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Enhanced Image Generation Abilities in Deaf Signers: A Right Hemisphere Effect

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Deaf subjects who use American Sign Language as their primary language generated visual mental images faster than hearing nonsigning subjects when stimuli were initially presented to the right hemisphere. Deaf subjects exhibited a strong right hemisphere advantage for image generation using either categorical or coordinate spatial relations representations. In contrast, hearing subjects showed evidence of left hemisphere processing for categorical spatial relations representations, and no hemispheric asymmetry for coordinate spatial relations representations. The enhanced right hemisphere image generation abilities observed in deaf singers may be linked to a stronger right hemisphere involvement in processing imageable signs and linguistically encoded spatial relations. © 1996 Academic Press, Inc.

Several recent studies have shown that deaf and hearing subjects who are proficient in American Sign Language (ASL) have better mental imagery abilities than subjects who have little or no experience with a signed language (Emmorey, Kosslyn, & Bellugi, 1993; McKee, 1987; Talbot & Haude, 1993). Emmorey et al. (1993) hypothesized that certain imagery abilities are integral to the production and comprehension of ASL, and that their constant use might enhance these imagery skills within a nonlinguistic domain. Spe-

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cifically, they hypothesized that during discourse signers *generate* mental images (i.e., form them on the basis of information in long-term memory) and then *transform* these images in various ways, particularly by shifting reference and perspective. A referential shift marks the discourse as expressing the point of view (both spatial and attitudinal) of a particular referent. The shift is marked by a slight change in body position and/or changes in eye gaze, head position, or facial expression (Loew, 1983; Padden, 1986). Liddell (1990) has argued that under referential shift, signers may imagine referents as physically present, and these visualized referents are relevant to the expression of verb agreement morphology. Liddell gives the following example involving the verb ‘‘ask,’’ which is lexically specified to be directed at chin height:

> To direct the verb ASK toward an imagined referent, the signer must conceive of the location of the imaginary referent’s head. For example, if the signer and addressee were to imagine that Wilt Chamberlain was standing beside them ready to give them advice on playing basketball, the sign ASK would be directed upward toward the imaged height of Wilt Chamberlain’s head. . . It would be incorrect to sign the verb at the height of the signer’s chin. . . This is exactly the way agreement works when a referent is present. Naturally, if the referent is imagined as laying down, standing on a chair, etc., the height and direction of the agreement verb reflects this. Since the signer must conceptualize the location of body parts of the referent imagined to be present, there is a sense in which an invisible body is present. The signer must conceptualize such a body in order to properly direct agreement verbs. (Liddell, 1990, p. 184)

In addition, ASL classifier verbs of location and motion often require precise representation of visual-spatial relations within a scene, and such explicit encoding may require one to generate detailed visual images. For example, when describing the layout of a room using the classifier system of ASL, it is impossible to sign ‘‘The bed is on the right and the chair on the left’’ without also specifying the orientation and location of the bed and chair, as well as their relation to each other. Figure 1 illustrates a simple ASL spatial description that uses classifier constructions. English does not require such explicit obligatory marking of spatial relations. Several adjunct phrases would be required to express the same relation; in fact, English speakers take longer than ASL signers to describe spatial scenes, despite the fact that ASL signs take longer than English words to articulate (Emmorey, 1996). Note, however, that other spoken languages, such as Navajo (Pinxten, van Dooren, & Harvey, 1983) or Tzeltal (Brown, 1991), require similar explicit linguistic marking of spatial relations on predicates of location and position.

What is unique about ASL is that space itself is used to express spatial relationships. Thus, not only does ASL have a very rich linguistic system for expressing complex spatial relations, but these relations are also directly encoded in physical space (for discussion, see Emmorey, 1996). We hypothesize that ASL signers generate images frequently because of the interaction

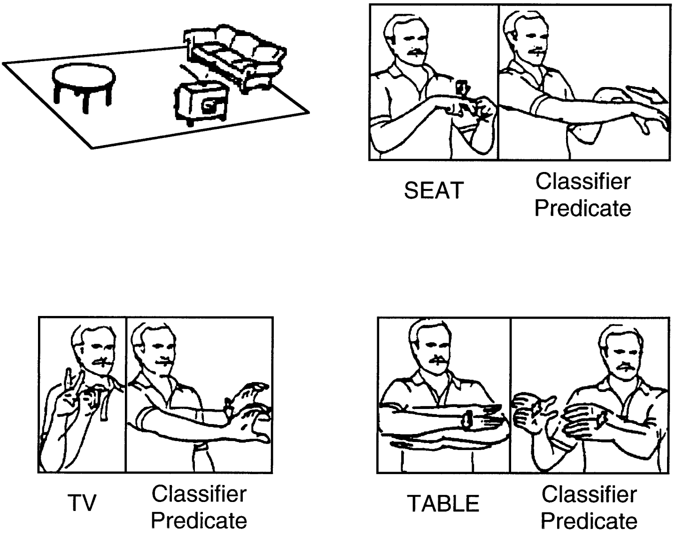

FIG. 1. Example of a simple ASL spatial description using classifier predicates. An English translation of the room description would be ''There is a long couch on the left, a TV on the far side, and a round table on the right.'' The classifier predicates in this example express the location, as well as the size and shape of the objects specified by a preceding lexical sign.

between what must be encoded from a referent object and how it is expressed in ASL.

If deaf subjects are in fact generating visual images prior to or during sign production, then such practice should lead signers to become adept at generating images. Using an image generation task devised by Podgorny and Shepard (1978) and modified by Kosslyn, Cave, Provost, and Von Gierke (1988), Emmorey et al. (1993) investigated whether ASL signers could generate visual mental images faster than could hearing nonsigners. In this task, subjects first memorized uppercase block letters. Following this, they were shown a series of 4 × 5 grids (or sets of brackets), each of which contained an X mark; examples of the stimuli are provided in Fig. 2. A lowercase letter preceded each stimulus, and subjects were asked to decide as quickly as possible whether the corresponding uppercase block letter would cover the X if it were present in the grid (or within the brackets). The crucial aspect of the experiment was that the probe X mark appeared in the grid only 500 msec after the lowercase cue letter was presented.

Kosslyn et al. (1988) have shown that 500 msec is not enough time for people to complete forming an image of the uppercase letter in this task. Thus, response times reflect in part the time to generate the image of the uppercase letter. Kosslyn et al. (1988) used this task to show that such visual mental images are constructed serially, a part at a time. They found that subjects tend to generate images of block letters segment-by-segment, in the

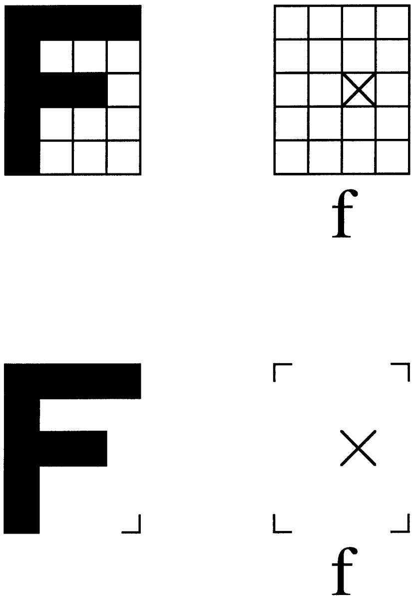

FIG. 2. Examples of the grids and brackets stimuli.

same order that the segments are drawn when the letter is printed. Therefore, subjects can evaluate a probe X faster when it is covered by a segment that is generated early (e.g., on the first stroke of the letter F, the vertical line on the left) than when the probe is covered by a segment that is generated late (e.g., on the last stroke of the letter F, the middle horizontal line). The characterization of the order was determined empirically, by covertly observing subjects when they were asked to reproduce the letters. Crucially, this difference in response time for different probe locations is not found when image generation is not involved (e.g., when both the probe X and letter, shaded gray, are physically present).

Using the task of Kosslyn et al. (1988), Emmorey et al. (1993) found that both deaf and hearing native signers generated images of complex letters faster than did non-signers. This finding supports the hypothesis that experience with ASL improves one's ability to generate visual mental images. Results from a perceptual baseline task indicated that the enhanced performance in image generation ability was not a consequence of differences in image scanning or inspection—signers and non-signers did not differ in their ability to evaluate probe marks when the shape was physically present. Moreover, signing and non-signing subjects were equally accurate, which implies that although signers create complex images faster than non-signers, they generate equally good images. In addition, both deaf and hearing subjects required more time and made more errors for probes located on late-imaged segments, and these effects were of comparable magnitude in the two groups. This result indicates that neither group of subjects generated images of letters as integral wholes, and both groups visualized segments in the same order. The fact that hearing signers performed similarly to deaf signers implies that it is experience with ASL, rather than auditory deprivation, that underlies the enhanced ability to generate visual mental images.

Kosslyn and colleagues have argued that each cerebral hemisphere can generate mental images, but that the images are constructed using two different types of spatial relations representations (Kosslyn, 1987, 1994; Kosslyn et al., 1988; Kosslyn, Maljkovic, Hamilton, Horwitz, & Thompson, 1995b). This hypothesis is based in part on the finding that the hemispheres apparently encode different types of spatial relations, which subsequently may be differentially available for use in juxtaposing parts of an object in a visual mental image. Specifically, several research groups have found that the left hemisphere encodes *categorical* spatial relations more efficiently than the right; such relations specify an equivalence class, such as ‘‘connected to’’ or ‘‘above.’’ In contrast, the right hemisphere processes *coordinate* spatial relations more efficiently than the left; these relations specify metric spatial properties, such as precise distance. Representations of categorical spatial relations are used when the precise arrangement among parts of an object can vary, but the general category on the relation remains constant. This type of spatial categorization has parallels to the categorical and symbolic nature of language. In contrast, coordinate spatial relations representations are used primarily to guide movements; for example, in navigation, one must be aware of precise distances in order to avoid collisions with objects (see Hellige & Michimata, 1989; Findlay, Ashton, & McFarland, 1994; Kosslyn et al., 1995b; Laeng, 1994, but see Sergent, 1991a,b; Kosslyn et al., 1992; and Kosslyn, Chabris, Marsolek, Jacobs, & Koenig, 1995a, for some qualifications regarding the nature and degree of hemispheric differences).

The present experiment was designed to determine whether the processes underlying image generation are lateralized in the same way in deaf signers and hearing nonsigning people. We wanted to know whether the enhanced image generation abilities found in ASL signers arise from a difference in how the brain constructs images from different types of spatial relations. To answer this question, we first asked deaf and hearing subjects to memorize block uppercase letters and the corresponding lowercase letters within a grid or within set of corner brackets (see Fig. 2). Subjects then received a set of trials, each of which required them to encode a probe mark in an otherwise empty grid (or set of brackets) to the left or right of a central fixation point, and then to decide whether the mark would fall on a specific uppercase letter if it were present.

Following the reasoning of Kosslyn et al. (1995b), we assumed that the grid lines act as a kind of crutch, which allow the subjects to use a description of the arrangement of segments to generate an image in the grid. For example, the subjects might encode the letter F as ‘‘A vertical bar on the left, a horizontal bar connected at its left to the top of the vertical bar, and a horizontal bar connected at its left to the middle of the vertical bar.’’ These sorts of descriptions, which presumably are in a propositional format, rely on categorical spatial relations; thus, if such descriptions are used to guide the image generation process, the subjects will rely on categorical spatial relations to arrange parts in the image.

In the brackets condition, the subjects memorized block letters that were within four brackets. The brackets defined the corners of the grid used in the other condition, but most of the sides and all internal lines were eliminated. In this condition, the probe marks were presented within an empty set of brackets during the test trials. As in the grids condition, the subjects decided whether the probe would have fallen on a specific uppercase letter if it were present. The brackets provide very little support structure, and subjects cannot easily use them to help arrange the segments of the letter correctly. Thus, the spatial relations among the segments need to be specified relatively precisely in order to determine whether a probe mark would fall on a letter segment. Categorical spatial relations are not suited for specifying specific, precise positions, and hence we expected coordinate spatial relations to be used with the brackets stimuli to form the images of the block letters.

Kosslyn et al. (1995b) provide converging evidence that supports these assumptions. In these experiments, subjects formed images within grid or bracket stimuli, and determined whether a single X mark would have fallen on an imaged pattern. In one experiment, subjects first memorized descriptions of how segments were arranged to form a pattern; these descriptions specified categorical spatial relations among segments. Subjects later could visualize the composite pattern more accurately when cued in the right visual field (left hemisphere) than when cued in the left visual field (right hemisphere). However, in another version of the task the subjects first were shown a sequence of individual segments on a screen, and were asked to ‘‘mentally glue’’ the segments into a single pattern. This technique forced the subjects to encode the precise positions of the segments on the screen; categorical spatial relations alone would not be sufficient to organize the segments into patterns. In this case, the opposite results were obtained: The subjects later could visualize the patterns more accurately when cued in the left visual field (right hemisphere). These versions of the task virtually forced the subjects to rely on categorical versus coordinate spatial relations when later constructing images. Kosslyn et al. were concerned that this heavy-handed approach may not have reflected the way images are constructed when subjects are not forced to rely on specific types of spatial relations, and thus they devised the grids/brackets version of tasks used in the present investigation as a way to induce the different strategies spontaneously. They found that subjects did in fact evaluate images in grids better when cued in the right visual field, but evaluated images in brackets better when cued in the left visual field.

As expected, these results were similar to those found in the first two tasks, when subjects were forced to rely on the different types of spatial relations. Kosslyn et al. also carried out a number of control experiments, which demonstrated that the results from the grids and brackets tasks were not a consequence of hemispheric differences in the ease of visualizing patterns at different sizes or in the ease of perceptually encoding the cues themselves.

METHOD

Subjects

Twenty deaf signers (mean age = 26 years) and 20 hearing non-signers (mean age = 22 years) participated as subjects. All deaf subjects were native signers,[1] and had an average hearing loss of 95 db in the better ear; 18 of the signers were deaf from birth, and the other two were prelingually deaf (before 18 months). American Sign Language was the preferred and primary means of communication for the deaf subjects. All subjects in both groups were right handed. Handedness was assessed by a short questionaire regarding which hand was preferred for various activities (e.g., writing, using a toothbrush). All subjects preferred their right hand for the majority of tasks, and no subject was ambidextrous. The deaf subjects (11 males/9 females) were tested either at The Salk Institute or at Gallaudet University. Deaf subjects were recruited by contacting student groups and advertising on campus. The deaf subjects were students either at Gallaudet University in Washington, DC (15) or at California State University, Northridge (5), and the mean number of years of college education was 4.5 years. The hearing subjects (11 males/9 females) were tested at the Salk Institute. According to self report, the hearing subjects had no knowledge of sign language and had normal hearing. The hearing subjects were all students at the University of California, San Diego, and their mean number of years of college education was 3.5 years. Hearing subjects were recruited through advertisements on the UCSD campus. All subjects were volunteers and were either paid for their participation or received course credit.

Materials

A set of 4 × 5 grids was prepared, and specific cells were blackened to depict eight different uppercase block letters: C, F, G, H, J, L, P, and U; each letter included at least one filled cell in each row and column. The corresponding lowercase letter was placed beneath each of these letters. A corresponding set of bracket stimuli was created by deleting the grid lines and outer framework of the grid such that only the four corners remained (as illustrated in Fig. 2). The stimuli were 2.5 × 3 cm and were centered on the screen; they were used to familiarize subjects with the appearances of the block letters in the grids or in the brackets.

In addition, a set of test stimuli was constructed. The same-sized grids or brackets were positioned 1.5° of visual angle to the left or to the right of an asterisk that was placed at the center of the screen, which served as a fixation point. The grids or brackets were empty except for a single X probe mark, which connected the corners of a single cell in the grids (and was the same size within the brackets). A lowercase version of one of the stimulus letters appeared beneath the grid or set of brackets. Half the stimuli appeared to the right of the fixation point and half appeared to the left. In addition, for half the trials, the X mark was positioned so

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[1] Native signers are subjects who were exposed to ASL from birth by their deaf parents ($N = 15$) or by an older deaf sibling ($N = 4$), and one subject was exposed to ASL prior to age 3 in a preschool for deaf children.

that it would have fallen on the corresponding block letter, had it been present (yes trials), and for the other half, the probe X was positioned so that it would have fallen adjacent to a segment of the letter, had it been present (no trials). Two yes and two no probes were constructed for each letter. For yes trials, one probe X mark was placed in a cell that would have been occupied by the first or second segment of the uppercase letter (an ‘‘early’’ imaged segment) and one X mark appeared in a cell that would be occupied by the last or penultimate segment (a ‘‘late’’ imaged segment). The procedure used to determine which letter segments are drawn (and visualized) early and which are drawn (and visualized) late is described in Kosslyn et al. (1988).

Each letter stimulus appeared twice in the left and twice in the right visual field, and yes/no trials and probe locations (early/late) were counterbalanced across presentations. A total of 256 trials was presented to each subject: 8 letters × 4 (2 presentations in each of the two visual fields) × 2 (yes/no response) × 2 (probe location: early/late) × 2 conditions (grids/brackets). The grid and bracket stimuli were presented in separate blocks of trials. Each letter was probed once before any letter was probed twice, each was probed twice before any was probed a third time, and so on; each condition occurred once within each set of eight trials. Respecting these constraints, the trials were ordered randomly, except that no more than three trials with the same response or probe location could appear in succession.

Procedure

Subjects were tested individually, with his or her head resting in a chin rest to ensure a constant viewing distance of 18 inches from the screen. Half of the subjects received the block of grids stimuli first and then the brackets, and half received the blocks in the reverse order. In both conditions, the experiment began with a study session. The subjects were asked to study the block letters and to memorize exactly how they appeared in grids or in brackets (depending on the condition). Subjects were asked to view the letters twice, presented in a random order, for as much time as they required. As soon as the subjects reported that they had memorized the stimuli, they were given practice trials. The subjects were asked to press the space bar and to maintain fixation on the asterisk placed in the center of the screen; 500 msec later they were presented with a grid or brackets stimulus displayed for 150 msec to the left or right of fixation. Subjects were asked to read the lowercase letter beneath the stimulus and to decide whether the corresponding block letter would cover the X mark in the grid or brackets, if the block letter were in fact present. If so, subjects were to press one key with the index finger of one hand; if not, they were to press another key with the index finger of the other hand. Subjects were asked to respond as quickly and as accurately as possible. Hand of response was counterbalanced within each group. After responding, the subjects were to press the space bar to initiate the next trial. Sixteen practice trials preceded the actual test trials in each block; each letter appeared twice during these trials, with probes that were not included in the test trials. Feedback was given only during the practice trials (the top of the screen ‘‘blinked’’ for incorrect answers).

RESULTS

Response times and error rates were submitted to separate analyses of variance. Response times greater than 2.5 times the mean of a cell for a given person were treated as outliers and discarded prior to analysis. Only the results from yes trials are reported because it is likely that no trials sometimes can be evaluated without using imagery (see Kosslyn et al., 1995b). Effects and interactions not noted below were not significant, $p > .1$ in all cases. The analyses included hemisphere, condition (grids/brackets), probe

TABLE 1
Mean Response Time (in Milliseconds) and Error Rate (Percentage) in Each Condition

Stimuli	Grids				Brackets			
Probe location:	Early-imaged		Late-imaged		Early-imaged		Late-imaged	
Hemisphere:	Left	Right	Left	Right	Left	Right	Left	Right
Deaf	983	931	1164	1133	989	925	1172	1121
	11.4	7.7	25.1	23.6	18.5	9.7	23.3	31.2
Hearing	934	997	1148	1163	1031	1045	1164	1169
	8.9	9.9	23.0	20.5	10.9	4.2	21.8	28.3

Note. Response time is provided in the first row for each subject group and error rate in the second row.

position (early/late), and subject group (deaf/hearing) as independent variables.[2]

Response Times

The response time means are provided in Table 1, and the major results are shown in Fig. 3. Overall, deaf signers generated images in both grids and brackets stimuli faster than hearing subjects when the stimuli were presented to the right hemisphere, $F(1, 38) = 8.87$, $p < .01$, for the interaction between hemisphere and group, but the groups did not differ when the stimuli were presented initially to the left hemisphere.[3] Post hoc tests revealed that deaf signers responded faster when stimuli were presented to the right hemisphere ($\bar{x} = 1028$ msec) compared to hearing subjects ($\bar{x} = 1094$ msec),

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[2] We also examined gender as an independent variable. Gender did not interact with subject group, but we found that males generated images faster than females, $F(1, 36) = 9.07$, $p < .01$ for the interaction between probe location and gender. However, there was also a three-way interaction between gender, probe location, and hemisphere for the error rate data, $F(1, 36) = 12.56$, $p < .01$. Females were more accurate at the initial stages of image generation (especially within the left hemisphere), but males were more accurate at later phases of constructing the images (they were more accurate with probes on late imaged segments). None of the results discussed in the body of the paper are altered when gender was included as a variable in the analysis.

[3] Because these subjects have intact corpora callosa, stimuli presented in one visual field are not processed exclusively by the contralateral hemisphere. Thus, we are not implying that the stimuli were available only to a single hemisphere. Rather, by lateralizing the stimuli, the input falls on one half of the retina and hence is projected *initially* to a single cerebral hemisphere. We reason that if the stimuli are presented initially to the hemisphere that is more efficient at performing the necessary processing, the subject will respond more quickly than if the stimuli are presented initially to the other hemisphere. For expository ease we will refer to the stimuli as having been ‘‘presented’’ to a single hemisphere as short-hand for noting that they are presented *initially* to that hemisphere.

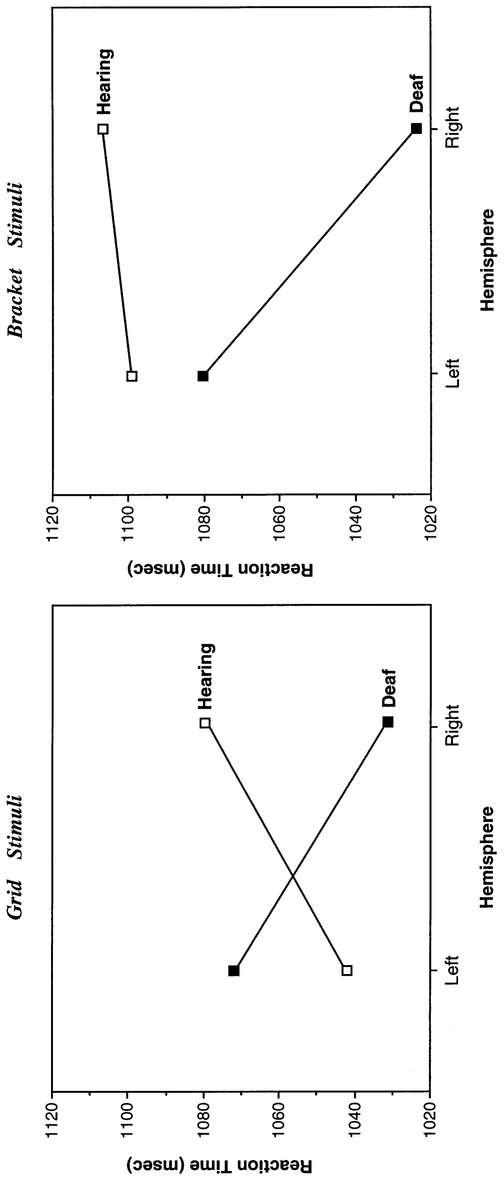

FIG. 3. Deaf signers generated images faster than hearing subjects in both grid and bracket stimuli presented to the right hemisphere.

Scheffe $F(1, 38) = 7.15$, $p < .03$. However, the two groups required the same amount of time when stimuli were presented to the left hemisphere ($\bar{x} = 1070$ and 1077 msec for deaf and hearing subjects, respectively).

Although the three-way interaction between hemisphere, subject group, and condition was not significant, planned comparisons revealed a different pattern in the grids and the brackets conditions. Hearing subjects generated images within grids faster when the stimuli were presented to the left hemisphere, as has been reported previously (e.g., Kosslyn et al., 1995b), but deaf signers generated such images faster when these stimuli were presented to the right hemisphere, $F(1, 38) = 5.68$, $p < .05$, for the interaction of hemisphere and group within the grids condition. In contrast, deaf signers generated images within brackets faster when stimuli were presented to the right hemisphere, whereas hearing subjects performed equally well when brackets stimuli were presented to either hemisphere, $F(1, 38) = 4.15$, $p < .05$, for the interaction of hemisphere and group within the brackets condition.

Both deaf and hearing subjects required more time to evaluate probes placed on late-imaged segments than probes on early-imaged segments (1154 msec vs. 979 msec), $F(1, 38) = 87.13$, $p < .001$. This result indicates that both deaf and hearing subjects were actively constructing images during the task (see Kosslyn, 1988; Kosslyn et al., 1988).

Error Rates

The error rate means are provided in Table 1. Unlike the analysis of response times, the analysis of error rates did not reveal an interaction between subject group and hemisphere, $F < 1$. This result indicates that the differences in response time were not due to speed–accuracy trade-offs. Deaf and hearing subjects had similar error rates for stimuli presented to the left and the right hemispheres. As expected, all subjects made more errors for probes located on late-imaged segments (24.6%) than for probes on early-imaged segments (10.2%), $F(1, 38) = 96.88$, $p < .001$. In addition, subjects made fewer errors for probes on early-imaged segments when stimuli were presented to the right hemisphere (7.9%) than when stimuli were presented to the left hemisphere (12.5%), but made similar errors for probes on late-imaged segments (25.9% for the right compared to 23.3% for the left hemisphere), $F(1, 38) = 11.85$, $p < .01$, for the interaction of probe location and hemisphere. However, as Fig. 4 shows, this pattern was primarily due to the brackets condition, and we found a three-way interaction between condition (grid/bracket), probe location, and hemisphere, $F(1, 38) = 13.86$, $p < .01$. In the bracket condition, subjects made fewer errors for early probes presented to the right hemisphere than for early probes presented to the left, Scheffe $F(1, 38) = 4.76$, $p < .05$; but they tended to made more errors for late probes presented to the right hemisphere, although this difference was not significant, Scheffe $F(1, 38) = 1.58$.

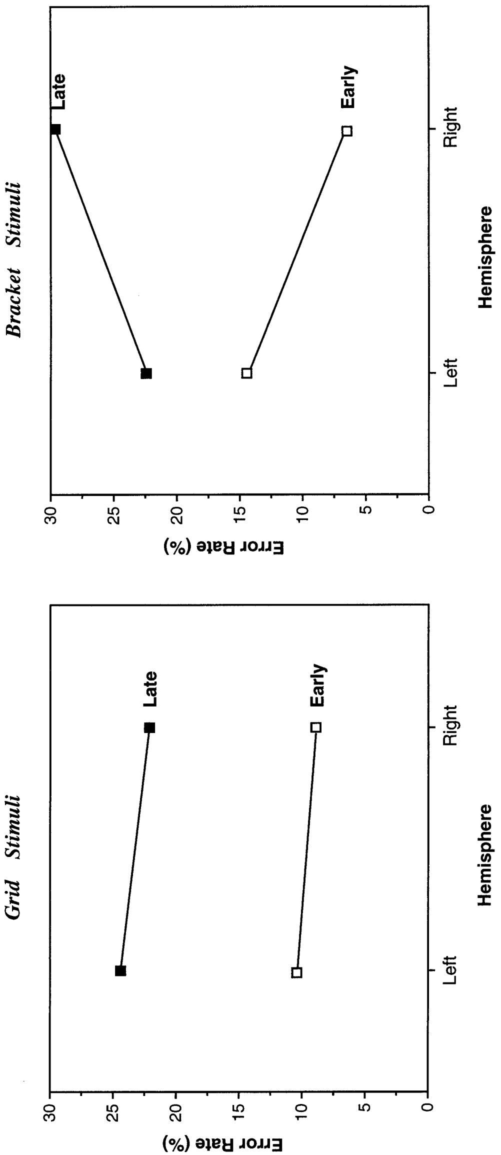

FIG. 4. Error rates for probes located on early-imaged segments were lower in the right hemisphere for bracket stimulu, but error rates were did not differ for probes located on late imaged segments in this condition.

DISCUSSION

Deaf signers generated images more quickly when stimuli were presented to the right hemisphere than the left and generally were faster than hearing subjects. These results suggest that the right hemisphere of deaf signers generates images relatively quickly, based on either categorical or coordinate spatial relations representations. In contrast, replicating previous work, hearing subjects were faster when grid stimuli were presented to the left hemisphere than when they were presented to the right hemisphere. This result is consistent with the hypothesis that hearing subjects used categorical spatial relations to generate images when the grids stimuli were presented to the left hemisphere. However, unlike previous findings, this sample of hearing subjects were no faster when brackets stimuli were presented to the right hemisphere than when they were presented to the left. This result may suggest that these subjects used coordinate spatial relations to generate images equally easily in both hemispheres, or that they were able to devise a way to use categorical spatial relations representations even with the brackets stimuli.

The pattern of findings suggests that for hearing subjects the left and right hemispheres used distinct processes to generate the two types of mental images, whereas the deaf signers did not. However, we must be cautious in our interpretation of the different patterns exhibited by deaf and hearing subjects because the overall three-way interaction between hemisphere, stimuli condition, and subject group did not reach significance. Nonetheless, it remains clear that deaf signers were faster than hearing signers at generating images for stimuli presented to the right hemisphere.

Our results replicate and are complemented by those reported by Emmorey et al. (1993). In both studies, deaf signers were faster, but not more accurate, than hearing nonsigning subjects at generating mental images. Emmorey et al. (1993) found that the enhancement in image generation was linked to experience with American Sign Language and not auditory deprivation from birth. Hearing subjects who had deaf parents and who learned ASL as their first language had the same enhanced image generation abilities found with the deaf ASL signers. Furthermore, Emmorey et al. found no difference between any of the deaf and hearing groups in baseline perceptual scanning abilities or in their familiarity and facility with English letters. Thus, it is unlikely that the results of the present study can be explained by reference to such possible differences. Rather, the present results suggest that enhanced image generation abilities in deaf ASL signers may be linked to right hemisphere processing.

In addition, it is clear that the enhanced image generation ability of the right hemisphere is not a consequence of a right hemisphere dominance for processing sign language. There is abundant evidence that the left hemisphere of deaf signers is primarily responsible for processing sign language

(Bellugi, Poizner, & Klima, 1983, 1989; Corina, Vaid, & Bellugi, 1992; Corina, Poizner, Bellugi, Feinberg, Dowd, & O'Grady-Batch, 1992; Poizner, Klima, & Bellugi, 1987). Bellugi, Poizner, and colleagues have shown that damage to the left hemisphere of the brain leads to sign aphasias similar to those observed with spoken language. In contrast, right hemisphere damage produces impairments of certain visual-spatial abilities, but does not produce sign language aphasias. Nevertheless, recent research has suggested that the right hemisphere may play a more important role in processing sign language in ASL signers than it does in processing spoken language in English speakers. For example, Emmorey and Corina (1993) found that deaf signers had a right hemisphere advantage for imageable ASL signs in a lateralized lexical decision task, whereas English speakers simply showed a weaker left hemisphere advantage for the English equivalents of the ASL signs. No study that we know of has documented a right hemisphere advantage for processing imageable English words, but Emmorey and Corina (1993) found such an advantage for imageable ASL signs (but not for abstract signs).

In addition, Emmorey (1996) and Corina, Bellugi, Kritchevsky, O'Grady-Batch, and Norman (1996) describe the case of a hearing signer (DN) who suffered right hemisphere damage and exhibited a selective deficit in producing and comprehending spatial descriptions in ASL but not in English. DN was not aphasic for English or for ASL, but she showed some subtle visuospatial deficits typical of patients with right hemisphere damage. When DN was asked to describe the spatial layout of her room in English, she produced a clear description with few errors. However, her signed description of the same room had a marked disorganization of elements in the room, and she incorrectly specified the orientation and location of items in the room. In addition, when DN was asked to set up real objects in accordance with spatial descriptions given in either English or in ASL (e.g. ''The pencil is on the paper''), she correctly interpreted most of the English commands (scoring better than other right hemisphere damaged patients), but she performed poorly when given ASL commands (39% correct). Emmorey and colleagues suggest that the dissociation between DN's comprehension of English and ASL spatial commands arises because in ASL spatial relations must be recovered directly from the position and orientation of classifier signs in space (see Fig. 1), which makes additional demands on spatial cognitive processes within the right hemisphere.

Note, however, that we are not claiming that the spatial relations expressed by classifier constructions are metric (a specialized domain of the right hemisphere). Supalla's (1982, 1986) research indicates that classifier predicates contain discrete, categorical morphemes and are not analogue gestures (although see Liddell, 1995, for a nonmorphemic analysis of location in these forms). Furthermore, Talmy (1988) has argued that languages do not grammaticize metric notions. That is, ''grammatical specifications of structure are relativistic or topology-like, and exclude the absolute or the metrically

Euclidean'' (p. 167). We would argue that ASL follows this universal constraint. Thus, the proficiency of right hemisphere image generation in deaf signers would not arise because metric expression of spatial relationships in ASL must be interpreted by the right hemisphere. Instead, it is possible that the right hemisphere of signers is more skilled at using representations of categorical spatial relations, compared to hearing nonsigners.

Alternatively, it is possible that when a person depends on visual language, the left hemisphere comes to use categorical spatial relations representations exclusively for language. If so, then the processing of categorical relations representations for non-language material gets shunted over to the right hemisphere, which relieves the left hemisphere of additional processing demands.[4] In this case, what determines the localization of function for deaf ASL signers is not the type of spatial relations representation (categorical vs. coordinate) that is used, but rather the nature of the information to be processed (linguistic vs. nonlinguistic).

In addition, we found that all subjects made fewer errors for probes on early-imaged segments when brackets stimuli were presented initially to the right hemisphere (see Fig. 4). This result suggests that the right hemisphere is particularly accurate at the initial stages of image generation when coordinate spatial relations were used. However, it was surprising that the right hemisphere was not more accurate for probes on late-imaged segments in this condition. This result is anomalous given the previous finding that the right hemisphere processes coordinate spatial relations more efficiently than the left (Cowin & Hellige, 1994; Hellige & Michimata, 1989; Hellige et al., 1994; Kosslyn et al., 1995b; Kosslyn, Koenig, Barrett, Cave, Tang, & Gabrieli, 1989; Laeng, 1994). It is possible that the hemispheres differ in how easily the different types of spatial relations can be stored and retrieved, but can use them equally well. If so, then the present result may suggest that once the representations are retrieved, they might be used equally well to generate images in either hemisphere. Alternatively, we may simply have not had the statistical power to detect the right-hemisphere superiority for brackets stimuli that has been observed previously with hearing subjects.

In summary, deaf signers generated both types of images, those based on categorical spatial relations and those based on coordinate spatial relations, faster when the right hemisphere received the cue. Hearing subjects generated images based on categorical spatial relations better when the left hemisphere received the cue. We hypothesize that this difference in lateralization between deaf signers and hearing subjects arises because of the linguistic experience of the deaf signers. There is evidence that the right hemisphere plays a larger role in processing certain aspects of sign language than it does in processing spoken language—namely, imageable signs and aspects of the linguistic expression of spatial relations (Emmorey & Corina, 1993; Em-

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[4] This possibility was suggested to us by Edward Klima.

morey, 1996). The role of the right hemisphere in these language-linked processes may also lead to a right hemisphere dominance for generating images.

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