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Mental rotation within linguistic and non-linguistic domains in users of American sign language

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Abstract

American sign language (ASL) uses space itself to encode spatial information. Spatial scenes are most often described from the perspective of the person signing (the 'narrator'), such that the viewer must perform what amounts to a 180° mental rotation to correctly comprehend the description. But scenes can also be described, non-canonically, from the viewer's perspective, in which case no rotation is required. Is mental rotation during sign language processing difficult for ASL signers? Are there differences between linguistic and non-linguistic mental rotation? Experiment 1 required subjects to decide whether a signed description matched a room presented on videotape. Deaf ASL signers were more accurate when viewing scenes described from the narrator's perspective (even though rotation is required) than from the viewer's perspective (no rotation required). In Experiment 2, deaf signers and hearing non-signers viewed videotapes of objects appearing briefly and sequentially on a board marked with an entrance. This board either matched an identical board in front of the subject or was rotated 180°. Subjects were asked to place objects on their board in the orientation and location shown on the video, making the appropriate rotation when required. All subjects were significantly less accurate when rotation was required, but ASL signers performed significantly better than hearing non-signers under rotation. ASL signers were also more accurate in remembering object orientation. Signers then viewed a video in which the same scenes were *signed* from the two perspectives (i.e. rotation required or no rotation required). In contrast to their performance with real objects, signers did *not* show the typical mental rotation effect. Males outperformed females on the rotation task with objects, but the superiority disappeared in the linguistic condition. We discuss the nature of the ASL mental rotation transformation, and we conclude that habitual use of ASL can enhance non-linguistic cognitive processes thus providing evidence for (a form of) the linguistic relativity hypothesis. © 1998 Elsevier Science B.V. All rights reserved

Keywords: American Sign Language; Mental rotation; Linguistic relativity

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1. Introduction

Deaf users of American sign language (ASL) have been shown to exhibit superior performance on standard tests of mental rotation compared to normally hearing subjects (McKee, 1987; Emmorey et al., 1993; Talbot and Haude, 1993). For example, deaf ASL signers have faster reaction times and are more accurate on Shepard-Metzler type rotation tasks compared to hearing subjects who do not know sign language. Deaf subjects' superior abilities appear to be tied to their experience producing and comprehending ASL rather than to effects of auditory deprivation. Evidence supporting a link between mental rotation skill and linguistic experience stems from two sources. First, hearing subjects who are skilled signers also exhibit enhanced mental rotation skills compared to hearing non-signers (Emmorey et al., 1993; Talbot and Haude, 1993). Second, deaf people who do not know sign language ('oral' deaf) perform similarly to hearing non-signers (Chamberlain and Mayberry, 1994). Thus, the skilled ability to comprehend and produce American Sign Language appears to enhance mental rotation skills. But why? What is it about processing ASL that might lead to such an effect within a non-linguistic domain of spatial cognition?

Emmorey et al. (1993) hypothesized that mental rotation may play a crucial role in sign language processing because of the mental transformations that the sign perceiver (i.e. the addressee) must perform while comprehending certain types of discourse. In descriptions involving spatial locations, ASL signers manipulate signing space (a 3D space in front of the signer at torso level) to create representations isomorphic to spatial configurations in the real or an imagined world. 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 scenes in ASL, the identity of each object is indicated by a lexical sign (e.g. TABLE, T-V, CHAIR).[1] The location of the objects, their orientation, and their spatial relation vis-a-vis one another is indicated by where the appropriate 'classifier' predicates are articulated. Classifier predicates express motion and location, and the handshape is a classificatory morpheme. For example, the B handshape is the classifier handshape used for rectangular, flat topped surface prominent objects like beds or sheets of paper. The C handshape is the classifier handshape used for bulky box like objects like televisions or microwaves, and there are many others. These handshapes occur in constructions which express the spatial relation of one object to another or the manner and direction of motion (for moving objects/people). Where English uses prepositions to express spatial relations, ASL uses the visual layout displayed by classifier signs positioned in signing space.

Critically, spatial scenes are most often described from the perspective of the

[1]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. Descriptions of how classifier signs (and some non-classifier signs) are articulated may be given as a subscript to the English gloss.

person signing (the 'narrator'), such that the viewer, if facing the signer, must perform what amounts to a 180° mental rotation to correctly comprehend the description. A simple example is provided in Fig. 1A. In this example, the narrator describes a scene where a table is on his left as he enters a room. He uses the sign I-ENTER at the beginning of the sentence which signals that the scene should be understood from his perspective. The narrator indicates that the table is to the left by producing the classifier sign appropriate for tables at a spatial location on his left. Because the addressee (the viewer) is usually facing the narrator, the spatial location for *table* is actually positioned on the addressee's *right*. There is a mismatch between the location of the table in the room being described (the table is on the left as seen from the entrance) and what the addressee actually *observes* in signing space (the classifier sign for *table* is produced on the addressee's right). The addressee must mentally transform the spatial location of the table in signing space to match the perspective of the narrator. We hypothesize that this habitual transformation during discourse comprehension may lead to enhanced mental rotation skills within the non-linguistic domain.

Although scenes are most commonly described from the narrator's point of view,

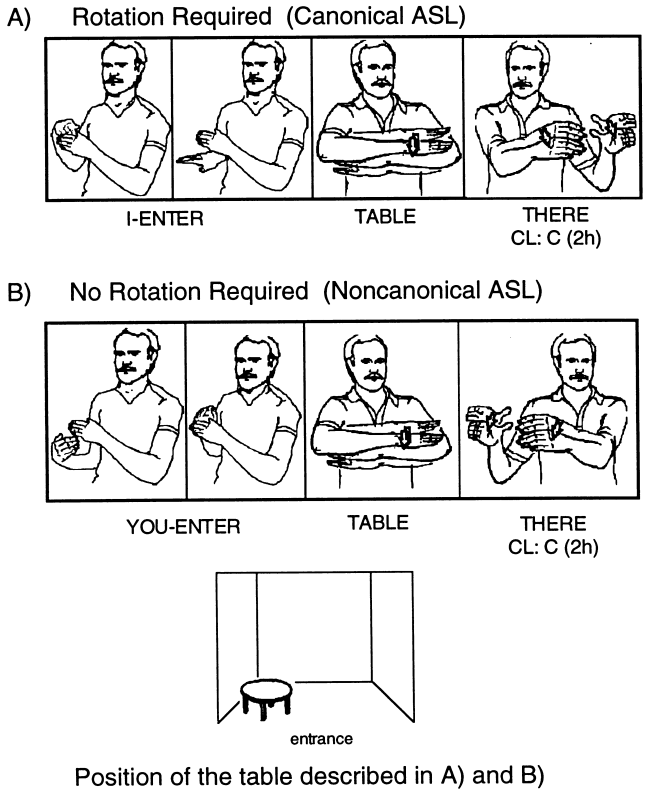

Fig. 1. For ASL, spatial transformations are required for the canonical narrator perspective (A) but not for the marked 'viewer' perspective (B).

it is possible to indicate a different point of view. ASL has a marked sign that we have glossed as YOU-ENTER which indicates that the scene should be understood as signed from the addressee's viewpoint. When this sign is used, the signing space in which the room layout is described is 'rotated' 180° so that the viewer is 'at the entrance' of the room. An example is shown in Fig. 1B. The spatial arrangement of the signs, as viewed by the addressee, exactly matches the spatial arrangement of the objects in the room if it were being viewed from the entrance. In Fig. 1B, the table is on the left side of the room as seen from the entrance, and the ASL classifier sign is produced on the left half of space from the viewer's perspective. Thus, the viewer does not have to mentally transform locations within the narrator's signing space into a rotated representation of that space. However, the ASL description using YOU-ENTER is quite unusual and rarely found in natural discourse.

It is well-known that tasks are more demanding when mental rotation is required (Shepard and Cooper, 1982). But given that the canonical form of locative descriptions in ASL requires mental rotation, the following questions arise. (1) Will the standard effect of mental rotation hold up in processing ASL? That is, will signers exhibit more difficulty when mental rotation is required during sign language processing, compared to when no rotation is required? (2) Is there a difference between mental rotation in a *linguistic* domain compared to a *non-linguistic* domain for ASL signers? We conducted two experiments which investigated how deaf ASL signers process locative relations perceived through *signs* in space versus locations of *objects* in space. The results should illuminate the relation between rotation within linguistic and non-linguistic domains and thus provide further insight into the source of enhanced performance by ASL signers on mental rotation tasks.

2. Experiment 1: scene-description matching

This study was designed to investigate whether ASL signers perform better when scene descriptions are presented from the canonical narrator point of view compared to the non-canonical viewer perspective. With the narrator perspective, mental rotation is required to correctly interpret the scene descriptions, but when the viewer's perspective is used, mental rotation is not required. In this experiment, subjects first viewed a videotape of a room and then a signed description of that room and were asked to judge whether the room and description matched. The ASL description was presented either from the narrator's point of view (introduced with the sign I-ENTER), or from the viewer's point of view (introduced with the sign YOU-ENTER). When signed from the viewer's perspective the description spatially matched the room layout shown on the videotape, but when signed from the narrator's perspective the description was the reverse of the layout. Fig. 2 provides an illustration. If the cognitive load of mental rotation is critical, then signers should perform better when the viewer perspective is used and no mental rotation is required. On the other hand, if the markedness of the description is critical, then signers should perform better when the narrator's perspective is used, even though this perspective requires mental rotation.

2.1. Method

2.1.1. Subjects

Eighteen deaf signers participated in the experiment (12 females, six males). Eleven subjects had deaf families and learned ASL from birth; seven subjects acquired ASL before age six. All subjects used ASL as their preferred means of communication, and all were prelingually deaf with severe to profound hearing loss. Subjects were tested either at Gallaudet University in Washington, D.C. or at the Salk Institute in San Diego, CA.

2.1.2. Design and procedure

Twenty-four test trials and three practice trials were presented. On each trial, a room containing between four and eight pieces of furniture was presented on videotape for 10 s (see Fig. 2A for an example room). The differing number of furniture pieces provided a range of room configurations for the task (for the eight-piece configuration, four chairs around a table were counted individually). After 3 s of

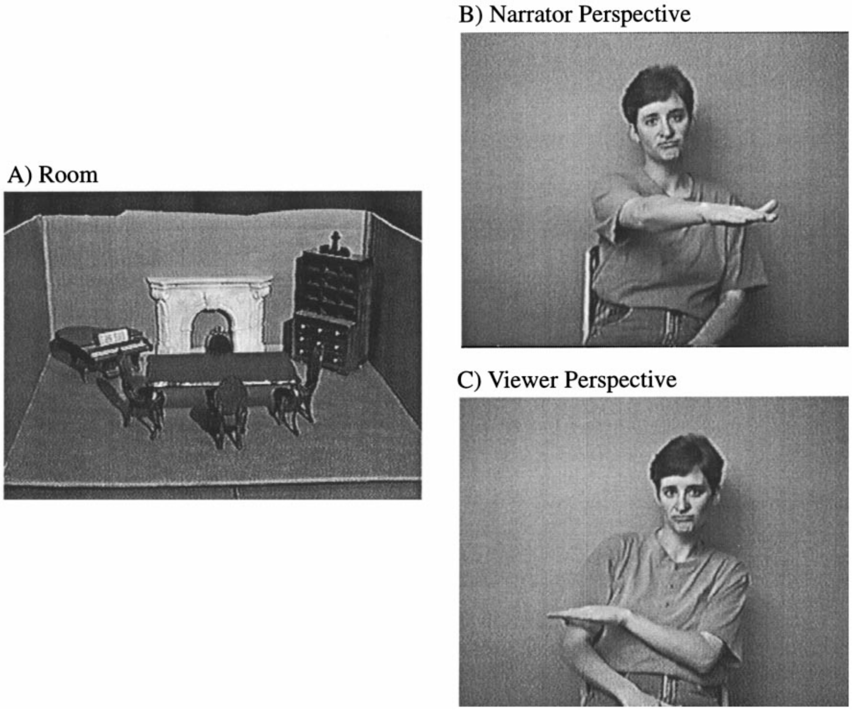

Fig. 2. Example stimuli from Experiment 1. The room (A) was initially presented for 10 s. The signs illustrated in (B) and (C) are the classifier signs used for describing the position of the piano from either the narrator's perspective (B) or the viewer's perspective (C). The room and the signs are taken from the actual test videotape. As a viewer facing the videoscreen, you can see that the location of the classifier sign visually matches the position of the piano shown in the room for the viewer perspective (C), but not for the narrator's perspective (B).

black videotape, a signed description of the room was presented, and subjects were asked to decide whether the description matched the room they had just seen. Half of the descriptions were presented from the narrator's perspective (beginning with I-ENTER) and half were presented from the viewer's perspective (beginning with YOU-ENTER). Perspective was randomly distributed across trials. Half of the descriptions of each perspective type matched the room (requiring a 'yes' response), and half of the descriptions did not match the room (requiring a 'no' response). Non-matching descriptions differed from the target room in two possible ways: (1) the locations of two objects were switched or (2) one object was replaced with another that had not appeared in the room. Six different target rooms were used. Each room appeared twice with each perspective (once requiring a 'no' response and once requiring a 'yes' response).

2.2. Results and discussion

The data were entered into an ANOVA with rotation condition (perspective) and gender as factors. Consistent with the canonical form of spatial descriptions in ASL and contrary to the typical mental rotation effect, signers were more accurate when the narrator's perspective was used (i.e. when mental rotation was required) than when the viewer's own perspective was used (i.e. when no rotation was required), $F(1,17) = 4.75, P < 0.05$. There was no effect of gender, and gender did not interact with rotation condition. In addition, if the data are broken down by response type, we find that the perspective effect is due primarily to the 'different' (no match) responses ($F(1,17) = 5.78$, $P < 0.05$, for the interaction between response type and rotation condition). Subjects were much more likely to detect an incorrect location or item when the description was from the narrator's point of view. The results are given in Table 1.

These findings suggest that the advantage for processing the canonical (most frequent) linguistic expression overrides the difficulty imposed by mental rotation. The results further document the assertion that not only narrators but addressees as well prefer spatial descriptions from the narrator's point of view, despite the mental rotation requirements for the addressee when this viewpoint is adopted.

In the next experiment, we wanted to directly compare mental rotation performance for objects located at various physical positions in a horizontal plane with rotation performance for signs located at various positions within the plane of signing space. Since the results of Experiment 1 showed the reverse of the standard

Table 1
Mean (±SE) percent correct for Experiment 1

	No rotation (Viewer perspective)	Rotation required (Narrator perspective)
Response		
Same	88.9 (3.3)	86.1 (3.1)
Different	79.6 (4.4)	94.4 (2.7)

mental rotation effect, we wondered whether signers would show a standard mental rotation effect when they had to perform a mental rotation task that was very similar to what was required during sign processing.

3. Experiment 2: rotation with non-linguistic versus linguistic stimuli

In this experiment, subjects viewed videotapes of objects appearing briefly and sequentially on a board marked with an entrance. The entrance of the board either matched the entrance on an identical board in front of the subject or was rotated 180° (see Figs. 3 and 4). Subjects were asked to place objects on their board in the

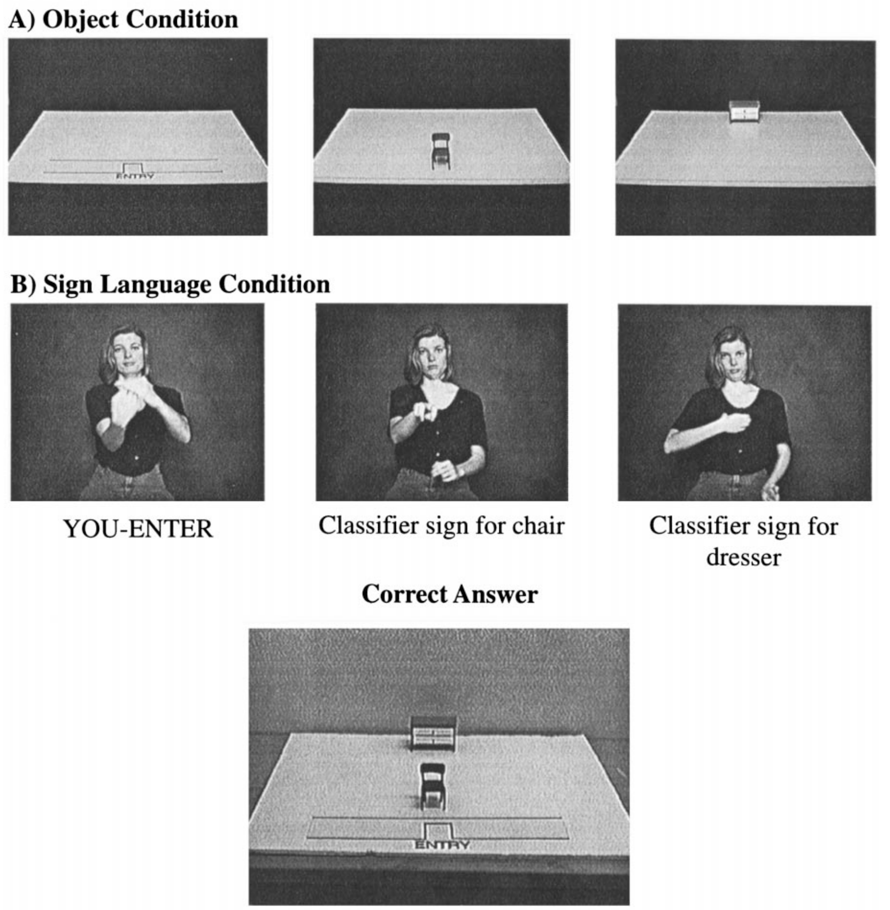

Fig. 3. Example stimuli from the ‘no rotation’ condition of Experiment 2. The blank boards are not pictured for the object condition (A), and the lexical signs CHAIR and DRESSER are not pictured for the sign language condition (B). The blank board precedes the presentation of each object (see text), and the lexical sign precedes each classifier sign. For sign language, the description requiring no rotation is non-canonical.

orientation and location shown on the video, making the appropriate rotation when required. Both hearing and deaf subjects participated in this part of the experiment. In a second condition, the deaf signers were shown a signed narration which described where the objects were located with respect to the entrance (see Figs. 3B and 4B). As in Experiment 1, these descriptions were either from the narrator's or viewer's perspective.

We predicted that when rotation involved real objects, both hearing and deaf subjects would exhibit a rotation effect, i.e. poorer performance when mental rotation was required. We also predicted that deaf subjects would be more accurate than hearing subjects when rotation was required. These predictions are based on the hypothesis that experience with ASL does not dramatically alter the nature of mental rotation within a non-linguistic domain, but it can improve rotation skill. Thus,

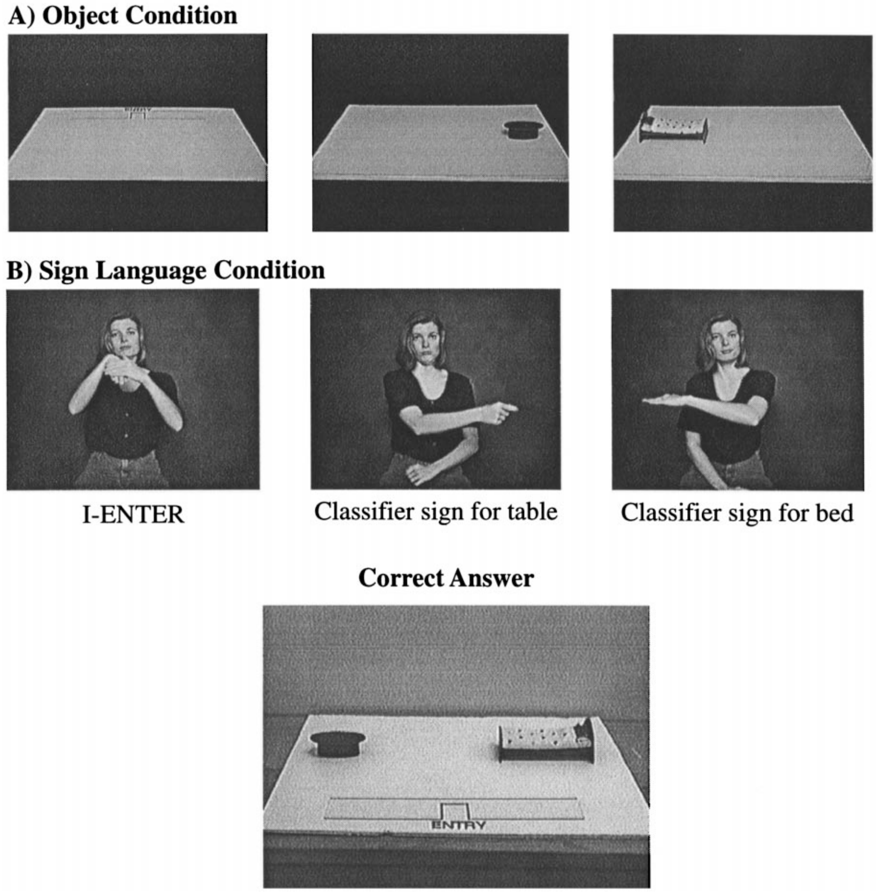

Fig. 4. Example stimuli from the 'rotation' condition of Experiment 2. The blank boards are not pictured for the object condition (A), and the lexical signs TABLE and BED are not pictured for the sign language condition (B). Each lexical sign precedes the classifier sign, and each object is preceded by a blank board (see text). For sign language, the description requiring rotation is canonical.

signing subjects should find mental rotation difficult, but they should outperform hearing non-signers. Within the sign domain, however, we predicted a very different pattern of performance. Signers may actually perform better when rotation is required. Such a pattern of results will indicate that signs located in signing space are processed differently than objects located in physical (non-signing) space. That is, when interpreting the position of the hands in space (representing object locations), signers may fail to show the standard mental rotation effect because of the nature of language processing in ASL.

3.1. Method

3.1.1. Subjects

Fifteen deaf signers participated in the experiment (10 females; five males).[2] Thirteen subjects had deaf families and learned ASL from birth; two subjects acquired ASL before the age of 10 years. All subjects used ASL as their preferred means of communication. All subjects were prelingually deaf with severe to profound hearing loss. Subjects were tested either at Gallaudet University in Washington, D.C. or at The Salk Institute in San Diego, CA. All subjects were either current students at Gallaudet University or had at least 3 years of college education.

Fifteen hearing subjects also participated in the experiment (eight females, seven males). All subjects were students at the University of California, San Diego and reported no knowledge of a signed language. All hearing subjects were tested at the Salk Institute.

3.1.2. Design and procedure

Stimuli. Three sets of stimuli were created using toy furniture (a bed, a chair, a chest of drawers, and a table), blocks (a green triangle, an orange tube-shaped block, a wide red rectangle, and a thin blue rectangle), and animates (a girl, a bird, a horse, and a dog). We chose this mix of stimuli because we wanted to compare objects that had no intrinsic orientation (the blocks) with objects that had intrinsic fronts and backs (all of the animate stimuli and most of the furniture). Items of furniture are most often described in a context where point of view is indicated by I-ENTER, and we included the animate stimuli to provide a broader (less canonical) context for scene descriptions.

For each set of stimuli, subjects were presented with three practice trials and 12 test trials. The order of stimulus set presentation was: furniture, blocks, animates. For each set of test trials, subjects first received four trials with two objects, then four trials with three objects, and finally four trials with four objects. For scoring purposes, there was a total of 108 objects that had to be placed correctly (36 in each of the three stimulus sets). Objects were placed either on the left/right axis or the front/back axis. The objects were not grouped together and were equally likely to appear on either axis. Half of the trials within each stimulus set required rotation and

[2]Five subjects also participated in Experiment 1.

half did not. Rotation/no rotation trials were randomly distributed across the experiment.

Sign language condition. For the furniture stimuli, narrator perspective (rotation required) and viewer perspective (no rotation) were signaled by using either the sign I-ENTER or YOU-ENTER at the beginning of each description (see Figs. 3 and 4). For the block stimuli, a thick black bar on the edge of the board nearest the subject marked the reference point for positioning the blocks. The signer (the narrator) produced the following phrase to indicate narrator perspective: BLACK BAR (classifier positioned in signing space near the narrator), I LOOK-AT (directed downward away from the narrator). To signal viewer perspective, the signer produced the following phrase at the beginning of the trial: BLACK BAR (classifier positioned in signing space toward the viewer, away from the narrator), YOU LOOK-AT (directed downward toward the narrator). For the animate stimuli, the entrance marker was a gate which marked the entrance to an imagined field where the different animals and the girl were standing. The signer produced the following phrase to signal the narrator viewpoint: FENCE (positioned near the signer) GATE-OPEN I-ENTER. To signal the viewer's perspective, the signer produced this phrase: FENCE (positioned near the viewer) GATE-OPEN YOU-ENTER.

When describing the position of the furniture, the classifier sign used for the chair was a bent V handshape. For this classifier handshape, the front of the fingers represent the front of the chair (see Fig. 3B). The classifier sign for the bed was a flat B handshape (see Fig. 4B). The B handshape could be oriented lengthwise or crosswise to indicate orientation (and many signers also interpreted the end of the hand near the wrist as representing the head of the bed). The classifier sign for the dresser was a C handshape (fingers and thumb curved), and the back of the hand represents the front of the dresser (see Fig. 3B). Finally, the classifier sign used for the table was a bent L handshape (thumb and index finger extended and curved), and this sign cannot be used to indicate the orientation of the table, even though the actual table is oval and therefore has a lengthwise/crosswise orientation (see Fig. 4B).

Unlike the furniture and animate stimuli, there are no lexical signs for the block stimuli. Thus, only one sign was produced to describe the location of a block. For these stimuli, the signer used a single classifier construction to describe each block. Each construction identified both the shape and position/orientation of the block on the board. The classifier constructions for each block are illustrated in Appendix A. These signs also differ from the classifier signs used for the furniture and animate stimuli because they do not encode intrinsic front/back features.

The classifier signs used for the animate stimuli were as follows: for the girl, the classifier for upright humans was used. This sign is a 1 handshape (fist with index finger extended upward), and the front of the hand represents the front of the person. The classifier sign for both the dog and the bird was a bent V handshape (used for small animals), and the front of the fingers indicate the front of the animal. Finally, the classifier sign used for the horse was a two handed construction using upside down V handshapes (representing the legs of the horse). The front of the horse is indicated by the front knuckles.

Procedure. Only the deaf subjects participated in the sign language condition which always followed the object condition. Subjects were told to set up the objects according to the signed description shown on the videotape. For each stimulus set, subjects were given a board with an appropriate reference marker (i.e. an entry, a black bar, or a gate) on the near edge of the board (see the 'correct answer' illustration in Figs. 3 and 4), and they were given all four of the objects in the appropriate stimulus set. Subjects were required to position objects in the correct orientation as well as the correct location, and they were not allowed to rotate their response board. Subjects were required to wait until the entire scene had been described before responding. Feedback was given during practice, but not during test trials. Instructions were given in ASL by a fluent signer.

Object condition. Both hearing and deaf subjects participated in this condition which preceded the sign language condition. The same order of trial presentation was used for both the object and the sign language conditions. At the beginning of each trial, an entrance marker appeared on the videotape (see Figs. 3 and 4). How long the marker appeared on the videoscreen depended upon how long it took the signer to produce the appropriate signed phrase describing the entrance for that trial. The timing of the appearance of each object was also linked to the length of the signed description for that object. For the furniture and animate stimuli, the signed description of an object's position consisted of two signs: the first sign was a noun which identified the object (e.g. TABLE), then the location of that object was specified by placing the appropriate classifier sign at a position in signing space. The appearance of objects was therefore timed as follows: After the entrance marker appeared, a blank board (no marker) was shown for the length of time required to produce the lexical sign for the object (the empty board is not shown in Figs. 3 and 4). Then the object appeared at the appropriate position for the length of time required to produce the classifier sign for the object for that trial. For the block stimuli, the transition time between each classifier construction was used for the duration of the empty board appearing between objects.

We chose this timing strategy because in the sign language condition the lexical sign provided no information about location, but within the object condition, both object identity and object location are perceived simultaneously. The blank board, like the lexical sign, provided no information about orientation and location. Subjects then saw the object (and its location/orientation) for the length of time it took the signer to produce the classifier sign for that object (which indicated object location and orientation in ASL). In addition, the empty board between object appearances produced timing sequences that were more similar to the sign condition because both conditions contained pauses of identical length between location specifications. Finally, the visual effect of an empty board between objects was that of an object appearing/disappearing and then another object appearing/disappearing. The timing thus eliminated apparent motion effects that occur when there is no delay between the disappearance of one object and the appearance of another in different locations.

Procedure. The procedure was essentially the same as that for the sign language condition. For each stimulus set, subjects were given the appropriate objects and response board. Subjects were told to set up the objects with respect to the appropriate reference marker (the entrance, the black bar, or the gate). Objects had to be placed in the location and orientation shown on the videotape. They were required to wait until the entire scene had been presented before responding. Subjects were given feedback for the practice, but not for test items. Instructions were given in ASL for the deaf subjects.

3.2. Results

We first present the results from the object condition, comparing deaf and hearing subjects. Then we compare the object and sign language conditions for the deaf subjects.

4. Object condition: deaf and hearing subjects

The design of the analysis was 2 (subject group: deaf, hearing) × 2 (gender: male, female) × 2 (rotation condition: required, not required) × 3 (stimulus set: furniture, blocks, animates). Subjects could make location errors (placing an object in an incorrect location) or orientation errors (placing an object in an incorrect orientation).[3] Location accuracy and orientation accuracy were analyzed separately. An object was scored as in the correct location if it was placed in the correct quadrant of the response board representing the room (i.e. left/right of the entrance, front/back of the room). An object was scored as in the correct orientation if it was placed in the correct orientation with respect to the room entrance (e.g. the correct orientation of the chair in Fig. 3 is facing the entrance). Location accuracy provides a measure of place rotation within a scene (without regard to whether the intrinsic orientation of the object was maintained), while orientation accuracy provides a measure of object rotation (regardless of the placement of the object within the scene).

For both location and orientation accuracy analyses, we found no main effect of gender, and gender did not interact significantly with any variable. Therefore gender was not included in the analyses reported below.

4.1. Location accuracy

Location accuracy is presented in Table 2. A repeated measures ANOVA revealed no main effect of either subject group or stimulus set. There was a main effect of rotation ($F(1,28) = 65.41, P < 0.001$). Both subject groups were less accurate when rotation was required. However, subject group interacted significantly with rotation condition ($F(1,28) = 5.15, P < 0.05$). This interaction is shown graphically in Fig. 5A. Planned (a priori) comparisons revealed that the subject groups did not differ in location accuracy in the no rotation condition ($t(28) = 1.12$, n.s.), but deaf subjects were more accurate than hearing subjects when rotation was required ($t(28) = 1.72$, $P < 0.05$, one tailed).

[3]Rarely, a subject might omit an object or select the wrong object. These errors were not included here.

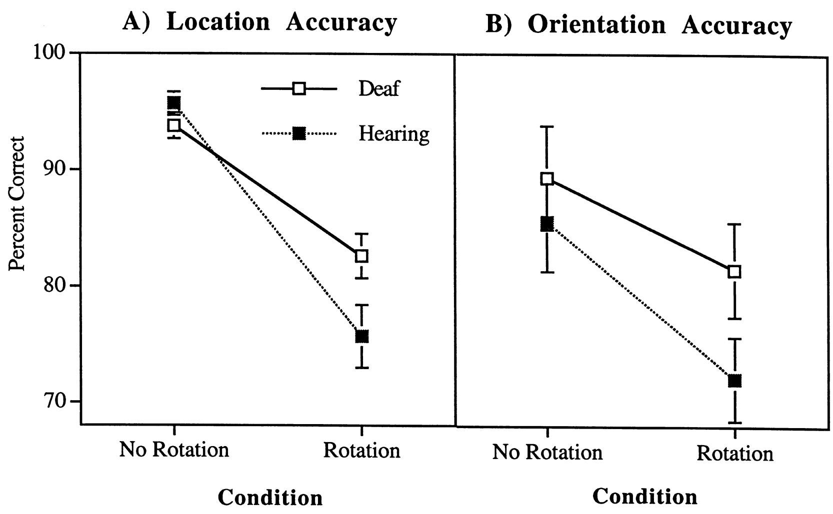

Fig. 5. Mean percent placement of objects in their correct (A) location and (B) orientation by deaf and hearing subjects. Bars indicate standard error.

Stimulus set interacted significantly with rotation condition ($F(2,56) = 6.12$, $P < 0.01$). No other interactions were significant. The stimulus sets did not differ significantly from each other when no rotation was required, but there was a significant difference between stimulus sets under rotation ($F(2,58) = 3.81, P < 0.05$). Subjects were significantly more accurate with the blocks stimuli than with either the furniture stimuli ($t(29) = 2.35, P < 0.05$) or the animate stimuli ($t(29) = 2.48$, $P < 0.05$). Performance did not differ significantly for the furniture and animate stimuli ($t < 1$).

4.2. Orientation accuracy

Orientation accuracy is presented in Table 3. A repeated measures ANOVA

Table 2
Mean (±SE) percent correct for placing objects in the correct location for the object condition for each stimulus set

	No rotation	Rotation required
Furniture		
Deaf	91.9 (1.9)	81.1 (3.4)
Hearing	97.4 (1.2)	70.4 (5.2)
Blocks		
Deaf	91.9 (2.4)	84.8 (4.2)
Hearing	94.1 (1.8)	84.1 (4.6)
Animates		
Deaf	97.8 (1.2)	81.9 (1.7)
Hearing	95.6 (1.9)	72.6 (3.7)

Table 3
Mean (±SE) percent correct for placing objects in the correct orientation for the object condition for each stimulus set

	No rotation	Rotation required
Furniture		
Deaf	80.7 (3.5)	70.7 (4.1)
Hearing	78.5 (3.4)	58.1 (4.3)
Blocks		
Deaf	91.9 (2.2)	91.9 (2.4)
Hearing	90.4 (2.2)	87.4 (2.3)
Animates		
Deaf	95.6 (1.5)	81.9 (3.1)
Hearing	88.5 (3.7)	70.7 (5.3)

revealed that deaf subjects were significantly more accurate than hearing subjects when placing objects in the correct orientation ($F(1,28) = 4.80$, $P < 0.05$). As expected, both subject groups were less accurate when rotation was required ($F(1,28) = 40.12$, $P < 0.001$). Furthermore, planned comparisons revealed that deaf subjects were significantly more accurate in the rotation condition than hearing subjects ($t(28) = 2.40$, $P < 0.02$, one tailed); however, the interaction between subject group and rotation condition did not reach significance for the orientation data ($F(1,28) = 2.89$, $P = 0.10$). The data are shown graphically in Fig. 5B.

There was a main effect of stimulus set ($F(2,56) = 45.98$, $P < 0.001$). All subjects were more accurate with the block stimuli compared to the furniture stimuli ($t(28) = 9.18$, $P < 0.001$) and the animate stimuli ($t(28) = 3.95$, $P < 0.001$). For the furniture and animate stimuli, subjects had to remember both the intrinsic orientation (e.g. where the head of the bed was), as well as the 'whole object' orientation (e.g. whether the bed was oriented lengthwise or cross-wise). For the block stimuli, only the 'whole object' orientation had to be remembered, which may account for subjects' higher orientation accuracy for these stimuli. There was also a significant interaction between stimulus set and rotation condition ($F(2,56) = 7.96$, $P < 0.001$). When rotation was required, orientation accuracy did not decline for the blocks stimuli ($t < 1$). Since the blocks have no intrinsic orientation, their orientation was not altered by rotation, and thus subjects performed equally well at remembering orientation in the rotation and no rotation conditions. In contrast, the intrinsic orientation of furniture and the animate stimuli must be taken into consideration under rotation. Subjects' performance reflected this difficulty: orientation accuracy was worse under rotation for both the furniture stimuli ($t(28) = 4.77$, $P < 0.001$) and the animate stimuli ($t(28) = 4.76$, $P < 0.001$).

4.3. Discussion: objects condition

When mental rotation was required, all subjects were significantly less accurate when placing objects in the correct location and orientation. However, ASL signers performed significantly better than the hearing subjects in this condition. Superior performance under mental rotation is consistent with previous findings that ASL signers exhibit enhanced mental rotation skills (McKee, 1987; Emmorey et al., 1993; Talbot and Haude, 1993). In the present experiment, however, the nature of the mental rotation task was parallel to the type of rotation that occurs during sign language comprehension. Subjects had to mentally rotate objects within a scene, rather than a single object, and they also had to keep track of the orientation of objects within a scene. Our results again support the hypothesis that habitual use of ASL can lead to enhanced non-linguistic mental rotation abilities.

In addition, deaf signers were significantly more accurate when placing objects in their correct orientation compared to hearing subjects, even when no rotation was required. It is likely that this superiority in remembering object orientation is a language-linked effect. Object orientation is often encoded in classifier constructions used to express spatial relations and object location. The orientation of the hand can reflect the orientation of an object. For example, different orientations of a bed can be indicated by changing the orientation of the appropriate classifier sign. Furthermore, many classifier handshapes encode intrinsic features of an object (see Methods). Thus, when signers are describing spatial scenes, they often must pay attention to the orientation of objects in order to produce the correct handshape orientation. Such habitual attention to orientation may lead to enhanced memory for object orientation. English does not habitually encode object orientation as part of spatial scene descriptions. Thus, compared to deaf ASL signers, hearing English speakers may pay less attention to object orientation and may therefore exhibit poorer memory.

We now turn to the comparison between viewing objects in space versus viewing signs in space. We have already seen that deaf signers show a strong mental rotation effect for objects. We now compare these results with signers' performance when viewing ASL descriptions of the same scenes. In this case, the hand rather than the actual object is positioned in space to indicate object location, and orientation of the hand indicates object orientation.

5. Object and sign language conditions: deaf subjects

The design of the analysis was two (gender: male, female) × 2 (stimulus type: objects, sign language) × 2 (rotation condition: required, not required) × 3 (stimulus set: furniture, blocks, animates). Again, both location and orientation accuracy were analyzed separately.[4]

[4]Slightly more lenient scoring was used for some of the items in the ASL condition because the location of the hand was occasionally difficult to determine because of reduced depth cues on the videotape. That is, it was difficult to see whether the hand was positioned near or far from the signer. This resulted in signers positioning the object in the center of the board rather than near or far from the entrance. Such a central placement was considered correct given the lack of clarity of the ASL stimulus on the videoscreen.

5.1. Location accuracy

Signers were significantly more accurate in placing objects in the correct location when viewing real objects than when viewing signed descriptions ($F(1,14) = 35.1$, $P < 0.001$). Subjects were also significantly less accurate when rotation was required ($F(1,14) = 8.53$, $P < 0.02$). However, stimulus type (objects vs. signs) interacted with rotation condition ($F(1,14) = 4.33$, $P = 0.05$). This interaction is shown graphically in Fig. 6A. When subjects responded to real objects appearing on the screen, their location accuracy was significantly reduced when mental rotation was required ($t(14) = 4.69$, $P < 0.001$, one tailed). However, when subjects responded to signed descriptions, there was no effect of rotation ($t(14) = 1.09$, n.s). No other interactions with stimulus type were significant.

There was also a three-way interaction between gender, rotation condition, and stimulus type ($F(1,13) = 4.7$, $P < 0.05$). For the object condition, there was a significant interaction between gender and rotation ($F(1,13) = 5.24$, $P < 0.05$), not found for the sign condition ($F < 1$). For objects, males were more accurate than females when rotation was required (88.5 vs. 79.6%), although this comparison just missed significance, ($t(13) = 1.78$, $P < 0.06$, one tailed). For the sign condition, males and females performed similarly under rotation.

5.2. Orientation accuracy

As with the location data, signers were more accurate in placing objects in the correct orientation when viewing the real objects compared to when viewing signed descriptions ($F(1,14) = 24.55$, $P < 0.001$). Again, subjects were significantly less accurate when rotation was required ($F(1,14) = 6.19$, $P < 0.05$). The interaction between type of stimulus (objects or signs) and rotation condition

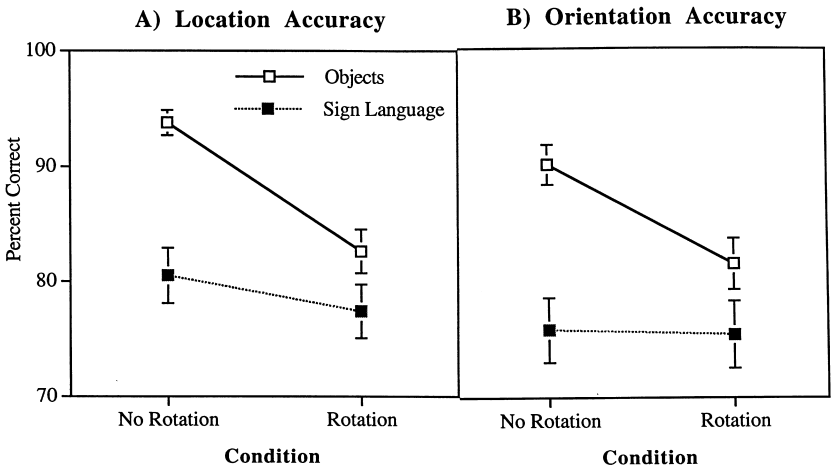

Fig. 6. Mean percent placement of objects in their correct (A) location and (B) orientation by deaf subjects when presented with either the actual objects or a signed description. Bars indicate standard error.

did not reach significance ($F(1,14) = 2.84$, $P = 0.11$) However, planned comparisons revealed that signers showed a significant negative effect of rotation when viewing object stimuli ($t(14) = 4.34$, $P < 0.001$, one tailed), but there was no effect of rotation when viewing signed descriptions ($t < 1$). These data are plotted in Fig. 6B.

Stimulus type (objects vs. signs) also interacted with stimulus set ($F(2,28) = 5.16$, $P < 0.02$). Orientation accuracy did not differ for signs and objects when block stimuli were presented ($t < 1$); however, signers were more accurate when viewing real objects for both the furniture stimuli ($t(14) = 2.92$, $P < 0.05$) and the animate stimuli ($t(14) = 3.5$, $P < 0.01$), compared to when viewing the signed descriptions. No other interactions with stimulus type were significant. Unlike the location data, a significant three-way interaction between gender, stimulus type, and rotation condition was not found for orientation accuracy ($F < 1$). There was also no two-way interaction between gender and rotation in the object condition (males were only slightly more accurate (2%) than females under rotation).

5.3. Discussion: sign language vs. object conditions

Consistent with Experiment 1, and in contrast to their performance with real objects, deaf subjects did not show the typical mental rotation effect when viewing signed descriptions of object locations. They were equally accurate in both rotation and no rotation conditions. Thus, despite the similarity between the presentation of objects in space and signs in space, the process of mental rotation within the linguistic domain did not pose the same difficulty for ASL signers. Interestingly, we also observed an effect of gender, but only for the object condition: when rotation was required, deaf males located objects more accurately than deaf females. Similarly, in the previous analysis, males as a group (both hearing and deaf) were more accurate than females with object rotation (males: 82.3%; females: 77.1%), but this comparison was not significant ($t(28) = 1.24$, n.s). This pattern replicates the well-known finding that males tend to outperform females on mental rotation tasks (e.g. Tapley and Bryden, 1977; Herman and Bruce, 1983; Halpern, 1992). However, this slight gender effect does not appear to cancel out the advantage gained with ASL experience. That is, under rotation, deaf males still outperformed hearing males: 89% vs. 78%, respectively. In contrast, within the linguistic domain, deaf males did not outperform deaf females when rotation was required.

The lack of an effect of mental rotation for sign language was not due to a ceiling effect for that condition. In fact, the sign condition was significantly more difficult than the object condition. Why might this be so? One possibility is that additional processing is required because signers must understand and interpret the linguistic signal, whereas in the object condition, the objects are perceived ‘directly’, i.e. the objects on the screen are exactly the same as the objects that must be manipulated (there is no linguistic ‘translation’). If this is the case, we would expect similar difficulty for spoken English descriptions compared to the presentation of actual objects.

Another possibility is that some signers may have conceptualized the woman on the videotape as sitting across from them, describing a jointly viewed scene (this was not our intention). In situations where both addressee and narrator are observing the same scene, signers use what we have termed *shared space*. The signing space used by the narrator is 'shared' in the sense that it maps to the physically observed space (i.e. the response board in our experiment) and to both the narrator's and addressee's view of the environment. In this case, use of shared space would look the same as the viewer's (addressee's) perspective. For example, describing the entrance in Fig. 3B would not be understood as 'you enter', but as 'entrance far from me and close to you on the board'. On the other hand, if the subject understood the woman as on videotape, describing a room (as was intended), then the narrator's perspective introduced with I-ENTER would be most appropriate; that is, the narrator's signing space would most naturally represent the view of the room from the entrance (and rotation would be required by the addressee). These two possible interpretations may have lead to the increased difficulty for the sign condition; for the object condition, there would be no conflict between a 'shared space' and 'narrator space' interpretation. The confusion within the sign language condition may also explain why subjects did not perform better with the narrator perspective, as they did in Experiment 1. For Experiment 1, shared space was not a likely interpretation because the room presented on the videoscreen could not easily be construed as jointly observed by the narrator on the videoscreen and the subject.

To test these two hypotheses, we ran another experiment with English descriptions using gesture to indicate object locations. The English condition was compared to an object condition in which the appearance of each object was timed to match the length of the corresponding English description. Twenty English speakers participated (14 males, six females); all were students at the University of California, San Diego. Only furniture stimuli were used because these stimuli provided the clearest pattern for ASL. There was a total of 20 trials: four trials with two pieces of furniture; 12 trials with three pieces; and four trials with four pieces. For the English condition, the speaker held a blank response board on her lap and initiated each description with 'the entrance is here', pointing to either the edge near her body (rotation required) or to the edge farthest from her body (no rotation required). The speaker then indicated the location and orientation of each piece by saying 'the X is located here, oriented this way'. The location gesture consisted of either a point toward a location on the board (for the chair and dresser), a flat B handshape (for the bed and table), or a traced-line for the couch. The orientation gesture was a point in a particular direction (e.g. toward the center of the board) which indicated the direction that the piece faced. For the bed the speaker said 'with its head at this end' pointing to one end of the B handshape, and for the table, no separate orientation gesture was needed because the orientation of the B handshape indicated the orientation of the oblong table. The object condition always preceded the English condition.

5.4. Results and discussion: objects vs. English with spatial gestures

The results of this study are given in Table 4. The English pattern was quite different than the ASL pattern. For both location and orientation accuracy, speakers performed equally well in the object and English conditions ($F < 1$ for both analyses), and there was no interaction between stimulus type and rotation condition ($F < 1$ for both). As expected, subjects performed worse when rotation was required for both objects and for English descriptions ($F(1,18) = 54.8$, $P < 0.001$ for location accuracy; $F(1,18) = 85.1$, $P < 0.001$ for orientation accuracy). We also observed an effect of gender with orientation accuracy. Interestingly, there was a three-way interaction between stimulus type, gender, and rotation ($F(1,18) = 7.07$, $P < 0.02$). This interaction is shown in Fig. 7. Similar to signers, in the object condition, males outperformed females under rotation ($t(18) = 4.42$, $P < 0.01$, one tailed). However, males and females performed similarly under rotation in the English condition ($t < 1$).

First, these findings suggest that understanding signed spatial descriptions of the type investigated here is more difficult than understanding parallel spoken English descriptions. In particular, the ASL condition may have contained an ambiguity in perspective because of the two possible ways of interpreting signing space. Some subjects may have interpreted the ASL description as a shared space description. In this case, the no rotation condition would be canonical, and the space on the videotape would map directly to the response board. Roughly half of the ASL signers (8) performed better in the no rotation ASL condition. The other half of the subjects (7) performed better in the rotation condition, suggesting that they interpreted the ASL description as a true room description and not as a description of the observable board. However, these preferences were not strong, and subjects may have vacillated between interpretations. This mix of possible interpretations may have led to overall lower accuracy for the ASL condition, compared to the object condition.

Second, as with the ASL signers, the superiority of male subjects with rotation was only observed when the stimuli were actual objects. These findings suggest that the gender difference in mental rotation skill is tied to the non-linguistic domain. When subjects must interpret a linguistic description that requires mental rotation, the male advantage disappears. This pattern may be related to the other well-known gender effect: females tend to outperform males on verbal tasks (e.g. Halpern, 1992). Within the linguistic domain, female performance improves under rotation, while the performance of male subjects gets worse, compared to the non-linguistic condition. In effect, the two gender differences cancel each other out when mental rotation is required within a linguistic task.

Table 4
Mean (± SE) percent correct for placing furniture in the correct location and for English speakers

	Objects	English
Location accuracy		
No rotation	96.5 (1.4)	95.4 (0.9)
Rotation	74.7 (4.0)	77.1 (3.2)
Orientation accuracy		
No rotation	90.8 (1.4)	92.9 (1.1)
Rotation	77.9 (2.4)	75.2 (2.5)

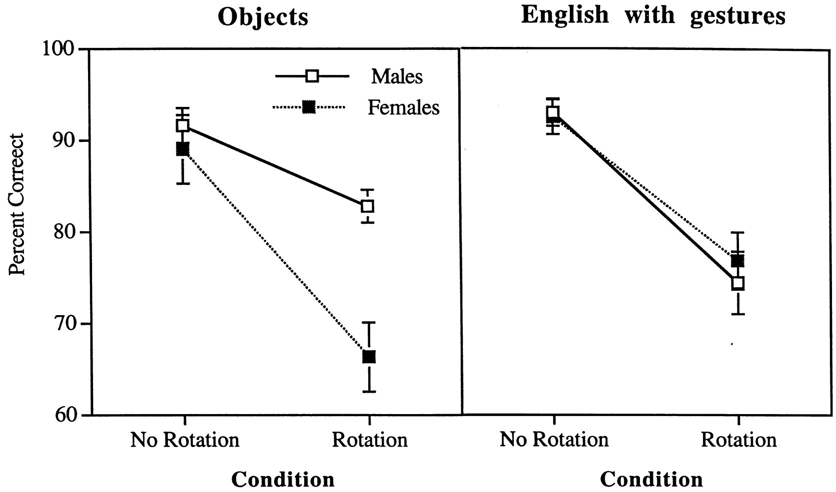

Fig. 7. Mean percent accuracy for placing objects in the correct orientation for hearing males and females in the object condition vs. English plus gesture condition. Bars indicate standard error.

Finally, this study revealed a clear difference between the interpretation of ASL and the interpretation of spatial gestures that accompany speech. English speakers showed a clear rotation effect in both the object and language conditions. ASL signers did not, and we hypothesize that the lack of mental rotation effect is due to the fact that signing space used in a room description most often reflects the narrator's view of the room from the entrance. Signers are used to conducting the mental transformation of observed signing space into a reversed representation; whereas, such a transformation of 'gesture space' does not appear to be part of English speakers' interpretation of spatial gestures.

6. General discussion

Experiment 1 indicated that ASL signers preferred descriptions from the narrator's point of view, despite the demands of mental rotation. Experiment 2 directly compared mental rotation for signs and objects arrayed sequentially in space. The results showed that transforming a spatialized linguistic signal in which signs are positioned in spatial locations into a rotated mental representation is not particularly difficult compared to when no rotation is required. However, when viewing actual objects rather than signs in space, signers exhibit a clear decrease in performance under rotation. In this sense, signs in space are treated differently than objects in space. It appears that the habitual use of mental rotation when comprehending ASL leads to the attenuation or reversal of the normal mental rotation effect during language processing.

One question raised by these results is why do addressees prefer scene descriptions that require mental rotation? In non-linguistic tasks, signers clearly have difficulty with mental rotation (as in the object condition of Experiment 2), so it is not the case that mental rotation has no cognitive processing cost. We suggest that the preference for narrator perspective over addressee perspective derives from constraints on the narrator and is a ramification of the spatialized nature of ASL, the fact that signing space is used to represent physical space. It is not unreasonable to suppose that a signer describing a room (or other scene) generates a mental image. Such a mental image may have little consequence for an English speaker, but for an ASL signer it can influence the nature of the description. We hypothesize that signers adopt a narrator point of view so that the locations within signing space match the locations within their mental image of the scene. For example, if the signer imagines a room with the table to the left, he will place the classifier sign for table on the left of signing space. He does not place the classifier sign so that it is on the addressee's left. For the signer, the location of the classifier sign in signing space maps onto his mental image of the table's location. Signers appear to obey a spatial mapping principle which states that locations within signing space map to isomorphic locations in either a physically observed space or an imagined space. Thus, addressees are forced to frequently perform the rotation transformation demanded by the narrator perspective which may lead them to expect and prefer this perspective over the less canonical, unexpected viewer perspective.

Thus far, we have been assuming that addressees are performing the same type of mental rotation operation when processing ASL and when viewing actual objects. If so, then our results indicate that there are constraints on the generalizability of ASL processing. That is, experience with rotation in the linguistic domain appears to eliminate the rotation effect within that domain, but such experience only reduces, rather than eliminates, rotation difficulty within the non-linguistic domain.

However, another possible interpretation for the lack of mental rotation effect within sign language is that signers do not actually mentally *rotate* locations within signing space when they are the addressee (the viewer). In fact, the intuitions of native signers suggest that they may not. Signers report that they 'instantly' know how to interpret the narrator's description. They do not experience a sensation of rotating a mental image of the scene or objects within the scene. How then, might signers transform observed signing space into a reversed mental representation of that space? One possibility is that signers perform a 'reversal' transformation in which an image is reversed or 'instantly' re-positioned in an opposite position within a horizontal plane.

Another possible interpretation for the lack of mental rotation effect in sign processing is that signers comprehend ASL spatial descriptions as if they were producing the description themselves. One mechanism for this transformation might be that addressees encode spatial relations by mentally imagining themselves at the narrator's position, perhaps a form of self-rotation. Another mechanism might involve a 'motor theory of sign perception' at the sentence level. Under this explanation, signers perform a transformation of the perceived articulation into a reversed representation of their own production (assuming both narrator and addressee are right-handed). Note that this is not what the English speakers did when understanding English descriptions using gesture to indicate spatial locations. Evidence for signers' superior ability to reverse perceived articulation is suggested by the results of Masataka (1995). He found that native signing Japanese children exhibited an enhanced ability to conduct perception-to-production transformations involving mirror reversals, compared to their hearing peers. Further, Masataka (1995) presented evidence that this ability was language linked: the larger the child's sign vocabulary, the better the performance.

If signers are not performing true mental rotation during sign language processing, then we must re-examine the explanation of enhanced mental rotation skills in ASL signers. To the extent that motor processes are recruited during mental rotation tasks (see Kosslyn (1994); pp. 346–349), the enhanced perception-to-production mapping suggested by the results of Masataka (1995) might improve the rotation performance of signers. Another possibility is that experience with ASL enhances other processes that are involved in mental rotation tasks. To perform mental rotation, subjects must generate an image, maintain that image, and then transform it (Kosslyn, 1980). Emmorey et al. (1993) and Emmorey and Kosslyn (1996) found that deaf and hearing ASL signers were faster at generating mental images than hearing non-signers. Thus, signers may also be faster at mental rotation tasks because they are able to quickly generate mental images prior to manipulating them. Emmorey et al. (1993) and Emmorey and Kosslyn (1996) provide several examples of processes in ASL that require image generation (e.g. referent visualization during referential shift).

The results from Experiment 2 also indicated that deaf signers remembered the orientation of objects better than hearing subjects, even when no rotation transformation was required. We argued that superior accuracy in remembering object orientation may be language-linked because object orientation is often explicitly encoded in classifier constructions used to describe spatial relations. Signers may thus have more experience attending to object orientation than English speakers who do not need to attend to this feature to use prepositional phrases. Another possibility is that ASL signers were labeling the objects with classifier signs, encoding object orientation relative to the entrance. But if recoding explains the memory superiority for orientation, then why did signers perform worse in the ASL condition? We have suggested that there were two potential interpretations of signing space which may have lead to lower overall accuracy. For the object condition, only one interpretation of space was available, and signers could have internally recoded object orientation using classifier signs without difficulty. In fact, some subjects did sign to themselves using classifiers during the object task.

However, hearing ASL signers need to be tested to be certain that superior memory for object orientation is a language-linked phenomenon. If hearing and deaf signers pattern together, then this skill will join a growing list of cognitive factors that are influenced by extensive experience with a visual-spatial language (see Emmorey (1998) for a review): motion processing (Neville and Lawson, 1987; Bettger, 1992; Klima et al., 1996; Wilson, 1997), image generation (Emmorey et al., 1993; Emmorey and Kosslyn, 1996), mental rotation (McKee, 1987; Emmorey et al., 1993; Talbot and Haude, 1993), face processing (Bellugi et al., 1990; Bettger et al., 1997; McCullough and Emmorey, 1997), and spatial memory (Wilson et al., 1997).

The results of Experiment 2 and those listed above suggest that knowing and using a signed language can influence non-linguistic cognitive processing. Is this a 'Whorfian effect'? That is, do these findings provide support for the linguistic relativity hypothesis? The answer depends upon how one defines this hypothesis (for excellent discussions of linguistic relativity see Lucy (1992a) and Gumperz and Levinson (1996)). The results of studies with ASL signers do not provide evidence for the hypothesis that the language one uses can qualitatively alter the very nature of cognitive processes or representations. However, the evidence does suggest that the language one uses can enhance aspects of cognitive processing through practice. Through habitual use within the language domain, cognitive processing can be faster (as with image generation), more fine-tuned (as with face discrimination and aspects of motion processing), or more adept at coding certain types of information (e.g. object orientation and spatial sequences). These effects of language use on cognitive behavior go beyond the 'thinking for speaking' relativity hypothesis put forth by Slobin (1991, 1996). Slobin's hypothesis is that the nature of one's language (in particular the grammatical categories of one's language) affect cognitive processes *at the moment of speaking*. Our results with users of American sign language, as well as recent work by Levinson (1996) and Pederson (1995) with users of various spoken languages (Tzeltal, Tamil, and Dutch), indicate that the language one uses can influence cognitive processes even when speaking/signing is not required.

Are these effects of language on cognition just practice effects? In some sense, the answer must be yes. Language does not appear to introduce *new* conceptual categories or processes; rather languages differ with regard to whether and how certain cognitive distinctions are grammatically encoded (e.g. number distinctions) and with regard to whether certain processes are utilized during their interpretation (e.g. imagery processes). It may be the habitual attention to or use of specific conceptual categorizations and processes that leads to varied patterns of cognitive behavior (see Lucy, 1992a). Differences in cognitive behavior may take the form of improved performance on non-linguistic tasks that utilize processes habitually required for either language production or comprehension (as in most of our ASL studies), or these differences may take the form of preferential attention to conceptual concepts that are obligatorily (i.e. habitually) encoded by a particular language (e.g. differential attention to the number of objects by English vs. Yucatec speakers (Lucy, 1992b)).

Finally, our results bear on the relation between language and other cognitive systems. The findings indicate that the visual-spatial processing required by ASL can impact non-linguistic visual-spatial processing. One could also investigate whether auditory language processing affects non-linguistic auditory processing. However, this question is difficult to study because auditory processing cannot be observed in the absence of experience with speech. The visual domain, in contrast, provides an ideal means of studying these questions because visual-spatial processes can be observed with and without the influence of a visual-spatial language. By comparing visual-spatial functions in deaf and hearing subjects, we gain a window into the nature of cognitive modularity and interactivity. The results described here suggest that aspects of higher level ASL visual-spatial processing interact with and influence other types of visual-spatial processing.

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Appendix A. Classifier constructions for blocks in Experiment 2