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Language, Modality and the Brain

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Biological Foundations of Language

Until recently, nearly everything learned about the human capacity for language has come from the study of spoken languages. It has been assumed that the organizational properties of language are inseparably connected with the sounds of speech, and that the fact that language is normally spoken and heard determines the basic principles of grammar.¹ There is good evidence that structures involved in breathing, chewing and the ingestion of food have evolved into a versatile and more efficient system for producing sound. Studies of brain organization indicate that the left cerebral hemisphere is specialized for processing linguistic information in the auditory-vocal mode and that the major language-mediating areas of the brain are intimately connected with the auditory-vocal channel. It has even been argued that hearing and the development of speech are necessary precursors to this cerebral specialization for language.² Thus, the link between biology and linguistic behavior has been identified with the particular sensory modality in which language has developed.

The existence of signed languages allows us to inquire about the determinants of language organization from a different perspective. What would language be like if its transmission were not based on the vocal tract and the ear? How is language organized when it is based instead on the hands and eyes? Do these transmission channel differences result in any deeper differences? Over the past decade, we have been specifying the ways in which the formal properties of languages are shaped by their modalities of expression, sifting properties peculiar to a particular language mode from more general properties common to all languages.^{3,4} American Sign Language (ASL) exhibits formal structuring at the same levels as spoken languages (the internal structure of lexical units and the grammatical scaffolding underlying sentences) as well as the same kinds of organizational principles as spoken languages. Yet the form this grammatical

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structuring assumes in a visual-manual language is apparently deeply influenced by the modality in which the language is cast.

Language in a Visuospatial Modality

American Sign Language, a primary linguistic system passed down from one generation of deaf people to the next, has been forged into an autonomous language with its own internal mechanisms for relating visual form with meaning. The grammatical processes of ASL are totally unrelated to those of English and thus add to the evidence that ASL is a separate language, though it uses hands in space.³⁻⁶ It can serve not only everyday conversation, but intellectual argumentation, scientific discussion, wit and poetry. ASL shares underlying principles of organization with spoken languages, but the physical realization of those principles occurs in formal devices arising out of the very different possibilities of the visual-gestural mode.⁷ We consider briefly the structure of ASL at three different linguistic levels: "phonology" without sound, vertically arrayed morphology, and spatially organized syntax.

"Phonology" without sound. Research on the structure of lexical signs in ASL has shown that signs are fractionated into sublexical elements just like the words of spoken languages. The contrasts that distinguish signs from one another (analogous to consonants and vowels of spoken languages) are a small set of "Handshapes," "Movements," and "Locations" that co-occur throughout the sign. Recent analyses focus on the segmental structure of signed languages, suggesting a sequential structure analogous to phonemes and syllables of spoken language.^{8, 9} Signed languages differ from one another, much as do spoken languages, and there are many different signed languages. We note that ASL and British Sign Language are mutually incomprehensible, having independent histories. Furthermore, analyses of unrelated signed languages reveal not only differences in lexicon and grammar, but even systematic phonetic differences that may cause native signers from one sign language to have an "accent" in a newly learned sign language.^{4, 10}

Vertically arrayed morphology. The grammatical mechanisms of ASL take full advantage of the spatial medium and of the possibility of simultaneous and multidimensional articulation. Like spoken languages, ASL has developed grammatical devices that serve as inflectional and derivational markers. These are regular changes in form across syntactic classes of lexical items associated with systematic changes in meaning. In ASL, families of sign forms are related via an underlying stem: the forms share Handshape, Location, and Movement shape. Grammatical processes represent the interaction of the stem with other features of movement in space (dynamics of movement, directions of movement, spatial array and the like all *layered* with the sign stem (see figure 18.1A).

In ASL, such grammatical processes can apply in combinations to signs, creating different levels of form and meaning. In these combinations, the output of one morphological process can serve as the input for another, and there are alternative orderings producing different levels of semantic structure as well, as figure 18.1A shows. The creation of complex expressions through the recursive application of hierarchically organized rules is also characteristic of the structure

of spoken languages.¹¹ However, the form such expression takes in a visual-gestural language is unique: the sign stem embedded in the pattern created by a morphological process, and nested spatially in a pattern created by the same or a different morphological process.

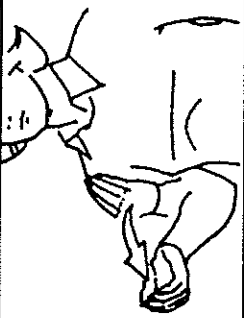
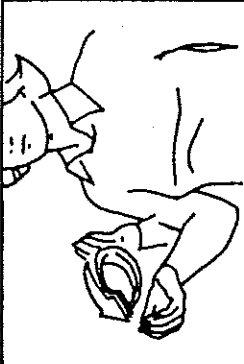

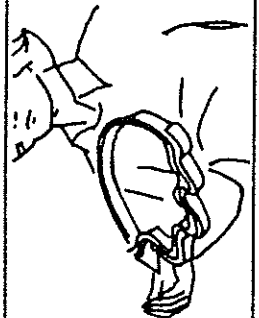
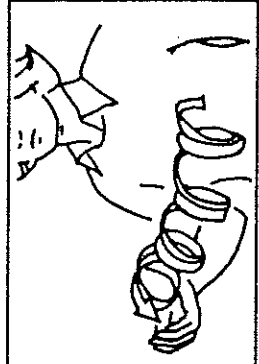
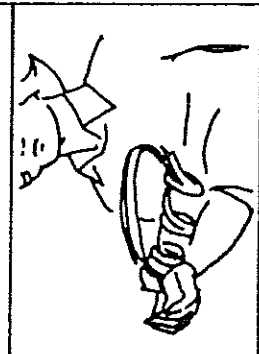
Spatially organized syntax. All spoken languages have grammatical elements and structure relating items to one another in sentences, providing the underlying scaffolding on which to build sentential meaning. Languages have different ways of marking grammatical relations among their lexical items. In English, it is primarily the order of the lexical items that marks the basic relations among verbs and their related nouns. ASL, by contrast, specifies relations among signs primarily through the manipulation of sign forms in space. In sign language, space itself bears linguistic meaning. The most striking and distinctive use of space in ASL is in syntax and discourse. Noun phrases introduced into ASL sentences may be associated with specific points in a plane of signing space: pointing again to a specific locus clearly 'refers back' to a previously mentioned noun, even with many other signs intervening.

The ASL system of verb agreement, like its system of pronouns, is also spatialized. Verb signs move between 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 18.1B. This spatialized system thus allows explicit reference through pronouns and agreement markers to distinct, third-person referents. The same signs in the same order, but with different spatial endpoints of the verb, may specify a reversal of grammatical relations. Furthermore, sentences with signs in different temporal orders can still have the same meaning, since grammatical relations are signified spatially. Different spaces may be used to contrast events, to indicate reference to time preceding the utterance, or to express hypotheticals and counterfactuals. This use of spatial loci for referential indexing, verb agreement, and grammatical relations is clearly a unique property of visual-gestural systems.⁴

ASL has developed as a fully autonomous language, with complex organizational properties not derived from spoken languages, thus illuminating the biological determinants of language. ASL exhibits formal structuring at the same levels as spoken language, and principles similar to those of spoken language (constrained systems of features, rules based on underlying forms, and recursive grammatical processes). Yet the surface form of grammatical processes in a visuospatial language is rooted in the modality in which the language developed. This difference in surface form between signed and spoken languages makes possible new investigations into the perception and production of language.

Perception, Language and Experience

Dynamic point-light displays. Linguistic analyses and experimental studies of sign language have been linked together, allowing the study of the interplay between the perception of language and the perception of motion. Specifically, one can now investigate the nature of perception of movement organized into a linguistic system.¹² To investigate linguistic movement in ASL experimentally, a method was developed to isolate movement of the hands and arms, adapting a technique

		
<p>a) GIVE (Uninflected) 'give to each'</p>	<p>b) GIVE [Durational] 'give continuously'</p>	<p>c) GIVE [Exhaustive] 'given to each'</p>
		
<p>d) GIVE [[Exhaustive]Durational] 'give to each, that action recurring over time'</p>	<p>e) GIVE [[Durational] Exhaustive] 'give continuously to each in turn'</p>	<p>f) GIVE [[[Durational] Exhaustive] Durational] 'give continuously to each in turn, that action recurring over time'</p>

A

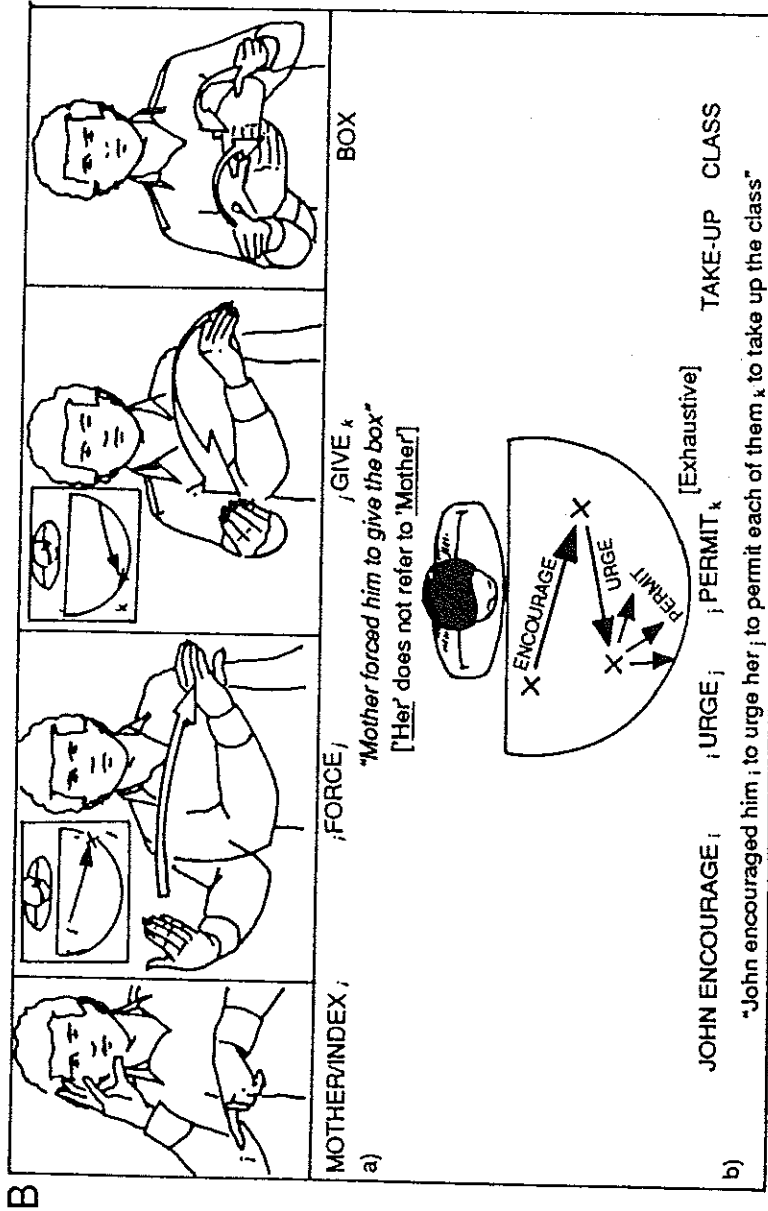
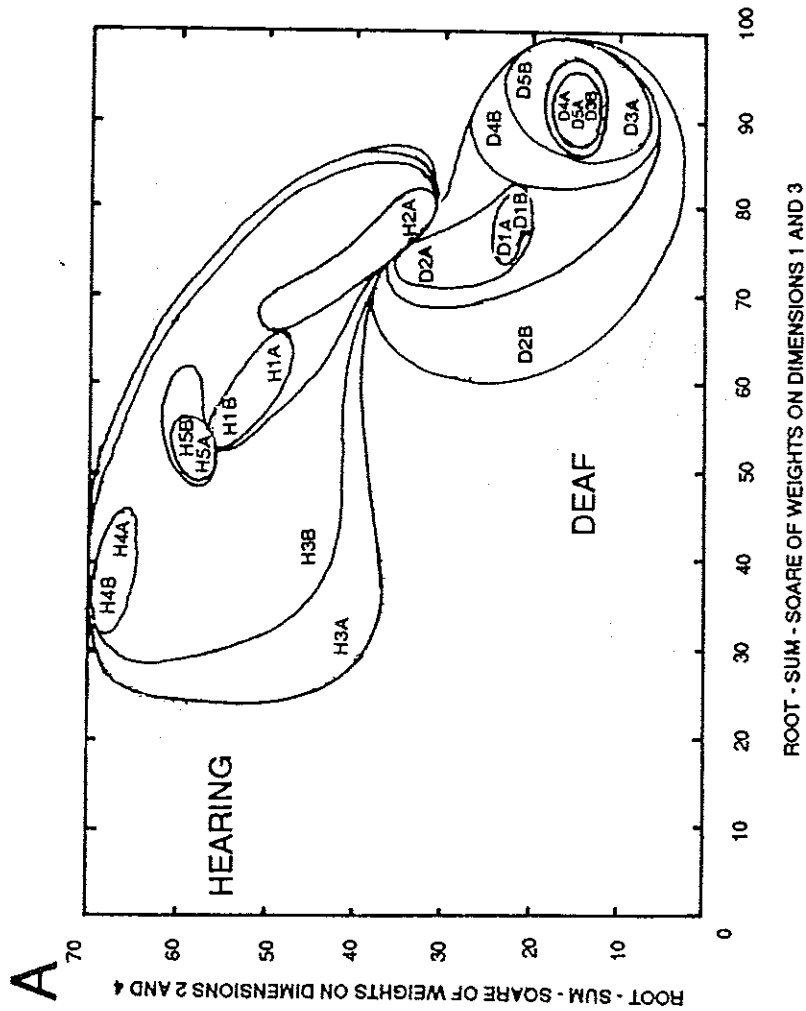


Figure 18.1 Layered morphology and spatially organized syntax in American Sign Language. (A) Hierarchical processes governing ASL grammatical inflections. The uninflected sign GIVE is shown (a), together with the sign GIVE under single inflections (b and c). The figure shows an ordered combination of inflections (Exhaustive in Durational, d) as well as a different ordering of inflections (Durational in Exhaustive with a distinct meaning, e). Finally, (f) illustrates the recursive applications of rules (Durational in Exhaustive in Durational). We note that ASL packages its grammatical information systematically in simultaneously occurring layers of structure. (B) Syntactic spatial mechanisms in ASL. The figure shows a spatially organized sentence in ASL, illustrating association of nouns with loci in space, and movement of verbs between spatial endpoints (verb agreement). Also shown is a spatial reference diagram for sentences with complex embedded structures in which co-referential nominals are indexed to the same locus point.



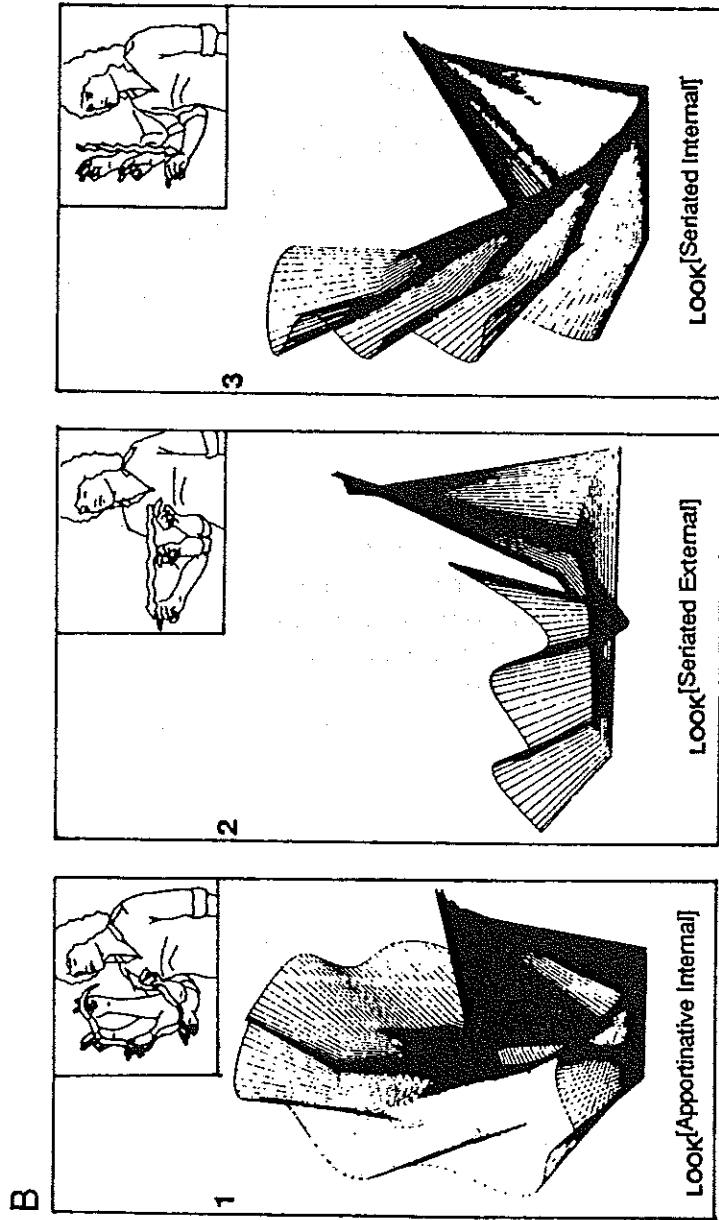


Figure 18.2 Multidimensional analysis of movement organized into a linguistic system. (A) Hierarchical clustering of correlations among subjects (closed contours) superimposed on the multidimensional scaling of judgements of movement similarity by deaf and hearing subjects. The position of each replication (A or B) of each deaf subject (D1 through D5) and each hearing subject (H1 through H5) was determined from each subject's combined weights on dimensions 2 (plane) and 4 (direction) versus his combined weights on dimensions 1 (repetition) and 3 (direction) of the scaling solution. Note the virtually complete separation between deaf and hearing subjects, reflecting the different perceptual salience of dimensions of movement for the two groups. (B) Three-dimensional reconstructions of the positions of the arm and hand for grammatical inflections in ASL contrasting in both planar locus and geometric array. The first and third reconstructions contrast minimally in geometric inflections in ASL (linear path movement), whereas the second and third reconstructions contrast minimally in planar locus (horizontal versus vertical).

introduced by Johansson¹³ to study the perception of biological motion.¹⁴ Small incandescent bulbs were placed at the major joints of the arms and hands, and signing recorded in a darkened room so that only the patterns of moving lights appeared against a black background. Even with such greatly reduced information, deaf signers identified morphological processes of ASL presented in these point-light displays with a high degree of accuracy, demonstrating that these patterns of dynamic contours of movement form a distinct, isolable layer of structure in ASL.

The interplay between perceptual and linguistic processes. To investigate the relation between basic perceptual processes and higher order linguistic ones, the psychological representation of ASL movement by native deaf signers was contrasted with that of hearing non-signers. Triads of ASL signs were presented as point-light displays for judgements of movement similarity. Multidimensional scaling and hierarchical clustering of judgements for both groups of subjects revealed that the inflectional movements were perceived in terms of a limited number of underlying dimensions. Furthermore, the psychological representation of movement differs for deaf and hearing subjects, with perception of movement form tied to linguistically relevant dimensions for deaf, but not for hearing subjects (figure 18.2A). Thus, the data suggest that acquisition of a visual-gestural language can modify the natural perceptual categories into which linguistically relevant forms fall.^{15, 16}

The study of sign languages provides a powerful vehicle for analysing language production since in sign language, but not in spoken language, movements of the hands are directly observable. In order to analyse the structure of movements that have been forged into a linguistic system, methods have been developed to track movements in three-dimensional space and reconstruct them computer-graphically.^{17, 18} Figure 18.2B presents three-dimensional reconstructions of the sequential positions of the arm and hand throughout the course of three grammatical inflections expressed in ASL through modulations of movement. These illustrate the essential nature of grammatical contrasts that have developed in ASL, conveyed through dimensions unique to visual-spatial language, such as planar locus and geometric array. Thus, processing grammatical relations in sign language also requires the processing of spatial relations, since in sign language the two are intimately intertwined. These powerful techniques for the three-dimensional computergraphic analysis of movement are now being coupled with linguistic analysis to explore how the brain controls movement at different levels – *linguistic, symbolic and motoric.*^{19, 20}

Brain Organization: Clues from a Visuospatial Language

American Sign Language (ASL) displays the complex linguistic structure found in spoken languages but 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 brain-damaged deaf signers offers special insight into the organization of higher cognitive functions in the brain, and how modifiable that organization may be. How is language represented in the brain when linguistic relations are expressed spatially?

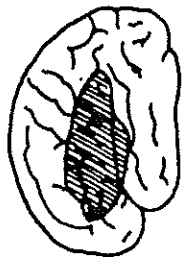
Systematic studies of the grammatical structure of sign language have only recently become available,^{4, 5, 21-26} allowing analyses of the nature of ASL breakdown following localized lesions to the brain.

The relative contributions of each cerebral hemisphere with special reference to the interplay between linguistic functions and the spatial mechanisms that convey them has recently been systematically investigated, focusing on the nature of the linguistic breakdown following localized lesions to the brains of deaf signers. We carried out three series of experimental studies, each bringing to bear a special property of the visual-gestural modality on the investigation of brain-language relationships. Right- and left-lesioned deaf signers (and matched controls) were given a battery of tests designed to assess their capacities for sign language, spatial cognition and motor function.²⁷⁻³⁰ Figure 18.3 shows the background characteristics and lateral reconstructions of brain lesions of six deaf signers reviewed below.

Language capacities of left- and right-lesioned signers. Signers with left hemisphere damage showed clear sign language aphasias, as indicated by results on tests for processing the structural levels of ASL, on a sign aphasia examination, and on linguistic analyses of their signing. To illustrate the nature of the aphasias that occur for a visual-gestural language, the deficits of several left-lesioned deaf signers with aphasia are briefly described. One left hemisphere damaged signer (GD) was agrammatic for ASL. After her stroke, her signing was severely impaired; it was halting and effortful, and reduced to single sign utterances, shorn of the syntactic and morphological markings of ASL (figure 18.4A). Her lesion was typical of those that produce agrammatic aphasia for spoken language. Another left hemisphere damaged signer (KL) had motorically facile signing, but made selection errors in the formational elements of signs, producing the ASL equivalent of phonemic paraphasias (figure 18.4B). She had a severe and lasting sign comprehension loss, although both major language-mediating areas for spoken language (Broca's and Wernicke's areas) were intact. Her lesion was in the parietal area known to function in higher spatial analysis. A third left hemisphere damaged signer (PD) showed primary impairment at the grammatical level. His signing before his stroke was articulate, even eloquent. After his stroke, he produced grammatically inappropriate signs (paragrammatisms) in the context of fluent sign output. Furthermore, he displayed errors of spatially organized syntax of ASL (figure 18.4C). Thus, differential damage within the left hemisphere produced sign language impairments that were not uniform, but rather broke down along lines of linguistically relevant components.³¹

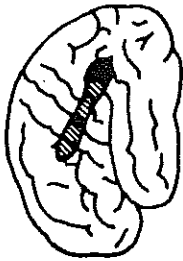
Quite remarkably, considering the spatial nature of sign language, the signers with right hemisphere damage were not aphasic. They exhibited fluent, grammatical, virtually error-free signing, with a good range of grammatical forms, no agrammatism, and no signing deficits. Their performance on our Sign Diagnostic Aphasia Battery (adapted from Goodglass and Kaplan³²) revealed intact sign language capacities for right-lesioned signers. Furthermore, only the right hemisphere damaged signers were unimpaired on our tests of ASL grammatical structure (phonology, morphology, syntax). Figure 18.5A shows the results of an ASL test equivalent of 'rhyming'. Importantly, right-lesioned signers had no impairment in the grammatical aspects of their signing, including their spatially

LEFT HEMISPHERE DAMAGED SIGNERS



PD

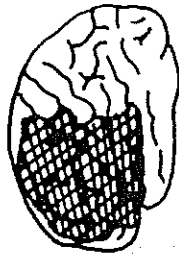
81yr. old ♂



KL

67yr. ♀

Rt. Hemiplegia



GD

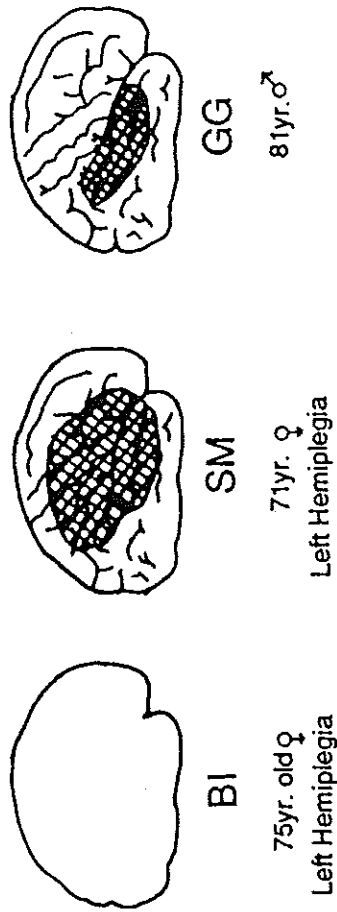
38yr. ♀

Rt. Hemiplegia

Language environment

Patient	Age at testing	Sex	Age at onset of deafness	Handedness	Parents and siblings	Language environment				Primary communication	Sign	Lesion
						School	Spouse	Cultural group	Hemiplegia			
Paul D.	81	M	5 yrs.	Right	Hearing	Residential deaf	Residential deaf	Deaf	Deaf	Deaf	---	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	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	Deaf	Sign	Right hemiplegic	Most of convexity of left frontal lobe; Broca's area damaged.

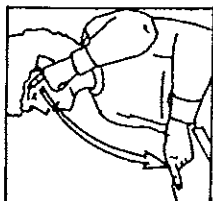
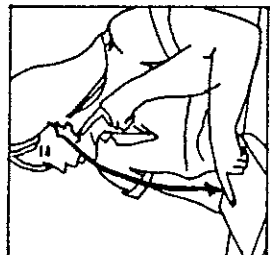
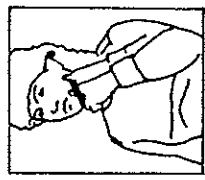
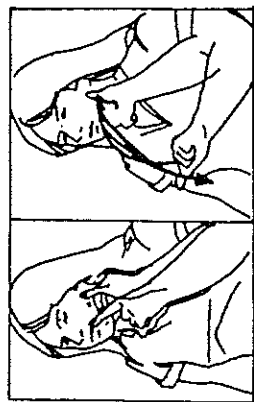
RIGHT HEMISPHERE DAMAGED SIGNERS



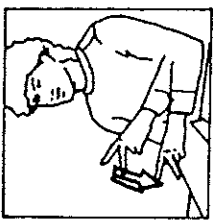
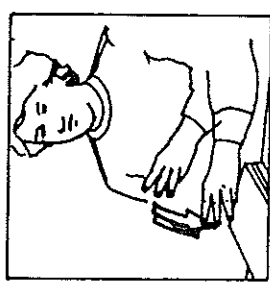
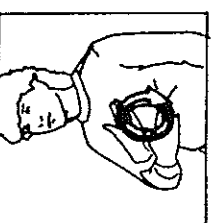
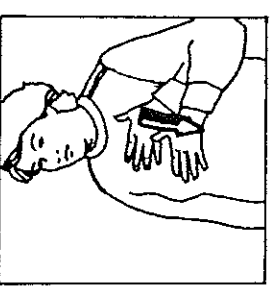

Subject	Age	Sex	Birth	Hearing	Right	Left	Sign	Deaf	Residential deaf	Right hemisphere
Brenda I.	75	F	Birth	Hearing	Right	Left hemiplegic	Sign	Deaf	Residential deaf	Right hemisphere
Sarah M.	71	F	Birth	Hearing	Right	Right hemiplegic	Sign	Deaf	Residential deaf	Right temporoparietal area; most of territory of right middle cerebral artery damaged
Gilbert G.	81	M	5 yrs.	Hearing	Right	—	Sign	Deaf	Residential deaf	Right superior temporal and middle temporal gyri extending into the angular gyrus.

Figure 18.3 Summary characteristics and lateral reconstructions of lesions of three left and three right hemisphere damaged deaf signers. All six were right-handed, had gone to residential schools for deaf children, married deaf spouses, and had used sign language as the primary form of communication throughout their lives. Note that no CT scan was available for BI.

A

<p>Correct form</p>  <p>BROTHER</p>	<p>Gail D.'s form</p>  <p>BROTHER</p>
<p>Correct form</p>  <p>GIRL</p>	<p>Gail D.'s form</p>  <p>GIRL</p>

B

<p>Correct form</p>  <p>CAREFUL</p>	<p>Karen L.'s Sublexical errors</p> 
<p>ENJOY</p> 	<p>Karen L.'s Handshape errors (/W/ for /K/)</p> 
	<p>Karen L.'s Movement errors (/N/ for /@/)</p> 

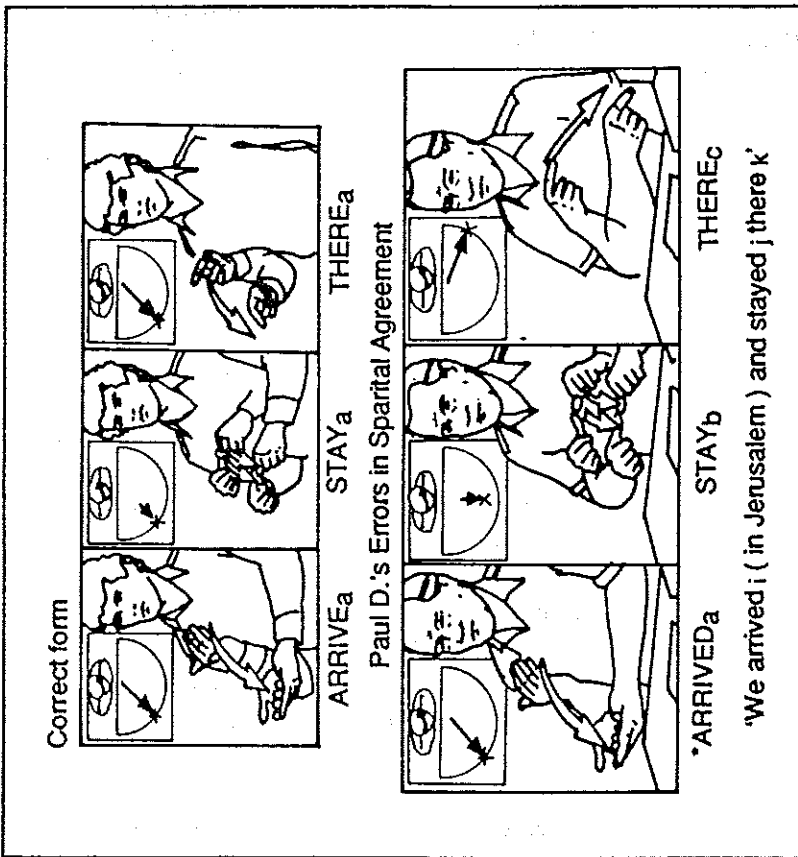


Figure 18.4 Characteristic errors of left-lesioned signers showing breakdown of American Sign Language at different structural levels. (A) Articulatory difficulty characteristic of GD's signing. In the example, she searches for the handshape, movement, and location of two signs, although on other occasions she can produce the signs smoothly. (B) Sublexical (or 'phonological') errors typical of KL's signing. Note selection errors within major formational parameters of ASL of handshape and movement. These are the equivalent of phonemic paraphasias in spoken language. (C) Failure of spatially organized syntax in PD's signing. Note the lack of spatial agreement in PD's sentence, rendering it ungrammatical in ASL.

organized syntax; they even used the left side of signing space to represent syntactic relations, despite their neglect of left hemisphere in non-language tasks.²⁸

Spatial cognition in signers with left and right hemisphere lesions. The preserved signing of the right-lesioned signers was in the face of their marked deficits in processing non-language spatial relationships. Across a range of tasks, including drawing, spatial construction, spatial attention, judgement of line orientation, facial discrimination, right-lesioned signers showed the classical visuospatial impairments seen in hearing patients with right hemisphere damage. In contrast, left-lesioned signers showed relatively preserved non-language spatial functioning. The severe disorganization of the spatial constructions of right-lesioned signers in contrast to relatively good constructions of the left-lesioned signers is shown in figure 18.5B. Even the right-lesioned signer who was an artist before her stroke showed disorganization, failure to indicate perspective, and neglect of left hemisphere in her drawings afterwards. These data show that the right hemisphere in deaf signers can develop cerebral specialization for non-language visuospatial functions. In light of their major non-language spatial deficits, the impeccable use of the spatial mechanisms for syntax in right-lesioned signers shows how little effect right hemisphere damage can have on language, even when spatial contrasts are crucial at all linguistic levels.^{30, 31}

The contrast between spatial syntax and spatial mapping. Spatial contrasts and spatial manipulations figure structurally at all linguistic levels in ASL. For syntactic functions, spatial loci and relations among these loci are actively manipulated to represent grammatical relations. As opposed to its syntactic use, space in ASL also functions in a topographic way: the space within which signs are articulated can be used to describe the layout of objects in space. In such mapping, spatial relations among signs correspond topographically to actual spatial relations among the objects described. We investigated the breakdown of two uses of space within sign language, one for syntax and the other for mapping. Subjects were asked to describe the spatial layout of their living quarters from memory; in this task, signing space is to describe space and actual spatial relations are thus significant. The descriptions given by the right-lesioned signers were grossly distorted spatially. In contrast, room descriptions of the left hemisphere damaged signers were linguistically impaired (matching their linguistic breakdown in other domains) but without spatial distortions.

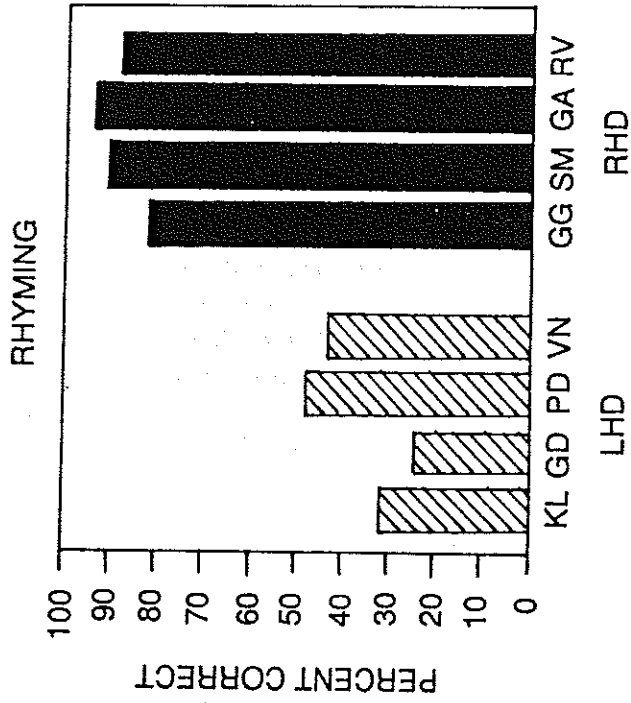
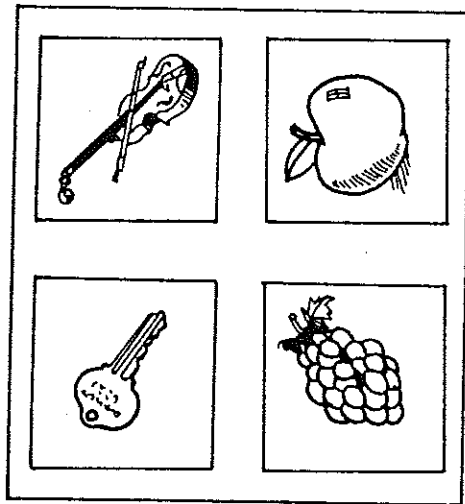
When space was used in ASL to represent syntactic relations, however, the pattern was reversed. The left hemisphere damaged signer, who showed consistent failure in his spatially organized syntax, was able to describe the layout of his room with some omissions but no spatial distortions. A dissociation was also dramatically displayed in a right-lesioned signer. The description she gave of her room showed severe spatial disorganization: furniture piled in helter-skelter fashion on the right, and the entire left side of signing space left bare. However, in her use of the spatial framework for syntax in ASL, she established loci freely throughout the signing space (including on the left) and maintained consistent reference to spatial loci. Thus even within signing, the use of space to represent *syntactic* relations and the use of space to represent *spatial* relations may be differentially affected by brain damage, with the syntactic relations disrupted by left hemisphere damage and the spatial relations disrupted by right hemisphere damage.^{28, 30}

The separation between apraxia and sign aphasia. In a long-standing controversy over the nature of aphasic disorders, certain investigators have proposed a common underlying basis for disorders of gesture and disorders of language. One position is that disorders of language occur as a result of more primary disorders of movement control. A second position is that both apraxia and aphasia result from an underlying deficit in the capacity to express and comprehend symbols.

Since gesture and linguistic symbols are transmitted in the same modality in sign language, the breakdown of the two can be directly compared. In addition to an array of language tests, a series of apraxia tests was administered to brain-damaged deaf subjects, including tests of production and imitation of representational and non-representational movements. The right hemisphere damaged signers were neither aphasic nor apraxic. However, for the left hemisphere damaged signers, all of whom were aphasic for sign language, some strong dissociations emerged between their language and non-language gesture and motor capacities.³⁰ The language deficits of these signers were on the whole related to specific linguistic components of sign language rather than to an underlying motor disorder, or to an underlying disorder in the capacity to express and comprehend symbols of any kind. This separation between linguistic and non-linguistic functioning is all the more striking since sign language and gesture are transmitted in the same modality.

Converging evidence regarding brain organization for signing. A recent study (Damasio *et al.*) analyzed the sign language of a hearing signer proficient in ASL during a left intracarotid injection of sodium amytal (Wada Test), and before and after a right temporal lobectomy for her epilepsy.³³ Neuropsychological and anatomical asymmetries suggested left cerebral dominance for auditory-based language. Single photon emission tomography (SPET) revealed lateralized activity of left Broca's and Wernicke's areas for spoken language (figure 18.6A). The Wada Test, during which all left language areas were rendered inoperative, caused a marked aphasia in both English and ASL. The patient's signing was markedly impaired, with many incorrect sign responses and sign neologisms. Interestingly, since she was hearing and could sign and speak at the same time, it was possible to compare her responses in two languages simultaneously – a unique possibility for languages in different modalities. This revealed a frequent mismatch between word and sign, the sign being frequently incorrect both in meaning and in form (figure 18.6B). Subsequently, the patient had the anterior portion of her right temporal lobe removed surgically (figure 18.6C). Analysis of her language after the surgery revealed no impairment of either English or sign language. These findings add further support to the notion that the left cerebral hemisphere subserves language in a visuospatial as well as an auditory mode.³³

Converging evidence also comes from a combination of behavioral and neurophysiological studies in deaf signers without lesions (Neville³⁴⁻³⁶). In Neville's studies, digitized sequences of ASL signs were presented to the left and right visual fields of deaf native signers and hearing non-signers. The deaf native signers, but not the hearing non-signers, showed a left hemisphere specialization for processing signs of ASL, providing further evidence for left hemisphere specialization for sign language. From these converging perspectives, it is becoming clear that the primary specialization of the left hemisphere rests not on the form of the signal, but rather on the linguistic function it subserves.



a) Test For Processing Sublexical Structure in ASL: Rhyming

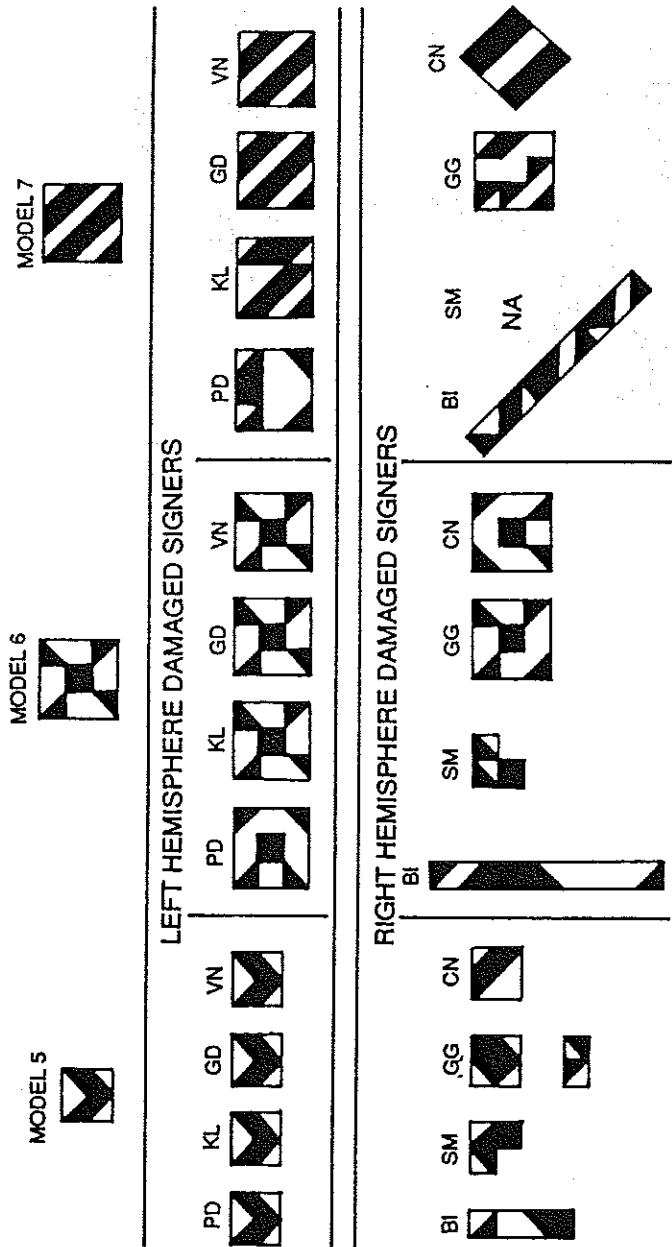
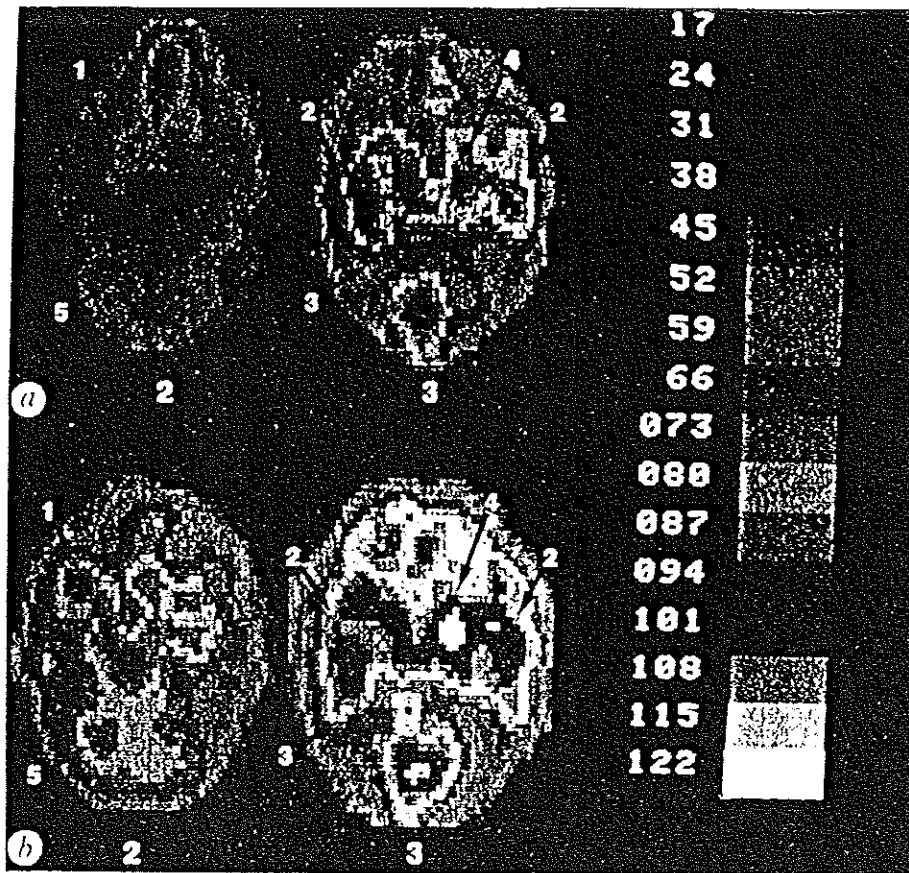


Figure 18.5 Impaired linguistic performance of left-lesioned signers contrasted with impaired spatial capacity of right-lesioned signers. (A) Results from a test of ASL phonology, the sign equivalent of 'rhyming'. Subjects were asked to indicate the two pictures that represented the sign equivalent of 'rhyme' in ASL. In the figure, the correct answer is 'apple' and 'key', since their associated signs are the same in all but one of the three major parameters of ASL (e.g. they have the same handshape and movement, and differ only in location). Right-lesioned signers (RHD) show far superior performance to left-lesioned signers (LHD) on this test. (B) Sample performance on a block arrangement task in which subjects must assemble either four or nine three-dimensional blocks to match a two-dimensional model of the top surface. On this non-language visuospatial task, left-lesioned signers were markedly superior to right-lesioned signers. The left-lesioned 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-lesioned signers (lower row) produced erratic and incorrect constructions and tended to break the overall configurations of the arrangements.



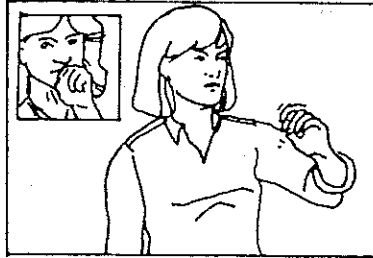
SPET Study At Rest (a) and During a Verbal Rhyme Detection Task(b).

Figure 18.6 Left hemisphere specialization for both spoken and signed language in a hearing signer. (A) Cuts 2 and 3 of a six-slice SPET study at rest and during an auditory rhyme detection task. During activation, there is an increase of radiosignal in Broca's region (the left frontal fields 44 and 45, indicated by arrow 1), and a bilateral increase of signal in auditory cortices (indicated by arrow 2). In the left hemisphere, the signal increase extends into Wernicke's area (the posterior sector of area 22, arrow 3), suggesting that the processing of spoken language is lateralized to the left hemisphere. During activation, there is also an increase in the right basal ganglia (arrow 4) and left cerebellar hemisphere (arrow 5), two motor structures that are engaged by the movement of the left foot required to signal appropriate rhyme detection. (B) Three errors produced by the patient during left Wada injection. Asked to name an object, the patient often produced simultaneously a correct English word and an incorrect ASL sign. Some sign errors were blends of formational components from different ASL signs, producing nonsense forms that were well-formed in ASL, but meaningless. During recovery from the left Wada injection, the patient frequently responded in speech and sign simultaneously (a possibility confined to languages using different transmission channels). The two languages were frequently mismatched and the sign was more often in error. Inserts in the upper left-hand corner of the illustrations indicate the correct ASL signs. (C) Magnetic resonance images obtained after surgical removal of portions of the right hemisphere. The top left-hand image is a mid-sagittal cut, showing the mesial aspect of one hemisphere. The vertical lines represent the level and incidence of the coronal cuts. Cuts 2, 4 and 5 are reproduced depicting the area of right temporal lobe ablation. Hippocampus, parahippocampal gyrus, fourth, third and second temporal gyri are missing. (Taken, with permission, from Ref. 33. Copyright © 1986 Macmillan Magazines.)

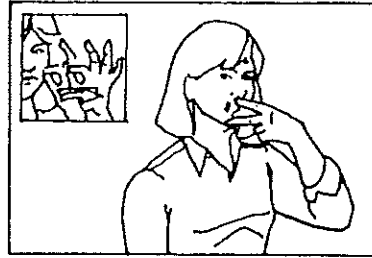
B



speech: ['cigarette']
sign: [SCISSORS]



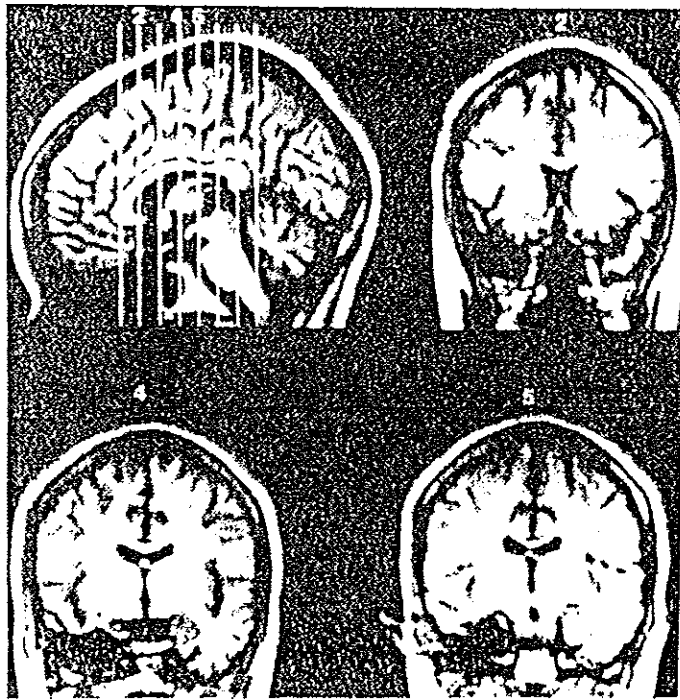
speech: ['orange']
sign: [Neologism]
ORANGE / SCISSORS blend



speech: ['cat']
sign: [Neologism]
different ORANGE / SCISSORS blend

The Conflict Between Sign and Speech Errors During left Wada Test

C



MRI Brain Scan Following Right Temporal Lobectomy

Concluding Remarks

We have reviewed studies that investigate language, its formal architecture, and its representation in the brain, by analysing visuospatial languages passed down from one generation of deaf people to the next. Analysis of patterns of breakdown in deaf signers provides new perspectives on the determinants of hemispheric specialization for language. First, the data show that hearing and speech are not necessary for the development of hemispheric specialization: sound is *not* crucial. Second, it is the left hemisphere that is dominant for sign language. Deaf signers with damage to the left hemisphere show marked sign language deficits but a relatively intact capacity for processing non-language visuospatial relations. Signers with damage to the right hemisphere show the reverse pattern. Thus, not only is there left hemisphere specialization for language functioning, but there is also complementary specialization for non-language spatial functioning. The fact that grammatical information in sign language is conveyed via spatial manipulation does not alter this complementary specialization. Furthermore, components of sign language (lexicon and grammar) can be selectively impaired, reflecting differential breakdown of sign language along linguistically relevant lines. These data suggest that the left hemisphere in man may have an innate predisposition for language, regardless of the modality. Since sign language involves an interplay between visuospatial and linguistic relations, studies of sign language breakdown in deaf signers may, in the long run, bring us closer to the fundamental principles underlying hemispheric specialization.

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