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14 SPATIAL COGNITION AND BRAIN ORGANIZATION: CLUES FROM THE ACQUISITION OF A LANGUAGE IN SPACE

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Intensive research over the past two decades has been directed at determining whether natural language is specific to the spoken modality. This research has uncovered the existence of natural languages residing entirely outside of the realm of sound, sign languages that are instead expressed and perceived in the visual-spatial modality. American Sign Language (ASL), a naturally evolved language that is used by most North American deaf persons, is the most closely understood of these visual-spatial languages. As a result of studies by Stokoe (1960), Klima and Bellugi (1979) and others, the basic organizational structure and grammatical components of ASL have been identified. Analyses of ASL have revealed that it exhibits formal organization at the same two levels found in spoken languages, including a sublexical level of structuring internal to the sign (analogous to the phonemic level; Battison, 1978; Bellugi, 1980; Stokoe, 1960), and a level that specifies the precise ways that meaningful units are bound together to form complex signs and signs to form sentences (analogous to the morphological and syntactic levels; Klima & Bellugi, 1979; Bellugi, 1980; Padden, 1981, 1982, 1983; Supalla, 1982; Wilbur, 1979; Wilbur & Petitto, 1981, 1983). ASL also shares important underlying principles of organization with spoken languages (e.g., constrained systems of features, rules based on underlying forms, recursive grammatical processes). Thus, research on ASL yields the surprising conclusion that human languages are not restricted to the speech channel.

The existence of signed languages presents a natural experiment providing data relevant to several essential problems in the study of human cognition, the fundamental one being how modality influences the knowledge and use of language. Until recently, the human linguistic capacity was studied exclusively with respect to spoken languages. Some researchers have argued that the structural properties of spoken languages reflect constraints imposed by the perceptual, cognitive and motoric capacities that subserve speech and hearing (e.g., Bellugi & Studdert-Kennedy, 1980). For example, the linear, sequential ordering of phonemes universally observed in spoken languages may be a consequence of biological constraints on the production of sound. However, a different set of constraints might be relevant to languages in the visual-gestural modality. On the one hand, it would seem that signed and spoken languages should differ in fundamental ways; they involve different types of signals (visual-gestural vs. auditory), they are differentially adapted to conveying various kinds of information (e.g., imagistic, analogic), perceived through different sensory systems, remembered using different memory structures, and may be subserved by different neural structures. On the other hand, both spoken and signed languages convey identical kinds of linguistic information and are used to perform the same communicative function. Because of the linguistic status of signed languages, several fundamental questions can be addressed, including how modality influences the structure of language, and how differences in the way information is represented in the two modalities affect the acquisition, processing, and neural representation of language. In particular:

- Are the properties of the Universal Grammar hypothesized by Chomsky (1965, 1975) "modality-independent?" Specifically, do these properties require an aural-oral basis, or can they be expressed in gesture and space?
- Which properties of languages are incidental consequences of the modality of transmission, and which are essential and modality-free?
- Do the differences in how information is represented in the two modalities affect how the languages are structured and processed? The visual-gestural channel affords greater potential for the perception and production of simultaneous sources of information; perception and production in the speech channel may make greater use of linear and temporal contrasts between discrete sources of information.

- Is the course of the acquisition process similar for languages in the two modalities or does acquisition differ because of modality-specific properties (e.g., the potential for iconic or indexical structures in a signed language)?
- Does the pattern of cerebral specialization for language differ depending on modality? Is the pattern of cerebral specialization for language speech-dependent, or is it neurologically modifiable depending on the mode of language transmission?

Moreover, signed languages make it possible to investigate the human capacity to process visual-spatial information from a wholly different vantage point, because they use space in an extraordinary way, incorporating it into the language in a conventional manner. The unique role of space in signed languages is perhaps their most significant distinguishing aspect, and one that is crucial for understanding spatial cognition. In ASL, for example, the space in front of the signer's body functions as a central component of the grammar of the language. Specifically, ASL makes *linguistic* use of visual-spatial information that is otherwise used only for *non-linguistic* functions in hearing (speaking) persons (such as negotiating within a three-dimensional world, etc). Interestingly, unlike spoken languages, ASL displays a marked preference for layered (as opposed to linear) organization of linguistic information in space, a situation that no doubt arises out of the very different possibilities of the visual-gestural mode (Bellugi & Studdert-Kennedy, 1980). The elements that distinguish signs (handshapes, movements, places of articulation) occur in contrasting spatial arrangements; grammatical mechanisms exploit the possibility of simultaneous and multidimensional articulation in the signing space. In the lexical items, the morphological processes, the syntax and discourse structure of ASL, such multi-layering of linguistic elements in space is a pervasive characteristic (Bellugi, 1980; Poizner, Klima, Bellugi & Livingston, 1983).

Because space is used linguistically, we can determine which aspects of the human capacity to process this information are due to the *form* of the information, and which are due to the *functions* it subserves. If it is the form of the information that matters, we should expect to see commonalities between both the linguistic and non-linguistic uses of space. These might be realized as commonalities in perception, learning, or memory that reflect a common neurological substrate. If it is the functions that are crucial, there may be differences in the representation of linguistic and non-linguistic uses of space, despite the fact that the nature of the information that informs these functions shares a common sense modality (i.e., visual-spatial).

LINGUISTIC USE OF SPACE IN ASL

Knowledge of the several important ways in which ASL uses space is critical to an understanding of this language and to the issues discussed above. The linguistic distinctions that are marked by spatial devices in ASL occur at all levels of language structure. Some ways that space functions linguistically in ASL are represented in Figure 14.1, and discussed below.

Lexical Use of Space. ASL uses space to differentiate between formationally identical signs. Signs in ASL are structurally differentiated by specifying the values of a closed set of three formational elements (or parameters), analogous in function to the phonemic inventory of a spoken language: hand configuration, movement of the hand(s), and spatial location of the hand(s) in front of the signer's body. Thus, signs that are formationally the same on other parameters, but differ only in terms of spatial location, are minimally differentiated by this spatial feature. For example, spatial locus minimally differentiates the lexical signs SUMMER, UGLY, DRY made with the same handshape and movement at the forehead, nose and chin (shown in Figure 14.1a. See Appendix for notation conventions).

Morphological Use of Space. Aspects of the space in front of the signer's body actually serve as morphological units in the language, conveying such grammatical information as person, number, and temporal aspect (specific information about the nature of the passage of time). For example, to indicate the grammatical subject and object in the phrase "I give to you," the ASL sign GIVE is positioned first at the space in front of the signer's body that indicates first person or subject (the signer's body), and then moves to the space denoting second person or object (a point that is directly in front of the signer). These spatial and movement changes on the root form of signs are obligatory components of ASL's structure, similar in function to grammatical inflections in spoken language (see Klima & Bellugi, 1979). They co-occur with the sign stem, using dimensions unique to a visual-spatial language. Some sample inflections on the single sign GIVE are shown in Figure 14.1b, including inflections for person, number, distributional aspect, temporal aspect, e.g., convey-

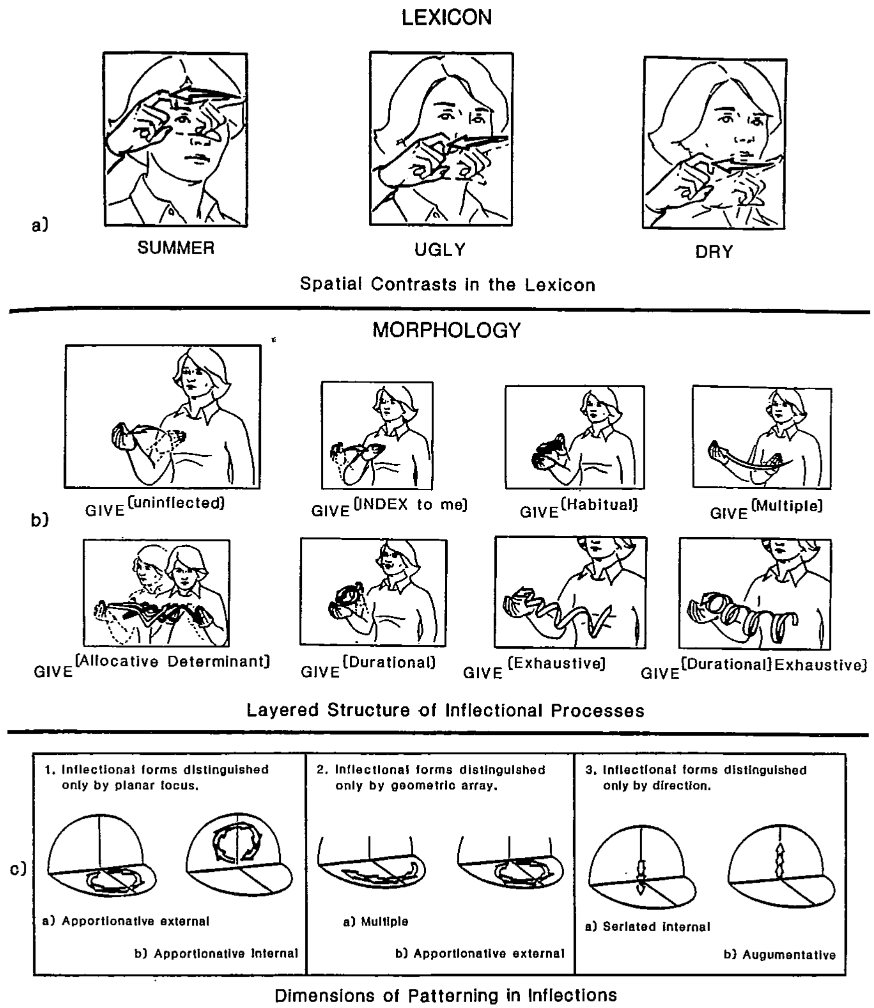

Figure 14.1. Lexical and morphological spatial contrast in ASL. (a) Spatial contrast in the lexicon; (b) Layered structure of inflectional processes; (c) Dimensions of patterning in inflections.

ing the meanings "give to me," "give regularly," "give to them," "give to certain ones at different times," "give over time," "give to each," "give over time to each in turn."

Dimensions of Patterning. In the kinds of distinctions that are morphologically marked, ASL is like many spoken languages; in the degree to which morphological marking is a favored form of patterning in the language, ASL is again similar to some spoken languages, but unlike English. In the *form* by which its lexical items are systematically modified in the sentences of the language, ASL has aspects that are unique. Figure 14.1c shows some of the dimensions of patterning, specific to a visual spatial language, used to build up morphological contrasts in ASL; planes in signing space; different geometric contours (lines, arcs, circles); directions of movement.

Syntactic Use of Space. A most striking and distinctive use of space in ASL is its role in syntax and discourse, especially in pronominal reference, verb agreement, and the anaphoric referencing systems. In this language, person indexing and re-indexing is accomplished primarily by manipulating the space in front of the signer's body. To refer to referents that are physically present in the discourse environment a signer may point directly to self, when indicating first person, and directly to others, when referencing either second or third person. However, an abstract use of space occurs when reference is made to referents that are either physically or temporally distant. Here, nominal referents are established at arbitrary and spatially distinct loci along an imaginary horizontal plane in front of the signer's body. Subsequent pronominal referencing is accomplished by pointing (gazing or shifting the body) to the previously established spatial locus. Further, the establishment of spatial loci is an obligatory syntactic device that interacts in complex ways with the verb agreement and anaphoric referencing systems, whereby verb signs move between established spatial loci in specifying grammatical relations such as subject of the verb and object of the verb. Thus, the linguistic manipulation of the space in front of the signer's body is used to denote central and universal features of human language: person, person roles, and anaphoric referencing (e.g., Klima & Bellugi, 1979; Padden, 1983; Bahan & Petitto, 1980; Wilbur, 1979). Finally, the language has other grammatical devices such as classifiers, size-and-shape specifiers and other means which are also used for representing *literal* (topographic) spatial relations (e.g., description of the layout of one's room, description of the size and shape of objects as in Supalla, 1982).

In sum, ASL is unique in its use of space at all levels of linguistic organization: lexical, morphological, syntactic, and discourse. While ASL is the most thoroughly analyzed of the signed languages of the world to date, other signed languages examined (e.g., Lange des Signes Quebecoise, the language used by most French Canadian deaf persons; Petitto, 1985) suggest that these characteristics may turn out to be universal characteristics of signed languages.

In addition to their use of space, signed languages are unique in the extent and degree of "motivatedness" between meaning and

form. Characteristically, ASL lexical items themselves are often globally iconic, their form resembling some aspect of what they denote. At the morphological and syntactic levels also, there is often some congruence (motivatedness) between form and meaning. Spoken languages are not without direct clues to meaning (reduplication processes and ideophones provide direct methods of reflecting meaning through form, for example). But in sign language such transparency is pervasive. ASL thus bears striking traces of its representational origins, but at the same time it is fully grammaticized.

In this chapter we will focus on how the spatial properties of ASL influence its acquisition in deaf children of deaf parents who are learning sign language as a native language. By examining the acquisition of specifically linguistic space in ASL (as opposed to other types of more general spatial cognitive knowledge), important information about both the representation and the organization of space in development may be uncovered.

THE ACQUISITION OF LINGUISTIC SPATIAL DEVICES IN ASL

Like hearing children, deaf children must be able to negotiate within the spatial environment of a three-dimensional world; that is, they possess a comparable (if not identical) spatial representational system as that found in hearing people, one that is rich enough to support the full range of general, cognitive (and actual) manipulations of visual-spatial information (e.g., knowledge of routes, landmarks, and relations among objects, ability to shift perspective, ability to view and manipulate mental images, etc.). However, it is the specific, linguistic use of space where the most dramatic differences between signed and spoken languages are found. Here, the space in front of the child's body must be carved out and used in the service of the language. How the deaf child comes to acquire a linguistic as well as a general cognitive representation of space is one of the most elusive, yet important questions in the study of sign acquisition today.

One might have every reason to believe that such surface differences between signed and spoken language will influence the course of language acquisition. Given the surface differences between signed languages and spoken languages, the task that the deaf child faces in learning sign language may be radically different from that faced by the hearing child. If, for instance, the mapping between meaning and form is more direct than in spoken language, then this might allow the child a more direct route into the language at all levels. Not only are there differences in the surface structure of the languages, but also differences in the channels used for production and perception. Would these spatial, iconic aspects of ASL influence the course of acquisition?

Over the course of a decade, we have studied the acquisition of sign language by deaf children of deaf parents by obtaining monthly videotapes of mother-child interaction in the home, augmented by experimental interventions. Longitudinal studies of ten children between the ages of one year and eight years have been undertaken and the course of acquisition of different grammatical domains (e.g., pronominal reference, verb agreement, inflectional processes, derivational processes) across the same children has been charted. There are cross sectional studies with deaf children of deaf parents between the ages of two and ten years old, as well as formal tests for each of the grammatical processes found in ASL (for phonological, lexical, inflectional, derivational, and compounding processes as well as syntax (Lillo-Martin, Bellugi & Poizner, 1985). These tests have been normed with young deaf adults and are being used with deaf brain damaged signers in studies of the effects of left and right hemisphere lesions on a visual spatial language (Poizner, Klima & Bellugi, in press). Further, acquisition studies have led to the investigation of the interplay and separation between the acquisition of a spatial language and its spatial cognitive underpinnings.

As a result of these studies, the basic course of language acquisition in signing deaf children of deaf parents is now fairly well understood. There are detailed accounts of the child's acquisition of "phonology," the stages of manual articulation (Boyes-Braem, 1973, 1981; McIntire, 1977; Petitto, 1980); acquisition of complex verb morphology (Bellugi & Klima, 1982; Lillo-Martin, 1984 and in press; Meier, 1982; Newport & Supalla, 1980; Supalla, 1982); development of grammatical and semantic categories (Launer, 1982; Newport & Ashbrook, 1977); and studies of the acquisition of pronominal and anaphoric referencing (Bellugi, in press; Bellugi & Klima, 1980; Hoffmeister, 1978; Lillo-Martin, Bellugi, Struxness & O'Grady, 1985; Loew, 1982, 1983; Petitto, 1977, 1980, 1983a & b, and in press). These studies have established that despite the differences in modality, deaf children acquire ASL as a first language in ways that are remarkably similar to those of hearing children acquiring spoken language. For an excellent overview, see Newport and Meier (1986).

Several studies, however, are especially revealing with regard to the acquisition of spatial and iconic properties of sign language. These studies will be summarized below.

The Transition from Gesture to Symbol

A study of the acquisition of personal pronouns in deaf children (Petitto, 1983 a & b, and in press) provides a striking demonstration of unexpected similarities between deaf and hearing children's acquisition of language. Three noteworthy features characterize hearing children's acquisition of pronouns. First, they are acquired in a particular order. Beginning around 16-20 months children begin producing the pronoun *me*, followed by *you* around 22 months, and then third person pronouns (e.g., Charney, 1978; MacNamara, 1982). Second, prior to the acquisition of these forms children and their mothers use proper nouns (e.g., "Jane do something" instead of "I do something"), rather than use the pronoun *I* or *me*. Third, around the time when *you* enters the child's lexicon some children—although not all—engage in systematic pronoun reversal errors. For example, mother might say to the child "Do *you* want to go to the store?" and the child would reply "Yes, *you* want to go store." Similarly, the child may understand and produce *me* to refer to the adult rather than to herself; although it is uncommon for symmetrical *you-me* error pairs to co-occur. Some researchers have proposed that these children initially regard pronouns as having fixed or stable referents like names (i.e., *you* is equivalent to child, or *me* is equivalent to addressee) rather than having changing or "unstable" referents that depend upon the speaker role (Charney, 1978; Chiat, 1981, 1982; Clark, 1978).

Although the use of personal pronouns in ASL is constrained by the grammar of the language, they are not formed by arbitrary symbols. Rather, they are represented by pointing directly to the addressee (e.g., YOU), or self (e.g., ME). Thus, the formational aspects of the functional equivalent of personal pronouns in ASL resemble extra-linguistic pointing gestures which commonly accompany speech and are used pre-linguistically by hearing and deaf children. This provides a means for investigating the deaf child's transition from pre-linguistic gestural communication to linguistic-symbolic communication because gesture and symbol are virtually identical in form.

Petitto (1983, a & b) investigated deaf children's acquisition of personal pronouns both experimentally and in spontaneous mother-child interactions. She found that despite the transparency of the pointing gesture deaf children acquire knowledge of personal pronouns over a period of time, displaying errors similar to those of hearing children. Although deaf children begin pointing at around 9 months, they do not use the pointing form to indicate "you" and "me" until around 17-20 months, the precise range that hearing children first begin to use verbal pronouns systematically. Soon after the sign ME has been established, deaf children gain productive control over the YOU pronoun (around 22-23 months), followed by third person pronouns. Like hearing children, they also use full proper nouns prior to the productive use of pronouns despite the fact that they use the pointing form in a rich, varied and communicative fashion. Surprisingly, the children used the pointing form to refer to aspects of their caretaker's body but seemed to avoid the use of the pointing form to indicate the adult. For example, one child (age 1:11) used the pointing form to refer to a spot on her mother's bathing suit but did not use it to refer to her mother as "you," not even in an experimental task specifically designed to elicit this and other pronouns. Although the phenomenon of "avoidance" has been noted previously in child language literature (e.g., Ferguson & Farwell, 1975), this case is especially intriguing because the children avoided a particular *function* of a form rather than the *form* itself. Further, like hearing children, the deaf children initially exhibited confusion over which pronouns were appropriate given a particular linguistic context, and they produced pronoun reversal errors as well. See Figure 14.2a for illustrations of some pronoun reversal errors.

Petitto's results provide dramatic evidence of the transition from gesture to linguistic symbol in a signed language. The child shifts from conceptualizing person pointing as part of the class of deictic gestures to viewing them as elements within the linguistic, grammatical system of ASL; this constitutes one form of evidence that the transition from gesture to sign requires a reorganization of the child's knowledge. Despite differences between the modalities that might be relevant to acquisition, both deaf and hearing children showed very similar performance in acquiring personal pronouns. The study provides evidence for a *discontinuity* in the child's transition from pre-linguistic gesture to linguistic communication system, even when they share a single channel of expression and the forms are wholly transparent. It appears to make little difference whether pronominal terms are symbolized by arbitrary streams of sound segments as in spoken language or by pointing signs which are indistinguishable in form from pointing gestures. Indeed, this study provides strong evidence that the structure of a gesture as a linguistic unit, rather than the iconicity of its form, determines the course of acquisition.

Acquisition of Verb Agreement for Present Referents

When expressing relations among present referents, a specific class of ASL verbs must "agree" with their noun arguments. Specifically,

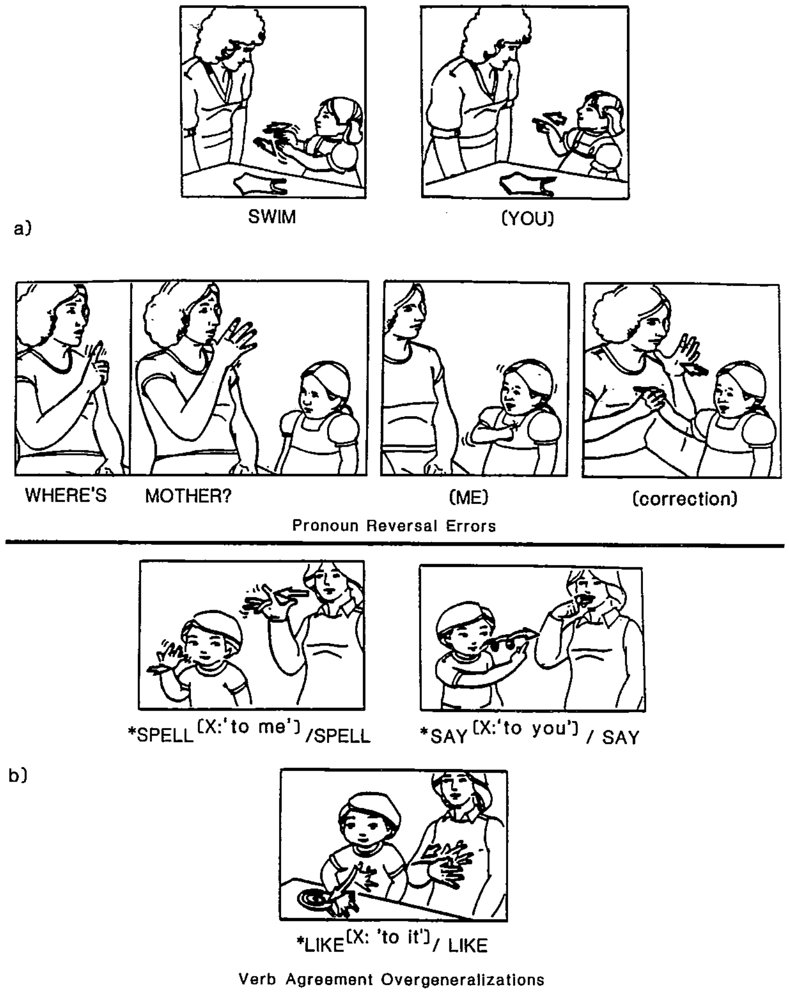

Figure 14.2. Young deaf children's acquisition of ASL. (a) Pronoun reversal errors; (b) Verb agreement overgeneralizations.

verb agreement in ASL is accomplished by moving an indexible verb from the spatial locus established for the subject to the spatial locus of the object (Padden, 1983). Some indexible verbs have obligatory double-argument agreement (i.e., the verb must inflect for both subject and object), some verbs can agree only with a single argument, and some undergo optional agreement. In all cases, however, the general mechanism for verb agreement is the same: the path movement of the verb "incorporates" the spatial loci that is associated with noun arguments, be they present in the signing environment or abstract spatial loci (Klima & Bellugi, 1979; Padden, 1983). Recall the example of the verb GIVE cited earlier. To express the meaning "I give to you," the verb is moved from a locus in a horizontal plane of space near the signer to a locus in that plane on the direction of the addressee. Similarly, to express "You give to me," the verb moves from the addressee to the signer.

Although the structural regularity in the ASL verb agreement system has led to its analysis as a morphological component of the language, aspects of the system nonetheless have an iconic basis. In particular, sentences using verb agreement with a verb such as GIVE could be said to resemble the iconic mime and action of giving and receiving. How do children acquire a morphological system which is grammaticized but which nevertheless displays a large amount of iconicity? A priori, one might expect the morphological variants of forms such as GIVE would be acquired relatively early; that the transparency in the forms of the sign would facilitate their acquisition, regardless of the fact that these are analyzed as morphologically inflected forms.

Meier (1981, 1982) analyzed the acquisition of the verb agreement system both longitudinally and experimentally, uncovering several stages. First, Meier noted that deaf children using two to three signs (around age two) do not make use of the inflectional apparatus of ASL. Instead, they use the *uninflected* (or citation) form of the verb. Interestingly, inflections are omitted even from the child's imitations of parental utterances. Additionally, Newport and Ashbrook (1977) show that young deaf children initially favor the use of sequential ordering of signs rather than spatial organization to mark grammatical relations in their signing.

Second, deaf children between the ages of two and three begin to produce inflected forms of verbs. However, children make revealing errors during this time. Although information about subject and object (i.e., the grammatical arguments of the verb) is reflected in verb's *path movement*, deaf children have been observed to include personal pronouns in their sentences involving such verbs nonetheless (Petitto, 1977, 1980, 1983a; Meier, 1981, 1982). For example, one girl (age 2:3) studied by Petitto (1983a) attempted to convey to her mother that grandmother gave her (the child) a book by signing the following: *GRANDMA GIVE [X: "to you"] ME. Despite the potentially mimetic and transparent quality of the sign sentence "give to me," the deaf child appears neither to perceive nor to exploit this iconicity, signing "give to you" instead. Rather, the child appears to analyze segments of her language morpheme-by-morpheme, and to integrate such segments into her linguistic system over time. (In this case, it appears that the child has realized that a verb's path movement is linguistically relevant, but she appears not to know that *direction* in addition to *path movement* is critical to mastering the verb agreement system.)

By age three to three and a half, deaf children master and consistently use the verb agreement system with present referents in required contexts (Meier, 1982). However, they inflect some verbs for subject and object which do not accept such inflections in the adult language. By inflecting non-indexible verbs, deaf children are exhibiting the same type of morphological overgeneralizations that are typically observed in hearing children with comparable linguistic competence (see Figure 14.2b for overgeneralizations of verb agreement in ASL).

Thus, we have seen that deaf children's mastery of the verb agreement system in ASL occurs at the same age as mastery of comparable linguistic processes in hearing children, despite the seemingly mimetic nature of the forms presented to them.

The Integration of the Lexical and Morphological Systems: Spatially Organized Syntax and Discourse

Evidence suggests that despite obvious differences in surface structure and modality, the time course of the acquisition of ASL is remarkably similar to that for spoken languages (Bellugi & Klima, 1982; Newport & Meier, 1986). We now turn to the acquisition of a domain in which the nature of the apparatus used in ASL may have its most striking effect: the means by which relations among signs are stipulated in sentences and in discourse. Languages have different ways of marking grammatical relations between their lexical items. In English, it is primarily the order of the lexical items that marks the basic grammatical relations; in other languages, it is the morphology of case marking or verb agreement that signals these relations. ASL, by contrast, specifies relations among signs primarily through the manipulation of sign forms in space. In sign language, space itself carries linguistic meaning. The most striking and distinctive use of space in ASL is in its role in syntax and discourse, especially in nominal assignment, pronominal reference, verb agreement, anaphoric reference and the referential spatial framework for discourse. In this section, we turn to some of the spatial cognitive, memorial, and linguistic requirements involved in a language whose syntax is essentially spatial, and then consider the consequences of these requirements for acquisition of such a language.

Consider a review of the use of spatial loci for referential indexing, coreference, verb agreement, and the fixed and shifting spatial framework underlying sentences and discourse. Nominals introduced into ASL discourse may be assigned to arbitrary reference points in a horizontal plane of signing space. In signed discourse, pointing again to a specific locus clearly "refers back" to a previously established nominal, even with many other signs intervening. This spatial indexing allows explicit coreference and may reduce ambiguity: In ASL, coreferential nominals must be indexed to the same locus point, both within and across sentences. Verb signs move between such points in specifying grammatical relations, thus the ASL systems of verb agreement is also essentially spatialized. Classes of verbs bear obligatory markers for person (and number) via spatial indices (see Figure 14.3 for an example sentence requiring spatial agreement).

The same signs in the same order, but with a reversal in direction of spatial endpoints of the verb, would indicate different grammatical relations. Because verb agreement may be given spatially, sentences whose signs are made in different temporal orders can still have the same meaning. The verb agreement system in ASL can be extended to complex embeddings as diagrammed in Figure 14.3b, an illustration of the spatial arrangement of an ASL sentence meaning "John encouraged him to urge her to permit each of them to take up the class." In function, this system is like grammatical devices in spoken languages. However, in its form—marking connections between spatial points—spatially organized syntax in ASL bears the imprint of the mode in which the language evolved (Padden, 1983; Bellugi & Klima, 1982; Lillo-Martin, 1985).

The horizontal plane in front of the signer's torso is the locus for indices of definite reference (that is, if the speaker has already introduced a referent into the discourse). Different spaces may be used to contrast events, to indicate reference to time preceding the utterance, to express hypotheticals and counterfactuals. It is also possible to embed a subspace within another subspace, as in embedding past-time context within conditional subspace, illustrated in Figure 14.3c.

Creating a spatial referential framework for syntax and discourse is complicated by some interacting mechanisms. Whereas the referential system described above is a fixed system in which nominals remain associated with specific points in space until "erased," the spatial referential framework sometimes shifts; third person referents may be assigned to the locus in front of the signer's torso which otherwise denotes self reference. When this shift occurs, the whole spatial plane rotates, and previously established nominals are

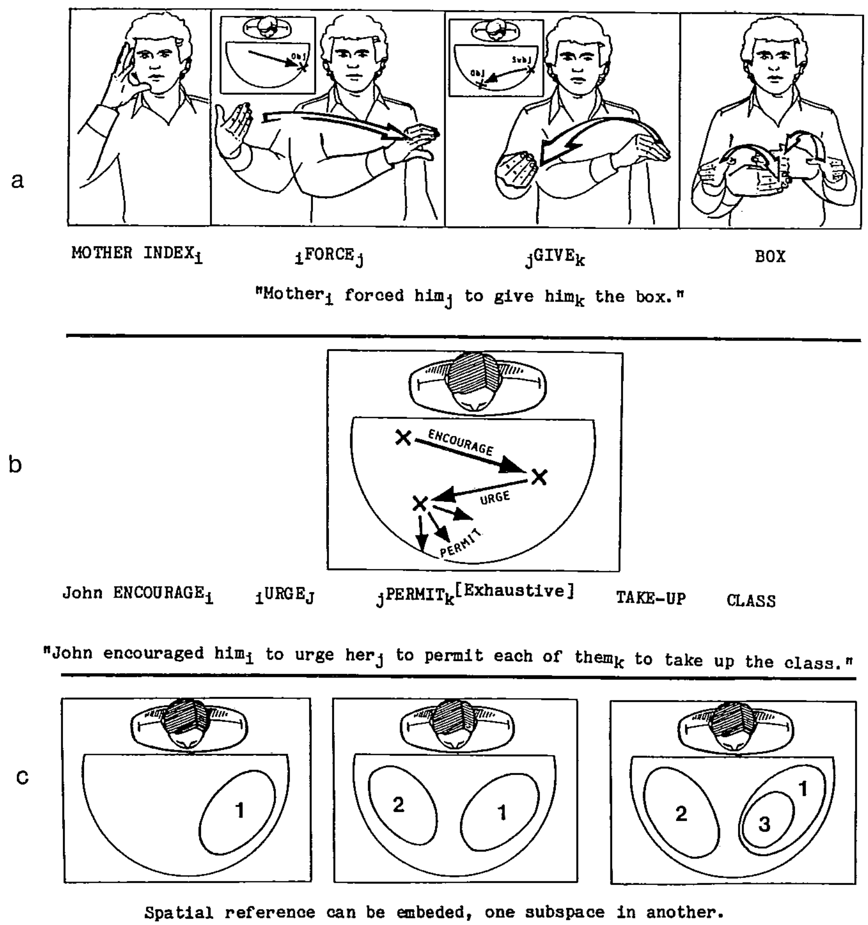

Figure 14.3. Spatially organized syntax in ASL. (a) ASL sentence requiring spatial agreement; (b) Complex embedding and spatial indices; (c) Spaces embedded in spaces in ASL discourse.

now associated with new points. In this system a fixed referential framework may be implied for the addressee, but it is not spatially fixed, thus adding complexity to the spatial cognitive requirements of the language (Bahan & Petitto, 1980; Padden, 1982, 1983, in press).

A Deaf Child's Storytelling. Petitto (1977, 1980) and Loew (1982, 1983) have completed studies of deaf children's spontaneous narratives, examining in particular the acquisition of the systems underlying anaphoric reference. For example, Petitto finds the following stages in the acquisition of storytelling in one signing child:

—At 3:0 Jason freely and happily told stories about non-present referents despite the fact that they were extremely difficult to understand, due to ambiguous spatial referencing. Although he was fully capable of indexing verbs to present referents at this time (i.e., verb agreement), he was not able to do so grammatically when it required that he first establish a nominal in space for non-present referents. Instead, Jason signed all story characters at a single, center space, using *uninflected* verbs to denote relations among characters, all signed in a list-like fashion. Unfortunately, the participants in conversation with Jason were left in a quandary as to who did what to whom, because none of the obligatory establishment and co-referencing procedures had been observed.

—At 3:9, Jason's first use of a grammatical spatial device in his referencing on non-present story characters was observed. For the first time, the child used double argument *inflected* verbs in reference to non-present characters, but did not first establish the identity of the nominals that he was expressing verbal relations about. Nor did he use space differentially, as he still favored the use of center space.

—At 4:3 a unique phenomenon occurred. Jason began to (1) explicitly establish referents in the signing space, (2) differentiate the signing space by using gross spatial distinctions (i.e., *left, center*, and *right* spatial regions in front of his body), and (3) use inflected verbs in storytelling, but did so in a most unusual way. Instead of establishing story characters at discrete spatial indices in front of his body, Jason recounted the "Wizard of Oz" story by establishing all 11 of his characters at a signed, undifferentiated *right* space, reserving the *left* space as the point of introduction of some characters; for example, he had the "Wicked Witch of the West" enter from a high left space and "land" and remain at the space to his right. Further, all of his indexible verbs were inflected with an onset point in right space and an endpoint in center space. Jason also used center space for the ongoing description of the story's plot. Thus, what has come to be known as the "stacking phenomenon" (Petitto, 1977, 1980) occurred, whereby the child stacks referents up at a *single* location, thus still leaving reference unclear and ambiguous. Loew (1983) describes another child's first use of abstract spatial loci, in which the course of acquisition is nearly identical to Jason's. Finally, it is intriguing to note that Jason did not yet explicitly establish his characters by using the indexical point, one linguistic means for pronominal reference in ASL. Instead, all characters were established either non-manually with explicit eye-gaze shifts to the right space (i.e., using the "pronominal sight-line"), or by inflecting verbs from right space. It was not until later that Jason was first observed using the pointing form to establish non-present referents in the signing space.

The importance of such findings is the following. At a time when the child appears to possess (a) the individual spatial components necessary to construct grammatically correct anaphoric referencing in storytelling, and (b) the ability to cognitively comprehend and convey events about non-present referents (albeit in ungrammatical ways), he does not seem able to *integrate* these devices into a rule-governed linguistic system at the discourse level. Indeed, at age five, Jason begins to establish referents at distinct points along the horizontal arc in front of his body—using sight-line and verb agreement—thereby establishing referents and differentiating space at the sentence-level, but fails to consistently maintain the identity of the previously established spatial loci.

In summary, the deaf child's knowledge of the linguistic use of space in ASL necessarily has to include information on the (a) general differentiation of the signing space, (b) explicit establishment of nominals at discrete spatial loci, (c) consistent spatial identity of loci, and (d) contrastive use of established loci in sentences and in discourse. Children appear to acquire this knowledge over time and it appears not to be until around ages 7-10 that the fully mature anaphoric referencing system is mastered in syntax and discourse.

These findings raise several important questions which are being addressed in a separate series of studies (Bellugi, in press). Central to these issues is the relationship between cognition and language. In a spatially organized language, the relationship between acquisition in such an alternative medium and the development of its non-linguistic spatial cognitive substrate is crucial. As Newport and Meier put it in their excellent review article, "it has sometimes been suggested that spatial representation is conceptually difficult for the child, and therefore is a cognitively complex medium in which to signal linguistic functions. On this view, the acquisition of morphological devices in ASL should occur somewhat later than the acquisition of formally similar devices in spoken languages, where spatial representation is not involved" (Newport & Meier, 1986). In fact, the available evidence suggests that spatial representation itself does not constrain the acquisition process—the acquisition of morphological devices in ASL occurs on a strikingly similar time table to the acquisition of spoken language devices that are formally similar in complexity. We are now comparing the acquisition of discourse functions (anaphoric reference and discourse organization) across hearing and deaf children in the same sets of tasks as part of our ongoing research (Lillo-Martin, Bellugi, Struxness & O'Grady, 1985; Bellugi, in press).

The Comprehension of Spatially Organized Syntax

In a series of studies, the spatially organized syntax has been broken down into component parts, to investigate the young child's processing and comprehension of separate aspects of linguistic structure (Lillo-Martin, Bellugi & Poizner, 1985). The first findings are reported here asking whether the young signing child can understand that nominals may be abstractly associated with arbitrary points in space, even when he is not producing such spatial mechanisms regularly in his ongoing signing. This question was examined with sixty-eight deaf children of deaf parents between the ages of one and ten, using a formal language test devised to examine in particular the association of nominals with spatial loci (Bellugi, in press). The Nominal Establishment Test examines perception, comprehension, and memory for spatial loci associated with specific nominals. In the test, nominals are assigned to arbitrary loci in the horizontal plane of signing space that serves for definite reference. Two kinds of questions are asked: (a) where a certain nominal has been established (to which the child answers by pointing to a specific locus); and (b) what nominal has been established at a certain locus (to which the child answers by signing the nominal). Two and three nominals are used in different parts of the test. In associating loci with their nominal referents, this test assesses a key aspect of coreference structure in ASL syntax and discourse, and has been used with deaf children, with deaf adults of different language background, and with left and right brain-lesioned deaf signers (Poizner, Klima & Bellugi, in press. Figure 14.4 presents sample test items and results with sixty-eight deaf children of deaf parents.

When we attempted to test one and two-year-old deaf children, they were quite unable to deal with the test. When the deaf experimenter signed "Where's the doll?" (after previously associating an arbitrary locus with the sign DOLL), these young children looked around the room as if looking for an actual doll; one ran to her bedroom to take one out. When asked "What is at point X?" (an arbitrary point in space previously associated with the sign BOY), the children seem nonplussed. Thus one-year-olds and most two-year-olds fail the test; but importantly, already by the age of three, deaf children perform well on the task, even with two and three nominal

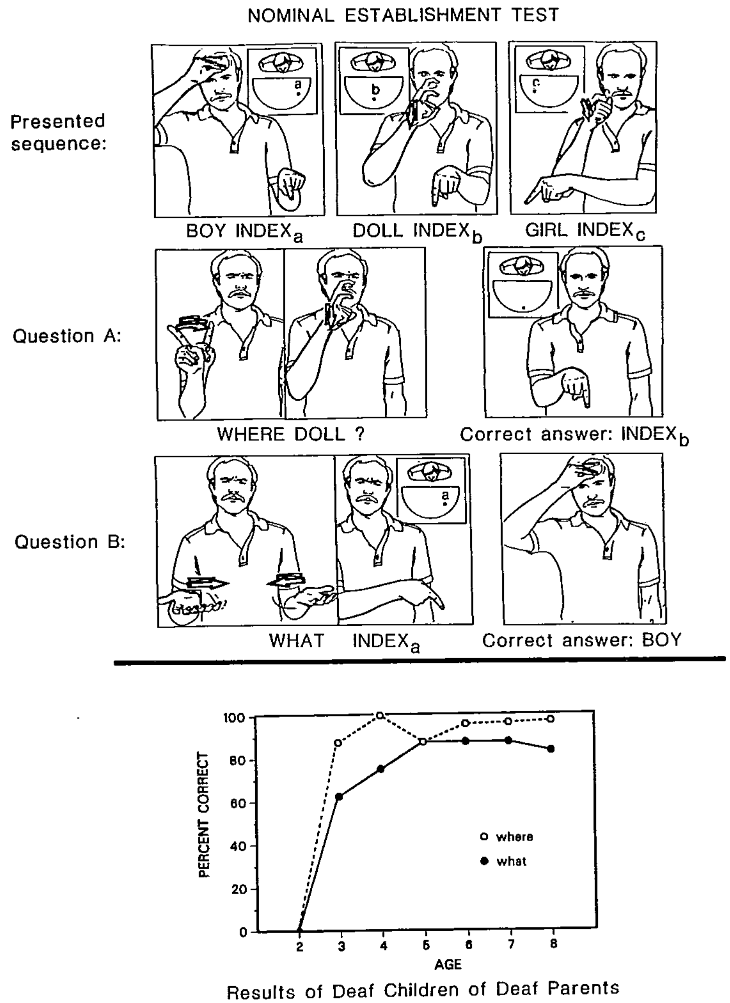

Figure 14.4. Results of the nominal establishment comprehension test. (a) Sample test items on nominal establishment comprehension test; (b) Results of test with deaf signing children between two and ten.

assignments to abstract points in a plane of signing space (Lillo-Martin, Bellugi, Struxness & O'Grady, 1985). This is despite the fact that such nominal establishment to spatial loci is not reported in deaf children's signing before the age of four and a half (e.g., Loew, 1983).

Such results suggest that the deaf child by the age of three does understand that in this language a nominal can be associated with an arbitrary point in abstract space; furthermore he is adept at processing this aspect of the language structure, and can handle two and three nominals at a time at different spatial loci with ease and facility. We have since found that young deaf children can also process the spatial syntax of the language in sentences involving minimal pairs, distinguished only by different spatial endpoints of the verb for subject and object marking (Bellugi, in press). To identify the source of the difficulty in deaf children's discourse structures we shall have to look further, and thus are investigating the comprehension of co-reference and shifting spatial frameworks as well as contrasting hearing and deaf children's narratives.

THE DEVELOPMENT OF NONLINGUISTIC SPATIAL COGNITIVE ABILITIES

At the same time, we are tracking the developmental course for the acquisition of the spatial cognitive underpinnings which may form the prerequisites for the mastery of linguistic system. In this manner we will investigate whether the acquisition of spatially organized syntax is yoked in particular ways to the development of its nonlanguage substrate; that is, to aspects of spatial cognition. So far our early studies suggest that deaf children who have early exposure to processing spatial relationships in a linguistic system perform at the same level (and in some cases even show early enhancement) compared to norms for hearing children (Bellugi, O'Grady, Lillo-Martin, O'Grady, van Hoek & Corina, in press). The studies suggest that deprivation of auditory experience from birth and exposure to a spatially organized linguistic system in no way impedes development of spatial cognition. In fact, the studies so far suggest that there may even be some *enhancement* of certain spatial cognitive abilities. These results are consistent with the studies by Neville of deaf and hearing adults showing that in a spatial attention task, deaf subjects are superior to hearing subjects (Neville, this volume).

THE BREAKDOWN OF SYNTAX AND SPATIAL COGNITION WITH BRAIN LESIONS

We find that despite the surface differences between signed and spoken languages, the acquisition process in deaf children is remarkably like that of the acquisition of spoken languages. Yet spoken and signed languages are very different in surface organization. One difference that we have highlighted is that processing linguistic structure in ASL implies processing complex spatial cognitive underpinnings as well, aspects that would be irrelevant to processing linguistic structure in spoken languages. We are currently studying the interplay between spatial syntax and spatial cognition from the special perspective of the intertwining of the two in a visual spatial language.

In a separate series of studies, the effects of unilateral lesions in deaf signers are being investigated (Poizner, Klima & Bellugi, in press; Bellugi, Poizner & Klima, 1983; Poizner, Kaplan, Bellugi & Padden, 1984). Since ASL displays the complex linguistic structure found in spoken languages, but conveys much of its structure by manipulating spatial relations, it exhibits properties for which each of the hemispheres of hearing people shows a different predominant functioning. The study of brain damaged deaf signers offers a particularly revealing vantage point for understanding the organization of the brain for language and spatial cognitive functions and addressing the central issue of whether they can be dissociated in deaf signers.

Subjects for these studies carried out at the Salk Institute are right handed prelingually deaf signers who have had either right or left hemisphere lesions and matched controls. Subjects are administered a battery of tests specially designed to assess their capacities with respect to each of the levels of ASL linguistic structure, as well as a version of a standardized aphasia battery adapted for ASL (the Boston Diagnostic Aphasia Battery). In addition, tasks which are sensitive distinguishers of visuospatial performance in right hemisphere damaged hearing patients are administered.

On spatial cognitive tasks, there were clear cut differences in performance between left hemisphere damaged signers and right hemisphere damaged signers across a range of tasks. In nonlanguage spatial tasks, the right hemisphere damaged signers were severely impaired; they tended to show severe spatial disorganization, were unable to indicate perspective, neglected the left side of space, reflecting the classic visuospatial impairments seen in hearing patients with right hemisphere damage. These nonlanguage data suggest that the right hemisphere in deaf signers develops cerebral specialization for nonlanguage visuospatial functions (Poizner, Kaplan, Bellugi & Padden, 1984).

On linguistic tasks and in analyses of ongoing signing, the two groups of patients were also markedly different. The signers with right hemisphere damage were not aphasic. They exhibited fluent, grammatical virtually error-free signing, with good range of grammatical forms, no agrammatism, and no signing deficits. This preserved signing ability existed in the face of marked deficits in their processing of nonlanguage spatial relations. The signers with left hemisphere damage, in great contrast, were not impaired in nonlanguage visuospatial tasks. The signers with left hemisphere strokes were, however, impaired in language functions—they showed frank sign language aphasias, including impairment of spatially organized syntax. Thus language functions in deaf signing adults are lateralized to the left hemisphere, even though ASL's linguistic units are visuospatial in nature (a function typically associated with the right hemisphere). Other important findings include the observation that the left hemisphere damaged signers exhibit selective loss of linguistic function, e.g., impairment in lexicon or in grammar (Bellugi, Poizner & Klima, 1983; and Poizner, Klima & Bellugi, in press).

These studies of brain damaged deaf signers suggest that hearing and speech are not necessary for the development of hemispheric specialization; furthermore, the data show that in these deaf signers it is the left hemisphere that is dominant for sign language. In addition, there is a complementary right hemisphere specialization for visuospatial nonlanguage functioning. This principled separation between brain organization for nonlanguage functioning and for language functioning—even in this unusual instance in which both involve visuospatial processing—is important, and supports from a new perspective the studies of impairment in spatial cognitive functions in the normal adult brain (Morrow & Ratcliff, this volume).

SUMMARY OF THE ACQUISITION OF SPATIAL SYNTAX AND SPATIAL COGNITION

In general, despite radical differences in language modality, deaf and hearing children show a dramatically similar course of development. The deaf child, as does his hearing counterpart, analyzes out discrete components of the language presented to him. Even when the modality and the language offer possibilities that seem intuitively obvious (for example, pointing for deictic pronominal reference), the deaf child appears to ignore their directness.

The study of the acquisition of American Sign Language in deaf children brings into focus some fundamental questions about the representation of language and the representation of space. Are these distinct forms of knowledge, or are these the manifestations of a general cognitive capacity that subserves both of them (i.e., language and space)? On the latter view, one's ability to use

language or perceive spatial relationships may be governed by general cognitive processes (e.g., memory, learning) implicated in all types of knowledge, rather than domain-specific types of knowledge. Signed languages provide a way to address this issue because linguistic and non-linguistic information are in the same visual-spatial mode. Comparative studies of the structure and processing of signed languages provide important information about the biologically governed, modality-free versus channel-specific constraints on the human language faculty. Further, differentiation between linguistic and non-linguistic use of visual-spatial information in language acquisition as well as language breakdown provides important behavioral evidence for the existence of domain-specific types of knowledge including distinct language faculty that exists irrespective of the mode of language transmission.

Sign languages offer a powerful way to explore the links between language and visual-spatial knowledge, and their organization in the brain. Comparative study of aphasias among signing and speaking persons provides a way to determine whether it is the *type* of information which is relevant to cerebral organization (e.g., language versus non-language), or the *modality* in which it is produced and perceived (visual-spatial versus oral-aural). Further, comparative studies of how children acquire (or "build up") a representation of their language and how this knowledge breaks down in brain-injured deaf adults are especially revealing.

The data from studies of brain damaged deaf persons show that hearing and speech are not necessary for the development of hemispheric specialization: sound is *not* crucial. Further, the data show that in these deaf signers, it is the left hemisphere that is dominant for sign language. In addition, there is a complementary right hemisphere specialization for visuospatial functioning. The fact that much of the grammatical information is conveyed via spatial manipulation appears not to alter this complementary specialization.

Aspects of the data from acquisition studies show very similar patterns of dissociations between linguistic and non-linguistic forms of knowledge. For example, we observed that deaf children did not acquire pronouns earlier than hearing children, even though the linguistic means for expressing this information is of the same form as children's non-linguistic pointing gestures (Petitto, 1983a). The child's linguistic knowledge (concerning, for example, the relationship between form and meaning) is not merely constructed out of the non-linguistic materials at hand. In this sense, the language acquisition process in signing children is strikingly discontinuous with other forms of knowledge, and, thus, can also be viewed as being modular.

Taken together, these data suggest that in deaf children who are deprived of auditory experience but exposed to a natural visuospatial language by deaf parents from birth, language and spatial cognitive functions unfold normally and without deficit. These findings are in sharp contrast with studies across a different group of children with a specific metabolic disorder that results in a fractionation of language and spatial cognitive functioning (Bellugi, Sabo & Vaid, this volume). Moreover, the data presented both from the acquisition and breakdown of spatial language and spatial cognition suggest that biological foundations underlying language rest not on the form of the signal but rather in the linguistic function it subserves.

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APPENDIX

We use the following notation in this chapter:

SIGN	=	Words in capital letters represent English labels (glosses) for ASL signs. The gloss represents the meaning of the unmarked, unmodulated, basic forms of a sign out of context).
SIGN$^{[X:]}$	=	A form that has undergone indexical change. The form or meaning may be specified, as in INFORM$^{[X:1 \text{ to } 2]}$ or INFORM$^{[X:I \text{ to you}]}$.
SIGN$^{[N;M]}$	=	A form that has undergone inflection for number and distributional aspect or for temporal aspect, focus or degree.
SIGN$^{[D:]}$	=	A form that has undergone derivational process.
*SIGN	=	An asterisk preceding a sign form indicates that it is ungrammatical within adult ASL.

CEREBRAL ORGANIZATION FOR SPATIAL ATTENTION

15

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Anatomical, physiological and behavioral research on non-human animals has documented an important role for early sensory experience in the functional development and organization of neurosensory systems. Similarly, in humans, several lines of evidence suggest that the nature and timing of early language experience impacts the organization of language relevant brain systems. However, very little evidence exists on the effects of early experience on the development of the cerebral systems that mediate different aspects of spatial cognition. In this chapter I will discuss evidence which suggests that both early sensory experience (auditory deprivation since birth) and early language experience (acquisition of a visual, sign language) have different and specific effects on the specializations of cortical areas important for visual spatial attention. Two large sets of literature provide background information relevant to this issue.

The first includes behavioral studies of humans conducted over the last century that have attempted to verify experimentally the idea that early unimodal deprivation may lead to compensatory enhancement of abilities in remaining modalities. Many such studies have employed tests which measure rather elementary sensory functions such as thresholds and acuity. Taken as a whole these results do not provide clear evidence for compensatory enhancement following early auditory or visual deprivation (reviewed by Burnstine,