a higher plane of signing space than factual statements. Thus ASL structures three-dimensional space according to multidimensional oppositions between basic axes of conceptual organization. The use of spatial loci for referential indexing, verb agreement, and grammatical relations is clearly a unique property of visual gestural systems.

BIOLOGICAL AND LINGUISTIC CONSTRAINTS ON STRUCTURE

Sign Language Universals

The study of ASL provides a new perspective on the question of linguistic universals and the role of modality in determining the forms by which universal principles are manifested within a language. Analyses have been performed on the structure and form of an unrelated sign language, Chinese Sign Language (CSL). ASL and CSL are mutually unintelligible sign languages that have arisen independently and differ at all linguistic levels. CSL was selected for study because it has developed in the context of a completely different spoken language, with essentially no inflectional morphology, and because it has developed in the context of a radically different writing system (logographic as opposed to alphabetic).

Despite the differences in the surrounding spoken and written languages, at each level of sign language organization—phonology, morphology and syntax—CSL and ASL have remarkable similarity in *surface* form (Fok et al 1988). Signs in both signed languages are composed of simultaneously layered elements, consisting of a small set of handshapes, locations, and movements. Moreover, CSL, like ASL, makes use of inflected forms to express a range of distinctions: Verbs in CSL inflect for agreement with subject and object and also for distributional distinctions such as dual, reciprocal, multiple, and exhaustive. In CSL, as in ASL, inflectional morphology and stem are fused into one simultaneously articulated unit, and spatial relations are used to convey syntactic relations. As would be expected between two unrelated languages, the grammatical inflections that have arisen in CSL and ASL differ in distinctions marked as well as in formation. There are also systematic differences in phonetic form between the two signed languages, so that, for example, when signers of one sign language learn the other, they sign with the equivalent of a foreign accent (Klima & Bellugi 1979/1988). The two unrelated signed languages use similar principles for grammatical processes, however, and make use of possibilities offered by the visual modality to convey linguistic structure in a highly layered manner, with the active manipulation of space. These studies of CSL and ASL are important both to determining how modality shapes language structure and to cross-modality universals of language organization (Fok et al 1986, 1988).

The Interplay between Perception of Movement and Perception of Language

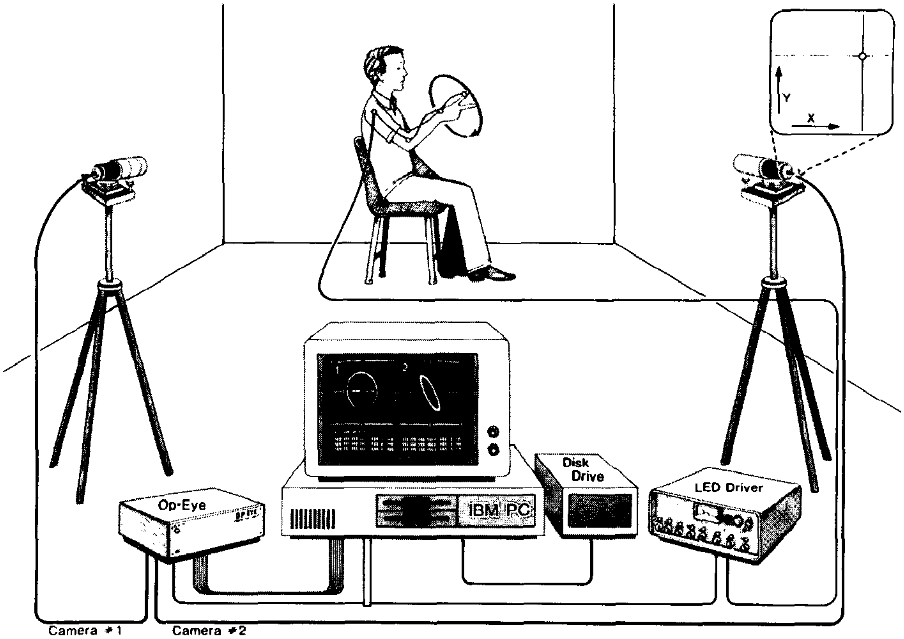
Since visual perception and signing differ so radically from auditory perception and speech, one can investigate the interplay between linguistic structure and biological processes quite apart from the particular channel through which the linguistic structure is conveyed. Acquiring American Sign Language can modify perception of some natural movement categories (Poizner 1981, 1983). Deaf ASL signers differ from hearing nonsigners in perception of meaningless ASL movements. The data indicates that the modification of natural perceptual categories after language acquisition is not bound to a particular transmission modality, but rather can be a more general consequence of acquiring a formal linguistic system. A recent experiment investigated the psychological representation of visual gestural languages from a cross-linguistic perspective, focusing on the perception of movement, since movement is a key formational building block of sign languages.

Signers from Chinese and American Sign Languages and nonsigning hearing subjects made triadic comparisons of movements that had been isolated from American Sign Language and presented as dynamic point-light displays. Multidimensional scaling of the triadic comparisons revealed marked differences between perception of both groups of signers from that of the hearing nonsigners, replicating and extending previous studies, that showed perceptual modification following acquisition of sign language. Furthermore, American and Chinese signers differed in their perception of one and the same set of movement elements based in part on the differing role of movement in the phonologies of the respective sign languages. Related experiments on the perception of speech make it clear that a speaker's perception of phonemes is determined partly by his phonological knowledge. Thai, for example, partitions the voicing continuum differently from English, and the discrimination functions of Thai and English speakers are correspondingly different (Abramson & Lisker 1970). By comparing perception of linguistic movement across signers from different visual gestural languages, one can begin to uncover—for language in general—how particular phonological knowledge constrains perception and how perception is determined by the psychophysiology of the input-output channels (Poizner et al 1989c, Poizner 1987).

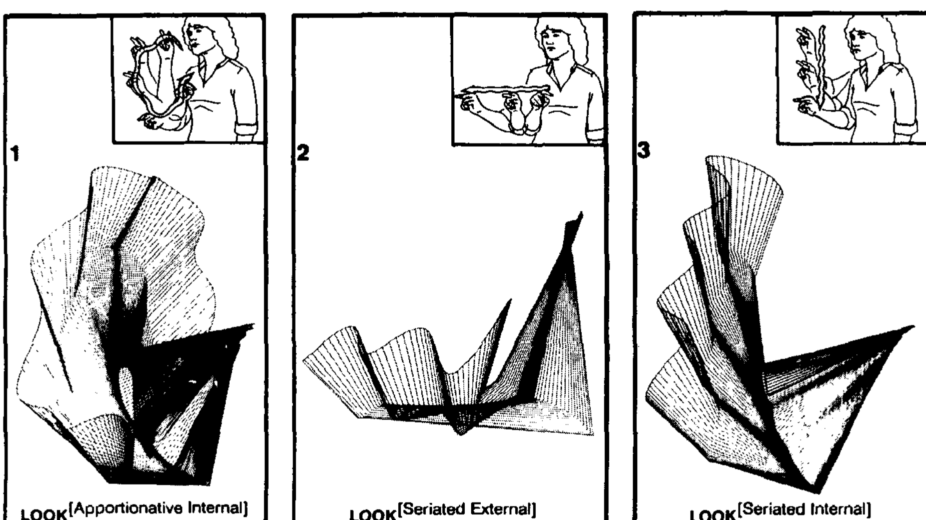
Three-Dimensional Computergraphic Modeling and Analysis

The study of sign language offers a special opportunity for the investigation of language production, since the movements of the articulators in sign are directly observable. Powerful techniques have been developed for the three-dimensional measurement and analysis of movement. American Sign Language displays all the complex linguistic structure found in spoken language, yet the mechanisms by which the essential grammatical information is conveyed are unique to the modality in which the language developed. This grammatical information is conveyed by changes in the movement and by spatial contouring of the hands and arms. The three-dimensional acquisition, reconstruction, manipulation, and graphic editing of such movement processes is now possible (Poizner et al 1986c, Jennings & Poizner 1988). Two optoelectronic cameras can be used to detect the positions of infrared emitting diodes attached to the major joints of the arms and hands (see Figure 3a). Three-dimensional coordinates are calculated and the movements reconstructed computergraphically. A sequence of positions of the arm in three-dimensional space can be displayed simultaneously, or the actual motion can be recreated in real time. Figure 3b shows stroboscopic reconstructions of three grammatical processes in ASL, and illustrate the fluidity of linguistic processes in the visual modality.

In conjunction with new methods of three-dimensional movement tracking, these computergraphic methods offer new approaches to the analysis of sign language and its underlying neural control. For example, Figure 4 presents reconstructed movements of the hands and arms for a control signer and a signer with Parkinson's disease producing the grammatically inflected sign, LOOK [Exhaustive], meaning "look at each of them." The reconstructions reveal markedly reduced movement amplitudes in the signing of the Parkinsonian signer. These reductions in movement amplitude seem akin to the micrographia, or reduced letter size in the writing of hearing patients with Parkinson's disease. Furthermore, the Parkinsonian signer made few arm movements through space, and utilized distal rather than proximal joints, thus suggesting a difficulty in maintaining over time



Three-Dimensional Data Acquisition System



Computergraphic Reconstruction of Inflected ASL Signs

Figure 3 Three-dimensional computergraphic analysis of morphological processes in ASL.

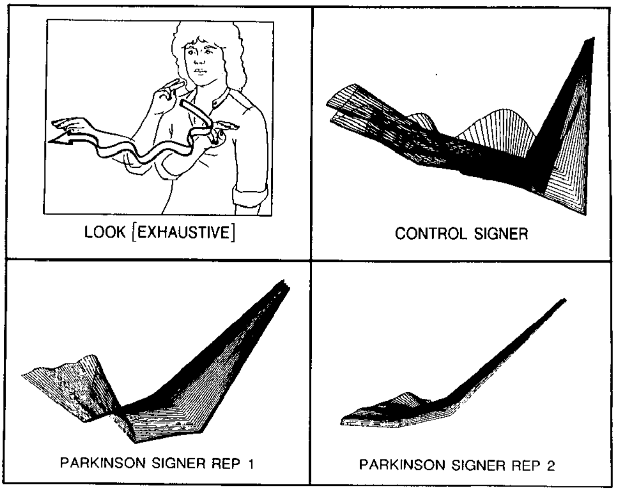


Figure 4 Three-dimensional computergraphic reconstructions of Parkinsonian signing.

appropriate force of muscular contraction required of proximal arm movements (Poizner et al 1988). The interactive control and three-dimensional visualization of reconstructed movements that do or do not serve a linguistic function make possible a powerful analysis of the breakdown of movements that serve *linguistic*, *symbolic*, or strict *motoric* functions.

BRAIN FUNCTION FOR A VISUOSPATIAL LANGUAGE

The study of sign language breakdown due to brain damage offers a direct window into cerebral specialization for language, since in sign language there is interplay between visuospatial and *linguistic* relations within one and the same system. One broad aim is to investigate the relative contributions of the cerebral hemispheres with special reference to the connection between linguistic functions and the *spatial* mechanisms that convey them. We review a series of studies of the language capacities of deaf signers having either left or right brain damage. An array of assessment tools, probes, methods of linguistic analysis, and formal tests have been administered that constitute a major comprehensive program for investigating the nature of sign language breakdown following unilateral lesions. The program includes: (*a*) an adaptation, for ASL, of the Boston Diagnostic Aphasia Examination (BDAE) (Goodglass & Kaplan 1979, 1983); (*b*) a battery of linguistic tests specially designed to assess capacities of brain-damaged signers vis-á-vis each of the levels of ASL linguistic structure: "phonology without sound," vertically arrayed morphology, and spatially organized syntax; (*c*) an analysis of production of ASL at all linguistic levels, (*d*) tests of nonlanguage spatial processing and motor control. The battery of language and nonlanguage tasks is administered to left- and right-lesioned signers and to matched deaf control signers. This uniform investigation of left- and right-lesioned signers is important because in this manner performance of these two groups can be directly compared and inferences made regarding the neural substrate underlying a language in a spatial mode (Poizner et al 1987, 1989a, Bellugi et al 1989, Klima et al 1988). These probes permit one to assess patterns of preservation and impairment with right and left hemispheres lesions, and thus gain a deeper understanding of the role of the two hemispheres in the processing of visuospatial language.

We report on on-going studies of brain lesioned signers, with left or right hemisphere lesions. All subjects in these studies were members of deaf communities, had been educated in residential schools for deaf children, and had deaf spouses. All were right handed before their strokes. For each subject, the primary form of communication with family and friends was ASL.

Nonlanguage Spatial Cognition

Since spatial relations and linguistic relations are so intimately intertwined in ASL, it is important to examine brain organization for nonlanguage spatial functions in order to determine whether the two cerebral hemispheres in deaf signers show differential specialization. Visuospatial deficits were extensive in right-hemisphere-lesioned signers. One subject with right hemisphere damage showed topographic disorientation. Another, who had specialized in building and repairing from blueprints before his stroke, was unable to do simple block designs afterwards. A third, who had been an artist before her stroke, also showed a marked visuospatial impairment, including highly distorted drawings and neglect of left hemispace. Figure 5 presents example performance of eight brain-lesioned signers 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 reflects their severe spatial loss. Across a range of tests, including drawing, block design, attention to visual space, perception of line orientation, facial

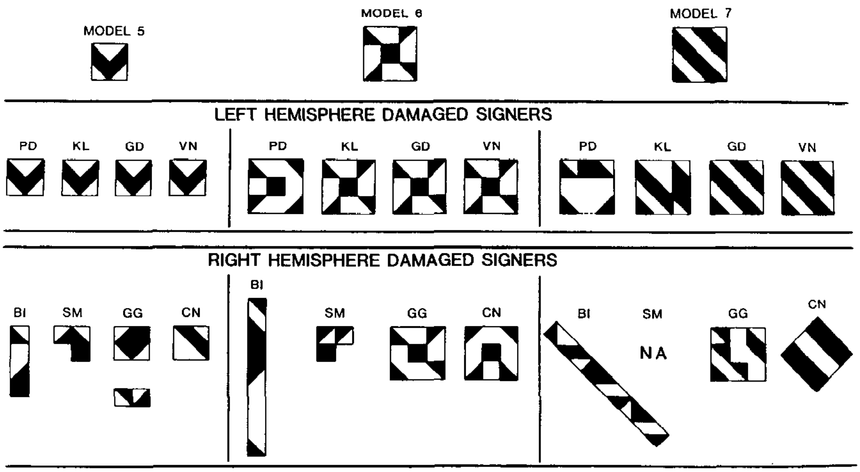


Figure 5 Performance of left- and right-lesioned signers on the WAIS-R block design task, a nonlanguage visuospatial task. Note the broken configurations and severe spatial disorganization of the right-lesioned signers.

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. In summary, right-lesioned deaf signers show severe impairments in processing of nonlanguage spatial relations. These nonlanguage data show that the right hemisphere in deaf signers develops cerebral specialization for nonlanguage visuospatial functions (Poizner et al 1987).

GRAMMATICAL IMPAIRMENT IN LEFT-LESIONED SIGNERS

Lesions to the left hemisphere have been found to produce frank sign language aphasias (and relatively preserved nonlanguage spatial functions). Importantly, the studies show that sign language breakdown was not uniform, but rather cleaved along lines of linguistic significance (Poizner et al 1987). Figure 6 shows the rating scale profiles from the ASL adaptation of the Boston Diagnostic Aphasia Examination for three signers with left hemisphere damage (*top*), for matched deaf control subjects (*middle*), and for three right-hemisphere-damaged signers (*bottom*). The middle portion of the figure presents the rating scale profiles of the matched control subjects and shows normal performance. Note that for the left-lesioned signers, the scores are scattered on each scale, spanning virtually the entire range of values. These profiles reflect marked sign language breakdowns. The performance of the right-lesioned signers reflect grammatical (non-aphasic) signing; in fact, their profiles are much like those of the control subjects.

The specific disruption of sign language following left hemisphere lesions is also clearly revealed by performance of brain-damaged signers on tests developed to assess processing various linguistic levels of ASL structure. For example, Figure 7a presents results from a test of the equivalent of phonological processing in sign language. Phonological processing has been considered one of the most strongly left-lateralized aspects of spoken language (Zaidel 1985). In a test for the sign equivalent of "rhyming" left-lesioned, but not right-lesioned signers showed marked impairment. Thus, the specialization of the left hemisphere for phonological processing does not appear to be specific to language in the spoken-auditory mode.

The individual sign language profiles of the left-lesioned signers deviate from normal in different ways, and represent distinct patterns of sign aphasia. We illustrate the nature of the differential breakdown of sign language, following left-hemisphere lesions, through some individual case studies.

Agrammatic Sign Aphasia

One left-lesioned signer was agrammatic for ASL. After her stroke, she no longer used the indexic pronouns of ASL, and her verbs were without any spatial indices whatever. In fact, her signing was devoid of the syntactic and morphological markings required in ASL; i.e. her signing was what would be classified as agrammatic in hearing aphasics. In addition, her signing was severely impaired, halting and effortful, reduced often to single sign utterances. Her language profile was very much like that of hearing subjects classified as agrammatic; moreover, her lesion was typical of those that produce agrammatic aphasia for spoken language.

Paragrammatic Sign Aphasia

Another left-lesioned signer was fluent in delivery after his stroke but showed many grammatical paraphasias. He made selection errors and additions within ASL morphology, and erred in the spatialized syntax and discourse processes of ASL. His signing was marked by an overabundance of nominals, a lack of pronominal indices, and failure to mark verb agreement correctly. Figure 7b shows his failure to maintain spatial indices in signed sentences. Such problems may be related to the organizational requirements of spatial planning and spatial memory involved in discourse in ASL, where the formal means for indicating pronominal reference is negotiated on-line and is spatialized. A signer must plan ahead to establish abstract loci for subsequent reference, and must remember where each locus

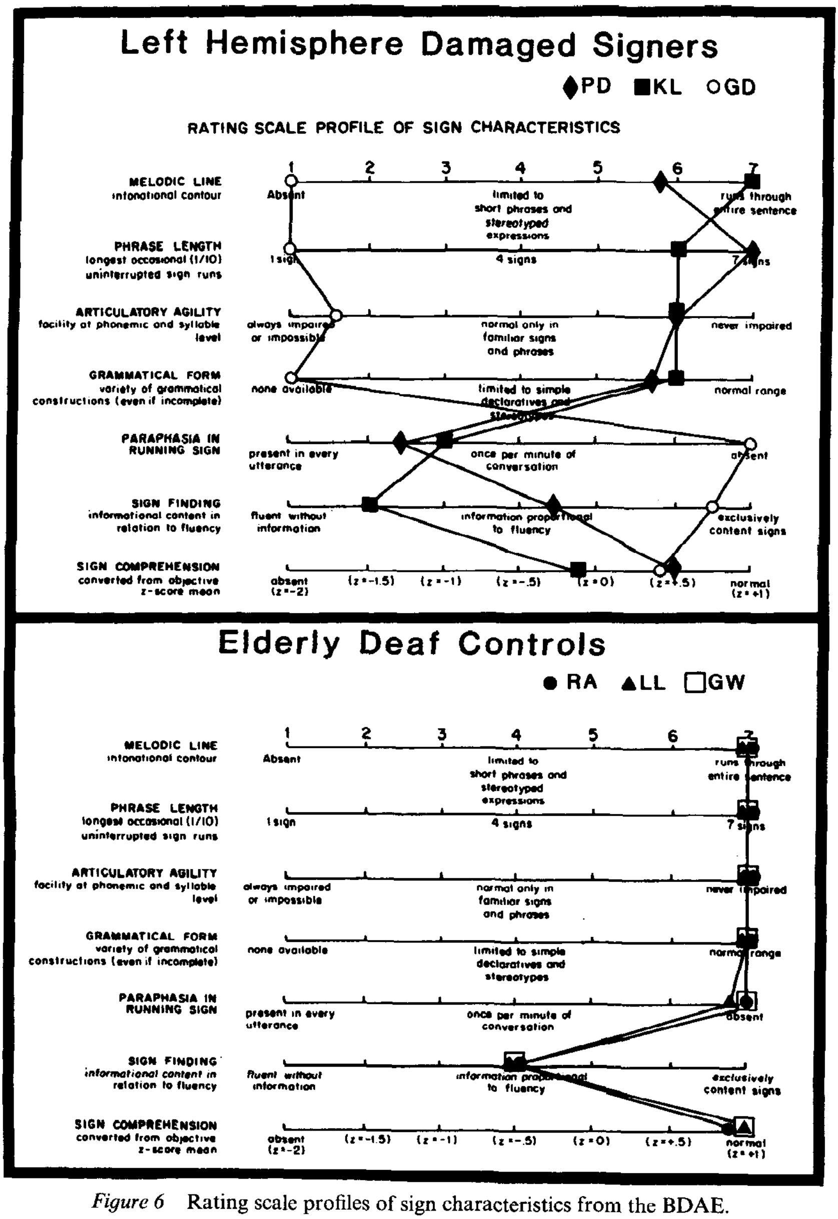


Figure 6 Rating scale profiles of sign characteristics from the BDAE.

is placed in the signing plane. Thus, the requirements of a spatially organized framework for syntax and discourse in sign language may be specifically (and differentially) impaired with focal lesions to the left hemisphere.

Breakdown of Sublexical Sign Structure

A third left-lesioned signer had a fluent sign aphasia after her stroke. She made selection errors in the formational elements of signs which produced the equivalent of phonemic paraphasias in sign language. Her signing, however, was perfectly grammatical, although vague, as she often omitted specifying to whom or what she was referring. She also had a marked sign comprehension loss. Interestingly, this marked and lasting comprehension loss would not be predicted from her lesion if she were hearing; both major language-mediating areas for spoken language (Broca's area and Wernicke's area) were intact. Her lesion was in the inferior parietal lobe, an area known to function for higher order spatial analysis.

Wernicke-like Sign Aphasia

The case of a fourth left-lesioned signer also had a marked and lasting sign comprehension loss, with a large perisylvian lesion that included the

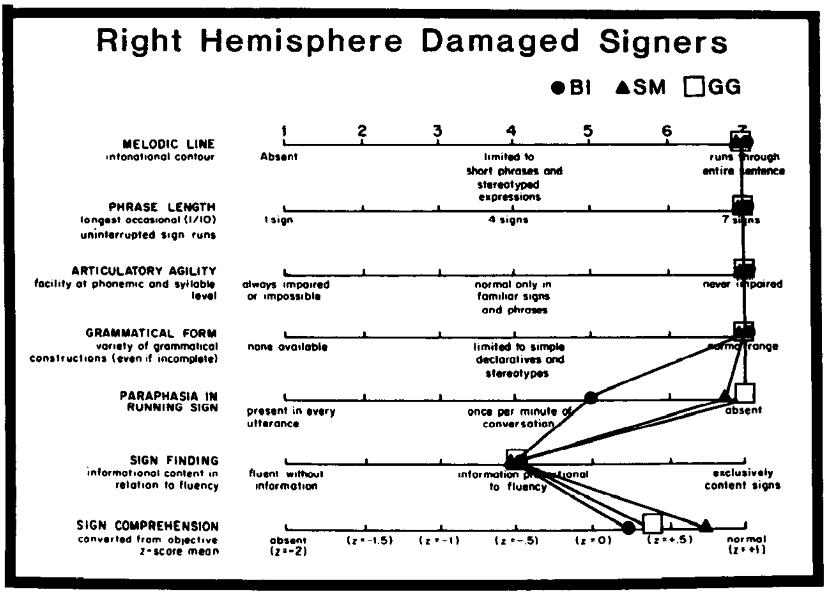
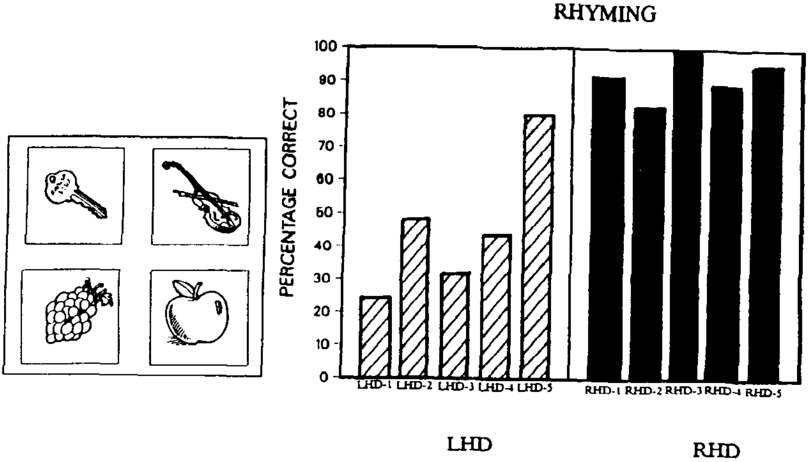
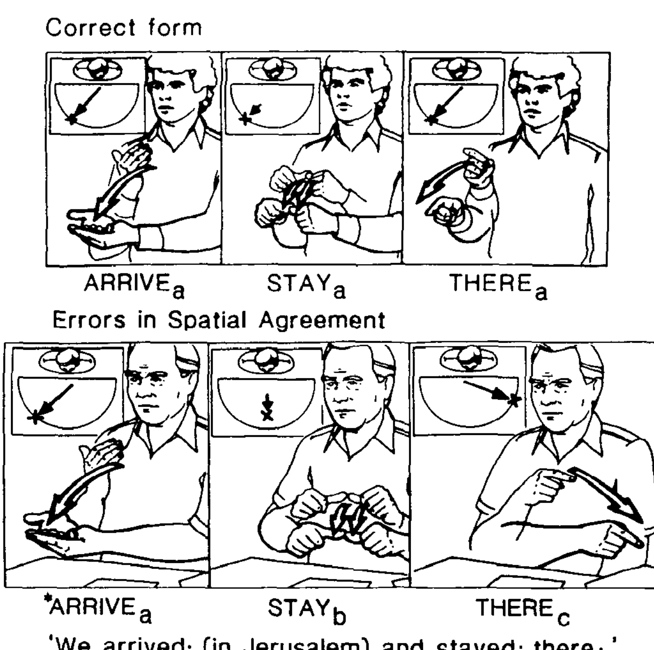


Figure 6 (continued)



a) Test For Processing Sublexical Structure in ASL: Rhyming



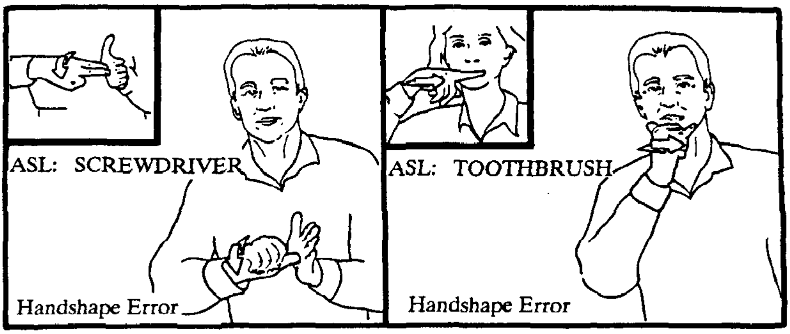
b) Failure to Maintain Spatial Indices in LHD Deaf Signer (P.D.)

inferior parietal lobe. The patient was markedly aphasic in his sign language production, making numerous paraphasias and elaborate semantic blends (see Figure 8a and b). Interestingly, this subject's paraphasias were specific to handshape, a finding that lends support to the view that this parameter may be considered a separate formational tier (Sandler 1987, Corina 1986). Finally, this case presents one of the most striking examples to date of the cleavage between linguistic signs and manual pantomime. In contrast to his severe aphasia for sign language, the patients abilities to communicate in nonlanguage pantomime and his comprehension for pantomime were remarkably spared. Although his comprehension of single signs was impaired, his comprehension of pantomimes depicting the same referents was unimpaired. His production of pantomimes also seemed intact, and he would insert mime into his signing (see Figure 8c). In identifying a flower, he gestured smelling a flower instead of making the sign FLOWER; in identifying a ball, he mimed the act of bouncing a ball instead of signing BALL. This differential brain processing of linguistic (sign) and nonlinguistic gestures (mime) provides an important indication of the left hemisphere's specialization for language-specific functions, and points to separate neuroanatomical pathways that mediate language and gesture (Poizner et al 1989b).

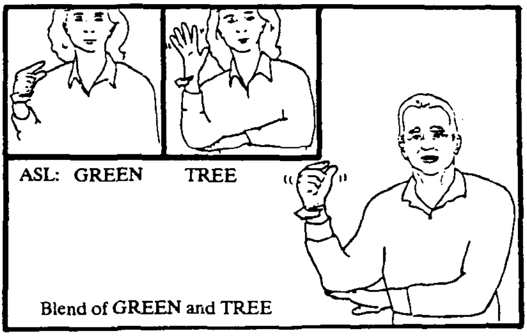
Converging Evidence from a Hearing Signer

A hearing signer proficient in ASL has been studied during the left intracarotid injection of a barbiturate (the Wada test), and before and after a right temporal lobectomy. The subject, like the deaf signers, was a strong right hander. Neuropsychological and anatomical asymmetries suggested left cerebral dominance for auditory-based language. Emission tomography revealed lateralized activity of left Broca's and Wernicke's regions for spoken language. The Wada test, during which all left language areas were rendered inoperative, caused a marked aphasia in both English and ASL. The patient produced sign paraphasias, preservations, neologisms, and grammatical errors during this temporary inactivation of the left hemisphere. Interestingly, during recovery from the left Wada injection, the patient frequently responded in speech and sign simultaneously—a unique possibility for languages in different modalities—with a mismatch between the two languages and the sign more often in error. The patient

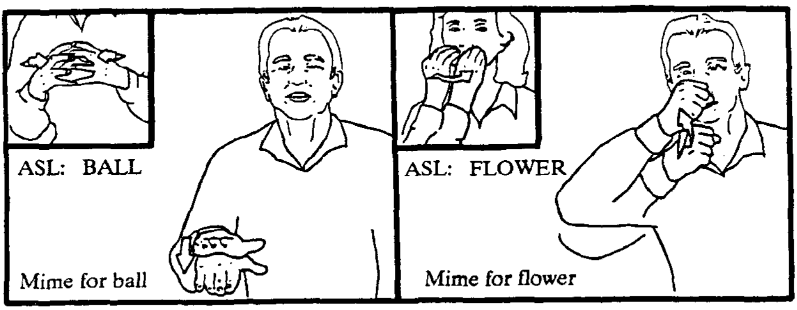
Figure 7 Impaired phonology and syntax in left-lesioned signers. (*a*) A sample item from the Rhyming Test is illustrated in the *top panel*. The correct answers are *key* and *apple*, since signs for these share all major formational parameters but one. Note the impaired performance of left-lesioned signers in processing sublexical structure. (*b*) Failure in spatially organized syntax in a left-lesioned signer.



a) **ASL Formational Paraphasias**



b) **Semantic Blend in ASL**



c) **Mime Substituting for ASL Sign**

Figure 8 Language breakdown in a left-lesioned signer. The signer produces numerous sublexical paraphasias (*a*) and semantic blends (*b*) in his signing. The signer substitutes mime for ASL signs as shown in (*c*), thus reflecting a separation between these two manual functions.

subsequently came to brain surgery, and after partial ablation of the right temporal lobe, the abilities to sign and understand signing were unchanged. These data add further support to the notion that anatomical structures of the left cerebral hemisphere subserve language in a visuospatial as well as an auditory mode (Damasio et al 1986).

The data reviewed provide clear evidence for hemispheric differentiation for various cognitive functions in deaf and hearing signers. Specifically, these results show that certain aspects of language processing in individuals whose primary language is a sign language are differentially affected by left versus right hemisphere damage. The findings suggest that the grammaticized aspects of sign language are left hemisphere dominated, and thus that hemispheric specialization for "language" is not specific to *spoken* language. These studies also bear on what may be the basis for this differentiation of hemispheric function. The research into functions of space in ASL and the varying degrees to which formal spatial distinctions are grammaticized or conventionalized in subsystems of the language can provide one important clue to a basis for left versus right hemisphere specialization. It is this issue that we turn to next.

PRESERVED SIGN LANGUAGE GRAMMAR IN RIGHT-LESIONED SIGNERS

The signers with right-hemisphere lesions present special issues in testing for language impairments; sign language makes linguistic use of space, and these signers show severe nonlanguage spatial deficits. As shown in Figures 6 and 7, the right-hemisphere-damaged signers examined in depth so far are not aphasic for sign language. On the whole, they exhibit error-free signing with a wide range of correct grammatical forms, no agrammatism, and no signing deficits. Furthermore, the right-lesioned signers, but not those with left-hemisphere lesions, were unimpaired on tests of processing ASL at the various linguistic levels. The right-lesioned subjects showed no impairment in the grammatical aspects of their signing, including their spatially organized syntax. They even used the left side of signing space to represent syntactic relations, despite their neglect of left hemispace in nonlanguage tasks. The dissociation between spatial language and nonspatial cognition is brought out in a strong way through an unusual case of a deaf signer who had been an artist prior to her right-hemisphere lesion.

Dissociations between Spatial Language and Spatial Cognition

As discussed above, signers with lesions to the right hemisphere, but not those with lesions to the left hemisphere, show marked nonlanguage spatial deficits. These marked impairments were found across a broad range of tasks that maximally differentiate performance of hearing subjects with right as opposed to left brain damage (Poizner et al 1987). The case of one right-lesioned signer is particularly dramatic because she had been an accomplished artist before her stroke, with superior nonlanguage visuospatial capacities. After her stroke, her visuospatial nonlanguage functioning showed profound impairment. Even when copying simple line drawings, she showed spatial disorganization, massive left-hemispatial neglect, and failure to indicate perspective. Her performance on other constructional tasks was extremely impoverished, even though these were tasks she excelled at before her stroke. And yet her sign language (including spatially expressed syntax) was unimpaired. Her sentences were grammatical and her signs without error. Her lesion was a massive one to the right hemisphere, including areas that would be crucial to language if the lesion had occurred in the left hemisphere of a hearing person. Nonetheless, she showed preserved sign-language functioning, as did the other signers with right-hemisphere lesions. These cases underscore the complete separation in function that can occur between specializations of the right and left cerebral hemispheres in congenitally deaf signers. In light of their severe visuospatial deficits for nonlanguage tasks, the correct use of the spatial mechanisms for signed syntax in right-lesioned signers underscores the abstract nature of these mechanisms in ASL.

Specialization for Facial Signals with Linguistic Function

The study of the effects of brain damage on deaf ASL signers affords a special opportunity to extend our understanding of brain-language relations and brain function underlying facial expression. In ASL, specific facial and body signals have arisen as a part of the grammar. They cooccur with manual signs and add an additional layer to the grammatical structure. Facial expressions in ASL serve two distinct purposes: they convey emotional information, as with hearing nonsigners; and, more interestingly, they serve to signal grammatical structures (Corina 1989, Reilly et al 1989a, b). Specifically, certain constellations of facial signals serve to mark syntactic structures (relative clauses, topics, and conditionals) and to mark adverbial constructions. Therefore, facial signals in ASL pose an interesting challenge to strict right-hemisphere processing of facial expression. As certain facial signals in ASL function as part of a tightly constrained linguistic system, they may be unaffected by right-hemisphere damage, despite the known mediation of the right hemisphere for facial signals that function effectively (Ley & Bryden 1979, Strauss & Moscovitch 1981).

AFFECTIVE AND LINGUISTIC FACIAL SIGNALS IN RIGHT-LESIONED SIGNERS The functional dissociation between control of affective as opposed to linguistic facial expressions is being investigated in right- and left-lesioned signers. A right-lesioned signer showed a sparing of linguistic facial expressions in the face of severely attenuated emotional expression. Instances of clear sentential contexts in which either affective facial expression would be expected or specifically linguistic facial signals would be required were examined. Figure 9 shows the dissociation between affective and linguistic facial signals in this right-lesioned signer. This is an important finding, since presumably one and the same muscular system is involved. Thus one cannot account for the finding in terms of weakness of facial musculature, but rather this must be accounted for in terms of a dissociation between linguistic and affective facial expression. Importantly, in contrast, a left-lesioned agrammatic signer showed the opposite dissociation, with preserved affective facial expression, but without required linguistic facial expressions. Converging evidence comes from studies with neurologically intact deaf signers compared with hearing nonsigners that demonstrates that the left hemisphere in deaf signers plays a dominant role in the processing of *linguistic* facial expressions (Corina, 1989). Thus, as for manual signs, these data on processing facial signals suggest that the linguistic function of the signal, rather than its physical form, is the basis for the specialization of the left hemisphere for language.

NEURAL MECHANISMS FOR SIGN LANGUAGE

Dissociations between Apraxia and Aphasia

In order to understand the principles of neural organization of language, some investigators have attempted to root speech in the general psychophysiology of motor function. In this view, neural disorders of purposive movement, the apraxias, have been linked to the aphasias, and the left hemisphere has been considered to be primarily specialized for the control of changes in the position of both oral and manual articulators (Kimura, 1982). Other investigators have considered the left hemisphere to be specialized for general *symbolic* functions, including language (Goldstein 1948). The study of the breakdown of sign language and the breakdown of nonlinguistic gesture offers new ways of investigating apraxia and its relation to aphasia. In sign language, one can directly evaluate whether both aphasia and apraxia result from the same underlying substrate, since the expression of language and gesture does not cross transmission modalities.

In order to investigate the relationship between apraxia and aphasia for a gestural language, a series of tests for apraxia were administered to the patients, including tests of production and imitation of both repre-

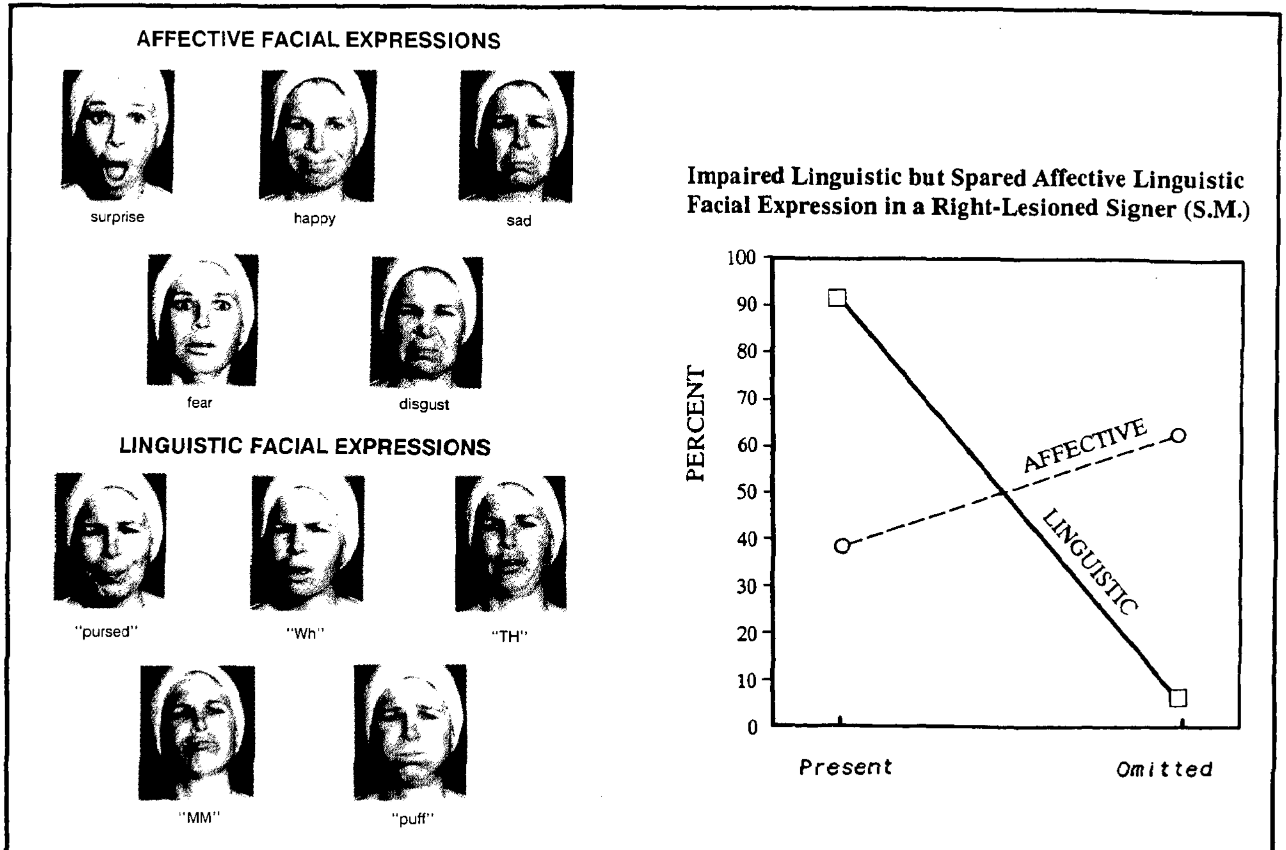


Figure 9 Dissociation between linguistic and affective facial signals in a right-lesioned signer. The *left panel* contrasts affective facial expressions with specifically linguistic facial expressions in ASL. The *right panel* shows impaired linguistic but spared affective facial expression in a right-lesioned signer.

sentational and nonrepresentational movements. The right-lesioned signers showed no evidence of either aphasia or apraxia. However, for the left-lesioned signers, all of whom were aphasic for sign language, some strong dissociations emerged between their capacities for sign language and their nonlanguage gesture and motor capacities. The language deficits of these patients were on the whole related to specific linguistic components of sign language rather than to an underlying motor disorder. Nor were these deficits related to an underlying disorder in the capacity to express and comprehend symbols of any kind (Poizner et al 1987).

Brain Systems for Signed and Spoken Language

The study of sign language can serve as a unique vehicle not only for uncovering the basic principles of hemispheric specialization, but also for investigating the nature of those anatomical structures within the left hemisphere that mediate language. Sign languages utilize channels for transmission and reception radically different from those of spoken language, and the anatomic structures important for language have certainly evolved at least in part in connection with the speech channel. Two major language-mediating neural structures, Broca's area and Wernicke's area, are linked to the speech channel. Broca's area is a portion of premotor cortex thought to program movements of the vocal tract. More importantly, Wernicke's area is part of *auditory* association cortex. Although it is clear that lesions in the left but not in the right hemisphere produce sign language aphasias, different areas within the left hemisphere may mediate language in the two modes. There are increasing reports of lesions to the parietal lobe of the left hemisphere that produce aphasias for sign language that would not be predicted for a hearing individual with that lesion (Poizner et al 1987, Chiarello et al 1982). It may well turn out that areas of the left hemisphere more intimately involved with gestural control and higher order spatial analysis emerge as language-mediating areas for sign language.

This research has broad implications for the theoretical understanding of the neural mechanisms underlying the human capacity for language. Patterns of breakdown of a visuospatial language in deaf signers allow new perspectives on the nature of cerebral specialization for language, because sign language entails interplay between visuospatial and linguistic relations within the same system. First, the 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. It thus appears that linguistic functions and the processing operations required, rather than the form of the signal, promote left hemisphere specialization for language. Finally, by uncovering the neural circuitry for sign language, one can uncover how the neural circuitry for spoken language (as well as sign language) operate for linguistic processing independently of language modality and how such circuitry is modality bound.

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