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Neural Systems Underlying Spatial Language in American Sign Language

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A [^{15}O]water PET experiment was conducted to investigate the neural regions engaged in processing constructions unique to signed languages: classifier predicates in which the position of the hands in signing space schematically represents spatial relations among objects. Ten deaf native signers viewed line drawings depicting a spatial relation between two objects (e.g., a cup on a table) and were asked either to produce a classifier construction or an American Sign Language (ASL) preposition that described the spatial relation or to name the figure object (colored red). Compared to naming objects, describing spatial relationships with classifier constructions engaged the supramarginal gyrus (SMG) within both hemispheres. Compared to naming objects, naming spatial relations with ASL prepositions engaged only the right SMG. Previous research indicates that retrieval of English prepositions engages both right and left SMG, but more inferiorly than for ASL classifier constructions. Compared to ASL prepositions, naming spatial relations with classifier constructions engaged left inferior temporal (IT) cortex, a region activated when naming concrete objects in either ASL or English. Left IT may be engaged because the handshapes in classifier constructions encode information about object type (e.g., flat surface). Overall, the results suggest more right hemisphere involvement when expressing spatial relations in ASL, perhaps because signing space is used to encode the spatial relationship between objects. © 2002 Elsevier Science (USA)

INTRODUCTION

For more than a century we have known that the left hemisphere of the human brain is critical for producing and comprehending spoken language. Damage to perisylvian areas within the left hemisphere produces various types of aphasia, whereas damage to homologous areas within the right hemisphere does not generally produce aphasic symptoms, such as effortful speech, phonological or morphological errors, or difficulty understanding words or sentences. Similarly, research over the past 2 decades has indicated that the left cerebral hemisphere is also critical to processing signed languages. Damage to perisylvian areas within the left, but not the right hemisphere lead to sign language aphasias, and the general dichotomy between anterior–posterior lesions and nonfluent–fluent aphasias holds for signed language as well (for reviews see Corina, 1998, and Hickok and Bellugi, 2000).

Although sign aphasia does not result from right-hemisphere damage, evidence indicates that some signers with right hemisphere damage exhibit a specific impairment in the topographic use of signing space (Poizner *et al.,* 1987; Emmorey *et al.,* 1995; Emmorey, 1996). In American Sign Language (ASL), as well as in other signed languages, signing space can function topographically to represent spatial relations among objects. *Signing space* is the term used for the three-dimensional space in front of the signer, extending from the waist to the forehead, where signs can be articulated. Signers schematize this space to represent physical space, as well as to represent abstract conceptual structure (see Emmorey, 2001). For most locative expressions in ASL, there is a schematic correspondence between the location of the hands in signing space and the position of physical objects in the world. When describing spatial relations in ASL, the identity of each object is first indicated by a lexical sign (e.g., HOUSE, BIKE[2]). The location of the objects, their orientation, and their spatial relation vis-a-vis one another is indicated by where the appropriate classifier signs are articulated. Figure 1 provides a simple illus-

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[2] Words in capital letters represent English glosses for ASL signs. Multiword glosses connected by hyphens are used when more than one English word is required to translate a single sign. English translations are given in quotes.

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HOUSE whole-entity CL + *loc* BIKE whole-entity CL + *loc*

FIG. 1. An illustration of a simple spatial description in ASL, using classifier constructions. An English translation would be "The bike is near the house." Whole-entity CL refers to the type of classifier handshape morpheme and +loc refers to the position movement morpheme (a short downward movement) that means to be located.

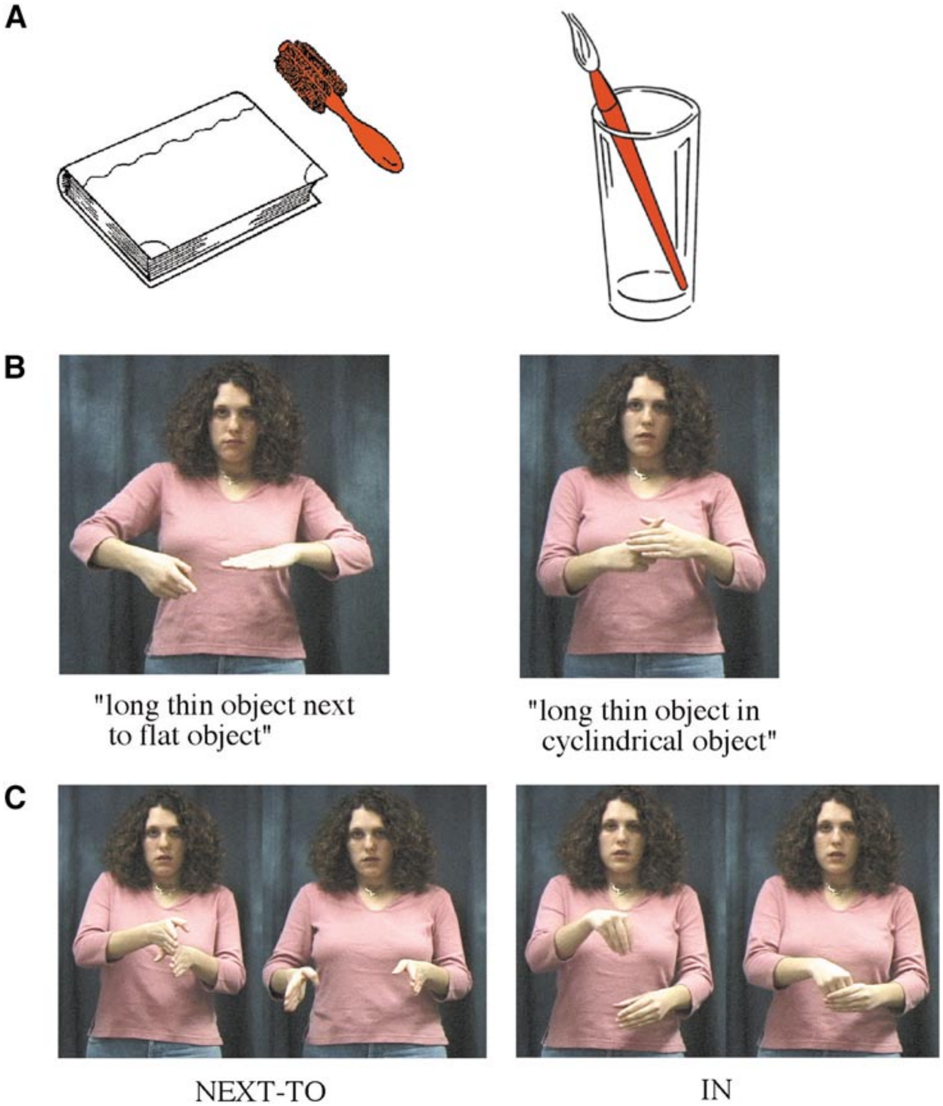
tration of an ASL locative sentence that could be translated as "The bike is near the house."

Classifier predicates are complex forms in which the handshape is a morpheme that encodes information about object type (Supalla, 1986; see papers in Emmorey, in press, for an in-depth discussion of classifier constructions in signed languages). For example, in Fig. 1 the hooked 5 handshape (fingers spread and curved) specifies a large bulky object (such as a house or box), and the 3 handshape (thumb, middle, and index fingers extended) refers to vehicles (such as a bicycle, car, or ship). The first and third signs of Fig. 1 are nouns that refer to the ground and figure objects, respectively (the sign for BIKE is made with the right hand, while the left hand holds the classifier sign referring to the house). This ordering of figure and ground may be an effect of the visual–spatial modality of sign languages (Emmorey, 1996). For example, to present a scene visually by drawing a picture, the ground object tends to be drawn first, and then the figure is located with respect to the ground. Thus, if drawing a picture of a bike next to a house, most people draw the house first. Crucially, the spatial relationship expressed by the classifier construction in Fig. 1 is not encoded by a separate word as it would be in English with the preposition *near*. Although ASL has prepositions such as NEAR, ON, or IN (see Fig. 2C), signers prefer to use classifier constructions when describing spatial relationships. Rather than encoding spatial information with prepositions, such information is conveyed by a schematic and isomorphic mapping between where the hands are placed in signing space and the locations of objects being described.

It is this topographic use of signing space that may be impaired with right hemisphere damage (RHD). For example, Poizner *et al.* (1987) report a RHD signer (BI) who when asked to describe her room, displaced all of the objects to the right in signing space, and did not respect spatial relations, haphazardly piling the furniture in one place. This signer also exhibited neglect on nonlinguistic drawing tasks. However, in other nonspatial contexts, BI was reported to use spatial locations on the left half of space for pronominal reference and verb agreement. Similarly, Corina *et al.* (1996) reported that the RHD signer JH exhibited neglect, but he produced signs using the left half of his body (e.g., LAZY is signed by tapping the left shoulder with an L handshape), and he also directed pronouns and verbs toward the left half of signing space in spontaneous signing. Interestingly, Corina *et al.* (1996) reported difficulty eliciting spatial descriptions from JH, who tended to "avoid using topographic space and simply list[ed] the contents of his room" (p. 338). It appears that left hemisphere control for linguistic production generally compensates for left-side attention deficits unless spatial complexity of the discourse requires the use of several locations representing left–right spatial distinctions.

Emmorey *et al.* (1995) described another RHD signer (DN) who was impaired in retelling ASL descriptions that involved spatial layouts. Her impairment was not in remembering the objects in the spatial descriptions, but in the correct placement of classifier signs within signing space to indicate the spatial relations among the objects. This patient was not aphasic for ASL—her descriptions of spatial layouts were fluent and grammatical, but the location and orientation of the objects were described incorrectly.

Further evidence that the right hemisphere is involved in the comprehension of the topographic functions of signing space, particularly within classifier constructions, comes from two other studies. The first further examined the RHD signer DN who was hearing and bilingual for ASL and English. When DN was asked to set up real objects in accordance with spatial descriptions given in either English or ASL, she performed well in English, but poorly when the same description was given in ASL (Corina *et al.,* 1990; Emmorey, 1996). For the English descriptions, the spatial relations were encoded by a preposition (e.g., "The pen is on the paper"), but in ASL the spatial relations had to be recovered from the spatial positioning of the



"long thin object next to flat object"

"long thin object in cylindrical object"

NEXT-TO

IN

FIG. 2. (A) Example stimuli with a flat-surface ground object and with a cylindrical ground object. (B) Example classifier construction responses for the example stimuli. (C) Example preposition responses for the example stimuli.

classifier signs within signing space (e.g., the classifier handshape for pen (a 1 handshape: fist with index finger extended) was placed on top of the classifier handshape representing a piece of paper (a B handshape: fingers together, palm down). A similar dissociation between the comprehension of ASL spatial prepositions and classifier constructions was reported by Emmorey (1997, 2002). In this study, two left hemisphere damaged aphasic signers and one right hemisphere damaged signer were compared in their comprehension of ASL prepositions and classifier constructions using a picture-matching task.[3] Illustrations of ASL prepositions are given in Fig. 2C. The signers were asked to pick the picture that best matched a preposition (e.g., IN) or a classifier construction depicting a similar spatial relation (e.g., the classifier for banana (a bent 1 handshape) placed within a C handshape representing a bowl). The LHD signers performed poorly on the preposition comprehension task, but the RHD signer performed relatively well. The reverse pattern was observed when location was conveyed by the placement of classifier signs in space: the RHD signer performed poorly, while the LHD signers performed well. Thus, data from lesion studies suggest that the comprehension of spatial prepositions may be subserved primarily by the left hemisphere, whereas the comprehension and production of classifier constructions, in which there is an isomorphic

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[3] This study was conducted in collaboration with Ursula Bellugi, Edward Klima, Kevin Clark, Antonio Damasio, Daniel Tranel, and Paul German.

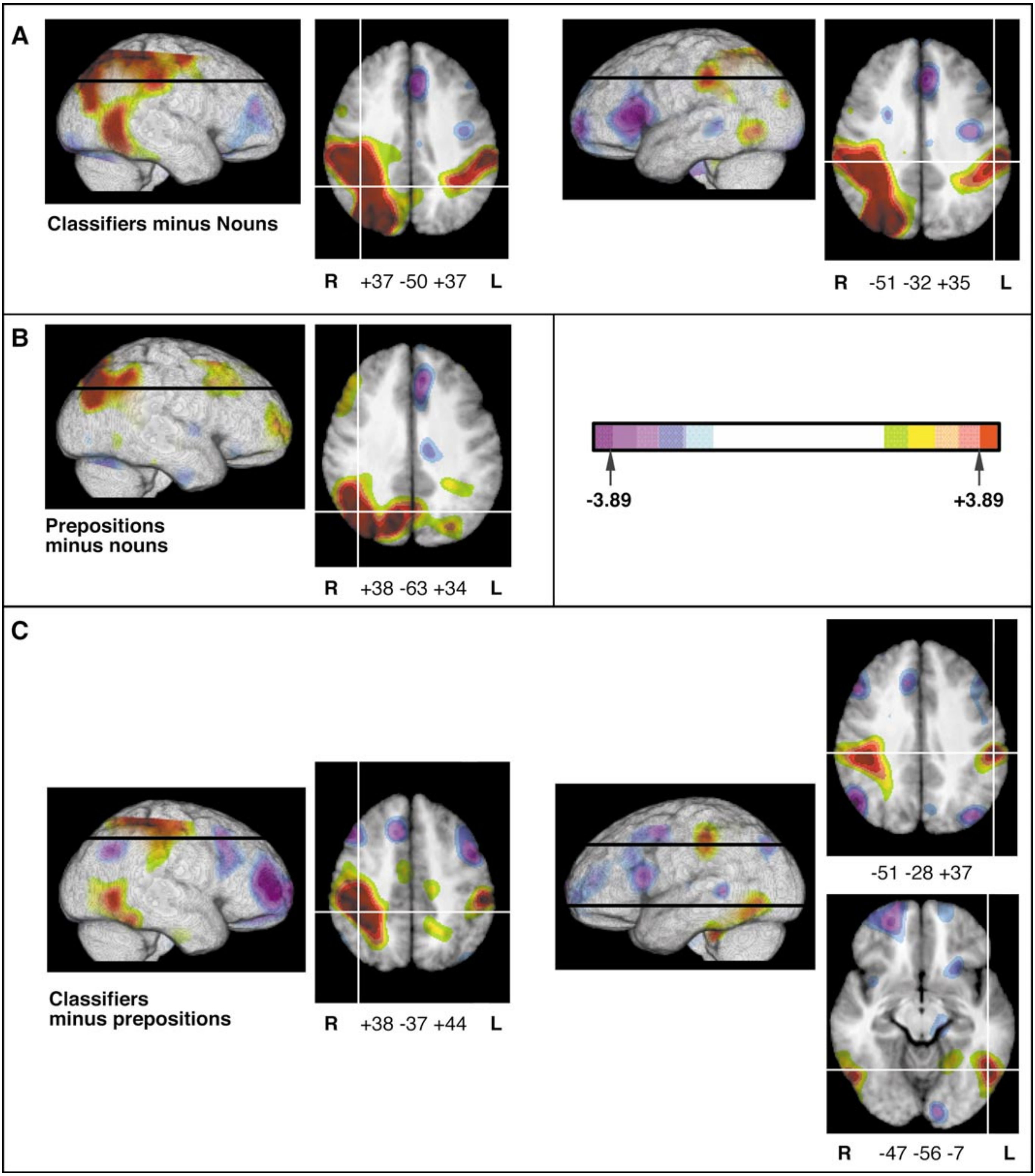

FIG. 3. Illustrations of the contrast among (A) naming spatial relations with classifier constructions and naming the figure objects in the scene, (B) naming spatial relations with an ASL preposition and naming the figure objects in the scene, and (C) naming spatial relations with classifier constructions and naming spatial relations with ASL prepositions. The color bar indicates the thresholds for statistical significance, corrected over the search volume of left IT and bilateral inferior parietal lobule.

mapping between the location of the hands in signing space and the locations of objects in physical space, may be subserved by structures within the right hemisphere.

We do not propose that the comprehension and production of classifier constructions are solely subserved by the right hemisphere. Structures within left hemisphere language areas are also very likely to be involved in the production and comprehension of classifier expressions. For example, a right visual field (left hemisphere) advantage was found when classifier expressions were presented in a hemifield experiment in which signers decided whether a motion or locative predicate contained a target classifier handshape (Emmorey, 1998). In addition, left lesioned aphasic signers produce grammatical and sublexical errors when producing spatial descriptions with classifier constructions, although the topographic use of signing space is intact (Poizner *et al.,* 1987). Finally, the linguistic complexity of classifier constructions would predict left hemisphere involvement. Linguistic constraints specify which classifier handshapes can be combined within a locative expression, how scale and perspective are expressed, and the lexical semantics of classifier handshapes within particular expressions. Mastery of classifier constructions is not attained until late in childhood by signing children (Newport and Meier, 1985; Schick, 1990), and these constructions are notoriously difficult for second-language learners to acquire.

With respect to the expression of spatial relations by hearing English speakers, recent positron emission tomography (PET) data indicate left and right hemisphere involvement for the production of English prepositions (Damasio *et al.,* 2001). Damasio *et al.* (2001) presented English speakers with pictures depicting a spatial relation either between two objects (e.g., a cup on a table) or between two abstract drawings (jagged meaningless shapes from Atteneave, 1957). Subjects were asked either to name the figure object (e.g., the cup) which was colored red or to name the spatial relationship with a preposition. For the abstract drawings, subjects were only asked to name the spatial relation between the two objects (the figure object was smaller and colored red). When naming of the figure object (concrete manipulable entities) was subtracted from naming of spatial relations, activation in the left supramarginal gyrus (SMG) was observed (see Table 2 under Results). Left parietal activation may reflect asymmetric engagement of the dorsal "where" system which is involved in recognizing and identifying object locations (Ungerleider and Mishkin, 1982). Left supramarginal activation may also reflect the engagement of cortices involved in the lexical retrieval of locative prepositions. For example, left lesioned aphasic patients often have difficulty producing and comprehending prepositions (Kemmerer and Tranel, 2000; see also Friederici, 1982).

In addition, when naming spatial relations between meaningless objects was contrasted with either naming concrete objects or naming spatial relations between concrete (nameable) objects, activation in *right* SMG was observed for hearing subjects (see Table 2; Damasio *et al.,* 2001). Naming spatial relations between meaningless shapes may have engaged the right SMG because speakers had to analyze the spatial relation between objects in more detail and could not rely on automatic linguistic encoding. For these stimuli, speakers may have analyzed the spatial relation in terms of coordinate spatial relations representations which specify more metric spatial properties, such as distance. Kosslyn and colleagues have found that the right hemisphere encodes this type of spatial representation more efficiently than the left (Kosslyn, 1987; Kosslyn *et al.,* 1995).

Based on the lesion data from ASL signers and the lesion and PET data from English speakers, we make the following predictions: (1) naming spatial relations with ASL classifier constructions will engage the inferior parietal lobules bilaterally, (2) naming spatial relations with ASL prepositions will engage the left inferior parietal lobule, and (3) naming manipulable objects will engage the left inferotemporal (IT) cortex (naming objects is the baseline control task for this study). The third hypothesis is based on PET data from English speakers who were asked to name tools and other manipulable objects (Damasio *et al.,* 1996). Damasio *et al.* (1996) found activation in the posterior left IT when English speakers were asked to name various tools and implements. This cortical area is hypothesized to mediate between the neural regions which support conceptual knowledge concerning tools and those which support the linguistic representations needed for the production of the name of the tool (Damasio *et al.,* 1996). We have no reason to suspect that deaf people have a distinct conceptualization of manipulable objects compared to hearing people, and therefore, we have no reason to predict differences in the left temporal activation when retrieving signs for tools.

METHODS

Subjects

Ten right-handed, adult native deaf signers were studied under a PET protocol using [^{15}O]water. The subjects were 5 men and 5 women, aged 20–28, with 12 years or more of formal education and were right-handed (handedness quotient of +90 or greater as measured by the Oldfield–Geschwind questionnaire). All participants had deaf parents and acquired ASL as their first language from birth. All were profoundly deaf (90-db loss or greater), and none had any history of neurological or psychiatric disease. All participants gave formal consent in accordance with federal and institutional guidelines.

Procedures

Image acquisition. All subjects underwent MR scanning in a General Electric Signa scanner operating at 1.5 T, using the following protocol: SPGR 30, TR 24, TE 7, NEX 1, FOV 24 cm, matrix 256 × 192. Each of three individual 1NEX SPGR data sets was obtained with 124 contiguous coronal slices with thickness of 1.5–1.7 mm and interpixel distance of 0.94 mm. The slice thickness varied so as to be adjusted to the size of the brain and the head in order to sample the entire brain, while avoiding wrap artifacts. The three individual data sets were coregistered post hoc with Automated Image Registration (AIR 3.03) to produce a single data set, of enhanced quality, with pixel dimensions of 0.7 mm in plane and 1.5 mm between planes (Holmes *et al.,* 1998). The MR sequences were reconstructed for each subject in 3D using Brainvox (Damasio and Frank, 1992; Frank *et al.,* 1997). Extracerebral voxels were edited away manually. The MR scans were used to confirm the absence of structural abnormalities, to plan the PET slice orientation, and to delineate regions of interest *a priori.*

PET-Brainvox (Damasio *et al.,* 1994; Grabowski *et al.,* 1995) was used to plan the PET slice orientation parallel to the long axis of the temporal lobes, so that the PET acquisition volume included the temporal lobes and the inferior parietal lobules in all subjects. Talairach space was constructed directly for each subject via user identification of the anterior and posterior commissures and the midsagittal plane in Brainvox. An automated planar search routine defined the bounding box and a piecewise linear transformation was used (Frank *et al.,* 1997), as defined in the Talairach atlas (Talairach and Tournoux, 1988). After Talairach transformation, the MR data sets were warped (AIR 5th-order nonlinear algorithm) to an atlas space constructed by averaging 50 normal Talairach-transformed brains, rewarping each brain to the average, and finally averaging them again (analogous to the procedure described in Woods *et al.,* 1999). For simplicity, we will henceforth refer to this standard space as “Talairach space.” The Talairach-transformed 3D scans of all 10 subjects were averaged. The search volume, encompassing the left inferotemporal cortices and the bilateral inferior parietal lobules (the supramarginal and angular gyri), was traced on the averaged brain, so as to establish the limits and the size of the search volume.

PET data were acquired with a General Electric 4096 Plus body tomograph (G.E. Medical Systems, Milwaukee, WI), yielding 15 transaxial slices with a nominal interslice interval of 6.5 mm. For each injection, 50 mCi of [^{15}O] water was administered as a bolus through a venous catheter. Arterial blood sampling was not performed.

Each subject received eight injections containing 50 mCi of [^{15}O]water.

Experimental tasks. Each subject performed four tasks, twice each. The tasks were as follows: (1) production of a classifier construction denoting the spatial relation between two objects (mostly manipulable objects) depicted by line drawings in which the figure object was colored red (interstimulus interval [ISI] 1.5 s; see Figs. 2A and 2B); (2) production of ASL prepositions denoting the spatial relation between objects (ISI 1.5 s; see Fig. 2C); (3) production of ASL signs denoting the red-shaded manipulable objects in the stimuli presented in (1) (the control task for (1) and (2); ISI 1.5 s); and (4) an orientation judgment performed on the faces of unknown persons requiring the response YES if the face was in the canonical position (up) and NO if the face was inverted (the control task for (3); ISI 1.0 s).

For the control task (4), subjects made a signed response, but no naming was involved. This task was chosen as the baseline task for naming objects (3) because it has been used in our previous word and sign retrieval experiments (Emmorey *et al.,* in press; Damasio *et al.,* 1996, 2001). Using the same control task consistently allows us to explore the retrieval of words/signs for different conceptual categories and across separate subject groups.

When producing classifier constructions in task (1), the left hand represented the ground object (either a flat or a cylindrical object), and the right hand indicated the location of the figure object, as illustrated in Fig. 2B. The configuration of the right hand depended upon the nature of the figure object, e.g., a 1 handshape for long thin objects, an F handshape (thumb and index finger touch, remaining fingers are extended) for small flat round objects. For one injection, the left hand was always in a B hand configuration (fingers together, palm down) indicating a flat surface, and the ground objects could all be represented by a B classifier handshape. For the second injection, the left hand was always in a C hand configuration (fingers together and curved, palm facing right) indicating a cylindrical object, and the ground objects were all cylindrical. The left hand remained relatively static, while the right hand was placed on top of, next to, behind, in front of, under, above, or inside of the left hand, depending upon the spatial relation described. Prior to each injection, subjects were told which hand configuration should be used to represent the ground object. Subjects were told not to name either the figure or the ground object, but to produce only the classifier predicate that expressed the spatial relation depicted in the picture. Subjects performed the classifier production task as the first task in the experimental session.

TABLE 1A

Contrasts between Naming Spatial Relations with Classifier Constructions or Prepositions and Naming Manipulable Objects, a priori Search Volume (Critical t − 3.89)

	Spatial relations named by classifier constructions (italic) minus naming objects (boldface)			Spatial relations named by prepositions (italic) minus naming objects (boldface)			Spatial relations named by classifier constructions (italic) minus prepositions (boldface)		
Region	T_{88} coordinates	Threshold t(dof)	Vol (mm^3)	T_{88} coordinates	Threshold t(dof)	Vol (mm^3)	T_{88} coordinates	Threshold t(dof)	Vol (mm^3)
Temp. lobe									
IT L							*−47 −56 −7*	*+3.99*	*375*
L				**−34 −27 −20**	**−3.93**	**34**	*−34 −33 −20*	*+4.20*	*194*
Parietal lobe									
SMG R	*+37 −50 +37*	*+5.32*	*19,763*	*+38 −63 +34*	*+4.97*	*8272*	*+38 −37 +44*	*+4.73*	*4224*
Angular									
G/SMG R	*−51 −32 +35*	*+4.07*	*939*				**+47 −63 +35**	**−3.93**	**51**
SMG L	*−38 −45 +42*	*+4.21*	*383*				*−51 −28 +37*	*+4.16*	*371*

When producing prepositions, object names, and the yes/no response for the control task, subjects signed with their right hand in a natural whisper mode so that the hand did not contact the face. One-handed signing is natural for whispering and also occurs during everyday signing (e.g., when one hand is occupied). The majority of signed responses involved only the right hand (this was also true for classifier constructions because the left hand remained in the same configuration for each stimuli set).

Data analysis. Reconstructed images of the distribution of radioactive counts from each injection were coregistered with each other using Automated Image Registration (AIR 3.03, Roger Woods, UCLA). 3D MR and the mean coregistered PET data were also coregistered using PET-Brainvox and Automated Image Registration (Woods *et al.,* 1993). PET data were Talairach-transformed as described above, masked to the coregistered MRI brain contour to exclude extracerebral voxels, and then smoothed with an isotropic 16-mm gaussian kernel by Fourier transformation, complex multiplication, and reverse Fourier transformation. The final calculated image resolution was 18 × 18 × 18 mm.

PET data were analyzed with a pixelwise linear model which estimated coefficients for global activity (covariable) and task and block/subject effects (classification variables) (Friston *et al.,* 1995; Grabowski *et al.,* 1996). We searched for increases in adjusted mean activity in images of t statistics generated for each of the planned contrasts. Critical t values were calculated using gaussian random field theory for t statistics (Worsley *et al.,* 1992; Worsley, 1994).

The planned contrasts were as follows:

(a) To address the hypothesis that naming spatial relations with classifier constructions will engage structures in the inferior parietal lobules bilaterally, naming of the figure objects was subtracted from naming spatial relations with classifier constructions.

(b) To address the hypothesis that naming spatial relations with prepositions will engage the left inferior parietal lobule, naming of the figure objects was subtracted from naming spatial relations with prepositions.

(c) To address how naming spatial relations with classifier constructions differs from naming spatial relations with prepositions, these tasks were subtracted from each other.

(d) To address the hypothesis that naming manipulable concrete objects will engage left IT, the standard control task (task 4) was subtracted from naming the figure objects.

RESULTS

The volume of the search volume (left IT and bilateral inferior parietal lobule) was 144 cm^3 (25 resels), and the critical t value was −3.89 for the *a priori* search volume (Table 1A) and −4.67 for the whole brain *post hoc* search volume (Table 1B). The results are illustrated in Fig. 3. The contrast between naming spatial relations with a classifier construction and naming concrete objects revealed activation in the left supramarginal gyrus with two maxima (−51, −32, +35; −38, −45, +42). This activation is more mesial and superior to the activation observed within the left SMG for English speakers naming spatial relations with prepositions (−62, −41, +27; with the same statistical post processing as this report, Damasio *et al.,* 2001; see Table 2). As predicted, this contrast also revealed activation in right SMG (+37, −50, +37), which was not observed for English speakers naming spatial relations with prepositions, when subtracting the same spatial relation and object naming tasks

TABLE 1B

Contrasts between Naming Spatial Relations with Classifier Constructions or Prepositions and Naming Manipulable Objects, post hoc Search Volume (Critical t − 4.67)

	Spatial relations named by classifier constructions (italic) minus naming objects (boldface)			Spatial relations named by prepositions (italic) minus naming objects (boldface)			Spatial relations named by classifier constructions (italic) minus prepositions (boldface)		
Region	T_{88} coordinates	Threshold t(dof)	Vol (mm^3)	T_{88} coordinates	Threshold t(dof)	Vol (mm^3)	T_{88} coordinates	Threshold t(dof)	Vol (mm^3)
Temp. Lobe									
Temp/occ. junction R	*+54 −58 −1*	*+5.24*	*1618*						
IT L							*−34 −33 −23*	*+4.75*	*60*
Parietal lobe									
SPL R				*+11 −69 +45*	*+5.05*	*4410*	*+35 −35 +49*	*+5.28*	*6139*
SPL L	*−32 −47 +46*	*+5.00*	*681*						
SMG R	*+31 −50 +43*	*+5.70*	*28,398*	*+37 −70 +33*	*+5.73*	*4835*			
Frontal lobe									
Pole R							**+38 +52 +9**	**−4.91**	**1033**
Subcortical									
Thalamus L	**−8 −15 1**	**−4.83**	**172**						
Retrosplenial L							**−16 −40 18**	**−4.89**	**180**

(Damasio *et al.*, 2001); however, right hemisphere activation was observed for English speakers when they named spatial relations between abstract drawings (see Table 2).

Contrary to our predictions, the contrast between naming spatial relations with ASL prepositions and naming concrete objects revealed no significant activation in the left hemisphere and only activation in the right angular gyrus/SMG (+38, −63, +34). The direct contrast between naming spatial relations with classifier constructions and with prepositions revealed bilateral activation in the supramarginal gyrus for classifier constructions (−51, −28, +37; +38, −37, +44). In addition, this contrast revealed activation in left IT with two maxima (−47, −56, −7; −34, −33, −20) when naming spatial relations with classifier constructions (Table 1A). Finally, the contrast revealed greater activation in right angular gyrus (just bordering SMG) when naming spatial relations with ASL prepositions (+47, −63, +35).

A post hoc analysis at the whole brain level was also conducted to determine whether there were additional areas of significant activity (Table 1B). This analysis revealed activity in the left superior parietal lobule (SPL) when classifier constructions were contrasted with naming objects (−32, −47, +46) and in right SPL when classifier constructions were contrasted with prepositions (+35, −35, +49). The contrast between naming spatial relations with ASL prepositions and naming objects also revealed activation in right SPL, but more posterior and mesial than that observed for classifier constructions (+11, −69, +45). Significant

TABLE 2

Summary of PET Activation Results for Hearing Subjects, a priori Search Volume, from Damasio *et al.* (2001)

	Spatial relations named by English prepositions (concrete objects) (italic) minus naming concrete objects (boldface)		Spatial relations named by English prepositions (abstract objects) (italic) minus naming concrete objects (boldface)		Spatial relations named by English prepositions (concrete objects) (italic) minus English prepositions (abstract objects) (boldface)	
Region	T_{88} coordinates	Threshold t(dof)	T_{88} coordinates	Threshold t(dof)	T_{88} coordinates	Threshold t(dof)
Temp. lobe						
IT L			**−38 −68 −6**	**−6.11**	*−37 −47 −10*	*+5.05*
Parietal lobe						
SMG R			*+34 −45 +39*	*+4.99*	**+46 −44 +41**	**−4.39**
SMG L	*−62 −41 +27*	*+4.29*	*−46 −39 +39*	*+4.06*		

Note. The contrast in column 2 was not reported in the original study and is reported here to provide additional data relevant to the comparison between English and ASL.

activation within superior parietal cortex was not observed for English speakers with the *post hoc* analysis contrasting naming spatial relations and naming concrete entities (Damasio *et al.,* 2001). A few other regions of activation were also observed with the *post hoc* analysis (see Table 1B).

Finally, when naming concrete manipulable objects and the control task were contrasted, we observed activation in left IT with two maxima (−50, −53, −6; −27, −38, −13), left SMG (−34, −66, +40), and right angular gyrus (+31, −80, +27). As predicted, the activation in left IT was similar to that found for English speakers naming tools (−50, −50, −11; −29, −28, −19; subtracting the same control task and with the same statistical post processing as in this report, Damasio *et al.,* 1996).

DISCUSSION

Production of ASL classifier constructions that specified the spatial relation between two objects engaged the parietal lobe within both left and right hemispheres. The activation within left parietal cortex was similar to that observed for English speakers in the parallel study by Damasio *et al.* (2001). However, for ASL classifier constructions, activation within the left supramarginal gyrus was superior and mesial to the activation observed for English speakers (see Tables 1A and 2). Although the contrast between naming spatial relations and naming objects did not reveal significant activation within the right hemisphere for English speakers, Damasio *et al.* (2001) found evidence of activation in the right SMG when speakers named spatial relations between abstract nonnameable objects. Furthermore, the activation peak within the right SMG for ASL signers was quite similar to that seen in English speakers (+46, −44, +41; using the same post processing procedures as in this report).

For ASL, we propose that naming spatial relations with classifier constructions engages the right hemisphere even when concrete nameable objects are involved because signing space is used topographically. As discussed in the Introduction, there is a schematic and analogue mapping between the location of the hands in signing space and the location of physical objects described by classifier constructions. Signers must analyze the spatial relation between objects in enough detail to place their hands in an analogous position in signing space. ASL does not encode metric contrasts, but the locative information expressed by classifier constructions is analogue rather than categorical, and locations in signing space are not morphemic representations (Liddell, 1990, 2000; Emmorey and Herzig, in press). In contrast, the locative information expressed by prepositions is categorical, and prepositions constitute a closed class set of morphemes in English.

In a related study, MacSweeney *et al.* (in press) used fMRI to investigate the neural areas engaged when deaf and hearing users of British Sign Language comprehended sentences that used space topographically (e.g., "The cat sat on the bed") compared to BSL sentences that did not (e.g., "The man telephoned the woman"). The topographic sentences generally involved classifier constructions, while the nonlocative sentences did not. Their results did not show more right hemisphere activation for processing topographic sentences compared to nonlocative sentences. Rather, the results revealed greater activation in *left* inferior parietal cortex when comprehending topographic BSL sentences. Importantly, when MacSweeney *et al.* (in press) translated their topographic and nontopographic BSL sentences into English and presented them audiovisually to hearing nonsigners, they found no differences in parietal activation in the left hemisphere for the two sentence types. This finding suggests that the comprehension of signed sentences that use space topographically engages parietal structures within the left hemisphere that may be uniquely required for processing signed language. The Talairach coordinates for the activation in left parietal cortex (−54, −37, +37; these coordinates represent centroids of 3D clusters; MacSweeney *et al.,* in press) were nearly identical to the activation maxima observed in our study for the contrast between producing classifier constructions and naming the figure objects (−51, −32, +35; see Table 1A). Thus, left parietal cortex may be engaged during both the comprehension and the production of sentences or constructions that involve the topographic use of signing space.

The lack of right hemisphere activation when comprehending signed sentences that used space topographically is most likely attributable to the task demands of the MacSweeney *et al.* (in press) study. Specifically, the BSL signers were asked to press a button when they detected a semantic anomaly. In our PET study, as well as in the lesion studies discussed in the introduction (Corina *et al.,* 1990; Emmorey, 1997; Poizner *et al.,* 1987), subjects were asked to translate the spatial relation between the hands in signing space into another spatial representation (i.e., the location of physical objects in nonsigning space). The right hemisphere may be specifically engaged when spatial locations in signing space must be related to another representation of spatial locations either in the form of a mental image (e.g., when describing a room from memory) or in the form of physical objects (e.g., objects in a manipulation task or pictures in a picture-matching task). A reasonable hypothesis suggested by Corina (1998) is that the difficulties that right hemisphere damaged patients exhibit in producing and comprehending classifier constructions and the topographic functions of signing space may stem from a more general problem with encoding external spatial relations into body-centered manual representations, particularly when two articulators are used. Thus, the right hemisphere may play a unique role in the interpretation and production of ASL spatial descriptions, a role that is not generally required for English spatial descriptions of everyday objects (or for simple comprehension of topographic signed sentences).

Furthermore, the regions of activation observed within parietal cortex for describing spatial relations with ASL classifier constructions correspond to regions found to be involved in visual motor planning and coordinate transformation processes. Anderson *et al.* (1997) argued that posterior parietal cortex is intimately involved in coding the spatial locations of goals for movement and in combining different coordinate frames. For ASL, activation within SMG in the right hemisphere was quite posterior and indicates engagement of posterior parietal cortex for classifier constructions (see Fig. 3A and Tables 1A and 1B). In addition, *post hoc* whole brain analyses revealed activation in the posterior superior parietal lobule (see Table 1B). The human superior parietal lobule has been implicated in spatial attention (e.g., Shibata and Ioannides, 2001; Corbetta *et al.,* 1993), and Wolpert *et al.* (1998) have suggested that SPL plays a key role in sensorimotor integration by actively maintaining an internal representation of the body and that attention may be shifted and directed with respect to this body schema representation. In the current PET study, ASL signers had to attend to the spatial locations of the figure and ground objects, and they had to keep track of the position of their hands in signing space to correctly depict these locations. Thus, parietal cortex may be engaged during the production of locative classifier constructions because to produce these constructions, visual information (either a mental image or an observed scene) must be integrated with goal-directed motor movements.

Contrary to our predictions, the contrast between naming spatial relations with ASL prepositions and naming concrete objects revealed activation only within the right SMG. Based on the PET data from English speakers (Damasio *et al.,* 2001) and on data from aphasic ASL signers (Emmorey, 1997, 2002), we had predicted more left hemisphere involvement for naming spatial relations with ASL prepositions in this experiment. However, these conflicting results may reflect the marginal status of ASL prepositions for describing spatial relations in everyday discourse, compared to English prepositions. For example, signers rarely used these forms when describing the spatial layout of furniture within a doll house (Emmorey, 1996) or when describing where to place puzzle blocks on a grid when solving a spatial puzzle (Emmorey and Casey, 1995). Furthermore, the grammatical analysis of these forms is controversial. Some linguists have argued that they are prepositions (e.g., McIntire, 1980), while others have argued that they are actually verbs (Shepard-Kegl, 1985). The right SMG activation observed for ASL prepositions may reflect the same spatial analysis that we hypothesize underlies the production of locative classifier constructions; in fact, the PET activation peaks in the right hemisphere are very similar (the maxima is slightly more posterior for the prepositions than for classifier constructions; see Table 1A). The left hemisphere may not be engaged when naming spatial relations with ASL prepositions because these forms are not generally used and are not preferred. ASL prepositions may occasionally be used for emphasis or contrast (e.g., "the box is UNDER the table, not ON it"). Unlike English prepositions, ASL prepositions are often used to label the spatial relation itself, rather than to specify the relation between particular figure and ground objects. Similarly, when English speakers had to focus on the spatial relation itself because the objects were nonnameable, right hemisphere activation was observed (Damasio *et al.,* 2001).

Although the RHD signer reported in Emmorey (1997, 2002) performed better than the LHD signers on the comprehension test for ASL prepositions, his performance was not perfect (79% correct). It is possible that his right hemisphere damage, which included parietal cortex, impaired his comprehension of ASL prepositions, but to a lesser extent than his comprehension of locative classifier constructions (44% correct). Furthermore, the LHD signers may have performed poorly on the preposition comprehension task (57 and 36% correct) due to other linguistic processing demands of the task. For example, the figure and ground arguments had to be correctly associated with the preposition since these arguments are not encoded in the form of the preposition. In contrast, the handshapes of the locative classifier constructions encode figure and ground information, and as noted, the LHD signers performed quite well on the classifier comprehension task (94 and 81% correct).

As predicted, the contrast between naming manipulable objects and our standard control task revealed activation in left inferotemporal cortex. The location of this activation is distinct from that observed in our previous PET study in which deaf native signers produced signs for animals (Emmorey *et al.,* in press). Specifically, lexical retrieval of names for animals engaged a region in left IT that was more anterior to the region engaged during the retrieval of names for manipulable objects (−38, −45, −11; using the same control task and with the same post processing as in this report). Similarly, Damasio *et al.* (1996) found that naming animals in English activated left IT in a region anterior to the region activated when naming manipulable tools. Furthermore, naming famous persons (unique entities) by both signers and speakers engages still another region within the temporal lobe: the left temporal pole (Damasio *et al.,* 1996; Emmorey *et al.,* in press). Damasio *et al.* (1996) hypothesize that these nonclassical language areas within the left hemisphere mediate between neural regions which support conceptual knowledge about objects and regions which support the phonemic representations needed for the production of the name of an object. Naming of distinct types of objects engages distinct neural areas because the neural mapping of conceptual knowledge is hypothesized to be determined by the physical characteristics of objects and by our sensorimotoric interaction with these objects *inter alia*, which of course differ for animals and tools (see Damasio and Damasio, 1994). The results of this study and our previous study (Emmorey *et al.,* in press) indicate that signed languages exhibit the same neural organization for lexical retrieval within nonclassical language areas as has been observed for spoken language (at least with respect to concrete entities).

The direct contrast between naming spatial relations with classifier constructions and with prepositions also revealed activation within the posterior left IT for classifier constructions (see Table 1A). We interpret this activation as a reflection of the fact that handshape within these constructions encodes information about object type. For prepositions, handshape is lexically specified and does not change with the nature of the figure or ground objects. For example, the B handshape of the sign NEXT-TO does not specify a flat surface prominent figure object (see Fig. 2C). In contrast, when deaf signers produce classifier constructions to indicate spatial relationships, they must choose the appropriate handshape for each figure object. For example, long thin objects such as pencils or fishing poles require a 1 handshape, while cylindrical objects such as cups or bowls require a C handshape. Thus, signers had to recognize and interpret details about the figure object's shape and other properties in order to produce the correct classifier handshape. We propose that a (subconscious) retrieval of this information underlies the activation observed in the posterior left IT when classifier constructions were contrasted with prepositions because retrieving a preposition does not require such complex processing of the figure object (linguistically, figure objects are treated as points for both ASL and English prepositions, see Emmorey, 1996; Talmy, 1983).

In conclusion, the production of ASL classifier constructions that express spatial relationships engages neural areas within both left and right parietal cortex. Parietal regions of the cortex in both hemispheres have long been known to be involved in the attention to and perception of the spatial location of physical objects in the environment (e.g., Posner and Petersen, 1990; Ungerleider and Mishkin, 1982). With respect to language, parietal regions may be uniquely engaged during the production (and comprehension) of spatial language in signed languages, particularly for locative classifier constructions in which the location of the signer's hands in space specifies the spatial relation between objects. Furthermore, right parietal cortex may be specifically engaged when external spatial relations must be translated into body-centered manual representations in which each articulator represents an object within the spatial relation. The nature of spatial language differs quite dramatically from spatial language in spoken languages where single closed class elements (i.e., prepositions or locative affixes) denote spatial relations. And it is precisely within this domain where we find variation between the neural systems underlying speech and sign production. In contrast, the results from this study in conjunction with those of our previous studies (Emmorey *et al.,* in press; Damasio *et al.,* 1996) indicate that the neural systems involved in the retrieval of ASL signs denoting concrete entities within distinct conceptual categories (i.e., animals, tools, and famous persons) are remarkably similar to those underlying the retrieval of spoken English words denoting the same types of entities. Thus, when naming concrete entities, the neural structures that mediate language output are the same regardless of the mode of output, either speech or sign. However, when expressing spatial relationships, the visual–spatial modality of signed languages has an impact on the neural systems that underlie language production.

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