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FROM SIGN TO SCRIPT: EFFECTS OF LINGUISTIC EXPERIENCE ON PERCEPTUAL CATEGORIZATION

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ABSTRACT

Three experiments were carried out to explore modification inperceptual categorization resulting from early childhood experiencein acquiring a sign language as a primary native language. Subjectsincluded two groups of Chinese children (deaf children whoselanguage was Chinese Sign Language and hearing ones whose languagewas Chinese) and two groups of American adults (deaf signers of American Sign Language and hearing speakers of English). Thestimuli were Chinese pseudocharacters, each presented either as a sequence of static fragments or as dynamic point-light displays of the trace of the character form as it is written in the air. Under each condition, the subjects were to reconstruct and draw the pseudocharacter from the manipulated stimulus. In Experiment 1, Reconstruction from Static Fragments, the deaf signing children showed an enhanced ability to reconstruct the target form, when compared to the hearing children, but only at zero inter-stimulus intervals. In Experiment 2, Reconstruction from Dynamic Point-Light Displays, both groups of Chinese children were asked to reconstruct the target from a continuous dynamic display of movement; the deaf signing children showed superior performance across the

board. The third experiment showed that even without any knowledge of Chinese characters, deaf signing Americans also exhibit an enhanced ability to analyze these complex displays of movement compared to hearing English speakers. Results of these experiments highlight some of the basic properties that may be critical for perceptual transfer from one domain to another.

INTRODUCTION

In recent years, the conception of what constitutes a natural human language has been broadened, if not radically modified, by a wealth of studies of the sign languages that have developed among deaf people of deaf parents. The most intensively studied so far is American Sign Language (ASL). Evidence has shown that ASL is a fully expressive linguistic system, autonomous from English or any other spoken language; it has its own grammar, with morphological and syntactic patterns distinct from those found in English (Klima and Bellugi, 1988; Bellugi and Studdert-Kennedy, 1980; Bellugi, Poizner and Klima, in press). Considerable scientific attention has been drawn to such sign languages, for they hold promise for aiding in the assessment of the extent to which the underpinnings of language are influenced by modality. For example, since visual perception and signing differ so radically from auditory perception and speech, the existence of sign languages affords a new vantage point for studying how formal properties and categories of a language can influence psychological processes such as discrimination and identification. Issues that have been addressed concerning effects of early linguistic experience that are connected with the acquisition of particular spoken languages can now be brought into broader perspective by including early acquisitional experience with visual- gestural languages. Results of such comparative studies across different modalities will not only allow an assessment of the generality of previous findings, but may also lead to an understanding of mechanisms underlying such effects.

In spoken languages, effects of early linguistic experience on the categorization of phonetic contrasts have been extensively studied. Experiments on the perception of speech indicate that early experience with a particular language can affect the perception of phonemes, even when linguistic categorizations run counter to natural auditory categories. Eimas (1975), for example, found that Japanese infants can discriminate acoustic differences that cue the distinction between /r/ and /l/, as can English-speaking adults, in whose language the distinction is phonologically contrastive. Japanese-speaking adults, however, fail to discriminate these acoustic differences. It has been argued that this effect is due to the fact that the distinction between /r/ and /l/ is not contrastive in the phonological system of the Japanese language. Similarly, observed differences in certain discrimination functions of Thai versus English speakers have been attributed to differences in how the phonological systems of the two languages partition the voicing dimension (Abramson and Lisker, 1970). Thus, it appears that appreciable modification of innate sensitivities can take place during the childhood years as one acquires the categories and relations that play a role in the structure of one's native language.

A similar question has also been raised concerning possible effects of early linguistic experience with sign languages. The first ASL studies were restricted to two of the parameters that figure in sublexical structure: Place of Articulation and Hand Configuration. In the "phonological" system of ASL, each of these parameters has a specific and distinct set of categories that are contrastive (i.e., that are "phonemic", if you will). Poizner and Lane (1978) asked deaf ASL signers and hearing subjects without knowledge of ASL to identify (under visual noise) the location, relative to the body, at which signs were made; Stungis (1981) similarly asked subjects to identify and discriminate the configurations of the hand. The studies found similar patterns of identification and discrimination for both the deaf and the hearing subjects. Thus these results did not reveal modification of natural perceptual categories due to linguistic experience, at least for the processing of static sign parameters of Hand Configuration and Place of Articulation. In a similar vein, neither of the static parameters of ASL (Place of Articulation or Hand Configuration) were found to be perceived categorically by native signers (Newport, 1982). And in early visual hemifield experiments involving the processing of ASL signs presented as static pictures, no left hemisphere dominance was found. However, in later visual hemifield studies, changing the stimulus materials from static to moving images was found to reverse the pattern of the visual-lateralization effects and to yield clear left- lateralization effects. Thus, when movement was actually present in the stimuli, results were consistent with those obtained in studies of sign aphasia, where it was found that linguistic impairment was selectively associated with damage to the left hemisphere in deaf stroke patients whose native language was ASL (Poizner, Battison, and Lane, 1979; Poizner, Klima, and Bellugi, 1987). Hence, the picture that emerged was that adequately capturing the movement in signs was a critical factor, and furthermore, that movement is processed differently from the other parameters. This is consonant with what has been found with spoken languages; studies of the perception of speech have found that listeners process temporal variation differently from steady state information (Liberman, Cooper, Shankweiler and Studdert-Kennedy, 1967).

In another series of studies involving movement, (Poizner, 1981; 1983; Poizner, Fok, and Bellugi, 1984), deaf native signers of ASL and hearing subjects unfamiliar with any sign language were asked to make triadic comparisons of movements that had been extracted from lexical and from grammatically inflected signs. The stimuli consisted of disembodied moving point-light displays. An analysis of the similarity judgments revealed that a small set of physically specifiable dimensions accounted for most of the variance. The most striking result was that the two groups differed significantly in their patterns of dimensional salience for these movements, both at the lexical and at the inflectional levels. Linguistically relevant dimensions (those relevant to the structure of ASL) were of increased salience to native signers of ASL. In other words, the perception of these sign movements is tied to linguistically relevant dimensions for the deaf signers, but not for the hearing subjects. This difference demonstrates that modification of natural perceptual categories in the process of acquiring one's language is not bound to a particular transmission modality, but rather can be a more general consequence of acquiring that language.

Results from another study of the perception of movement demonstrate cross sign language effects on perception (Poizner, Fok and Bellugi, 1989). That study involved two unrelated sign languages, namely ASL and Chinese Sign Language (CSL). The two are separate sign languages and are mutually incomprehensible. Like spoken languages, both of these sign languages exhibit levels of formal structure: a sublexical level internal to the signs (the equivalent of phonological structure) and a level of structure that specifies how signs are linked together within sentences (syntactic structure). CSL and ASL both exhibit linguistically significant contrasts ("phonological" contrasts) within each of the three parameters: Hand Configuration, Place of Articulation and Movement. But the contrasts selected as distinctive are not the same in the two languages; and significantly, the two languages organize aspects of movement in very different ways. In addition, the lexicons of ASL and CSL are distinct and the syntactic systems are unrelated. To repeat, CSL and ASL are separate full-blown human languages.

In the CSL/ASL movement study, four groups of subjects (deaf Chinese CSL signers, hearing Chinese nonsigners, deaf ASL signers and hearing American nonsigners) were asked to make triadic comparisons of 15 videotaped moving signs displayed as point-lights. Similarity matrices were constructed for each subject by counting the frequency with which that pair was judged as most similar in the triads in which it occurred. SINDSCAL scalings on all 31 matrices were performed in one through seven dimensions. Perceptual dimensions important to the hearing subjects provide clues to the natural visual categories into which ASL movements. Perception in both groups of signers differed markedly from perception in the hearing non-signers. Furthermore, American signers differed from Chinese signers in their perception of one and the same set of movement elements. This difference appeared to be based in part on which features of movement are significant in the separate phonologies of the respective sign languages. The difference suggests that particular modifications of natural perceptual categories can be a function of the structure of the specific sign language acquired. These results provide some of the first cross-linguistic data on the perception of sign languages and point to the language-specific effects of acquiring a language in the visual-gestural modality (Poizner, Fok & Bellugi, 1989).

The above results reveal the effects that acquiring a specific visual-gestural language can have on perception. These effects have a parallel in the role of language-specific linguistic experience on the perception of speech. Despite the differences between auditory and visual processing, acquiring a primary language in either modality can modify perception of natural categories into which language elements fall. It is a separate question, however, whether such modifications in perception extend beyond the processing of the linguistic signal itself. How robustly, for example, will native signers differ from non-signing hearing people in the processing of visual-gestural material which is not directly a part of their sign language but which, nonetheless, exhibits the dynamic aspects of movement through space? In a series of studies, Neville and Lawson (1987) obtained behavioral as well as neurophysiological evidence which showed that deaf ASL signers differed from hearing nonsigners in the patterns of their performance in detecting a moving signal in the peripheral visual field. Such a finding is interesting; however, it tells little about higher level organization of movement through space. In the following experiments, we will examine the perception of movement and visual patterns by deaf children who have acquired, as their native language, a visual spatial language, and who are learning a logographic writing system which is also visual spatial. We are interested in whether processing characteristics associated with the one are transferred to the other.

The Chinese writing system was chosen for our experiments for two reasons. First, these studies are part of a program of research in which we are investigating the acquisition of script (alphabetic and logographic) by hearing and deaf children. The focus is the intersection between sign, speech and script and the relation between primary and secondary representational systems. The unique spatial layout of the Chinese logographs and their apparent lack of direct grapheme-phoneme correspondence with the words of the primary language make it a particularly interesting script to examine. This is especially the case from the perspective of how deaf Chinese children learn to read such a script. Second, even though Chinese characters, as they appear on a written or printed page, are static in a two dimensional plane, evidence from both experimental and clinical studies (Mann, 1986; Tzeng, Hung, Chen, Wu & and Hsi, 1986) suggests that a graphomotoric code is involved, under special conditions, in the recognition of characters and also when children are learning to read them. Moreover, literate Chinese adults have every-day experience with reading characters "written in the air". In a conversation it is not unusual to see them attempt to disambiguate words by tracing, in the air with the index finger, the stroke sequence of the character representing the intended word (Martin, 1972). Thus, by choosing Chinese logographs as experimental stimuli, we can ask the question: Can the perceptual organization of movement due to the linguistic experience of acquiring CSL readily transfer to a totally different perceptual domain, namely, the processing of Chinese characters? Given the spatial properties of Chinese characters and the spatial properties of CSL, as well as the evidence mentioned above for a graphomotoric coding scheme for Chinese characters, such a transfer would appear to be a real possibility.

In fact, preliminary results from another study have already hinted in this direction (Fok and Bellugi, 1986). In that study of entry into script by deaf and hearing first grade Chinese children, it was found, as was expected, that the deaf differed from the hearing children in the number of correct responses made. The deaf children, even in first grade, lagged behind the hearing children in writing correct Chinese characters as names for simple objects presented in pictures. This difference in performance between the two groups is undoubtedly attributable in part to sociolinguistic and pedagogical factors. The first grade teachers of both groups of children were all hearing, speaking individuals and did not sign to the children in class. In attempting to teach the children the characters, the teachers gave all explanations and instructions in spoken Chinese. In addition, there may be sporadic structural factors that could give the hearing children an advantage. The relation between the spoken words (for the objects presented and the pictures used in the study) and the form of the corresponding characters is often not totally arbitrary. The deaf first graders in the study would not have had the benefits of such clues, for they have never heard the spoken language and knew only Chinese Sign Language. What the results of the Fok and Bellugi study also showed was that, on the whole, even the erroneous responses of the deaf children were nonetheless spatially well formed, with well-formed character components in allowable spatial configurations. There was also another way in which the responses of the deaf signing children differed from those of the hearing children. It was found that some of the errors in character form made by the deaf children could be attributable to formal devices proper to CSL, but alien to Chinese characters (Fok and Bellugi, 1986; Fok, van Hoek, Klima and Bellugi). The deaf Chinese children apparently utilized mechanisms inherent to one visuospatial system (their native language CSL) in attempting to master another visuospatial system (that of Chinese logographic script).

In the present paper, we specifically examine the perception of Chinese script by two groups of Chinese children (deaf children whose language is CSL versus hearing children whose language is Chinese) and two groups of American adults (deaf adults whose native language is ASL versus hearing adults whose language is English). We presented to the Chinese children two tasks, in each of which the stimuli were constructed by manipulating Chinese pseudocharacters in complex ways that made demands on mental reconstruction, perception, and spatial analysis. Experiment 1: Reconstruction from Static Pieces (Visual 'Gluing') investigates deaf and hearing Chinese children's processing of successive fragments of a pseudocharacter presented as static displays. Experiment 2: Reconstruction from Dynamic Point-Light Displays investigates deaf and hearing Chinese children's ability to analyze dynamic continuous movement displays from Chinese pseudocharacters "written in the air" and to extract from the total display the underlying character form. Experiment 3 is an extension of the previous experiment with dynamic point- light displays, but this time with deaf American adults whose language is ASL and hearing American adults whose language is English (both groups without any knowledge of Chinese). The objective of Experiment 3 is to evaluate separately the contributions of visuospatial cognitive abilities, as differentiated from knowledge of a spatial script.

EXPERIMENT 1. RECONSTRUCTION FROM STATIC PIECES: VISUAL GLUING (*Chinese Children*)

Experiment 1 examines deaf and hearing Chinese children's processing of static displays of fragments of characters presented one by one in sequence and in their proper spatial locations within the character. The subjects were asked to view the entire sequence of fragments, and then mentally "glue" these fragments into a whole character. Past experimental data have shown that Chinese readers have little problem in identifying the target characters provided that the fragments are presented in an appropriate sequence (Huang, 1986). Tzeng et al (1986) have also used such a 'visual gluing' task to demonstrate the importance of the graphomotoric code in the identification of Chinese characters by agraphic and alexic patients. For the purposes of the present experiment, we decided to use pseudocharacters (i.e., invented characters which were well-formed, possible but not actual characters) in order to minimize the possible confounding effect due to greater familiarity with actual characters on the part of hearing Chinese children. Each pseudocharacter was broken down into fragmentary pieces which were presented one by one in such a way as to preserve the order of conventional stroke sequence (left to right, top to bottom, and so on). The subjects' task was to reconstruct the pseudocharacter after the presentation of the last piece, and to give a written response. An independent variable which was also manipulated was the duration of the interstimulus interval (ISI). Three ISIs (0 msec, 300 msec and 800 msec) were chosen. The two critical response conditions to be examined were the zero msec and 300 msec ISI conditions. In a series of experiments, Loftus and his associates (Loftus and Ginn, 1984; Loftus, Hanna, and Lester, 1988) found that for successive picture presentations, a 300 msec ISI seemed to represent the critical boundary which separated perceptual processes from conceptual processes. If it should be found that deaf signing children show a positive transfer from the perception of their sign language to other non-sign visual stimuli, then it would be important to know at what stage of visual information processing such a transfer takes place.

Method

Subjects. Twelve deaf and 12 hearing Chinese children from Hong Kong schools all of whom were in the equivalent of the eighth grade were subjects in this experiment. The deaf children were all profoundly deaf, most were from deaf families, and all of them were fluent in Chinese Sign Language.

Stimuli and Procedures. Thirty Chinese pseudocharacters were created, using actual component parts of frequently occurring Chinese characters. Some of the invented characters had only one component, while some contained two components side-by-side, some contained two components arranged vertically, and some of the characters had an 'inclusion' relation, with one component contained in another. All of the pseudocharacters were possible characters in Chinese, conforming to the implicit architectural rules of graphemic formation. The stimuli were generated on a Gerbrands 4-Channel Tachistoscope controlled by a timer for the interstimulus interval (ISI). The character pieces were presented in sequences of four frames at 50 ms. each. There were three sets of ten items each, varying with respect to ISI (zero, 300 ms., and 800 ms.), plus ten practice items. ISI conditions were randomized across subjects. The stimuli were presented on videotape filmed directly from the tachistoscope. Figure 1a shows two pseudocharacters used in the experiment, and their breakdown into sequences of pieces.

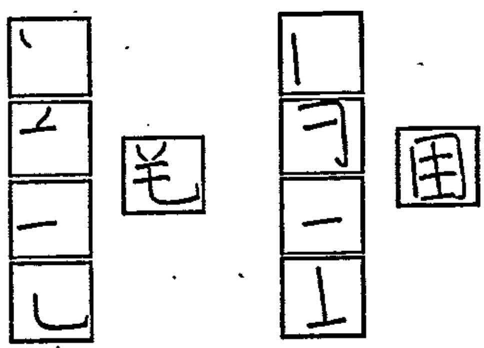

Figure 1a. Visual Gluing — Two Stimuli

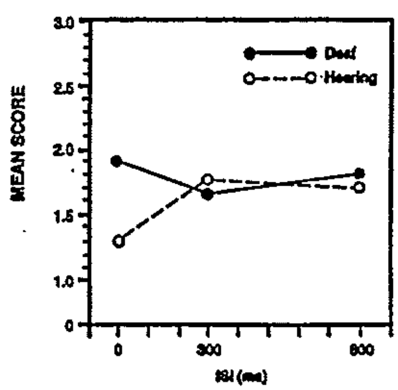

Figure 1b. Visual Gluing — Results

Figure 1. Exp. 1: Visual Gluing.

(a) Stimulus sequences for two target pseudocharacters used in Experiment 1, and (b) Mean scores for the hearing and deaf subjects as a function of the three interstimulus intervals (ISI).

Both groups of children were shown a temporal sequence of static pieces representing the strokes that form the pseudocharacter. The subjects' task was to view the fragmentary pieces frame by frame, and then to mentally `glue' together the individual strokes into a unified image of the target pseudo character. The subjects were tested individually and were instructed to watch the videotape until the four fragments had been presented. Only then were they to write down their mental reconstruction of the pseudocharacter, using a felt tip pen.

Results and Discussion

The subject's response for each item presented was scored on the basis of a three point rating scale: 3 for an entirely correct response, 2 for a response which was correct except for one stroke missing and displaced, 1 for half or more than half of the strokes present or in the right place. The item received a score of 0 if the response was less than half correct. For each subject, a mean correct score was obtained across the ten items for each of the three ISI conditions. The results are presented in Figure 1b. They suggest that at longer ISIs (i.e. 300 ms and 800 ms) deaf and hearing subjects perform equally well. But at zero interval deaf children continue to maintain their performance level while the hearing suffer a tremendous drop in performance.

An ANOVA for a 2 x 3 factorial design was then performed on the mean correct scores of the subjects' responses, with Group (deaf vs. hearing) as the between subject factor and ISI (zero, 300 ms., and 800 ms.) as the within subject factor. The statistical analysis confirms our observation that the deaf subjects outperform the hearing when the fragmentary pieces presented were not separated by any time interval. Overall, the main effect of Group (hearing and deaf) was not significant. Nor was the main effect of condition (ISI). However, the interaction between the two was significant (F df = 2, 44 = 5.36, and $p < .01$). Tukey's HSD post hoc test of this interaction revealed that the only difference between the deaf and the hearing subjects is at the zero ISI interval ($p<.01$). At this zero interval the deaf subjects performed significantly better than the hearing in reconstructing the target pseudocharacters.

These results suggest strongly that the linguistic experience of knowing a sign language has an effect also on behavior not directly involved in processing signing. The results also suggest that the effect may be perceptual rather than conceptual (Loftus et al, 1988). Treisman and Gormican, 1988 have demonstrated convincingly that visual perception involves conjoining visual-figural features onto their appropriate locations and that such conjoining operations (or 'gluing,' in their terms) make demands on the attentional resource on the part of the viewer. Accordingly, the data obtained here may be interpreted as suggesting that the deaf children's long experience with the production and/or reception of signing has resulted in a reduced demand on attentional resources for `gluing' a particular visual- gestural feature onto its appropriate location in space. If this is the case, then it is important to find out whether such an enhanced perceptual ability can also be observed in the perception of movement through space. Since previous studies in our laboratories have identified motion as one of the most salient perceptual dimensions for both Chinese and American deaf signers, we wondered whether their linguistic experience with signing would enhance their ability in gluing a moving signal onto its appropriate spatial track and also whether this experience would improve their ability to reconstruct discrete units (the strokes) of the underlying structural representation on the basis of the continuous, moving signal. This was tested in the next experiment.

But before proceeding to the description of the second experiment, we should note an alternative interpretation which is based upon the consideration of the possible sensory enhancement of one modality due to the impairment of the another modality. That is, it may be argued that the superior performance of the deaf subjects is attributable to deafness per se, rather than to the effect of specific signing experience, as advocated above. However, such a deprivation-compensation-across-modality hypothesis can be disputed on several empirical ground. First, empirical studies over the last 70 years since the classic work of Seashore and Ling (1918) have generally shown that the senses of the unimpaired modality do not become more sensitive as a result of impairment in one of the other sensory modalities; in fact, measurements based upon psychophysical methods (e.g., threshold, acuity, etc.) usually suggest little enhancement (Hollins, 1989). Second, in a series of carefully designed experiments which employed event-related brain potentials and measures of signal detectability to compare attention to peripheral and central visual stimuli among three different subject populations, namely, hearing signers who were born to deaf parents, congenitally deaf signers, and normal hearing non-signers (control group), Neville and Lawson (1987) obtained results suggesting that auditory deprivation and the acquisition of a visual language have marked and different effects on the development of cortical specialization; in fact, only the latter was found to correlate with the detection of movement. Third and most importantly, even within the population of all congenitally deaf signers (and thus all auditorily deprived) who had at least 40 years command of the language but were exposed to this language at varying ages, it was found that the proficiency of their production and comprehension of ASL morphology show a linear decline with increasing age of exposure. (Newport, 1991). This result indicates very clearly that the effect of linguistic experience on the perceptual categorization of signs cannot be attributable to auditory deprivation. Any single point listed above may not by itself constitute a strong evidence against the deprivation-compensation hypothesis. However, all three points together clearly suggest that the perceptual enhancement we observed in the experiment should be attributed to the effect of the linguistic experience of signing.

EXPERIMENT 2. RECONSTRUCTION FROM DYNAMIC SPATIAL DISPLAYS *(Chinese Children)*

The first experiment investigated deaf and hearing children's ability to remember and mentally reconstruct Chinese pseudocharacters from fragmentary pieces, presented statically. Deaf and hearing children were found to be alike in their performance on the task at longer interstimulus intervals, but there appears to be an advantage for the deaf children at the most rapid presentation; that is, with zero interval between pieces. This result suggests that the deaf signers' enhanced ability is at the perceptual stage, rather than the conceptual stage, of processing visual information. The enhancement may suggest that because of their experience in the production and perception of linguistic signs, deaf signers are able to construct very rapidly a coherent perceptual representation based upon stroke patterns which have been presented frame by frame. However, since each stroke pattern is also clearly defined by a distinctive spatial location, the superior performance of the deaf signers may reflect their familiarity with the use of location as mnemonic device (e.g., the method of loci), rather than the ability to relate stimulus information presented across space (i.e., movements). Therefore, it is important to find out whether the perceptual enhancement observed in the last experiment also applies to experimental stimuli which capture the dynamic nature of continuous movements across various spatial locations.

The following experiments investigated the processing of Chinese characters presented as dynamic continuous movements, rather than as static forms, as was the case in the previous experiment. In order to capitalize on movement and to extract the movement of Chinese characters in a direct way, a technique highlighting movement patterns was used. This involved attaching a small light emitting diode to the fingertip and recording the pattern of light displays as the character was written in the air. The display was videotaped in a darkened room, so that only the pattern of movement of the single light emitting diode was visible. This technique had been used in previous experiments to isolate the movement of signs, and study the perception of movement organized into linguistic systems (Poizner, 1981, 1983; Poizner, Fok and Bellugi, 1989).

By presenting Chinese pseudocharacters as dynamic point-light displays, Experiment 2 investigates whether or not deaf and hearing children differ in their abilities to abstract away from dynamic moving displays and reconstruct the underlying structural representation. The question addressed is not how the children can create a mental reconstruction by mentally 'gluing' static pieces into a character-like pattern, but rather how they can reconstruct the underlying sequence of individual strokes from a continuous dynamic display that includes the transitional movements between the strokes.

Method

Subjects. Thirty hearing and thirty deaf Chinese children from three grades in Hong Kong schools who had the same number of years of education (grades 1, 4, and 8) served as subjects. There were ten hearing and ten deaf children at each grade level, mean ages were approximately 6, 10 and 14, respectively. The deaf children were all profoundly deaf, most were from deaf families, and all were fluent in Chinese Sign Language.

Stimuli and Procedures. Twenty Chinese pseudocharacters of five or six strokes were used, a subset of those used in Experiment 1. These pseudocharacters were then videotaped as point-light traces. Stimuli were made by videotaping a native Chinese speaker writing the character in the air in a darkened room, with a small light-emitting diode attached to the fingertip. This procedure yields a connected trace of light, with the component strokes along with the transitions between them appearing in one smooth, continuous dynamic display. Filming was done using a reversible image Sony video camera, Model AVC3260, and presented as reversed images (that is, subjects saw the display on the videoscreen in the same orientation as if they were writing in the air themselves). In addition, practice items (described below) were videotaped in a similar manner.

The top part of Figure 2 illustrates how the stimuli were produced. The lower portion of the figure shows eight sample stimuli. The black- on-white representations show the pseudocharacters which the subjects were attempting to reconstruct; the white-on-black representations illustrate the continuous path of movement that appeared on the videoscreen, taken from tracings made by tracking the continuously moving point-light display frame by frame from the videotape. ----Figure 2 here----- Chinese Pseudocharacters in Point-Light

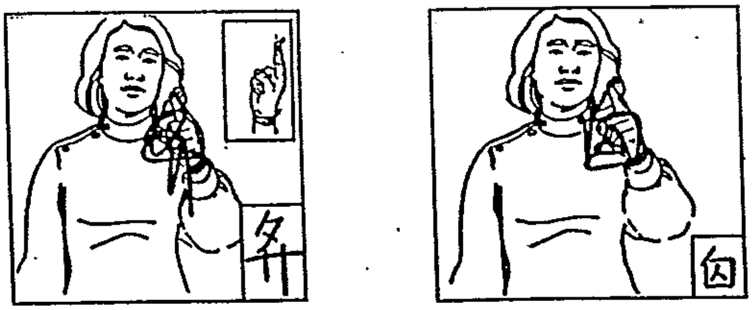

Figure 2a. Chinese Pseudo-character — Point Light Display Set-up

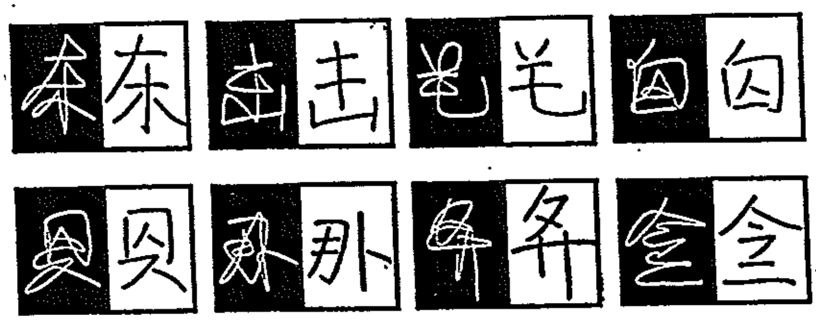

Figure 2b. Chinese Pseudo-character — Eight Sample Stimuli

Figure 2. Chinese Pseudo-characters in Point-Light Displays.
(a) Illustration of set up for creating point-light versions of pseudocharacters with finger-tip light in a darkened room used for Experiments 2 and 3. For purposes of illustration we reverse the contrast of point-light path, presented as black on white rather than actually occurring light trace.
(b) Eight sample stimuli traced from videotape and their corresponding target pseudocharacters.

The subjects were tested individually and were given a series of practice trials after they were briefed on the nature of the task. First, simple real Chinese characters were drawn in the air with the index finger. The children were asked to look at the display and write down the character (using a felt tip marker). Immediate feedback was given as to the correct answer. Then, ten real Chinese characters were presented as moving point-light displays, and the children were asked to decompose the continuously moving display and to write down the character underlying it; no feedback was given. All the children completed this task. Finally, ten Chinese pseudocharacters were presented as practice items. The subjects were told that the experiment was designed for a variety of grade levels, and that therefore some of the stimuli might be characters they did not know. The children were encouraged to guess, even if they were not sure, and to write down whatever they could of the underlying character traced by the light.

The actual experiment consisted of 20 pseudocharacters in point-light displays presented on videotape. The children were told to write as much of the underlying character presented as possible. Again, the experimenter ensured that the child was attending before each trial began, and that the child began writing only after the stimulus ended.

Results and Discussion

The written responses of both groups of children were analyzed by two different methods: a forced choice rating method and a quantitative absolute scoring method. The rating procedure was used to determine whether group differences were present in the data, while the absolute scoring provided a quantitative assessment of how the responses differed between the deaf CSL signers and the hearing subjects. The results of these two different scoring procedures are described separately below. In addition, item analysis of some of the responses by deaf and hearing subjects at different grade levels is presented in order to highlight the differences.

Rating Analysis (Group Differences). The subjects' response sheets were photocopied and their responses for the target item were separately affixed to 3 x 5 index cards. The backs of the cards were labeled with numbers to identify each subject, without indicating group membership. This procedure yielded a total of twenty cards per pseudocharacter per grade (ten deaf children and ten hearing children for each grade). A target stimulus card with a drawing of the correct pseudocharacter was included in each packs of 20 cards. Ten adult Chinese raters (all hearing and literate) were asked to sort the 20 responses for each stimulus into four piles, ranging from `most similar to target' to `least similar to target.' The raters were unaware that the cards being sorted were from two different subject groups. In order to control for a rater's response bias toward one end or another, each rater was instructed to place equal numbers of cards (exactly 5 cards) into each pile. Upon completion of the sorting task, the cards categorized as most similar to the target were assigned 4 points each, those categorized as least similar to the target were assigned 1 point, and those categorized in between were assigned 3 and 2 according to the degree of similarity to the target. Thus, if a rater's five choices for 'most similar to target' are comprised of three deaf children's responses and two hearing children's responses, the deaf group receives 12 points (three deaf responses at 4 points each) and the hearing group receives 8 points (two hearing response worth 4 points each). These group point values, summed across the four sorted piles, constitute similarity scores for that particular character. The two group scores were further averaged across the ten characters and the resulting mean judgment scores constituted the dependent measures.

Comparing similarity scores by grade, we find that the first grade hearing children's responses have a mean point value of 20.8, while the deaf children's responses have a mean of 29.1. A dependent t-test was performed on the rating scores and the result showed that between the first grade deaf children and the hearing children there is a significant difference ($t(9) = 23.97$, $p<.01$) in their ability (as reflected by the ratings) to reproduce the target stimuli presented. Using this procedure we find that at each grade level, the significant differences between deaf and hearing groups persist. That is, the deaf subjects' responses are consistently judged as being closer to the target than the comparable hearing children's responses (see Table 1). No significant differences were found between the raters.

Table 1.
Mean Rating Scores for the Hearing and Deaf Children

	Subjects		
Grade	Hearing	Deaf	t-Test
1	20.8	29.1	$t_{(9)} = 23.97^*$
4	22.6	27.3	$t_{(9)} = 30.10^*$
8	22.6	27.2	$t_{(9)} = 20.72^*$

*$p<.01$

Note that for each target item, the raters were asked to sort the 20 response cards (10 from each of the two groups) into 4 piles (with the restriction of exactly 5 cards per pile) ranging from those representing the best to the worst. On the basis of this, we calculated the relative proportion of cards from each group in each of the 4 piles. Figure 3a illustrates the results of the proportion scores summed across items and raters. It should be noticed that the responses of the deaf children and those of hearing children were categorized very differently.

Of the responses that were categorized as 'most similar' to the target, 70.3% were responses made by deaf children and only 29.7% were responses made by hearing children. Conversely, of the responses that were categorized as 'least similar' to the target, only 21.8% were responses made by deaf children, while 78.7% were responses made by hearing children. There is a high degree of agreement among raters, particularly in assigning the deaf and the hearing children's responses to the category of 'most similar' to target.

striped

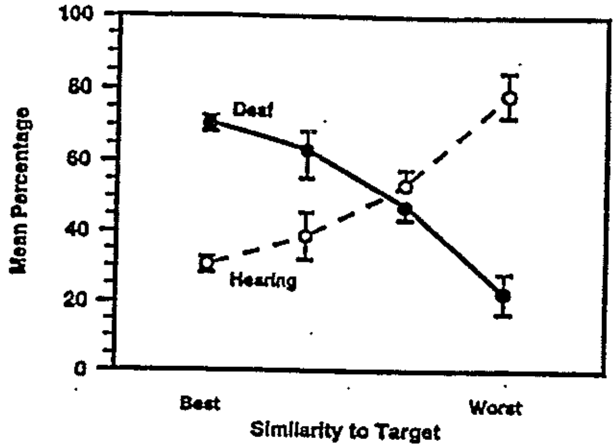

Figure 3a. Spatial Analysis of Hearing and Deaf Children – Grade 1, Rating Results

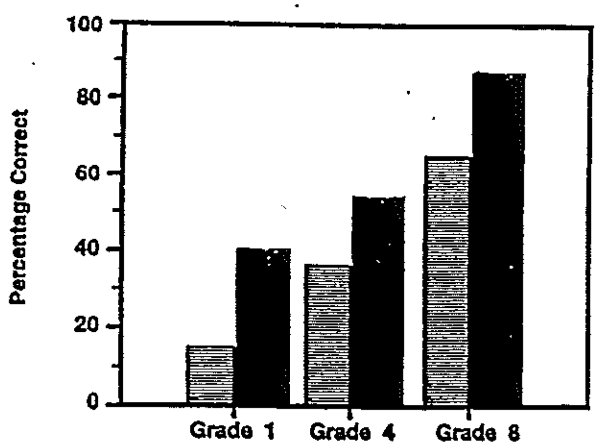

Figure 3b. Spatial Analysis of Hearing and Deaf Children – Grades 1-8, Scoring Results

Figure 3. Exp. 2: Spatial Analysis of Hearing and Deaf Children.

(a) Rating analysis: Proportion of cards from the hearing and deaf first-grade subjects in each of the four piles rated according to their similarity to the target as judged by 10 raters.

(b) Quantitative scoring: Percent correct by the hearing and the deaf subjects, as a function of grade. striped = hearing; solid = deaf

It is clear from these results that, based upon the ratings of ten independent raters, the deaf and the hearing children's responses have been categorized significantly differently at all grade levels, with the deaf children rated as superior to the hearing children.

Quantitative Scoring. A more detailed analysis was also carried out to quantify the resemblance of the responses to their respective targets. Three points were given to responses which were exact reproductions of the target; two points for those with one stroke missing or displaced; and one point for any other responses consisting of half or more than half of the target. All the response protocols from the hearing and the deaf children in each of the three grades were scored according to the above criteria by one of the authors (Dr. Fok). The results in general were consistent with those using the scoring procedure of forced choice by independent raters. The deaf subjects' responses were consistently closer to the target than those of the hearing children. Importantly we see that across grades there is a consistent improvement in performance, for both deaf and hearing subjects (see Figure 3b). Note, however, that at each grade level, the deaf children perform far better than grade-equivalent hearing children. The figure shows that the deaf children, even at the first grade level, performed as well as the hearing fourth grade children. It is intriguing that these deaf children, at a time when they are just learning to read and write Chinese characters, should demonstrate performance far superior to that of the hearing children in analyzing the spatial displays of pseudocharacters.

Item Analysis (First Grade). From the rating analysis and quantitative scoring discussed above, it is clear that the responses from the deaf children at all grade levels are judged as being closer to the underlying target than the hearing children's responses. The following question arises: What aspects of the subjects' responses led to these consistent group differences. We now turn to an item analysis which may shed light on the possible sources of these differences.

Figure 4 shows two sample items with the children's responses, taken from the first grade group. It is clear from even a superficial examination of these responses that the hearing children had great difficulty with the task. A significant number of the responses are continuous squiggles, with no apparent attempt at analyzing or representing internal structure; even the responses that do evidence an attempt to segment the moving point-light display show patterns which are very different from the target (underlying) pseudocharacter. Only occasionally are the responses made by the hearing children character-like, and even then they are different from the target. In sharp contrast, the deaf children on the whole show a remarkable ability to meet the demands of the task. Nearly all of their responses are composed of discrete strokes with transitions correctly omitted; far more important, most of their responses closely resemble the target.

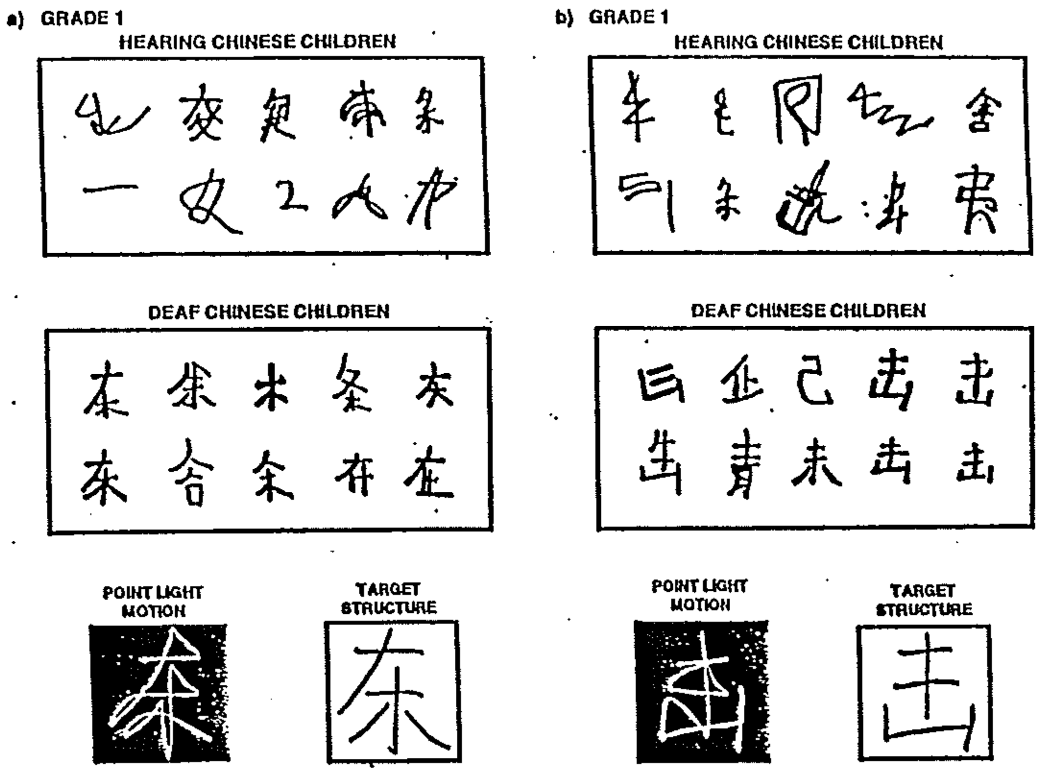

Figure 4. Experiment #2 Responses – Two Items From Grade 1 Chinese Children

Figure 4. Exp. 2: Responses on Two Items from Grade 1 Chinese Children. Response protocols of Chinese hearing (upper panels) and deaf (middle panels) first graders for two point-light displays of Chinese pseudocharacters (bottom panels).

The CSL-signing deaf children in this task clearly show a higher sensitivity to the visuospatial units which make up the Chinese characters than do the hearing Chinese-speaking children. Analysis of the internal structure of the responses shows that the deaf children's responses conform far more to the principles of character formation for Chinese writing than do the hearing children's responses. Of the responses that contained discrete pieces, fewer than 1% from the deaf subjects had components that were not allowable Chinese character pieces; whereas of those from the hearing, as many as 17% contained components that are not acceptable pieces. The deaf subjects thus evidence a surprising knowledge of the principles of character formation. From the above results, we see that even very young deaf children have superior ability in the analysis of spatial displays of characters, as compared with the hearing subjects. Given the fact that the hearing Chinese children are superior to the deaf in both reading and writing, and hence presumably in their knowledge of Chinese characters, the deaf children's performance on this task is all the more surprising. deaf and hearing children at the higher grades. Our focus is the development of the ability to analyze and code these spatial point- light displays of pseudocharacters "written in the air". The responses produced by the older children show that both groups are now able to deal with the task, the hearing children as well as the deaf. By the time the children are in the eighth grade,

Item Analysis (Eighth Grade). We now turn to the responses from the there are almost no responses that do not have discrete pieces in either group. Both the deaf and the hearing children are now able to segment the continuous movement into discrete strokes as separate from the transitional movements. It is the discrete strokes that appear written down in the reconstruction.

Figure 5 shows the results from two items from the oldest children. As the figure shows, there has been a dramatic advance in both groups in reconstructing the pseudocharacters from moving point-light displays, as compared with the responses from the youngest children, previously shown. In fact, to the `foreigner's eye, the results from deaf and hearing children look highly similar. Yet, as seen above, the two groups are rated as significantly different by the Chinese raters.

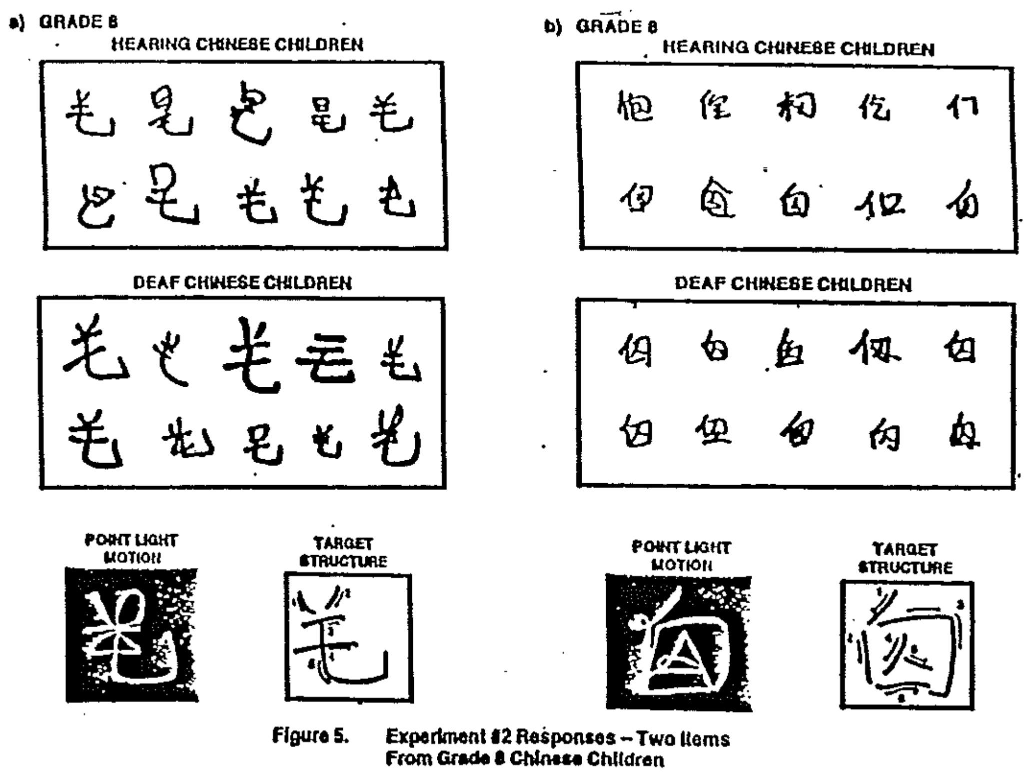

Figure 5. Exp. 2: Responses on Two Items from Grade 8 Chinese Children. Response protocols of Chinese hearing (upper panels) and deaf (middle panels) eighth graders for two point-light displays (bottom panels).

Closer examination of the raw data suggests that there are subtle, yet important, differences between the two groups in the reconstruction of underlying pseudocharacters from the moving light displays. As the figure shows, almost all the responses made by the eighth-grade children, both the hearing and the deaf, are possible Chinese characters; they are also very close to the target. Even so, there appears to be a decided advantage for the deaf children in decoding and separating out the transitions between strokes, in recovering the underlying discrete target. For example, in Figure 5a, consider the top portion of the pseudocharacter, i.e. the first two strokes. In the production of the character as a light display written in the air, the transition between strokes 1 and 2 appears as a continuous loop. To recover the underlying form, the subject has to disregard the circular movement that forms the transition between strokes 1 and 2, and isolate the last part of the movement as the intended second stroke. As Figure 5a shows, more than half of the hearing children failed to segment the loop-like continuous structure into its two underlying strokes, whereas eight of the ten deaf subjects succeeded in isolating the underlying strokes.

A more striking difference between the deaf and hearing subjects is seen in Figure 5b. The overall configuration of the target pseudocharacter is one substructure included in another, larger structure. The square enclosure is written discontinuously: strokes 1 and 2 move downward, with a transition upwards to begin stroke 3 at the junction of 1 and 2; the included component (strokes 4 and 5) are completed before the final stroke of the larger square (stroke 6). Reconstructing the target from this sequence requires sensitivity to the relationship between strokes and the transitions between them.

Most of the hearing children failed to perceive the relationship between the second and the third stroke, which constitute part of the box-like structure. They represented the strokes instead as two separate components; i.e., they wrote down a character with separate left and right components. parts. In contrast, nearly all the deaf subjects accurately analyzed the relationship between the strokes, from which they were able to reconstruct the underlying form correctly. With respect to the inner freestanding component (strokes 4 and 5), there is also a clear difference between the deaf and hearing. Most of the deaf subjects perceived the orientation and the relationship of the two small strokes correctly, whereas only one of the ten hearing subjects produced the correct response. The other hearing subjects missed the inner component completely. This shows the extreme sensitivity of the deaf children to the distinction between inherent and transitional movement, even when the relationships between movement segments are very complex.

In summary, the results from Experiments 1 and 2 suggest an enhanced perceptual ability on the part of these deaf CSL signers both to static and to dynamically moving visual signals. In these tasks, a number of cognitive abilities are brought into play. Clearly the deaf children demonstrate heightened sensitivity to moving spatial displays in their ability to sort out inherent from transitional movement. By eighth grade, Chinese hearing children are also able to extract stroke information from continuous movement patterns. This suggests that knowledge of Chinese script and of the implicit rules of character formation play a role in both the deaf and the hearing children's responses. For children learning Chinese script, the task thus taps a combination of abilities, both visuospatial and linguistic.

EXPERIMENT 3. RECONSTRUCTION FROM DYNAMIC SPATIAL DISPLAYS (*American Adults*)

In order to separate out the effects of knowledge of Chinese characters and the principles of writing them from purely spatial cognitive abilities, Experiment 2 was replicated with two groups of American adult subjects who had no knowledge of Chinese writing: deaf ASL signers and hearing (non-signing) speakers of English. We wanted to investigate the possibility of a difference between these two groups in the spatial analysis of point-light displays as a purely spatial cognitive task, with no influence from knowledge of the Chinese orthographic system.

Method

Subjects. The subjects in this experiment were twenty American adults between 20 and 40 years old, ten hearing and ten deaf. The deaf subjects were all prelingually deaf signers, competent in American Sign Language, most from deaf families. All the deaf subjects were profoundly deaf and used sign language as a primary form of communication throughout their lives; none had knowledge of any form of Chinese. The hearing English speakers also had no knowledge of Chinese, nor did they know any American Sign Language.

Stimuli and Procedures. The stimuli and procedures used were the same as in Experiment 2, with the exception of a slight modification in the trials. In the American version there were two practice sets. In the first, to accustom the subjects to the task, they were presented with four-letter English words, printed in the air in capital letters as point-light displays (e.g., BEAD, FADE, COME, BACK). It should be borne in mind that when the discrete parts of a single letter are formed in the air in sequence, the transitional movements between the parts also appear in the continuous light display. The same holds when the letters of a word are printed one after the other in point-light display. The subjects were asked to decompose the practice items into printed capital letters and to write their responses using a felt tip marker as before. The subjects then saw on the videotape a very brief description of some general characteristics of Chinese writing (exemplifying, e.g., the order and direction of strokes). Then they were presented with three simple characters written in point-light display, which they attempted to reconstruct. The subjects were given feedback as to the correct underlying form. A second practice set, consisting also of actual Chinese characters (the same ones presented in Experiment 2), was presented. The experimental test items followed; they were the pseudocharacters from

Experiment 2. As before, all subjects were tested individually and no feedback was given during testing.

Results and Discussion

Both groups of American subjects, hearing and deaf, found this an extremely difficult and challenging task. This is not surprising. After all, we saw from the results of Experiment 2 that the task was very difficult even for the Chinese children who could read Chinese characters. This suggested that the task might present an even greater challenge to the American subjects, who would presumably be approaching it as a purely visuospatial constructive task. And, indeed, the written responses of the American adults did look different from those produced by the Chinese children, even the youngest ones.

In order to determine whether there were group differences between deaf and hearing American subjects, we used the same rating procedure as in Experiment 2, with one major modification. For this experiment, we asked ten American hearing adults who had no knowledge of either the Chinese writing system or of ASL to categorize the response protocols from the deaf and the hearing subjects for each item into four categories, from 'most similar' to 'least similar' to target. Figure 6 illustrates the relative proportions of cards from each of the groups across the four categories from the best to the worst (see Figure 3 for detailed procedures). The results show that the raters categorized the responses made by the deaf American adults very differently from those made by the hearing American adults. Far more responses of the deaf subjects were categorized as most similar, and far more responses of hearing subjects were categorized as least similar to the target.

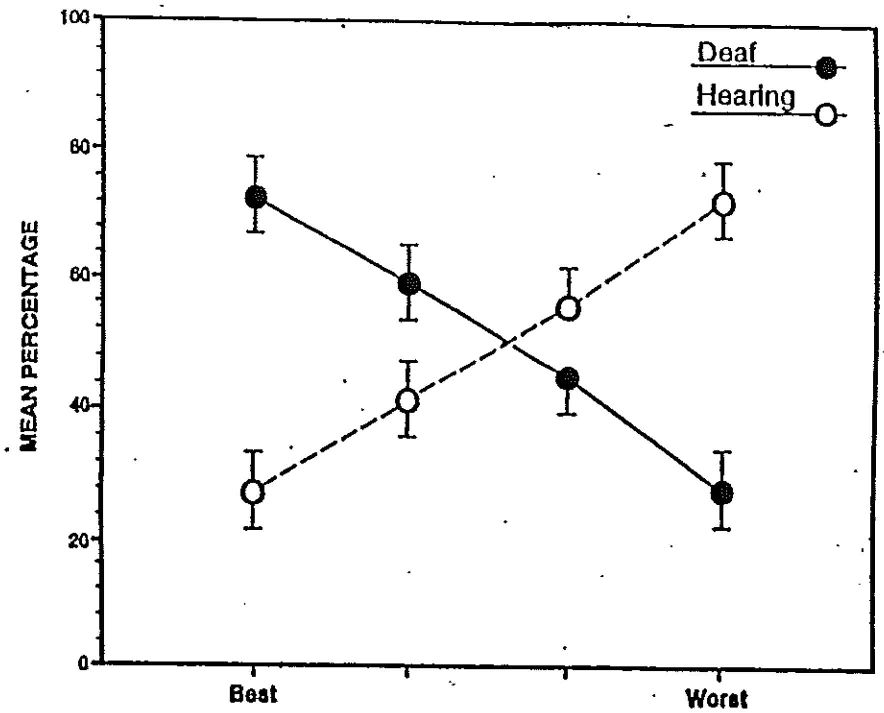

Figure 6. Spatial Analysis of American Hearing and Deaf Adults: Rating Results

Figure 6. Exp. 3: Spatial Analysis of Hearing and Deaf Adults.
Rating analysis: Proportion of cards from American hearing and deaf subjects sorted into each of the four piles according to their similarity to target as judged by 10 American raters.

Again, similarity scores (response protocols to target characters) were generated for the deaf and the hearing responses in exactly the same way as before, with cards categorized as most similar to target assigned 4 points, those categorized as least similar assigned 1 point, etc. The respective scores for the deaf and hearing subjects were 29.04 and 20.54, and the difference is statistically significant, $t(9) = 18.14$, $p<.01$. Clearly even in the case of the adult American subjects, who have no knowledge of the construction of Chinese logographs, the deaf subjects are much better at processing and analyzing these moving spatial displays. The superiority of the performance of the deaf ASL signers is brought out in the following item analyses.

Item Analysis. The American subjects in Experiment 3, none of whom knew Chinese script, were not attempting to construct well formed characters, but were only attempting to analyze the complex spatial displays. It was not possible to score the results from either hearing or deaf American subjects in terms of accuracy with respect to character components, since they were so wide of the mark. The responses showed little or no resemblance to the spatial architecture and components of the target pseudocharacter. There are not the appropriate combinations of strokes, stroke patterns, or character components; nor is there any evidence of the appropriate spatial layout of Chinese characters, as there is in the data from Chinese children. Figure 7 shows responses on two items from the two groups of American adults.

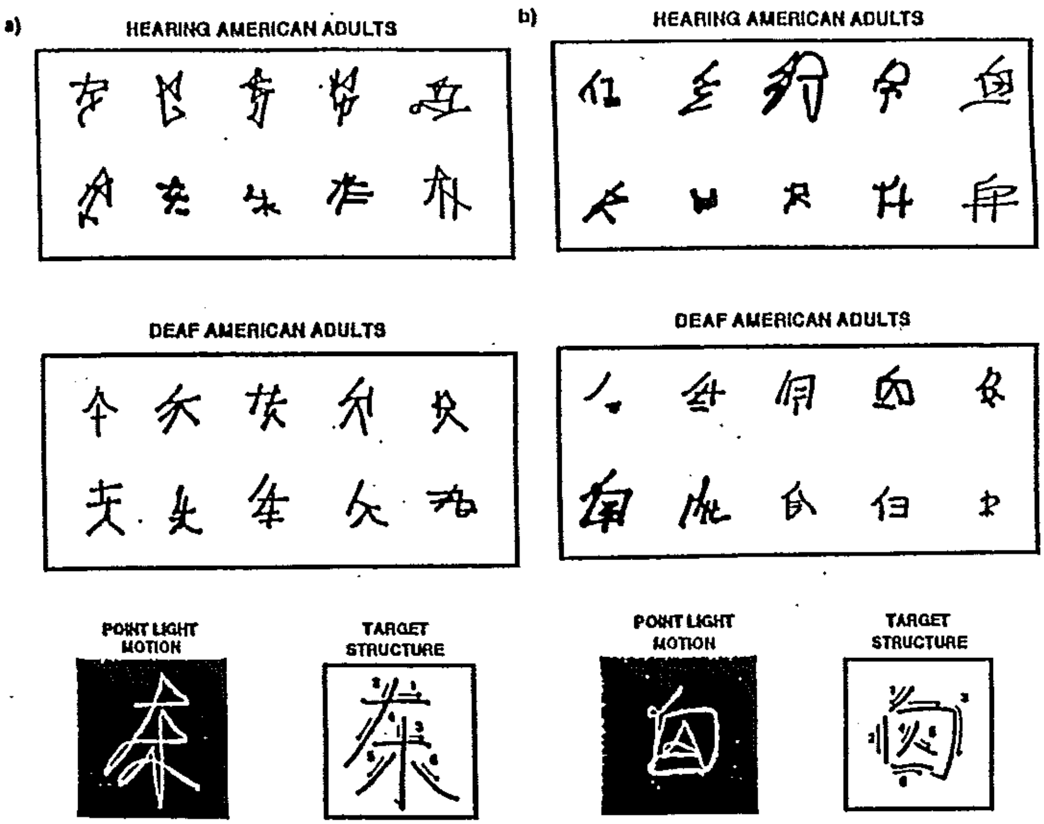

Figure 7. Experiment #3 Responses - Two Items From American Adults

Figure 7. Exp. 3: Responses on Two Items from American Adults.
Response protocols of hearing (upper panels) and deaf (middle panels) American adults for two point-light displays (bottom panels).

Note that overall, the deaf adult ASL signers are better than the hearing English-speakers at segmenting the continuous light image and at reconstructing some of the underlying movements, although the final renditions of both groups bear extremely little resemblance to the target pseudocharacter. Although the responses are not made up of well- formed Chinese character components, one can still see traces of resemblance between the deaf ASL signers' responses and the underlying target character. In Figure 7a, we see that eight of the ten deaf subjects in fact perceived much of the final portion of the continuous display correctly: they captured the two diagonal downward strokes and the horizontal crosspiece, and two of the subjects also captured the vertical stroke crossing the horizontal stroke. Only one of the ten hearing English speakers succeeded in segmenting the movement in this way. Figure 7b illustrates more global differences between the deaf and hearing subjects in terms of segmentation of the movement into discrete pieces. Most of the deaf subjects produced six clearly distinguishable strokes. In contrast, the majority of the responses of the hearing subjects contain four or fewer distinguishable discreet strokes.

Comparing globally the results on the same item from both groups of first- grade Chinese children and from both groups of American adults (Figures 4a and 7a), it is clear that even the youngest Chinese children are far superior to the American adults at the task (see also Figures 5b and 7b). The advantage of even a modest, first-grader's knowledge of characters is undisputed in this demanding experiment. However, our results also show a significant advantage for both groups of deaf subjects (with or without knowledge of Chinese writing), suggesting that these subjects may have certain heightened spatial cognitive abilities.

GENERAL DISCUSSION

There has been a growing appreciation of the impressive ability that the human mind has for perceiving events that take place over time. For example, J. J. Gibson (1979), Johansson (1975), and others (see review by Freyd, 1987) have demonstrated the perceptual system's natural competence with information carried dynamically. Of particular relevance to our study here is the finding that some linguistic information can be conveyed, in the dark, to perceivers of ASL if the signer has a few tiny lights attached to his/her fingertips and the hands move continuously (Poizner, Bellugi, & Lutes-Driscoll, 1981). This suggests that the mental representation of signs is better characterized as dynamic. Since higher cognitive functions are often thought to have their evolutionary roots in the perceptual system (Shepard, 1981), and to the extent that dynamic information is important to the perception of moving signs, we might expect the same dynamic representation to be used in general information processing, such as perception, memory, and imagination. This consideration immediately raises the possibility that the kind of mental representation rendered by the experience of acquiring

ASL may be unique in its functional characterization of spatial relations. That is, the mental representation of a native deaf signer must have explored those spatio-temporal parameters which capture the dynamic nature of movements. It is, therefore, theoretically important to seek empirical support for the psychological reality of such a dynamic representation.

We conducted three experiments to specify the nature of modified perceptual categories resulting from the experience of acquiring a sign language as a native language. The subjects consisted of two groups of Chinese children (deaf signers of CSL and hearing speakers of Chinese) and two groups of American adults (deaf native signers of ASL and hearing speakers of English). With respect to the Chinese children, both groups were acquiring a visual spatial system (that of Chinese characters); but only the deaf group had a visual spatial primary language (CSL). With respect to the American adults, neither group had acquired the visual spatial system of Chinese characters, but the deaf group had acquired a visual spatial language (ASL). In the first experiment, Chinese deaf signers were found to have an enhanced ability to conjoin visual features with spatial locations, and further, this ability was identified at the perceptual stage rather than at the conceptual stage. In the second experiment, it was shown that such an enhancement in the perception of movement applied readily to stimuli presented in a dynamic rather than static fashion. Item analyses of the performance by deaf and hearing Chinese subjects suggested that both knowledge of the stimuli and the modified perceptual categorization contribute to the enhanced performance of the deaf subjects. In the third experiment, similar results were found with American subjects, deaf and hearing, who had no knowledge of Chinese characters, confirming the hypothesis that such an enhanced ability was indeed perceptual in nature. This point can be further illustrated with the following example.

An important distinction between the Chinese and the American subjects is highlighted in Figure 8, separating knowledge of Chinese characters from spatial abilities. The underlying pseudocharacter target is made up of two components, one on the left and the other beside it on the right, without any overlap. However, in the production of the point-light `finger writing' in the air, the spatial separateness of the two components was not strictly maintained. The videotracing shows that the two components of the character were in fact partially overlaid. Recall that for each group, raters differentiated the hearing responses from the deaf responses, categorizing the deaf subjects' responses as significantly superior to those of the hearing. This occurred for each group, regardless of whether the subjects had knowledge of Chinese characters or not. Among the hearing Chinese children, about half were able to retrieve a two part structure, whereas none of the American hearing adults reconstructed two spatially differentiated underlying pieces from the overlaid dynamic display. In contrast, nearly all the deaf Chinese children, including most of those in the first grade, successfully parsed the stimulus into a two part structure. None of the Americans were able to do so. Here we see dramatically the separability of the effects of linguistic knowledge and of spatial cognitive abilities.

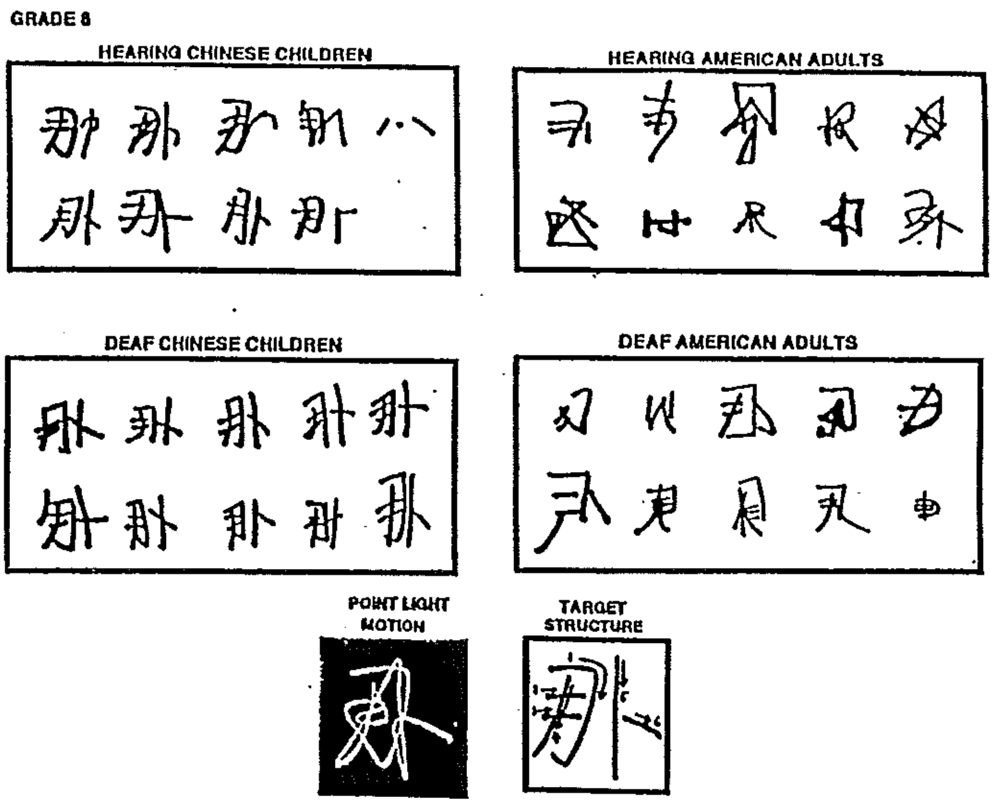

Figure 8. Comparison of Responses Across American and Chinese Subjects

Figure 8. Exp. 3: Comparison of Response Protocols across American and Chinese Deaf and Hearing Subjects

The results of Experiment 3, taken together with the findings of Experiment 2, show that factors other than exposure to Chinese characters are contributing to the findings in both the Chinese and the American samples. Given previous reports of deaf signers' enhanced abilities in certain

ASL may be unique in its functional characterization of spatial relations. That is, the mental representation of a native deaf signer must have explored those spatio-temporal parameters which capture the dynamic nature of movements. It is, therefore, theoretically important to seek empirical support for the psychological reality of such a dynamic representation.

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Thus perhaps this parsing task requires some abilities similar to those involved in segmenting and analyzing speech from the input of a more or less continuous ever changing pattern of sound waves. That is something which hearing humans do well. In fact, this ability has been said to be innate in man, and aspects of speech perception are evident in very young infants (Mehler, 1985; Eimes, 1974; Jusczyk, 1985). Moreover, relevant to this point is evidence that higher order transitional information carried in speech is emphasized by the perceptual system. For instance, Remez, Rubin, Pisoni, and Carrell (1981) found that the essential features used in perceiving words are determined by the transitional from one phoneme to the other, as opposed to context-independent features of each individual phoneme. In the present set of experiments, we speculate that deaf individuals -- or at least those who have acquired a sign language as a native language -- may employ similar abilities visually. Looking at the ever changing patterns from the continuously moving point-lights, they reconstruct an underlying pattern of discrete structural targets. This account would explain why the deaf ASL signers, who have no knowledge of Chinese script and who presumably should only be able to analyze the dynamic displays as general spatial patterns, still perform better than comparable hearing adults. The deaf Chinese children bring to the task their sensitivity to movement and spatial relationships and are able to relate these to their knowledge of script; in fact, perhaps for the deaf children, the task may bear some similarity to analyzing language as ever changing patterns of light waves--segmenting and reconstructing their language for the eye.

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