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Bellugi, U. & Klima, E. (1997). Language, spatial cognition and the brain. In M. Ito, Y. Miyashita and E.T. Rolls (Eds.), *Cognition, computation and consciousness* (pp. 177-189). Cambridge, England: Oxford University Press.

Language, spatial cognition, and the brain

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Introduction

For a book on consciousness, cognition, and computation, the study of language and its representation in the brain is clearly crucial. There is general agreement that language expression, processing, and even aspects of internal representation may be co-extensive with consciousness and that language, at the minimum, considerably enriches consciousness. The scientific study of language, until recently, has involved primarily the study of spoken languages; in fact, nearly all that was known about language and its representation in the brain had come from the study of spoken languages. New research into signed languages has revealed that there are primary linguistic systems, passed down from one generation of deaf people to the next, which have been forged into autonomous languages and are not derived from spoken languages. Thus, we can now examine properties of linguistic systems that have developed in alternate modes of transmission. Studies of signed languages have shown that fully expressive languages can arise outside of the mainstream of human spoken languages, and exhibit the same kinds of linguistic organization found in the thousands of spoken languages the world over (Bellugi and Hickok 1995; Bellugi and Studdert-Kennedy 1980; Klima and Bellugi 1988).

Although spoken and signed languages are structurally similar at their core, the surface properties of the two modes are radically different—each deeply rooted in the modalities involved in its production and perception. Both spoken and signed languages involve the same kinds of organization (phonology, morphology, syntax, semantics, hierarchically governed complex rule systems, argument structure, lexical categories, and syntactic constraints). Signed languages serve not only everyday conversation, but intellectual argument, scientific discussion, wit, and poetry. Yet, on the surface, the formal devices subserving signed and spoken languages are markedly different. Whereas spoken languages rely primarily on rapid temporal sequencing for each of their linguistic layers, signed languages are deeply rooted in their modes of perception and production. Multilayering of linguistic elements and the structured use of space in the service of syntax are major modality-determined aspects of signed languages. Thus, the most striking surface difference between signed and spoken language is the reliance on *spatial* contrasts at all linguistic levels. We describe a programme of studies, illuminated by new techniques in brain imaging, leading toward a deeper understanding of the neural systems that subserve language and other higher cognitive functions. Using a multidisciplinary approach we seek to gain insight into the often inaccessible workings of the brain by studying unusual languages and populations with differing cognitive and language abilities (Bellugi 1980; Bellugi *et al.* 1990; Poizner *et al.* 1990).

Perspectives from language in a different modality

Experimental findings concerning the neural basis of language necessarily bear on neurolinguistic systems only as they relate to auditory and phonetic processing. In fact, 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, as well as the organization of the brain for language. Studies of brain organization indicate that the left cerebral hemisphere is specialized for processing linguistic information in the auditory–vocal mode; thus the link between biology and behaviour has been identified with the particular sensory modality in which language has developed.

Although evolution in humans has been for spoken language (there is no group of hearing people that has a sign language as its primary linguistic system), recent research into sign languages has revealed the existence of primary linguistic systems that have developed naturally in visual/manual modalities. These signed languages have all of the complexities of spoken languages, and are passed down from one generation of deaf people to the next. Importantly, these sign languages are not derived from the spoken language of the surrounding community: rather, they are autonomous languages with their own grammatical form. Indeed, the sign language developed by deaf people in Great Britain is *mutually incomprehensible* with the sign language that has developed among deaf people in the United States. There are now numerous studies of primary signed languages arising independently in different countries around the world, including Bali, Brazil, China, Japan, and many more. The existence of these primary visual/manual linguistic systems can provide a new perspective on the determinants of brain organization for language: how is language organized when it is based instead on moving the hands in space, and on visually processing? We can now investigate the neurobiology of language when language itself is spatially realized (Bellugi *et al.* 1993).

American Sign Language (ASL) exhibits formal structuring at the same levels as spoken languages, and similar kinds of organizational principles as spoken languages. At the core, spoken and signed languages are essentially identical in terms of rule systems. Nevertheless, on the surface, signed and spoken languages differ markedly. The formal grammatical structuring assumed by a visual/manual language is deeply influenced by the modality in which the language is cast, at all structural levels. ASL displays complex *linguistic* structure, but unlike spoken languages, conveys much of its structure by manipulating *spatial* relations, making use of spatial contrasts at all linguistic levels.

In our research, we have been specifying the ways in which the formal properties of language are shaped by their modalities of expression; sifting properties peculiar to a particular language mode from more general properties common to all languages. As noted, the most striking surface difference between signed and spoken languages is the reliance on *spatial* contrasts, most evident in the grammar of the language. Figure 12.1 shows some aspects of grammatical structure in ASL and its reliance on spatial contrasts. Instead of relying on linear order for inflectional marking, as in English (*act, acting, acted, acts*), ASL grammatical processes nest sign stems in spatial patterns of considerable complexity; thereby marking grammatical functions such as number, aspect, and person. Grammatically complex forms can be spatially nested, one inside the other, with different orderings producing different meanings (A). Similarly, the syntactic structure specifying relations of signs to one another in sentences of ASL is also essentially spatially organized. Nominal signs may be associated with abstract positions in a plane of signing space, and direction of movement of verb signs between such end-points marks grammatical relations. Pronominal signs directed towards these previously established loci clearly function to refer back to nominals, even with many signs intervening (B). This spatial organization underlying syntax is a unique property of visual–gestural systems.

Neural systems subserving a visuospatial language

Not only is sign language independent from spoken language, it is transmitted in a different modality and encodes linguistic structure in essentially *spatial* distinctions rather than temporal distinctions. These differences between signed and spoken languages provide an especially powerful tool for understanding the neural systems subserving language. Consider the following: in hearing/speaking individuals, language processing is mediated by the left cerebral hemisphere, whereas visuospatial processing is mediated by the right cerebral hemisphere. But what about a language that is communicated using spatial contrasts rather than temporal contrasts? On the one hand, the fact that sign language has the same kind of complex linguistic structure as spoken languages and the same expressivity might lead one to expect left hemisphere mediation. On the other hand, the spatial medium so central to the linguistic structure of sign language clearly suggests right hemisphere mediation. In fact, the answer to this question is dependent on the answer to another, deeper question concerning the *basis* of the left hemisphere specialization for language. Specifically, is the left hemisphere specialized for language processing *per se* (i.e. is there a brain basis for language as an independent entity)? Or is the left hemisphere's dominance generalized to processing any type of information that is presented in terms of temporal contrasts? If the left hemisphere is indeed specialized for processing language itself, sign language processing should be mediated by the left hemisphere just as spoken language is. If however, the left hemisphere is specialized for processing fast temporal contrasts in general, we would expect sign language processing to be mediated by the right hemisphere. The study of sign languages in deaf signers permits us to pit the nature of the signal (auditory/temporal vs. visual/spatial) against the type of information (linguistic vs. non-linguistic) that is

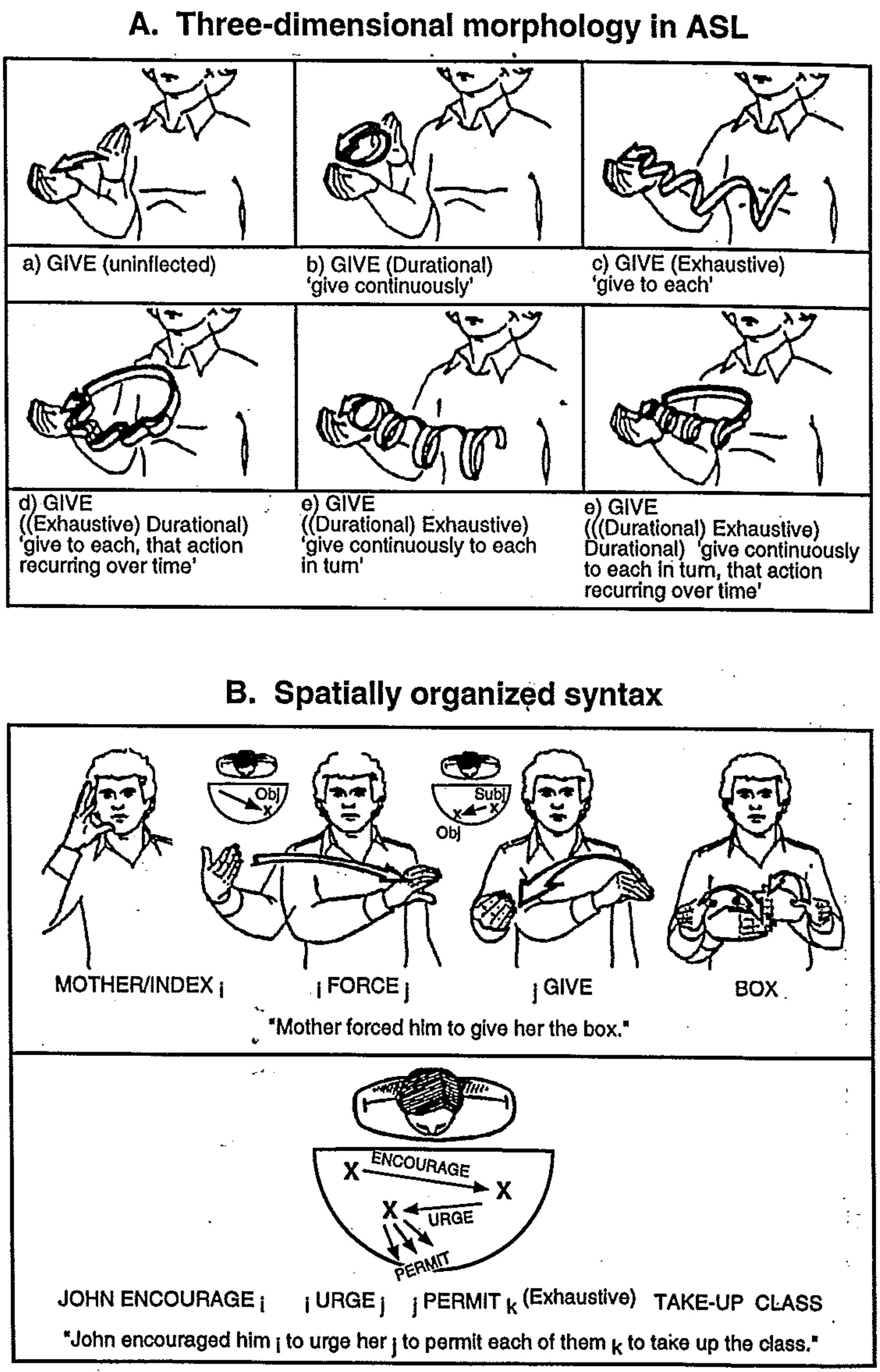

Fig. 12.1 Morphology and syntax in ASL.

encoded in that signal as a means of examining the neurobiological basis of language.

We address these questions through a large programme of studies of deaf signers with focal lesions to the left or the right cerebral hemisphere. We investigate several major areas, each focusing on a special property of the visual–gestural modality as it bears on the investigation of brain organization for language. We have now studied intensively more than twenty deaf signers with left or right hemisphere focal lesions; all are highly skilled ASL signers and all used sign as a primary form of communication throughout their lives. Our subjects are examined with an extensive battery of experimental probes, including formal testing of ASL at all structural levels, spatial cognitive probes sensitive to right hemisphere damage in hearing people, and new methods of brain imaging. Figure 12.2 shows the superimposition of lateral reconstructions of lesions from a large number of deaf signers, separated into those with left hemisphere lesions versus those with right hemisphere lesions. This programme allows us to begin to map out the differential effect of lesions in various regions of the brain on language and cognitive systems. The large pool of well-studied and thoroughly characterized subjects thus allows a new perspective on the determinants of brain organization for language (Bellugi and Hickok 1995; Hickok *et al.* 1995, 1996; Damasio *et al.* 1986).

Left hemisphere lesions and sign language grammar

Our first major finding is that only deaf signers with damage to the left hemisphere show sign language aphasias. Marked impairment in sign language after left hemisphere lesions was found in the majority of the left hemisphere damaged (LHD) signers but not in any of the right hemisphere damaged (RHD) signers, whose language profiles were much like matched controls. Figure 12.3(a) presents a comparison of LHD, RHD, and normal control profiles of sign characteristics from our Sign Diagnostic Aphasia Examination—a measure of sign aphasia. The RHD signers showed no impairment at all in any aspect of ASL grammar; their signing was rich, complex, and without deficit, even in the spatial organization underlying sentences of ASL. By contrast, LHD signers showed markedly contrasting profiles: one was agrammatic after her stroke, another made frequent paraphasias at the sign internal level, and a third showed grammatical paraphasias, particularly in morphology. A fourth deaf signer showed deficits in the capacity to perform the spatially encoded grammatical operations which link signs in sentences, a remarkable failure in the spatially organized syntax of the language. Figure 12.3(b) presents illustrations of aphasic errors at the lexical level, a movement substitution and a location substitution, made by two different left lesioned signers. In contrast, none of the RHD signers showed any within-sentence deficits; they were completely unimpaired in sign sentences and not one showed any hint of aphasia for sign language (in contrast to their marked non-language spatial deficits, described below).

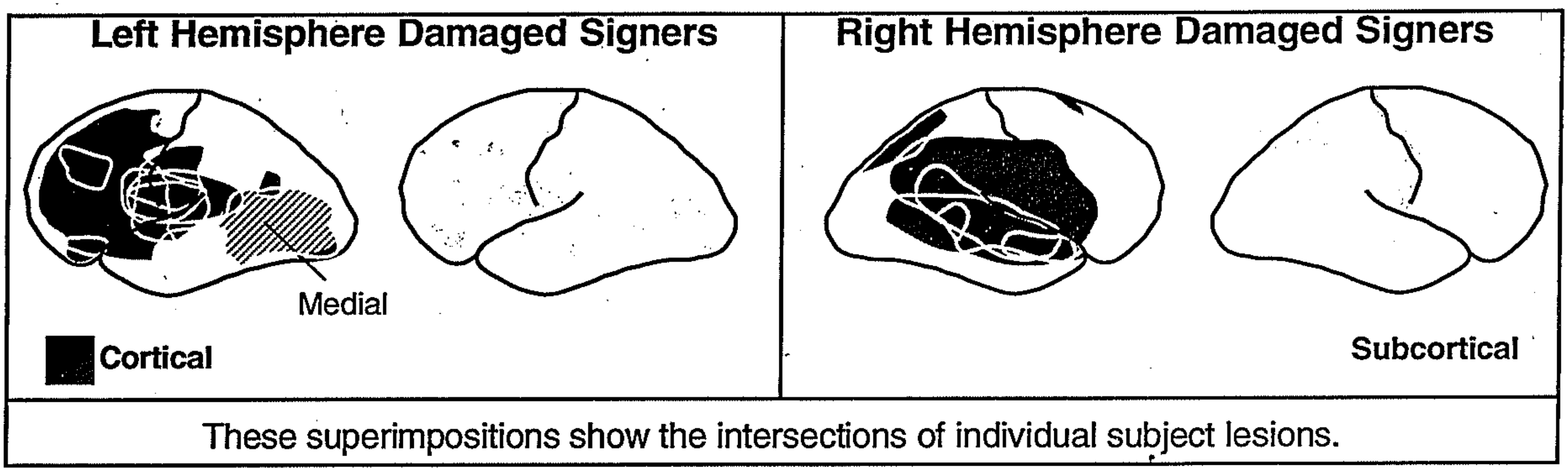

Fig. 12.2 Superimpositions of lesions from left- and right-lesioned deaf signers, lateral reconstructions.

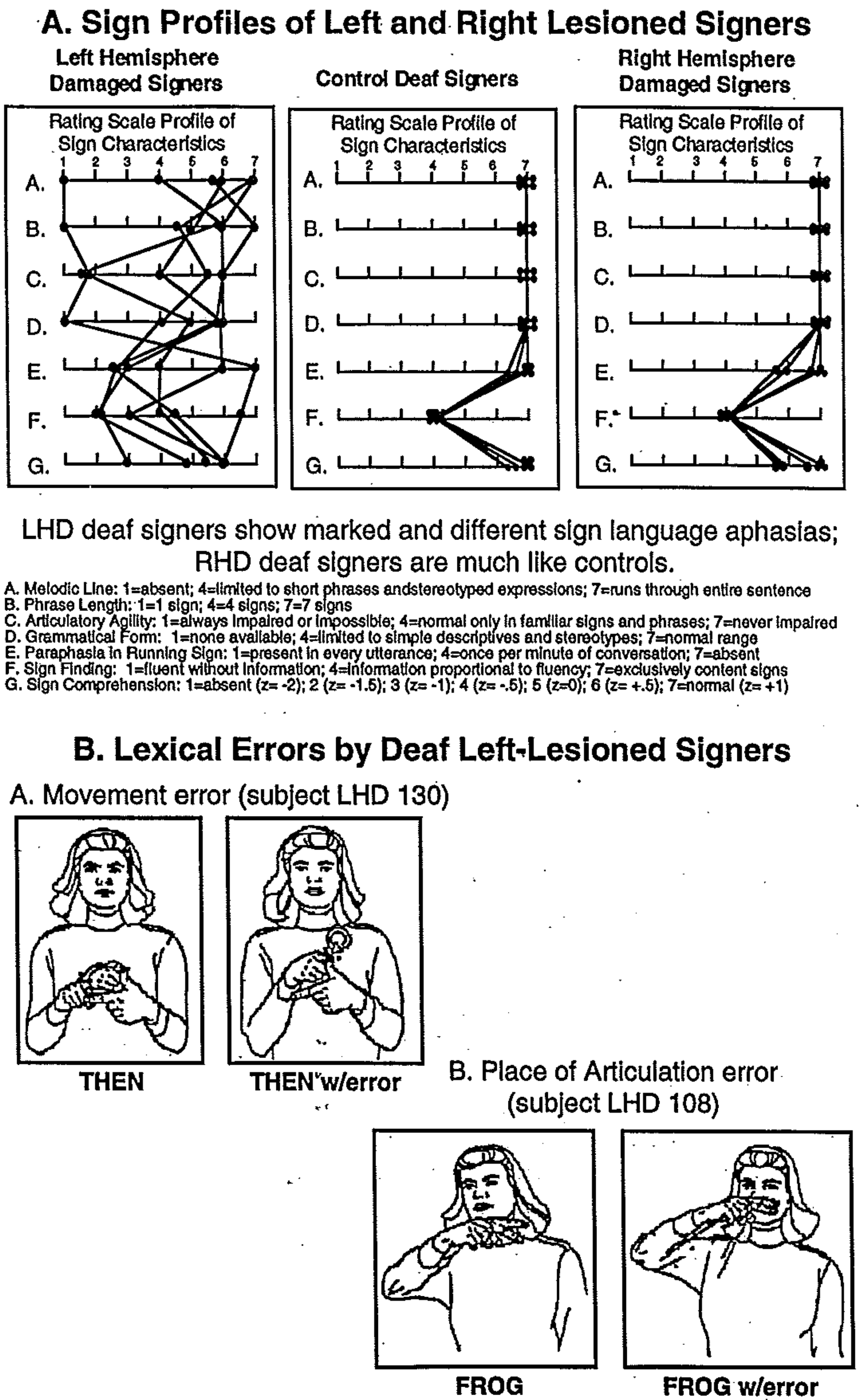

Fig. 12.3 (a) Sign profiles of left- and right-lesioned signers. LHD deaf signers show marked and different sign language aphasias; RHD deaf signers are much like controls. (b) Lexical errors by left-lesioned deaf signers.

Moreover, we find dramatic differences in performance between left and right hemisphere damaged signers on formal experimental probes of sign competence. For example, we developed a test of the equivalent of rhyming in ASL, a probe of phonological processing. Two signs 'rhyme' if they are similar in all but one phonological parametric value such as handshape, location, or movement. To tap this aspect of phonological processing, subjects are presented with an array of pictured objects and asked to pick out the two objects whose signs 'rhyme', that is, differ only in one parameter (e.g. handshape) but are identical on other parameters (e.g. location and movement). LHD signers are significantly impaired relative to RHD signers and controls on this test, another sign of the marked difference in effects of right and left hemisphere lesions on signing. On other tests of ASL processing at different structural levels, we found similar distinctions between left- and right-lesioned signers: with the right-lesioned signers much like the controls, but the signers with left hemisphere lesions significantly impaired (Bellugi *et al.* 1990; 1993).

Right hemisphere lesions and non-language spatial processing

These results from language testing contrast sharply with results on tests of non-language spatial cognition. RHD signers are significantly more impaired on a wide range of spatial cognitive tasks than LHD signers, who show little impairment. Drawings of many of the RHD signers (but not those with LHD) show severe spatial distortions, neglect of the left side of space, and lack of perspective. On tasks of spatial construction, such as a block design task, there is strong evidence of a spatial deficit following right hemisphere damage, similar to that found in hearing people. We note RHD signers' tendencies to break the overall configuration of the design in the block design task and their spatial disorganization, compared to deaf signers with LHD. Yet, astonishingly, these sometimes severe spatial deficits among RHD signers do not affect their competence in a spatially nested language, ASL.

The finding that sign aphasia follows left hemisphere lesions but not right hemisphere lesions provides a strong case for a modality-independent *linguistic* basis for the left hemisphere specialization for language. These data suggest that the left hemisphere is biologically predisposed for language itself, independent of language modality. Thus, hearing and speech are not necessary for the development of hemisphere specialization—sound is not crucial. Furthermore, the finding of a dissociation between competence in a spatial language and competence in non-linguistic spatial cognition demonstrates that it is the type of information that is encoded in a signal (i.e. linguistic vs. spatial information) rather than the nature of the signal itself (i.e. spatial vs. temporal) that determines the organization of the brain for higher cognitive functions (Poizner *et al.* 1987; Bellugi *et al.* 1990).

Sign language has been found to be preserved in right-lesioned signers. Signers with right hemisphere damage present special issues, since they often show non-language spatial deficits. Several right-lesioned signers have severe left hemispatial neglect—that is, selective inattention to the left side of space, which is apparent in

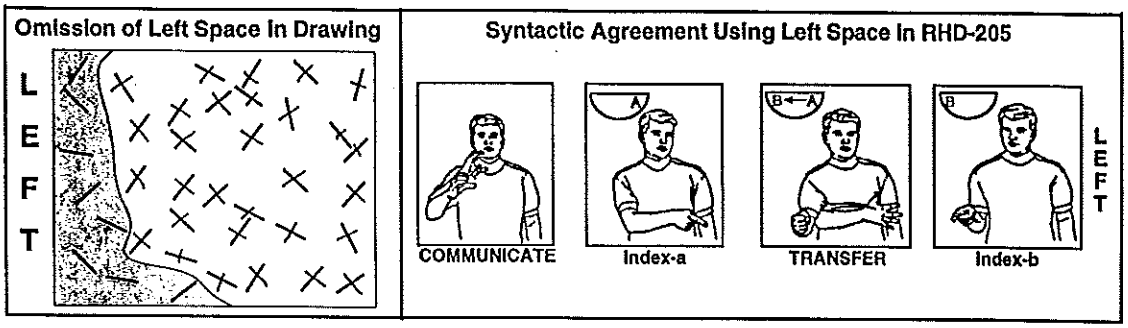

Fig. 12.4 Neglect for spatial cognition but not sign language in a right-lesioned signer.

drawings, where the left side is frequently omitted. In a task where they are asked to cross out all the lines on a page, they characteristically omit several lines on the left side of space (Fig. 12.4, left portion). This left field neglect shows up on almost all visual tasks. Such a distortion in spatial cognitive abilities might certainly be expected to impact the processing and production of a visual spatial language. Remarkably, this does not impact signing or ability to understand signing, which is unimpaired. Inattention to the left portion of the visual field *does not hold* for linguistic stimuli.

In one experiment, we contrasted presentation of signs with presentation of objects to both visual fields. The sign trials used bimanual signs which have one meaning if information from both hands was processed, but have a different meaning if information from only one hand was taken into account. The object trials involved simultaneous presentation of different objects in the two visual fields presented in the same spatial relations as the signs. The subject was nearly perfect on the sign identification task, but only half of the object trials were correctly identified, with all the errors involving omission of the object in left hemispace. This pattern of left hemispace omission was not observed in the sign trials. Moreover, although his drawings show left neglect, he used the left side as well as the right in producing signs, and even used the left side of his signing space for establishing nominals and verb agreement appropriately in his sign language syntax (Fig. 12.4, right portion). This shows what little effect right hemisphere damage can have on core linguistic functions, even when the language is essentially visuospatial (Corina *et al.* 1996).

The contrast between spatial syntax and spatial mapping in ASL

Until now, we have considered the spatial organization underlying grammatical contrasts, most notably syntax in ASL. That is, ASL uses spatial relations to encode syntactic information, such as grammatical subjects and objects of verbs, through manipulation of arbitrary loci and relations among loci in a plane of signing space. As opposed to its syntactic use, space in ASL also functions in a topographic way. The same plane of signing space may also be used in spatial mapping: that is, the

Fig. 12.5 RHD lesion reconstructed by BrainVox (Damasio and Frank 1992). The images are from MRI reconstructions of RHD-207. The reconstructions may be viewed from any perspective desired, and may be sliced and re-sliced to examine both cortical and subcortical structures.

space within which signs are articulated can also 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, as opposed to representing arbitrary grammatical information. We investigate the breakdown of two uses of space within sign language, one for spatially organized syntax and the other for directly representing spatial relations in ASL. Right- and left-lesioned deaf signers provide striking dissociations between processing spatial syntax versus spatial mapping. They were given tests designed to probe their competence in ASL spatial syntax, and spatial topographic processing. The combined results on the spatial syntax tests reveal significant differences between the two groups: left-lesioned signers were significantly impaired on syntax tests, but right-lesioned signers' performance was not distinguishable from normal controls. Contrastingly, on the tests of spatial topographic processing, right-lesioned signers revealed significant deficits whereas left-lesioned signers performed well (Hickok *et al.*, in press; Bellugi *et al.* 1993).

A powerful example of the dissociability of spatial syntax from spatial mapping comes from an RHD signer (RHD,207). Her lesion involves the right superior parietal cortex with medial extension to the corpus callosum. This is illustrated in a three-dimensional reconstruction from *in vivo* MRI images using BrainVox, a system developed by Damasio and Frank (1992) (see Fig. 12.5). Like other right-lesioned signers, she is not at all aphasic. Her processing on ASL grammar tests was nearly perfect, and her use of spatially organized syntax is error free. However, when she was asked to repeat short stories in ASL that involved spatial descriptions—describing the layout of a particular dentist's office, for example—she was severely impaired. This right-lesioned signer does quite well in remembering and reproducing the actual items within a description (unlike some of our normal controls), but she completely fails in her ability to place these objects in their correct spatial locations in her signed story. Control subjects correctly locate nearly all the items

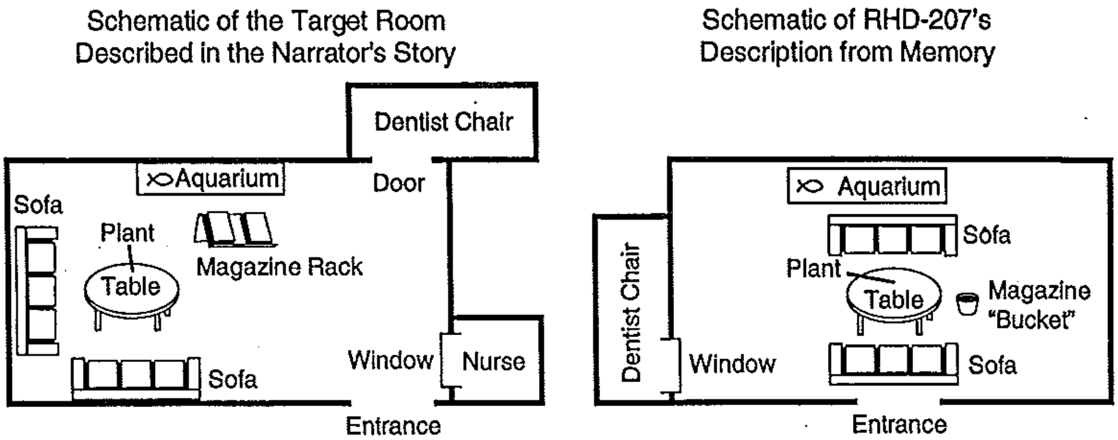

Fig. 12.6 Disorganization in spatial mapping in right-lesioned signer.

that they remember from the story, whereas she correctly locates only about a third of the items she remembers. Figure 12.6 illustrates the reconstructed layout of her signed description of a dentist's office in comparison to the ASL description in the experiment. Her signed description shows a marked spatial disorganization of elements within the room; she incorrectly specified the orientation and locations of items of furniture. She tended to 'lump' all of the furniture within the centre of the room, thus showing marked impairment in spatial mapping in ASL. Thus, even with 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 the left hemisphere damage and the spatial relations disrupted by right hemisphere damage (Emmorey *et al.* 1995; Bellugi *et al.* 1993).

Language, modality, and the brain

We are investigating similarities as well as differences between the neural systems subserving signed versus spoken language. Our growing database of deaf and hearing signers, combined with powerful new techniques in brain imaging including functional magnetic resonance imaging (fMRI), allows us to explore *within*-hemisphere neural systems subserving signed and spoken language. We are now beginning to amass evidence that suggests both some central commonalities and some peripheral differences between the neural systems underlying signed and spoken languages. 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 which is specialized for sign language. Thus, there appear to be neural systems within the left hemisphere that emerge as special-purpose linguistic processors in persons who have profound and lifelong auditory deprivation and who communicate with linguistic systems that use radically different channels of reception and transmission from those 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 language 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. We are now mapping out the differences between spoken and signed language neural systems within the left hemisphere which may arise from the nature of the different visual input pathways and manual output pathways. Several left-lesioned signers exhibit sign language aphasias from lesions to systems that would not be expected to lead to language disruption in spoken language. Nonetheless, it is the similarities between signed and spoken language in interhemispheric organization that are most revealing. These studies of language in a different modality show that the left hemisphere in man is biologically predisposed for language itself, independent of language modality. These findings lead towards a neurobiology of language, and are critical for a new understanding of consciousness and cognition.

Acknowledgements

This research was supported in part by National Institutes of Health grants RO1 DC00146, RO1 DC00201, R37 HD13249, as well as grants from the March of Dimes. Illustrations copyright Ursula Bellugi, The Salk Institute for Biological Studies, La Jolla, CA.

References

Bellugi, U. (1980). The structuring of language: clues from the similarities between signed and spoken language. In *Signed and spoken language: biological constraints on linguistic form*, Dehlem Konferenzen (ed. U. Bellugi and M. Studdert-Kennedy), pp. 115–40. Verlag Chemie, Weinheim/Deerfield Beach, FL.

Bellugi, U. and Hickok, G. (1995). Clues to the neurobiology of language. In *Neuroscience, memory, and language*, Decade of the Brain Series, Vol. 1 (ed. R. Broadwell), pp. 89–107. Library of Congress, Washington, DC.

Bellugi, U. and Studdert-Kennedy, M. (ed.) (1980). *Signed and spoken language: biological constraints on linguistic form*, Dahlem Konferenzen. Verlag Chemie, Weinheim/Deerfield Beach, FL.

Bellugi, U., Poizner, H., and Klima, E.S. (1990). Mapping brain functions for language: evidence from sign language. In *Signal and sense: local and global order in perceptual maps* (ed. G. M. Edelman, W.E. Gall, and W.M. Cowan), pp. 521–43. Wiley-Liss, New York.

Bellugi, U., Poizner, H., and Klima, E.S. (1993). Language, modality and the brain. In *Brain development and cognition* (ed. M. Johnson), pp. 403–23. Blackwell Publishers, Cambridge, MA.

Corina, D., Kritchevsky, M., and Bellugi, U. (1996). Visual language processing and unilateral neglect: evidence from American Sign Language. *Cognitive Neuropsychology*, **13**, 321–56.

Damasio, H. and Frank, R. (1992). Three-dimensional *in vivo* mapping of brain lesions in humans. *Archives of Neurology*, **49**, 137–43.

Damasio, A., Bellugi, U., Damasio, H., Poizner, H., and Van Gilder, J. (1986). Sign language aphasia during left hemisphere amytal injection. *Nature*, **322**, 363–65.

Emmorey, K., Corina, D., and Bellugi, U. (1995). Differential processing of topographic and referential functions of space. In *Language, gesture, and space* (ed. K. Emmorey and J. Reilly), pp. 43–62. Erlbaum, Hillsdale, NJ.

Hickok, G., Klima, E.S., Kritchevsky, M., and Bellugi, U. (1995). A case of 'sign blindness' following damage in the left occipital cortex in a deaf signer. *Neuropsychologia*, **33**, 1597–1606.

Hickok, G., Bellugi, U., and Klima, E.S. (1996). The neurobiology of signed language and its implications for the neural organization of language. *Nature*, **381**, 699–702.

Hickok, G., Say, K., Bellugi, U., and Klima, E.S. The basis of hemispheric asymmetries for language and spatial cognition: clues from focal brain damage in two deaf native signers. *Aphasiology*, Special Issue, **10(6)**, 577–91.

Klima, E.S. and Bellugi, U. (1988). *The signs of language*. Harvard University Press, Cambridge, MA.

Poizner, H., Klima, E.S., and Bellugi, U. (1987). *What the hands reveal about the brain*. MIT Press/Bradford Books, Cambridge, MA.