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This study investigated whether deafness contributes to enhancement of visual spatial cognition independent of knowledge of a sign language. Congenitally deaf school children in India who were born to hearing parents and were not exposed to any sign language, and matched hearing controls, were given a test of digit span and five tests that measured visual spatial skills. The deaf group showed shorter digit span than the hearing group, consistent with previous studies. Deaf and hearing children did not differ in their performance on the visual spatial skills tests, suggesting that deafness per se may not be a sufficient factor for enhancement of visual spatial cognition. Early exposure to a sign language and fluent sign skills may be the critical factors that lead to differential development of visual spatial skills in deaf people.

People who are deaf rely primarily on the visual modality to receive and communicate information. Deaf people often say that they can attend to the visual world much better than their hearing friends. Furthermore, teachers often anecdotally report that their deaf students seem to use their visual spatial skills better than hearing students and that they display confidence in their visual spatial skills. However, little is known about which visual spatial skills might be enhanced due to deafness and what specific factors associated with deafness might be responsible for such enhancement.

Clearly, older notions of across-the-board deficits (the perceptual deficit hypothesis) or enhancements (the perceptual compensation hypothesis) in the development of visual spatial skills by deaf people, relative to hearing people, are not supported by early visual spatial skills studies. Instead, those studies show that deaf-hearing group differences are specific to particular visual spatial tasks (Parasnis, 1983). Given this, Parasnis suggested that differences between deaf and hearing people might emerge only on tasks that tap special skills that deaf people may have developed, such as the ability to attend to visual information. Parasnis and Samar (1982) specifically proposed that the visual attentional mechanism in deaf people might be organized differently than in hearing people due to their increased reliance on the visual modality for alerting and analyses functions. In a later study, Parasnis and Samar (1985) found that deaf signers were superior to hearing nonsigners in redirecting their visual attention in tasks that stress the attentional system's perfor-

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mance, lending some support to this hypothesis. At that time, Parasnis and Samar also proposed that the use of American Sign Language (ASL), which imposes a linguistic structure on visual space, may be an additional factor leading to a differential development of visual spatial skills for deaf people.

Considerable evidence has now accumulated to suggest that deaf signers display advantages over hearing people on a wide variety of visual spatial tasks. Enhanced abilities have been reported for imagery (Emmorey & Kosslyn, 1995; Emmorey, Kosslyn, & Bellugi, 1993; McKee, 1987), memory for simultaneously presented shapes (Todman & Seedhouse, 1994), visual attention (Parasnis & Samar, 1985; Neville & Lawson, 1987), visual closure (McKee, 1987), face recognition (Bellugi, O'Grady, Lillo-Martin, O'Grady, van Hoek, & Corina, 1990; Bettger, 1992), and motion detection in peripheral vision (Neville & Lawson, 1987). There is also some evidence that deaf signers are better in mental rotation tasks (Emmorey et al., 1993; Talbot & Haude, 1993), and in a light writing task in which complex Chinese pseudocharacters were drawn in space with a light wand and the viewer was asked to draw the pseudocharacters (Klima, Tzeng, Fok, Bellugi, Corina, & Bettger, in press).

The relative roles of deafness, per se, versus exposure to ASL in determining differences in visual spatial skills have not yet been determined, since in most studies deafness and knowledge of ASL are confounded. There are a few notable exceptions. Neville and Lawson (1987) employed event-related brain potentials and measures of signal detectability to compare visual attentional processes in deaf fluent signers, hearing fluent signers, and hearing nonsigners. Their findings suggest that ASL and deafness may each have a separate effect on the development of visual attention and, therefore, on a potentially large variety of visual spatial skills that depend on attention. However, in a recent Canadian study (Chamberlain & Mayberry, 1994), which used four two- and three-dimensional mental rotation tasks to compare adult oral deaf nonsigners with adult hearing nonsigners, no performance differences were found, suggesting that the enhanced performance on mental rotation tasks found in earlier studies might have been specifically due to experience with ASL, rather than to deafness per se. Thus, the role of deafness, independent of knowledge of sign language, remains unclear.

This study further examined the role of deafness, per se, in determining the visual spatial skills of deaf children on a variety of tasks, independent of the influence of knowledge of a sign language.[1] Separating the effects of deafness and knowledge of a sign language is difficult to do in the United States because the majority of schools for deaf children now allow the use of some type of sign communication in formal classroom instruction. Many educators and parents have become aware of the benefits of using sign communication, and some have argued for the use of ASL as a primary language for teaching deaf children. Thus, the probability is high that deaf children will be exposed to ASL or some form of sign communication when they attend school. Children who are mainstreamed may not necessarily be exposed to ASL. However, there are practical difficulties in identifying and testing these children. An alternative approach is to test deaf children from a country that does not use any sign communication in the educational setting and where hearing parents in general are not familiar with a sign language or are not even aware that a sign language can be used with deaf children. In India this circumstance appears to be the case, according to educators and researchers there who work with deaf children.[2]

This study was undertaken in India in Pune, a large city in the state of Maharashtra, to investigate whether the performance of deaf children who are not exposed to a sign language is different from the performance of hearing children on a variety of tests of visual spatial cognition and a digit-span test.

Method

Subjects. A total of 24 children participated in this study. All children had normal binocular vision, had no learning or reading disabilities, and had no known history of neurological disorders according to school records. Twelve of these children were deaf and 12 were hearing. The deaf children were from two schools for the deaf in Pune, Maharashtra, India. Both of these schools rely on speech in teaching deaf children and are day schools for the deaf, as is the norm in India. All the deaf children selected for this study had severe to profound hearing loss according to their audiological records, and, according to school officials, they were prelingually deaf, most likely from birth. They did not know any sign language according to their self-report and according to their teachers and parents. All the deaf children had hearing parents, and there were no other persons who were deaf in their immediate families. All deaf children were between 10 years and 12 years, 7 months of age.

The twelve hearing children were also from a school in Pune, Maharashtra, India, and were matched closely for age with the deaf children (see Table 1). Both deaf and hearing groups contained eight boys and four girls each, and all children were from similar socioeconomic backgrounds according to their school records.

Tests. A total of six tests were administered to the children. The first two tests listed below were given to determine if the children were within normal limits for short-term memory span and perceptual-motor integration skills for their age group. The other four were tests of visual spatial skills selected for this study after a thorough review of the literature. These tests were chosen because they measured a variety of aspects of visual spatial cognition and were easy to administer. The tests were administered and scored using standard protocols. The following paragraphs describe these tests.

1. The VADS: Visual Aural Digit Span Test, Visual-Written Subtest (Koppitz, 1977). This test measures how well a child can process, sequence, and recall visual stimuli by presenting a series of digit sequences. Each sequence may be from two to seven digits in length, and the sequences are presented in increasing order of length. A child is shown a digit sequence written on a card for 10 seconds. When the card is removed, the child writes down the digits of that sequence on a blank piece of paper. If the child reproduces the digits correctly, the next longer sequence of digits in the series is shown. If the child is incorrect, another trial is given consisting of a different sequence of digits of the same length as the incorrect sequence. If the child fails in both trials for a given sequence length, the test is discontinued.

2. The VMI: Developmental Test of Visual Motor Integration (Beery, 1989). This test measures the integration of visual perception and motor behavior. It consists of a sequence of geometrical forms that become progressively more difficult. These forms are arranged in a test booklet with three forms per page. The subject's task is to copy each form in the blank square below it. There is no time limit on responses, and testing can be discontinued if the subject fails to copy three consecutive forms correctly.

3. WISC-R: Wechsler Intelligence Scale for Children-Revised, Mazes (Wechsler, 1974). This test measures a child's performance on a series of progressively more difficult mazes. The subject's task is to start from the center of the maze and find the way out without crossing any lines and without lifting the pencil from the paper. There is a time limit for each maze. When the subject fails on two consecutive mazes, the test is discontinued.

4. The Facial Recognition Test (Benton, Hamsher, Varney, & Spreen, 1983). This test measures the capacity to identify and discriminate photographs of unfamiliar human faces presented in black and white. There are short and long forms of this test. The long form was used for this study. The test consists of three parts: (1) matching of identical front-view photographs, (2) matching of front-view with three-quarter-view photographs, and (3) matching of front-view photographs under different lighting conditions. For each trial, a single stimulus picture is presented above the six response-choice pictures. Depending on the trial type, the subject's task is either to point at one picture that matches the stimulus picture or at three pictures that match the stimulus picture. There is no time limit for responding, but the subject is asked to make the best guess and move on to the next trial in case of difficulty in making the choice.

5. Judgment of Line Orientation (Benton, et al., 1983). This test measures the ability to judge the orientation of partially drawn lines. For each trial, a pair of partially drawn lines is presented above a multiple-choice response set, which consists of an array of 11 lines, each of which is fully drawn at 18-degree intervals from the point of origin. Each partial line in the stimulus represents, with respect to the origin, either the distal, the middle, or the proximal segment of a re-

sponse-set line. The subject's task is to point to the pair of response-set lines that corresponds to the stimulus pair. There is no time limit for responding. However, if a subject has not made a choice after 30 seconds, the subject is encouraged to make the best guess and move on to the next trial.

6. The Revised Visual Retention Test (Benton, 1974). This test measures visual perception, visual memory, and visuoconstructive abilities. There are three alternate forms of the test and four methods of administration. On each trial a design is presented that consists of one or more geometrical figures. The subject's task is to draw the design either by copying or from memory, depending on the administration method. Any of the forms can be used for any method of administration. Forms C and E were used in this study in administration methods A and D, as detailed below. There is no time limit on this test.

Procedure. Standard administration procedures described in the manuals were followed with two exceptions: The VADS test and the Judgement of Line Orientation test were administered using the Indian numeral system, which is different from the Arabic numeral system used in the United States, and the instructions were translated into Marathi, the state language of Maharashtra. In a pilot test, all tests were administered to a deaf child who was not part of the deaf subject group for this study. These pilot data indicated that deaf children could easily understand the instructions and perform the tasks.

The VMI was administered to all children and was followed by the VADS test. A quick check of the performance scores showed that there were no severe perceptual-motor integration problems or severe short-term memory deficits that would preclude further testing for any child. Subsequently, the children were tested individually on the remaining four tests of visual spatial cognition. The order in which each child received these four tests was determined by a modified Latin square design, with the constraint that the two forms of the Visual Retention Test were given in the same sequence: Form C was always followed by Form E. These two equivalent forms of the Visual Retention Test were used to test the performance in the immediate and the delayed recall conditions, respectively. In both conditions each design was displayed for 10 seconds and then removed. In the immediate recall condition (administration method A), the child then drew the design from memory immediately. In the delayed recall condition (administration method D), the child then drew the design from memory after a 15-second delay.

The children were tested by the first and fourth authors of this study, who are originally from India and are native speakers of Marathi, the language spoken in the state of Maharashtra. One of them (K.S.) is a retired teacher and principal of one of the schools for deaf children from which the children were tested. She is very experienced in effectively communicating with oral deaf children using speech and gestures. The instructions for all tests are short and simple, and they were slightly modified in such a way that the same spoken instructions and gestures (such as pointing at the figures on the test) could be used for deaf and hearing children. The practice components of the tests were completed by all children adequately, indicating that they understood the instructions and the task. All children completed their tests voluntarily.

Results

The data from individual subjects on each of the six tests were coded following the manuals' instructions[3] and were statistically analyzed to determine if group differences existed in performance. The mean scores of the groups on these tests are reported in Table 1 along with the mean age of the two groups. For each test, where appropriate and available, normative means for hearing American children based on information presented in the test manuals are included. These normative values show that the means of the hearing Indian children in this study are very similar to those for hearing American children in the same age range, indicating no general cultural biases operating to influence the test scores in this study.

Group t tests showed no significant group differences in performance on the VMI ($t = -.61$, $df = 22$, n.s.), the WISC-R mazes test ($t = -.05$, $df = 22$, n.s.), the Facial Recognition Test ($t = -1.34$,

Table 1 Mean correct scores of deaf and hearing children on all tests along with age and hearing normative means

Measure	Deaf (n = 12)	Hearing (n = 12)	Hearing norm
Age			
M	11 yrs 2 mo	11 yrs 2 mo	
SD	10.6 mo	10.5 mo	
VADS Digit Span			
M	4.08	6.67	6.56
SD	.90	.49	
VMI Standard Scores			
M	98.36	99.17	standardized
SD	17.68	8.49	
WISC-R Mazes			
M	19.17	19.25	not available
SD	4.43	3.72	
Face Recognition			
M	39.67	42.33	41.35
SD	5.63	3.96	
Judgment of Line Orientation			
M	16.17	19.17	21.97
SD	4.28	4.74	
Visual Retention Accuracy			
Immediate			
M	5.83	6.58	6
SD	1.4	1.08	
Delayed			
M	5.08	5.67	not available
SD	1.24	1.78	

$df = 22$, n.s.), or the Judgment of Line Orientation Test ($t = -1.63$, $df = 22$, n.s.). On the VADS test the groups were significantly different ($t = -8.72$, $df = 22$, $p < .001$).

A group (deaf, hearing) × time of recall (immediate, delayed) analysis of variance (ANOVA) was conducted on the accuracy scores for the Visual Retention Test. Group was a between-subjects factor and time of recall was a within-subjects factor. There was no main effect nor any interaction involving group. There was a main effect for time of recall—$F(1, 22) = 5.15$, $p < .05$—indicating that subjects in both groups were less accurate in the delayed recall condition (immediate $M = 6.2$, delayed $M = 5.37$).

Performance errors on the Visual Retention Test were also analyzed. Specific errors on the test were classified and scored according to the manual instructions. There are six major categories into which specific errors can be grouped. Within each major category of error, there are many subcategories. However, for the error analyses reported here, the data were collapsed over these subcategories to get overall error scores for each of the six major categories: omission, distortion, perseveration, rotation, misplacement, and size. An error is scored as an omission error when any figure in the design is completely omitted, or when only one or two lines of the figure are drawn that are not a recognizable attempt to reproduce the figure. An error is scored as a distortion error when there is an inaccurate reproduction of any figure in the design by simple substitution of another figure. An error is scored as a perseveration error when a simple substitutive or additive response is made consisting of the reproduction of a figure present in the immediately preceding design. An error is scored as a rotation error when any figure in the design is rotated in reproducing the design. An error is scored as a misplacement error when there is any distortion of the spatial relationships among the figures of a design. Finally, an error is scored as a size error when there is any distortion of the relative size of the figures in a design.

A group (deaf, hearing) × time of recall (immediate, delayed) × error type (omission, distortion, perseveration, rotation, misplacement, size) ANOVA was conducted on the error scores for the Visual Retention Test. Group was a between-subjects factor and time of recall and error type were within-subjects factors. There was no main effect nor any interaction involving group. There was a main effect for error type—$F(5,110) = 19.19$, $p = .0001$—indicating that both deaf and hearing subjects showed the following difficulty order on the six error types: distortion ($M = 2.48$), misplacement ($M = 1.08$), omission ($M = .94$), rotation ($M = .79$), perseveration ($M = .50$), and size ($M = .21$). There was also an error type × time of recall interaction, $F(5,110) = 2.49$, $p < .05$. Simple effects analyses indicated that this interaction was solely due to an increase in the number of misplacement errors in the delayed recall condition ($M = 1.54$) compared to the immediate recall condition ($M = .62$), $F(1,22) = 16.04$, $p < .001$.

Discussion

The finding that the deaf children showed a shorter memory span for digits compared to the hearing children is consistent with previous findings reported in the literature (e.g., Blair, 1957; Tomlinson-Keasey & Smith-Winberry, 1990). The basis for this difference is not yet understood. Nevertheless, these results show that the subject sample used in this study behaved in a manner similar to their American peers on digit span tests. These results also suggest that the frequently reported difference between deaf and hearing children on digit span tests is robust across cultures and numerical writing systems. Further, the fact that the deaf and hearing children in this study did not differ on the Visual Retention Test suggests that the digit span difference is not due to a general short-term memory limitation for deaf children.

The finding that both deaf and hearing subjects were less accurate in their performance on the Visual Retention Test in the delayed recall condition should be interpreted with caution since the immediate recall format of the Visual Retention Test was always given prior to the delayed recall format. Although recall accuracy would generally be expected to be reduced in the delayed recall condition relative to the immediate recall condition, it is possible that fatigue may have partially contributed to reduced accuracy in the delayed recall condition. The absence of a significant main effect for group and of a group × time of recall interaction suggests that both groups were similar in their memory for these drawings.

The Visual Retention Test error type analysis indicated that both the deaf and hearing groups produced similar error patterns. The sole difference between delayed and immediate recall for misplacement errors, displayed by both groups, is not easily interpreted.

This study showed no evidence of enhancement on any of the five visual spatial skills tests. The nonsignificant difference in performance by deaf and hearing children on the VMI is consistent with previous findings (Bellugi et al., 1990) and suggests that the two groups were similar in their perceptual-motor integration. The nonsignificant difference on the Facial Recognition Test contrasts with previous findings by Bellugi et al. (1990) and Bettger (1992). Bellugi et al. (1990) reported better performance on the Facial Recognition Test by deaf children who knew sign language compared to nonsigning hearing children; Bettger (1992) reported that adult deaf and hearing signers performed better on the test than adult hearing nonsigners. Coupled with the present findings, these results suggest that enhancement of facial recognition in deaf people is specifically related to exposure to a sign language. The other three tests of visual spatial skills—namely the WISC-R mazes test, the Judgment of Line Orientation Test, and the Visual Retention Test—have not been previously used with deaf children or adults. Thus, it is not known if performance on these tasks is enhanced in deaf signers.

The precise nature of the potential influence of knowledge of a sign language on various visual spatial skills tests is difficult to specify. However, we can offer a few reasonable speculations that might guide further research. For example, previous findings that fluent deaf signers perform better on the Facial Recognition

Test than hearing or deaf nonsigners may relate to the use of facial expression as a linguistic code in ASL. Specifically, the use of facial expression to code grammatical features may lead fluent signers to better recognize the invariances in faces presented at different angles and at different contrasts. Similarly, if future research shows that fluent deaf signers perform better on the Judgment of Line Orientation Test than hearing or deaf nonsigners, it may be because signers must develop sophisticated visual topological maps in order to scan the field and process information effectively. Signing is a dynamic process that requires ongoing analysis, quick shifts of attention, and an overall awareness of the surrounding visual context. Projecting full spatial relations from partial information about where objects are in relation to each other may be useful for efficiently extracting the spatially and relationally coded linguistic information in signs. Finally, if future research shows that fluent deaf signers perform better on the Visual Retention Test than hearing or deaf nonsigners, it may be because becoming fluent in a sign language may require enhanced coding and memory of visual features and relational information in complex displays.

In summary, these results suggest that deafness itself may not be a sufficient factor for enhancement of visual spatial cognition, but early exposure to a sign language and fluency in that sign language may be the critical factors. Imposing a linguistic structure on visual spatial information may be the necessary condition that leads to a differential development of visual attention, visual memory, and visual spatial skills in deaf people.

Notes

1. In this article the term sign language refers to any of the large variety of visual-gestural languages used by deaf people around the world. The term sign communication here refers to the large variety of signed communication systems used by deaf people, including PSE, Sign English, and simultaneous communication.

2. The first author obtained this information in many discussions with administrators and teachers, as well as government officials, during a one-month national training workshop for teachers and rehabilitation counselors conducted by the Ali Yavar Jung National Institute for the Hearing Handicapped, Bombay, Maharashtra, India, in June 1987, at which she taught as an invited U.S. expert on the education of deaf people. Although clubs for deaf adults exist at least in large cities and club members often use sign communication, apparently the opportunity for systematic exposure to a sign language is generally not available to a deaf child of hearing parents in formal school and social settings. As recently as 1995, the first author found that the situation in the schools for the deaf in Pune has remained largely the same, although in the Deaf clubs, more awareness has arisen that deaf members are routinely using a sign language among themselves for communication. However, this sign language is not used in schools by the few teachers who are aware of the importance of sign communication. These teachers have started introducing Western signed communication systems to their students.

3. The VMI and Visual Retention Test, which required professional judgment in the classification of errors, were coded blind by a licensed psychologist. All other data were coded by the experimenters.

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