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# The basis of hemispheric asymmetries for language and spatial cognition: clues from focal brain damage in two deaf native signers

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## Abstract

The existence of hemispheric asymmetries for language processing and visuospatial processing is well established. In this report we investigate the *basis* of these asymmetries through the window of American Sign Language (ASL). ASL uses spatial contrasts to encode grammatical information at all levels of representation, including phonology, morphology, and syntax. In addition, however, ASL uses space in an *iconic* fashion to represent spatial information directly, as, for example, in describing the layout of objects in a room. We tested the performance of two deaf, native signers—one with left hemisphere damage (LHD) and one with right hemisphere damage (RHD)—on tasks involving the use of space, within ASL, to represent linguistic versus spatial information. We found a double dissociation: the LHD signer was impaired on tasks involving the use of space for encoding grammatical information, but performed well on tasks involving the use of space to encode spatial information iconically; the RHD signer showed the reverse pattern. These data suggest that hemispheric asymmetries for language and spatial cognition are driven by the type of representation that is ultimately constructed from the signal (grammatical vs spatial), rather than by the physical properties of the signal itself.

## Introduction

Signed languages, such as American Sign Language (ASL), are structured linguistic systems with all the grammatical complexity and communicative capacity of spoken languages. Unlike spoken languages, however, signed languages convey linguistic information spatially. Indeed, manipulations of signing space in the production of ASL can subserve a number of different linguistic functions (Emmorey and Reilly 1995, Klima and Bellugi 1979, Lucas 1990, Padden 1988). Spatial contrasts in sign can signal phonological distinctions, spatial modulations on root signs can yield distinct morphological forms, and abstract loci in the signing space can serve to identify the referents of syntactic functions such as the grammatical subject and grammatical object of a verb (see Figure 1).

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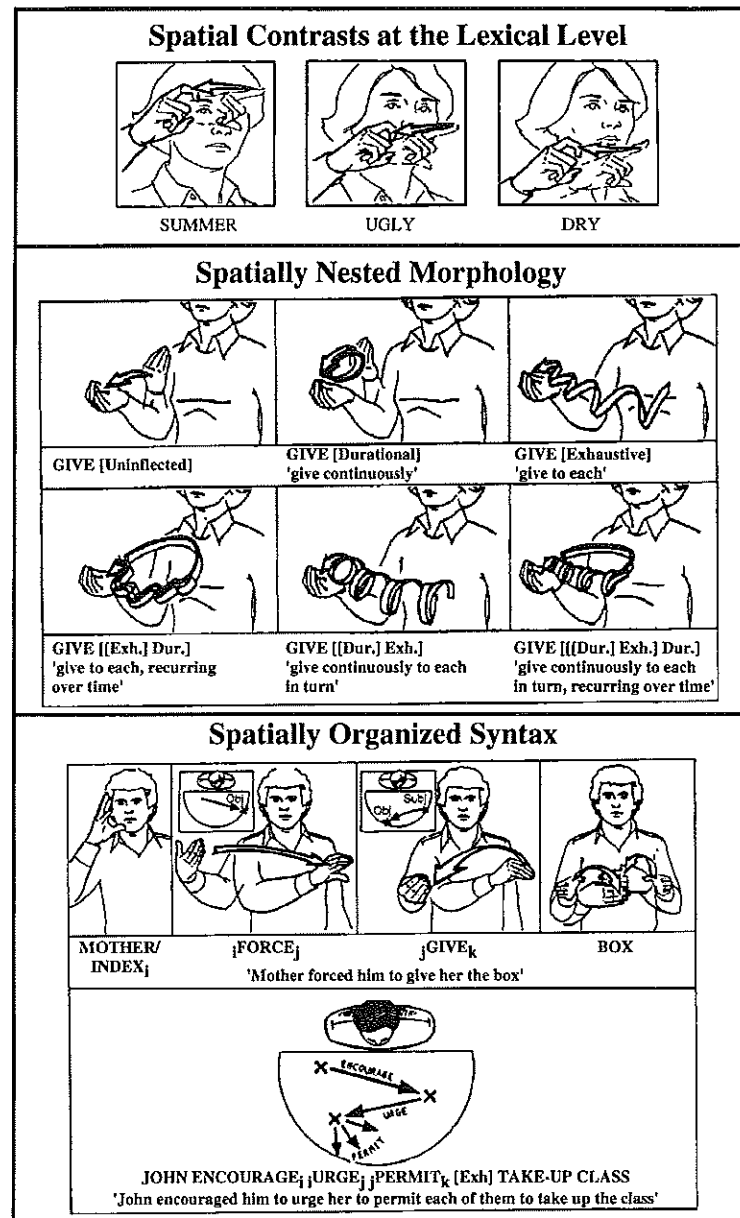
Figure 1.    Spatial mechanisms in the structure of ASL phonology, morphology, and syntax.

This situation raises some interesting questions concerning the underlying neurobiology of a system such as ASL. It has been known for some time that the neural systems underlying spoken language predominantly implicate the left cerebral hemisphere, while the neural systems underlying spatial cognition predominantly implicate the right hemisphere. But what happens when these two domains of cognition are conflated in a single system? What happens when you have a *language* that encodes much of its linguistic structure in *spatial* manipulations and spatial contrasts? Research on the neurobiology of ASL has revealed that,
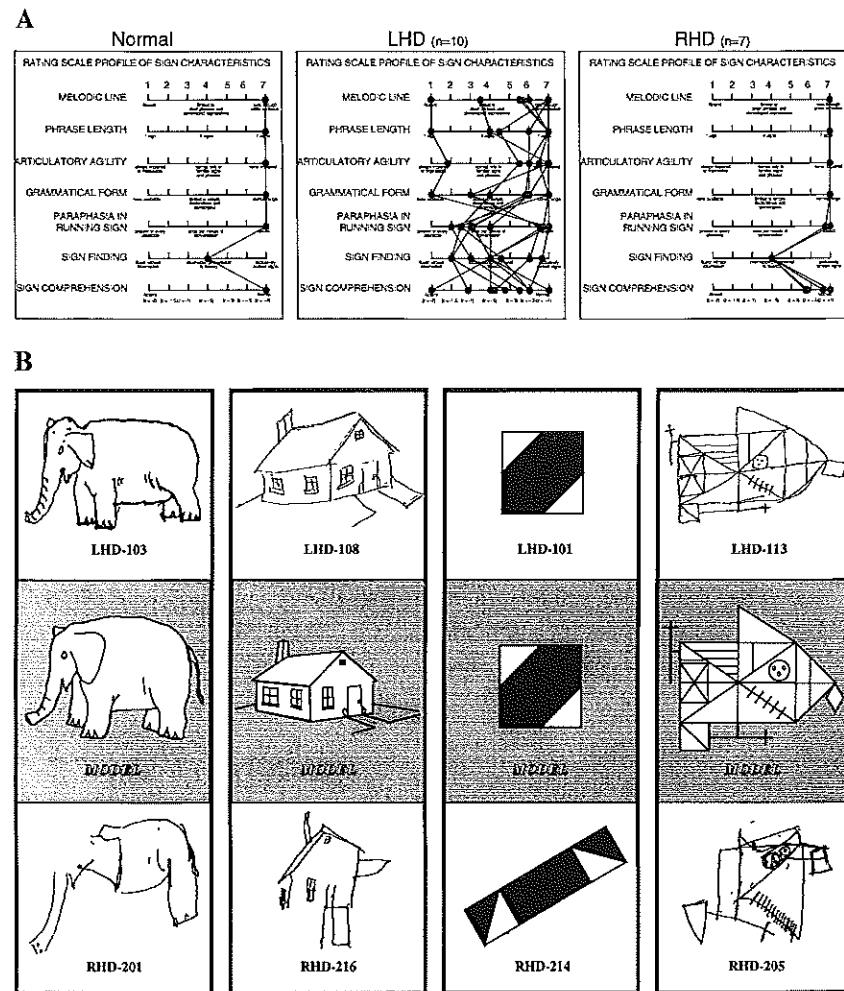
**A**



**B**



Figure 2.   **A**: Profile of sign characteristics from the Salk–Sign Diagnostic Aphasia Examination. This profile provides ratings on seven characteristics of a subject's signing. See Poizner *et al.* (1987) for details on the rating system for each scale. The figure shows profiles for normal matched controls, left hemisphere-damaged (LHD) signers, and right hemisphere-damaged (RHD) signers. Note that LHD signers present with varied profiles representing distinct aphasias, whereas RHD signers show virtually no deviation from normal. **B**: Samples of LHD (top) and RHD (bottom) performance on visuospatial cognition tasks. All samples represent efforts made with the model (centre) present. Note evidence of hemispatial neglect and configuration distortion in RHD patients. All of the LHD patients, despite well-preserved visuospatial abilities, presented with marked aphasias.

despite the visuospatial nature of the signal, the neural systems underlying ASL predominantly implicate the left cerebral hemisphere. For example, we have studied a number of left and right hemisphere-damaged signers and have found that left hemisphere damage often leads to aphasias for sign, whereas right hemisphere damage does not (Bellugi and Hickok 1995, Bellugi *et al.* 1989, 1990, Poizner *et al.* 1987). Conversely, right-lesioned signers are often impaired in non-linguistic visuospatial tasks while left-lesioned signers are significantly less impaired (Poizner *et al.* 1987, Venturini *et al.* 1995) (see Figure 2). Thus, processing

core aspects of language is a left hemisphere dominant function; the modality in which that signal is transmitted appears to be irrelevant to neural organization of language at the hemispheric level.
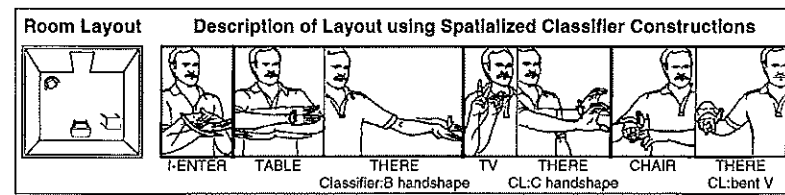
As the research cited above demonstrates, most of the work on the neurobiology of signed languages has focused on the effects of spatial encoding of linguistic information. That is, the focus has been on aspects of ASL in which a spatial signal gives rise to linguistic representations whose content is inherently non-spatial. However, ASL can also use spatial media to communicate *spatial* information directly; that is, in an iconic fashion. For example, if one wishes to describe the spatial layout of objects in a room in ASL, the signer can set up a spatial model of that room in signing space: in this mode of expression, lexical signs for the various objects in the room are produced and then associated with various spatial loci in signing space, showing spatially the relations of objects to one another and to the room as a whole (see Figure 3a). Thus, in this situation, the actual spatial relations between loci established in the signing space carry information about the spatial relations between objects in the room that is being described. In other words, space in ASL can be used to represent space itself. This is in sharp contrast to the situation in which space is used in the service of representing grammatical information. For example, when nominals are associated with spatial loci and then used for interpretation of grammatical functions like the subject and object of a verb that moves between them, the spatial relation between the loci themselves is irrelevant to the grammatical relations. Indeed, in the service of grammatical functions, loci can be associated with abstract concepts such as 'religion' or 'politics' that patently are not localizable in any real-world space.[1]

The question that we investigate in this paper is the following: is there a differential hemispheric organization for the use of space in ASL to encode linguistic information versus the use of space in ASL to encode spatial information represented iconically? An answer to this question is likely to provide considerable insight into the *basis* of hemispheric organization for language and spatial cognition. These functions of space are quite similar in surface form, with similar motoric complexity and temporal characteristics, yet they give rise to qualitatively different types of representations, linguistic versus spatial. So, are *surface similarities* in the signal driving neural organization? If so, we would expect these two functions of space in ASL to be non-dissociable. Or is neural organization sensitive to the *type of representation* generated by the signal? In the latter scenario we might expect left hemisphere damage in deaf signers to impair the capacity to extract linguistic representations from space in ASL, while sparing the capacity to extract spatial representations from space in ASL. Conversely, we might expect right hemisphere damage in deaf signers to impair the capacity to extract (and/or sufficiently maintain) spatial representations, while sparing the capacity to extract linguistic representations.

The earliest investigations into this issue relied on informal observation of left and right hemisphere-damaged signers. For example, Poizner *et al.* (1987) report the case of a RHD signer who was not aphasic, i.e. she did not have any remarkable deficit in sign production in terms of spatially organized syntax, morphology, or

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[1] This is not to say that spatial loci cannot serve multiple functions simultaneously. Scott Liddell, for example, points out that loci that are used for linguistic functions can also have topographic localization functions (Liddell 1990).

**A**

| Room Layout | Description of Layout using Spatialized Classifier Constructions |
|---|---|



**B**

Schematic of the Target Room Described in the Narrator's Story



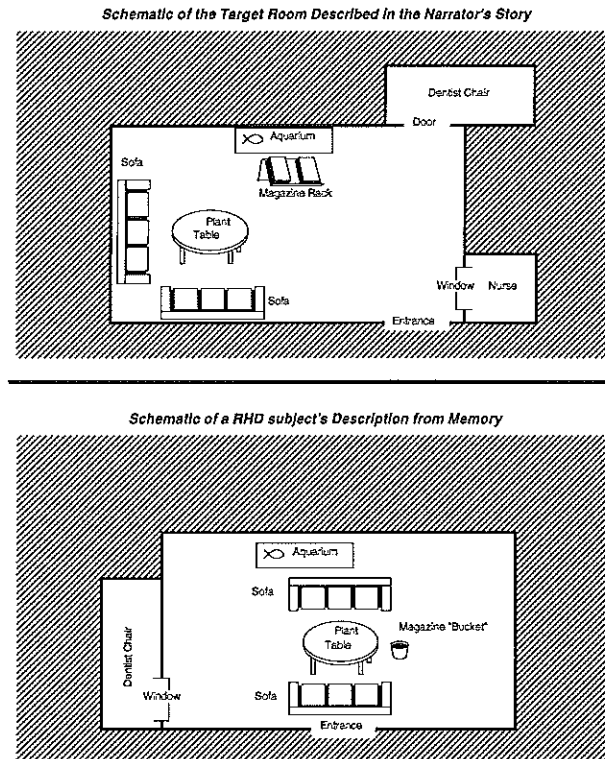Schematic of a RHD subject's Description from Memory



Figure 3.   **A**: Simplified example of spatial mapping in ASL. Note the topographic relation between the spatial layout of furniture in the room and the spatial positions in signing space at which the classifier signs are articulated. **B**: Schematic depiction of one RHD signer's spatial errors in retelling a narrative about the spatial arrangement of a dentist's office. Most of the items in the room are recalled, but the spatial arrangement is distorted (Emmorey *et al.* 1995).

phonology. However, that same patient, when asked to describe the layout of her room, produced a grammatical but *spatially* incorrect description: the spatial arrangement of the furniture, as conveyed through spatial mapping in the patient's signing, was distorted, with all of the furniture mapped onto the right portion of the signing space. Again, her description was perfectly grammatical, but happened to be incorrect with respect to the actual spatial locations of the objects in her room.

In a more recent effort Emmorey and Reilly (1995) focused on a different RHD signer's ability to repeat immediately stories, each 30 seconds long, that contained either topographic information (e.g. a description of the layout of a dentist's office
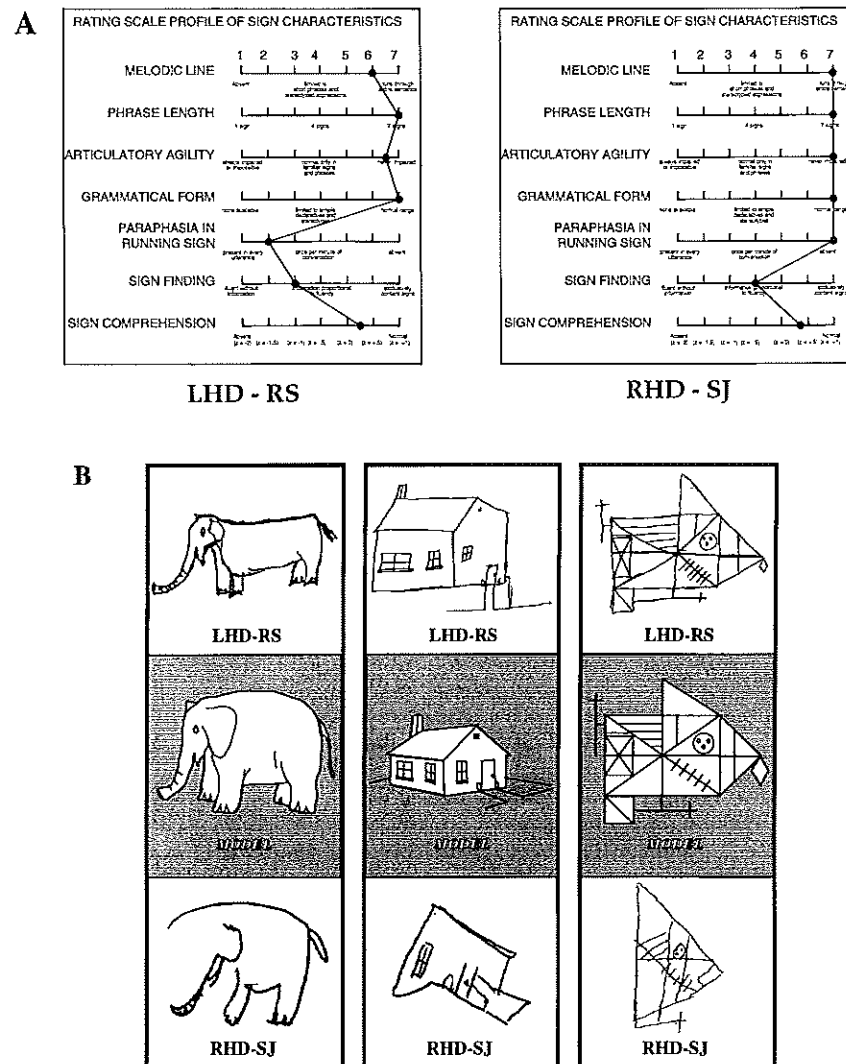
**A**

RATING SCALE PROFILE OF SIGN CHARACTERISTICS

MELODIC LINE
PHRASE LENGTH
ARTICULATORY AGILITY
GRAMMATICAL FORM
PARAPHASIA IN RUNNING SIGN
SIGN FINDING
SIGN COMPREHENSION

**LHD - RS**

RATING SCALE PROFILE OF SIGN CHARACTERISTICS

MELODIC LINE
PHRASE LENGTH
ARTICULATORY AGILITY
GRAMMATICAL FORM
PARAPHASIA IN RUNNING SIGN
SIGN FINDING
SIGN COMPREHENSION

**RHD - SJ**

**B**

LHD-RS          LHD-RS          LHD-RS

RHD-SJ          RHD-SJ          RHD-SJ

Figure 5.   Profile of sign characteristics for LHD-R.S. and RHD-S.J. (A) and samples of their drawings (B). Profiles reflect: (i) marked aphasia in LHD-R.S. including frequent paraphasias and moderate sign finding problems, and (ii) spared linguistic functions in RHD-S.J. Drawings reveal: (i) relatively preserved spatial abilities in LHD-R.S. and (ii) severe visuospatial deficit in RHD-S.J., including hemispatial neglect and configurational distortions.

Kaplan 1976). LHD-R.S.'s ASL production was generally fluent and grammatically well formed with a normal range of syntactic structures; however, she made many paraphasic errors. In this signing sample, which totalled 4 min 25 s of uninterrupted signing (with the examiner's signing time subtracted) she produced six paraphasias, averaging 1·5 errors per full minute of uninterrupted signing. Figure 4 depicts some characteristic paraphasias noted in LHD-R.S.'s signing. In addition, her signing was frequently interrupted by sign-finding problems, at which time she would stop and struggle for the correct sign.

RHD-S.J., in contrast, made no errors in his signing during this sample (3 min 10 s total uninterrupted signing). His ASL production was fluent and relevant to

the questions asked by the examiner, and consisted of complete, well-formed ASL sentences with a normal complement of complex syntactic forms. There were no paraphasic errors. Figure 5a presents LHD-R.S.'s and RHD-S.J.'s profiles of sign characteristics from the Salk-SDAE.[2]

### Visuospatial abilities

Tests of non-language spatial cognition were also administered to both patients. LHD-R.S. showed only very mild visuospatial impairment on these tests, consistent in degree and nature with what has been reported for LHD spoken language aphasics (Goodglass and Kaplan 1983). In contrast, RHD-S.J. was severely impaired on a range of spatial cognitive tasks. RHD-S.J.'s deficits include hemispatial neglect and configurational distortions. Figure 5b presents sample drawings (copied from a model) by both patients, and their performance in copying the Rey–Osterrieth complex figure.

### Experiments

#### Experiment 1: Using space to extract linguistic information in ASL

Both patients were presented with a test designed to probe their comprehension of simple sentences in which information concerning the subject and object of the sentence is encoded in terms of spatial distinctions. The sign-sentence stimuli consisted of simple semantically reversible sentences. A sample sentence is given in Figure 6. Note that the nouns in the sentence are signed first, with each followed by an index in space; this establishes a referentially dependent spatial locus for each nominal. The verb is then produced with movement between the loci. The initiation and termination points of the movement of the verb in space determine the identity of the subject and object of the sentence. The nominal associated with the locus at which the verb movement is initiated is the subject of the verb, and the nominal associated with the locus at which the verb movement terminates is the object of the verb. The sentence would have the opposite meaning with respect to who is doing what to whom if the direction of the verb movement were reversed, while the referentially associated spatial loci in the sentence remained the same.

Twenty-eight sentences of this type were presented, preceded by four practice trials. On half the trials a sentence–picture matching task was used: subjects were shown a vertically arranged pair of pictures and then the sentence was signed; the subject's task was to point to the picture that matched the meaning of the sentence. On the other half of the trials (presented in a different block) the examiner questioned the subject for knowledge of the meaning of the sentence. For example, after presenting a sentence like the one in Figure 6, the examiner asked in random order the ASL equivalent of both 'who was bitten?' and 'who did the biting?'. A preliminary analysis of variance (ANOVA) with subject (LHD vs RHD) and task type (sentence-to-picture matching vs 'verbal' response) revealed that the subjects'

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[2] The somewhat depressed score for RHD-S.J. on the comprehension scale reflects, primarily, items missed in the body-part-identification task. This is a subtest that involves comprehension of finger-spelled *English* words for various body parts; it is not a test of comprehension of phonologically structured ASL signs. On the sign discrimination subtest—a test which does involve comprehension of phonologically structured ASL signs—RHD-S.J. scored 34/36 correct; his two errors involved numbers. Experiment 1 below further attests to RHD-S.J.'s preserved comprehension.
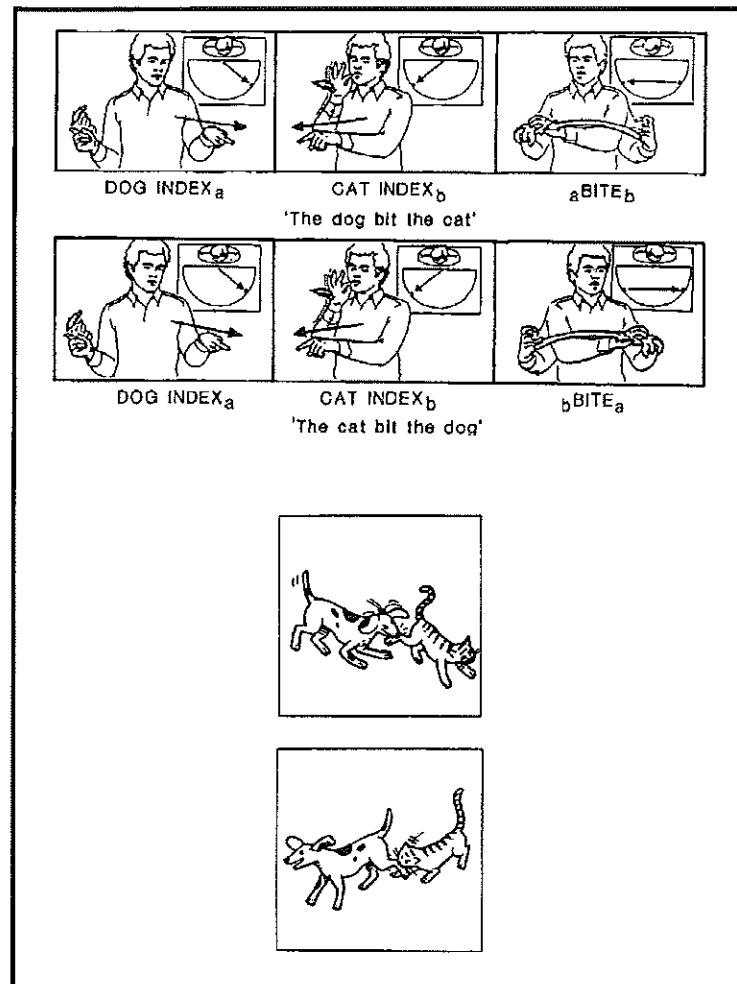
Figure 6. Sample stimulus item for sentence-to-picture matching task. The pair of sentences contrast only in the direction of movement of the verb sign BITE, leading to thematic role reversals in meaning. Only one version of a given sentence was used in the experiment.

error rates did not interact with task type $(F(1,26) = 0.23, p > 0.6)$ and so all further results will be presented collapsed across tasks. A group of 32 deaf elderly control subjects were also tested for baseline comparison.

### Results

The mean percentage correct on this comprehension test in the control group was 92%. LHD-R.S. performed considerably worse than controls at 64% correct. RHD-S.J., in contrast, performed on par with controls at 89% correct. Statistical analyses were conducted treating items as a random variable and correct versus incorrect response on each item as the dependent variable (see Pinker *et al.* (1987) for justification in using categorial data in ANOVAs). The difference in performance between RHD-S.J. and LHD-R.S. is significant $(t[54] = 2.28, p = 0.027)$. Further, RHD-S.J.'s score is significantly better than would be expected by

chance in a binary forced-choice task (i.e. 50 % correct) ($t[27] = 6·6$, $p < 0·001$), whereas LHD-R.S.'s score was not reliably different from chance ($t[27] = 1·5$, $p > 0·1$).

The results of Experiment 1 demonstrated that visuospatial ability does not predict performance on language comprehension tests, even in a visuospatial language. LHD-R.S.'s visuospatial ability is relatively preserved, yet her comprehension of simple spatially organized ASL sentences is significantly disrupted. Conversely, RHD-S.J. has severe visuospatial deficits, yet his performance on our comprehension tests that tap the ability to extract linguistic information from spatial distinction is on a par with normal controls. This finding suggests that the neural systems underlying visuospatial *linguistic* functions and *non-linguistic* spatial cognitive functions are non-identical.

### Experiment 2: Using space in ASL to represent spatial relations directly

As pointed out in the introduction, space in ASL can be used iconically to represent real-world spatial information. Again, the layout of a room can be described simply by associating the sign for each item in the room with an isomorphically related position in the signing space. Signing space thus serves as a spatial model for the actual spatial arrangement in the real (or imagined) world.

Each patient was presented with two 'spatial mapping' tests; that is, tests designed to assess competency in the use of space to represent space iconically in ASL. One test probed comprehension of spatial mapping, and the other tested production of spatial mapping. Each test began with the subject viewing simple room layouts. The comprehension test employed a sign-to-picture matching paradigm: the subject viewed a room layout and then a signed description of a room layout; the task was to indicate whether the room layout matched the signed description. In the production test, the subject viewed a room layout and then produced a signed description of that room. Production was scored in terms of three types of errors, errors of *omission*, *location*, and *orientation*. Omission errors refer to a failure to recall an item that was pictured. Location errors involved locating an item in space that was incorrect relative to the spatial position of other items—for example, the placement of a cabinet on the wrong side of a table. Orientation errors refer to errors in the directional orientation of an item located in signing space—for example, a bed placed perpendicular to an adjacent rug rather than parallel to it. Information on orientation is analysable because most signs that are used for establishing the position of objects in signing space (classifier signs) are orientation-specific, with distinct fronts, backs, tops, and bottoms. The two tasks were given in separate consecutive blocks. Each pictured room contained from three to five common items that might be found in a household room, such as a rug, a table, chairs, a dresser, and a bed. Six trials were presented in the comprehension task and five trials were presented in the production task.

### Results

The patients' performances on these mapping tasks differed sharply from their performances on the sentence comprehension test of Experiment 1. On the mapping comprehension task, LHD-R.S. scored 100 % correct, and RHD-S.J. scored 50 % correct. This difference is significant ($t[10] = 2·24$, $p < 0·05$).
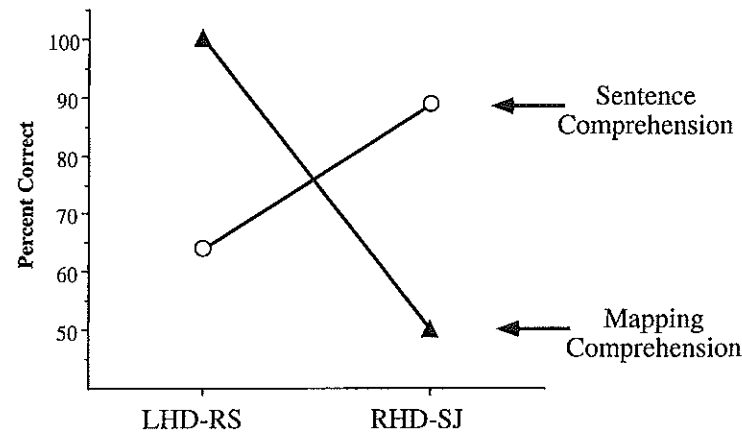
Figure 7. LHD-R.S. vs. RHD-S.J.'s performance in percentage correct on the sentence comprehension versus the mapping comprehension task. The significant interaction reveals a double dissociation between these functions of space in ASL.

In order to make a more direct comparison between functions of space in ASL, we analysed the two sign-to-picture matching tasks used to probe the capacity to comprehend in ASL spatially encoded linguistic information (Experiment 1) versus spatially encoded spatial information (Experiment 2). Data from these tests were entered into an analysis of variance (ANOVA) with Subject (LHD vs RHD) and Test (sentence vs mapping) as factors. Items were treated as a random variable and correct versus incorrect response on each item served as the dependent variable. The main effects of Subject and Test did not approach significance ($Fs < 1$), but the interaction was highly reliable ($F[1, 36] = 10.71, p = 0.002$). This interaction is demonstrated graphically in Figure 7. What is clear from the figure is that RHD-S.J. shows preserved performance on the sentence-comprehension test, but is impaired on the mapping-comprehension test, whereas LHD-R.S. shows the inverse pattern, with preserved performance on the mapping-comprehension test and impaired performance on the sentence-comprehension test.

RHD-S.J. also performed more poorly than LHD-R.S. on the mapping production task. As noted above, this task was scored according to three types of possible errors: omission, location, and orientation. Across the whole production test there were 20 items to be arranged in the signing space (between three and five per trial).Out of these 20 items LHD-R.S. omitted two, whereas RHD-S.J. omitted seven. From those items that the signers did include in their spatial layouts, we tallied the number of location and orientation errors. LHD-R.S. did not make any errors of location or orientation. That is, all of the 18 items that she produced were correctly arranged in the signing space with respect to location (the spatial relations between items in the signing space) and orientation. Of the 13 items produced by RHD-S.J., two were incorrectly located (15 %)—in one case a bed was incorrectly placed on top of the left half of a rug rather than at the back of the right half of the rug, and in another a dresser was incorrectly placed to the right of a bed rather than the left—and four items were incorrectly oriented (31 %)—two instances involved orienting a table on its side rather than its legs, and two instances involved placing a bed in the wrong parallel/perpendicular orientation relative to a correctly placed
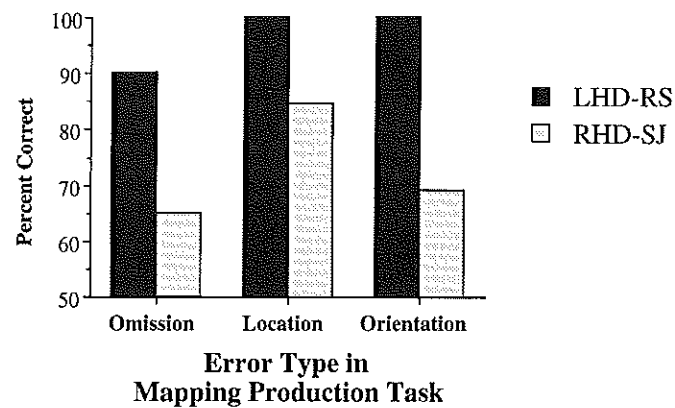
Figure 8. LHD-R.S. and RHD-S.J.'s performance on the mapping production task. RHD-S.J. was significantly impaired relative to LHD-R.S. on all measures in this task.

and oriented rug. RHD-S.J.'s errors on this task did not appear to be interpretable in terms of hemispatial neglect or visual field defects, as his errors were equally distributed across items in left and right spatial positions. Results from this task are given in Figure 8.

These data from the Mapping Production task were entered into a $2 \times 3$ factorial ANOVA with Subject (RHD vs LHD) and Error type (omission, location, and orientation) entered as factors. Correct versus incorrect response per opportunity in each error-type category served as the dependent variable. Thus, with omission-type errors each subject had 20 opportunities, for both the location and orientation-type errors LHD-R.S. had 18 opportunities and RHD-S.J. had 13 opportunities. The ANOVA yielded a highly reliable main effect of Subject, with RHD-S.J. performing significantly worse than LHD-R.S. (mean proportion correct = 0·72 and 0·96, respectively; $F[1, 96] = 12·32, p = 0·0007$). The main effect of error type was not significant ($F = 1·68$, n.s.), and the interaction did not approach significance ($F < 0·5$). While the results are quite clear, the nature of the dataset is such that interpretation of the statistical analyses should be made with some caution. The number of items that are omitted dictates how many remaining items are available on which to make errors of location and orientation. Thus, all of the factors are not totally independent. To address this technical problem, separate analyses were carried out first on omission errors alone, and then on location and orientation errors together in a 2 (subject) $\times$ 2 (error type) factorial design (the location and orientation factors are, in fact, independent). The omission error analysis yielded a difference that was significant at the $p = 0·06$ level in a two-tailed test ($t(1, 38) = 1·93$). The $2 \times 2$ ANOVA yielded a highly reliable main effect for subject ($F(1, 58) = 10·45, p = 0·002$) confirming that LHD-R.S. made significantly fewer orientation and location errors than did RHD-S.J. The main effect of error type, and the interaction of subject $\times$ error type were not significant ($p > 0·25$ for both). It seems, then, that the statistical reliability holds up even when separate analyses are carried out. In sum, RHD-S.J. performed significantly worse than LHD-R.S. on all aspects of this task.

## General discussion

The set of studies described above explored the neural organization of two functions of space in ASL. The first function involves the use of space to encode linguistic information; in particular, to identify the referent of each of the arguments of the verb, and the second involves the use of space to encode spatial information iconically. We have suggested that, despite surface similarities in the form of the signal, these spatial manipulations give rise to fundamentally different representations. In one case the spatial signal gives rise to a linguistic (i.e. morphosyntactic) representation; in the other case the spatial signal gives rise to a spatial representation.

The issue of the basis of hemispheric asymmetries for language and spatial cognition has been studied quite extensively in a more general case, that of the contrast between processing a spatially organized language and non-linguistic spatial cognition, as it is assessed through, for example, drawing and visuo-constructional tasks. As we pointed out above, there is an extensive functional and neurobiological independence of these domains. But the contrast between uses of space *within* ASL allows a more direct test of the basis of hemispheric asymmetries. On the one hand, if hemispheric asymmetries for language and spatial cognition turn on perceptual properties of the signal (to an extent more subtle than the perceptual similarities between processing a visuospatial language and processing a non-linguistic visuospatial task), then one would expect these two functions of space in ASL to be equally disrupted following focal brain damage. On the other hand, if hemispheric asymmetries for language and spatial cognition turn on the nature of the *representations* that are generated by a signal, and not on properties of the signal itself, then it should be the case that these two functions of space in ASL break down differentially. Specifically, if the left hemisphere is dominant for processing morphosyntactic representations, and the right hemisphere is dominant for processing spatial representations, then left hemisphere damage should lead to deficits in processing spatially encoded *morphosyntactic* information in ASL, yet spare the capacity to process spatially encoded *spatial* information in ASL. Right hemisphere damage should yield the inverse effect: spared processing of spatially encoded linguistic information in ASL, with impaired processing of spatially encoded spatial information in ASL.

Our data do show that the linguistic and spatial uses of space in ASL are dissociable. We found a double dissociation in the two brain-damaged signers reported above. LHD-R.S. was impaired in processing the linguistic use of space, with preservation of competence in the spatial use of space in ASL. RHD-S.J. showed the inverse effect—normal performance on tests of the linguistic use of space, but severe impairment on tasks involving the use of space to encode spatial information in ASL. This result suggests that hemispheric asymmetries for language and spatial cognition are driven by functional representations (linguistic vs spatial) rather than by perceptual properties of the signal itself.

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