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Visual and Visual-Spatial Memory Measures in Children with Cochlear Implants[1]

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Visual and Visual-Spatial Memory Measures in Children with Cochlear Implants

Abstract. Recent findings suggest that children developing spoken language while using a cochlear implant (CI) perform more poorly than normal-hearing (NH) children on short-term visual/visual-spatial sequence memory tasks, particularly when verbal recoding and verbal rehearsal strategies for the visual/visual-spatial information are possible. The present study examined the performance of children with CIs using two measures from the Children's Memory Scale (CMS): memory for static patterns of dots and recognition memory for unfamiliar faces. The study included 31 eight- and nine-year old deaf children implanted before age five and 31 age- and gender-matched normal-hearing children. Published norms for normally-developing children were also available for comparison. On the dot locations task, the implanted children performed comparably to the published norms, but not as well as the normal-hearing comparison group. On the face recognition task, the CI group did more poorly than the published norms. Their scores were also lower than the normal-hearing comparison group. Although small, these differences reached statistical significance. Interestingly, face memory scores in the implant group showed a modest but significant positive correlation with short-term memory for sequences of auditory stimuli but not with short-term memory for sequences of visual stimuli. These results suggest that the pediatric CI users may have attempted some form of verbal recoding for these complex static (non-sequenced) visual/visual-spatial face stimuli. The degree to which children with CIs have developed age-typical verbal coding and rehearsal skills may influence how they process certain complex visual stimuli such as unfamiliar faces, sequences of colored light or other visual patterns that can be rapidly encoded using phonological representations.

Introduction

Hearing-impairments in children have long been associated with delays in spoken language acquisition (Conrad, 1979; Furth, 1966; Mayberry, 1992). Of particular concern has been the case of the child who has experienced a severe to profound hearing loss since birth, making auditory sensory input unavailable during infancy and early childhood. In the study of these children, an understanding of their language-learning difficulties is an area of primary concern. In addition, however, our present understanding of human information processing suggests that it may be important to examine the performance of hearing-impaired children in certain tasks formerly believed to involve more "amodal," general cognitive processing. Many abilities related to learning and memory, for example, are now believed to be interconnected and closely coupled with linguistic knowledge and language skills (Adams & Gathercole, 2000; Montgomery, 2000). Also of interest is whether certain cognitive processing skills show *enhancement* attributable to hearing-impairment, perhaps due to greater reliance on sensory cues from the non-auditory sensory modalities. Several models of neural development suggest that compensatory strategies and neural reorganization arise when organisms encounter sensory deprivation. These models predict that enhanced skills may be observed for hearing-impaired individuals in domains such as visual processing (e.g., Bavelier, Tomann, Hutton, Mitchell, Corina, Liu, & Neville, 2000; Bellugi, O'Grady, Lillo-Martin, O'Grady-Hynes, Van-Hoek, & Corina, 1990).

The present study examined visual memory in children who were born with or acquired a profound hearing-impairment very early in life and who experienced a period of auditory deprivation before receiving a cochlear implant. Cochlear implants are a relatively new form of treatment for sensorineural hearing loss, available to children in the U.S. only since the early 1990s. Because of their relatively recent introduction and because most implant research has focused rather narrowly on basic audiological and language measures (Pisoni, 2000), there is relatively little data available on the long-term effects of auditory deprivation followed by cochlear implant use on the development of memory skills in this clinical population.

There does exist, however, sizable literature on memory and cognitive processing in non-implanted children with hearing-impairments. Although cochlear implants provide an input signal unlike that provided by conventional hearing aids, past findings on memory function in non-implanted hearing-impaired children can provide some insights regarding memory skills in children with CIs.

Not surprisingly, many studies have found that children with hearing-impairments tend to score more poorly than age-matched peers on auditory list memory tasks, even when care is taken to insure that the stimuli are familiar and audible to the hearing-impaired children (e.g., Conrad, 1972; 1979; Pisoni & Cleary, 2003). More interestingly, it has also been repeatedly observed that children with hearing-impairments tend to score more poorly than age-matched peers when they are asked to recall lists of stimuli presented via the visual modality and these stimuli readily lend themselves to spoken language labeling. This finding has been reported for stimuli such as printed letter names, printed numerals, orthographically presented words, drawings of common objects, and pictures of shapes (Conrad, 1979; Furth, 1966; Kelly & Tomlinson, 1976; Pintner & Paterson, 1917; Waters & Doehring, 1990).

Lower average levels of spoken language fluency in children with hearing impairments appear to contribute to these findings. Although manually-signed equivalents to verbal labeling and verbal rehearsal can be used by signing individuals to aid memory, effective use of such skills appears to be predicated on the stimuli being suitable for encoding using signs, and on the individual being a fluent user of a sign system (Bebko, 1984; Mayberry, 1992). Because most children who receive cochlear implants come from homes in which spoken language is used (most deaf children are born to hearing parents), fluency in a manual communication system is unlikely to develop spontaneously for these children.

Thus, because lower levels of language fluency are associated with poorer memory performance for stimuli that can be linguistically labeled, it is reasonable to expect that children with cochlear implants may, on average, display reduced performance on memory tasks involving readily namable visual stimuli, relative to children with more advanced language skills. Several recent studies have provided data supporting this hypothesis.

Cleary, Pisoni, and Geers (2001) examined list memory in eight- and nine-year old children with cochlear implants. All of the children had a congenital or early-acquired hearing-impairment, had undergone cochlear implantation before the age of 5 years, and had used an implant for at least four years. Normal-hearing children matched for age and gender were also studied for comparison. Cleary et al. compared performance across three different presentation conditions of a list memory task. In one condition, sequences of colored-lights were presented using a response box consisting of four backlit colored buttons. In a second condition, sequences of colored lights were presented in synchrony with auditorily presented color-names of the lights. Finally, in a third condition, only the auditory color-names were presented. In all conditions, the children were asked to reproduce the patterns by pressing the colored response buttons on the response box in the correct order. The stimulus lists differed from trial to trial and the child's ability to reproduce successively longer lists of items was assessed and compared across conditions.

Cleary et al. found that normal-hearing children scored significantly higher on average, than the children with cochlear implants in all three presentation conditions. Even when the stimulus patterns were visual-spatial “lights-only” sequences, the children with cochlear implants had more difficulty with the task than did the normal-hearing children. This result contrasted with data previously reported for congenitally deaf users of sign language who performed at least as well as normal-hearing students on a closely analogous lights-only list memory task (Tomlinson-Keasey & Smith-Winberry, 1990). Although their correlational analyses did not entirely support such a hypothesis, several aspects of Cleary et al’s results suggested that the children with cochlear implants were attempting to use a verbal-labeling strategy to help them remember the sequences of visually-presented colored lights. Their decreased facility with such a verbal-labeling strategy may have contributed to the finding of lower scores in this lights-only condition for the CI group as compared to the NH group.

More recently, Dawson, Busby, McKay, and Clark (2002) reported data from pediatric cochlear implant users consistent with the findings of Cleary et al. (2001). Dawson et al. studied the list memory skills of 24 early-deafened children, ranging in age from 5 to 11 years, implanted in their preschool-age years, and having, on average, at least 4.5 years of cochlear implant experience. Twenty-four age- and gender-matched normal-hearing children were also tested as a comparison group. Dawson et al. compared performance across five different list memory conditions. One set of conditions used two auditory stimuli—the recorded words, “fish” and “dog.” Children heard sequences of these two auditory words, and, in one condition, were asked to reproduce the sequence in their preferred communication mode (speech or speech and sign). In another condition, the children used associated manual button presses to reproduce the auditory sequence. In a third condition, picture sequences of “fish” and “dog” images were presented and the child again was asked to use associated button presses to reproduce the sequence. Two additional conditions included a “hand movement” imitation task in which an examiner presented a sequence of fist vs. open-palm gestures that the child was asked to reproduce, and a tone imitation task in which the child used associated button press responses to reproduce each target sequence.

Dawson et al. found that the CI group scored more poorly than the NH group, on average, in all five of the conditions tested, with only differences in two of the conditions failing to reach statistical significance (hand movements and tones).[3] Significant differences were found even when the picture stimuli of “dog” and “fish” were used. In the hand-movement condition, which also made use of visual-spatial stimuli, the observed p-values reached marginal significance ($p = .06$). These results provide additional converging evidence that children who use CIs have more difficulty encoding and recalling lists of visual-spatial stimuli than their peers, when these stimuli lend themselves to being rapidly encoded in memory using highly familiar verbal labels.

Neither of these two previous studies, however, investigated the performance of children with cochlear implants on visual or visual-spatial memory tasks that discourage linguistic labeling strategies. In light of previous research on nonimplanted hearing-impaired children, it is conceivable that children with cochlear implants would perform at least as well as, or perhaps even better than, normal-hearing children on memory tasks that rely more exclusively on visual and visual-spatial processing.

Moreover, Cleary et al. (2001) and Dawson et al. (2002) were both primarily concerned with memory for *sequences* of temporally ordered stimuli. Neither study assessed implanted children’s memory for “static” visual-spatial stimuli. The present study addressed pediatric cochlear implant users’ memory for static visual-spatial stimulus configurations by measuring memory performance for visual-spatial dot-pattern stimuli. If the difficulties displayed by the implanted children are specific to temporal sequences of visual-spatial information and ordered recall, we would expect to observe normal levels of

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[3] In the tone list memory condition, a statistically reliable difference was not obtained, probably due to the larger within-group variability observed in this condition relative to the other conditions.

performance in pediatric cochlear implant users on this visual/visual-spatial memory task which does not require the encoding of sequential order information.

The previous studies reviewed above also did not compare memory skills for simpler versus more visually complex visual-spatial stimuli. The present study addressed this issue by examining recognition memory for briefly studied, previously unfamiliar faces. A number of published studies in the literature on non-implanted hearing-impaired individuals have reported that face processing skills measured by discrimination and memory tasks, are enhanced in children and adults who are fluent users of manual language, relative to non-signing individuals (e.g., Arnold & Mills, 2001; Arnold & Murray, 1998; Bellugi et al., 1990). This "visual advantage" appears not to be specific to human faces, per se, but rather to the visual processing of complex visual objects that are encountered frequently along with variation among members in the visual category. The unavailability of simple and familiar verbal labels to uniquely identify these perceptually similar category members, it has been argued, leads to a situation in which visual/visual-spatial processing skills are heavily drawn upon during discrimination and memory tasks involving members of such categories.

The hearing-impaired children in the present study were not, however, fluent users of a manual-only language, making unclear whether it is reasonable to expect a "visual advantage" in this population. Because these children use a spoken linguistic system (either alone, or in combination with manual signs), it may be the case, that they, like normal-hearing children, attempt linguistic coding even when visual/visual-spatial stimuli do not lend themselves to this form of encoding, and, indeed even when it is disadvantageous to try to use linguistic labels (e.g., Brandimonte, Hitch, & Bishop, 1992; Carmichael, Hogan, & Walter, 1932). Implanted children would then be unlikely to perform measurably better on a face memory task than their age-matched normal-hearing peers.

In summary, the present investigation was designed to address several unresolved issues regarding visual/visual-spatial memory skills in pediatric cochlear implant users. More specifically, the performance of children with CIs was compared against that of normal-hearing age-matched peers, for their ability to remember dot pattern configurations and recently studied unfamiliar faces. These particular tasks were chosen because linguistic coding strategies are unlikely to be helpful in carrying out these visual/visual-spatial tasks. If the previously reported memory difficulties of pediatric cochlear implant users are due primarily to their less well-developed linguistic encoding strategies rather than to some more general, modality non-specific aspect of memory function, then the performance of implanted children on these visual/visual-spatial memory tasks is predicted to be at least as good as that of normal-hearing children.

Method

Participants

Cochlear Implant Group. Thirty-one eight and nine-year-old children with cochlear implants took part in the present study. These children were a subset of 45 implanted children who took part in a larger project at the Central Institute for the Deaf in St. Louis, Missouri entitled "Cochlear Implants and Education of the Deaf Child" in the summer of 2000. The present subset of 31 children completed all of the experimental tasks included in this report, and were also able to accurately identify all items in the set of four auditory stimuli used in an auditory list memory task. The performance of these children on the list memory task has been previously detailed in Experiment 3 of Cleary et al. (2001). Only a brief description of the children's list memory performance as it relates to the visual memory measures will be provided in the present report.

The mean age of the children at onset of deafness was 0.2 years with 26 of the 31 children believed to have been deaf since birth. The average duration of deafness prior to implantation was 2.72 years (range, 0.75-4.67 years). The children had used a cochlear implant for an average of 5.78 years at time of testing (range, 4.3-6.9 years). The group included children who use primarily oral communication methods as well as children who use total communication methods (i.e., a combination of speech and sign). The mean chronological age of the group was 8.7 years (range, 7.92-9.91 years). The group included 15 female and 16 male children.

All implanted children were using either a Nucleus 22 or Nucleus 24 device manufactured by Cochlear Corporation. The mean number of active electrodes per implant was 18.7 electrodes (range, 12-22 electrodes). On average, this group of pediatric CI users scored about 1.5 years below their expected language age given their chronological age, as measured by their performance on the Test for Auditory Comprehension of Language Revised (TACL-R, Carrow-Woolfolk, 1985), which was administered using both speech and sign to all children within one week of the present testing (Geers, Nicholas, & Sedey, 2003).

Normal-Hearing Comparison Group. Thirty-one age- and gender-matched normal-hearing children were tested at Indiana University-Bloomington in the spring and summer of 2001. Each child passed a simple pure-tone hearing screening administered at 250, 500, 1000, 2000, and 4000 Hz. A response was required at 20dB HL for frequencies of 1000 Hz and above, and at 20 or 25 dB HL for frequencies below 1000 Hz. Each ear was screened separately. Each normal-hearing child was also judged to display receptive language skills appropriate for his/her age, as determined by administering the Peabody Picture Vocabulary Test (PPVT-III, Form A, Dunn & Dunn, 1997).

Materials and Procedure

The published materials for two subtests of the Children's Memory Scale (CMS, Cohen, 1997) were used as described in the test manual. The two CMS measures used were the Dot Locations subtest and the Faces subtest, as described below. An examiner experienced with working with young hearing-impaired children administered the tasks to the children with cochlear implants. Task instructions were provided using total communication methods to children who used this form of communication. The normal-hearing children were tested at Indiana University by trained graduate research assistants.

Dot Locations Subtest. The Dot Locations task from the CMS involves showing the child a picture of six large identical blue "dots" inside a large white rectangle (see Figure 1). The child is told to remember the placement of the dots. After five seconds have passed, the pattern is hidden and the child must immediately reproduce the pattern by placing six plastic disks on a 3 by 4 grid. No constraints are placed on the order in which the child can place the disks on the grid during the recall procedure, and no feedback is given regarding performance. The disks are then removed and the child is shown the same pattern of dots again for 5 seconds, and then asked to reproduce it. This process repeats one additional time, for a total of three "practice/learning" trials. The child is then shown a new pattern of (red) dots and asked to remember and reproduce this new pattern. This serves as a distracter trial. Finally, in a delayed recall trial, the child is again given the disks but is shown no pattern and is asked to recall the pattern of blue dots that was practiced three times. The child receives one point for each disk correctly placed at the right location on the grid. The distracter trial is not scored, but the three practice trials and single delayed recall trial are each worth 6 points, for a summed "Total Score" worth a maximum of 24 points.

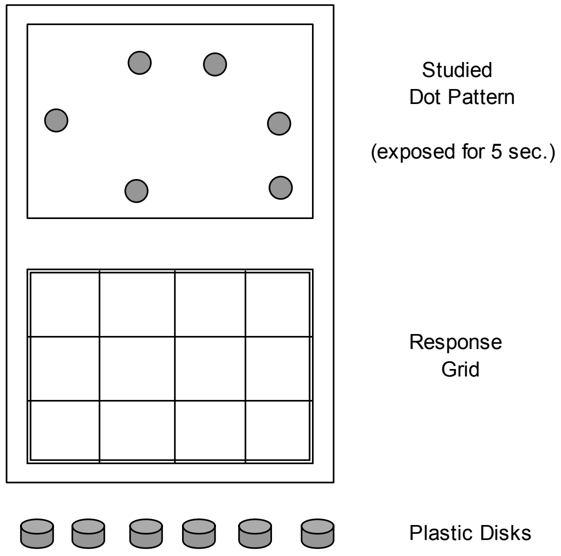

Figure 1. Schematic illustration of a stimulus plate and response grid for the Dot Locations task. (Not an actual stimulus.)

Faces Subtest. The Faces Subtest of the CMS involves showing the child a series of 12 unfamiliar faces. Each photographed face is shown to the child for approximately 2 seconds (see Figure 2). The child is asked to look closely at each face and to remember what the person looks like, because, as the child is warned, later, he/she will be asked to look at some more photos and to decide if particular faces are ones the child was asked to remember. Immediately following presentation of the 12 "study faces," the child is shown a series of 36 test faces. The child is told to respond "yes" if the face is one he/she remembers seeing during the study portion of the test, and "no" if the face is a new one that he/she was not asked to remember. During test, 18 new faces are mixed into the set of 12 studied faces with six of the studied faces shown twice, for a total of 18 "old" faces. One point is awarded for each correct response, for a maximum possible score of 36 points. No feedback is provided regarding performance on individual trials.

Each face stimulus consists of an oval cutout showing the photographed face of an adult or school-age child. A wide variety of ages and ethnic backgrounds are represented in the photographs. The cutout limits the view of the individual's hair and clothing. No persons with glasses, beards, or mustaches are included.

Subtest Selection Issues. The 1997 version of the CMS provides two forms of each subtest, one for children ages 5;0-8;11 and one for children ages 9;0-12;11. In this initial study, we decided to use the test forms designed for the younger age group for both the 8- and 9 year-old children in our study. (There were 22 eight-year-olds and 9 nine-year-olds in each subject group.) Because the mean age of the children tested was 8.7 years, we judged that this choice was reasonable, given that we wished to administer the same form of each test to both the 8- and 9-year-old children. We also based this decision on advice that the longer, more difficult forms, designed for the older age group, might be too difficult for some pediatric cochlear implant users to complete.

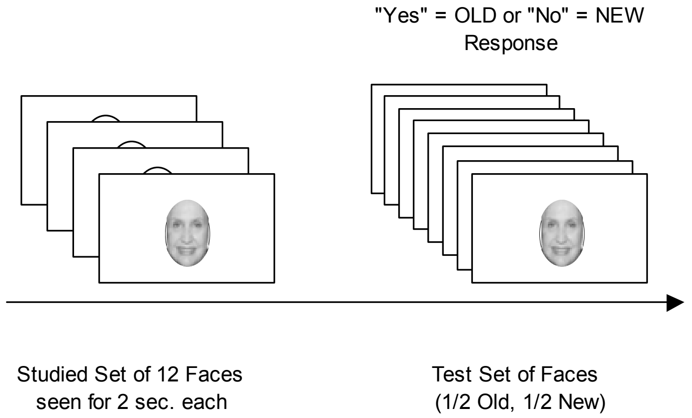

Figure 2. Schematic illustration of sample stimulus plate and procedure for the Face recognition task. (Not an actual stimulus.)

List Memory Measures. The list memory (or "memory span") measures gathered from these children have been described extensively elsewhere (Cleary, Pisoni, & Geers, 2001). Briefly, as described in the Introduction, each child was tested on his/her ability to reproduce sequences presented under three different conditions. A response box consisting of four backlit colored response buttons was used by the child to make all of his/her responses. In one condition, sequences of colored lights were presented on the response box. In a second condition, the colored light sequences were shown synchronously with matched recorded auditory color-names presented over a loudspeaker. In a third condition, only the auditory color-names were presented with no colored lights. An adaptive testing procedure was used to lengthen the sequence if the child correctly reproduced the list on a given trial, or to shorten the sequence if an incorrect response was detected. The test sequences were different from trial to trial and 20 lists were tested in each of the three counterbalanced conditions. Each child's score in each of the three conditions was tabulated by adding up the proportion of lists correctly reproduced at each list length tested, starting with a list length of 1 item.

Task Administration. The children first completed the dot locations task then the face recognition task. The list memory measures were collected during the same week as the dot and face measures for the children with cochlear implants and before the dot and face measures during the same testing session for the children with normal-hearing. The children were thanked and praised for their participation after the test session. The implanted children and their families received tickets for organized activities planned for the afternoon of each day of testing. The normal-hearing children received $6 and a T-shirt or cap for their participation.

Results and Discussion

Dot Locations Subtest

As shown in Figure 3, the CI group displayed no problems with the Dot Locations subtest relative to the published test norms for normally-developing eight-year olds. Indeed, the CI group's mean score of 21 points on this subtest did not differ statistically from the expected 50th percentile score for normally-developing children as provided by the test norms ($p = .95$). However, as can also be seen in Figure 3, the normal-hearing comparison group scored significantly higher, on average, than the test norms for eight-year olds on this same task (*t*(30) = 3.784, *p* = .001, 50th percentile score = 21 points, NH group mean = 22.5 points).

In general, the score distributions obtained for this task were quite negatively skewed, with a substantial number of scores at ceiling, particularly for the NH group. We nevertheless also conducted statistical tests between the means obtained from the two groups of children. The CI and NH groups differed significantly from each other on the Dot Locations task (*t*(60) = 2.440, *p* = .018), with the normal-hearing group having a significantly higher mean score despite the ceiling effect which limited the upper range of possible scores for these participants.

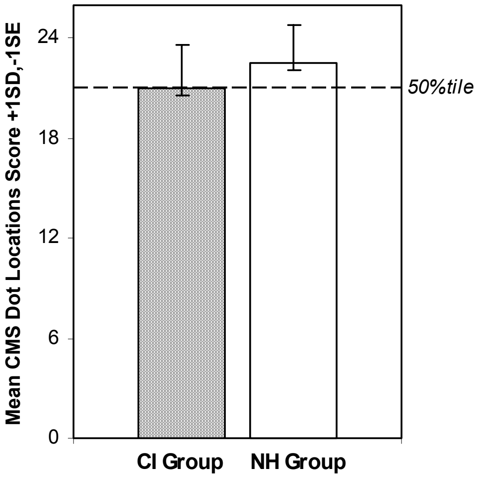

Figure 3. Mean performance for each group of children on the Dot Locations task. Error bars in the positive direction indicate one standard deviation. Error bars in the negative direction indicate one standard error. The dashed line shows the 50th percentile score predicted for 8-year-old normally-developing children as provided by the Children's Memory Scale test manual (Cohen, 1997). The maximum score possible on this task was 24 points.

Faces Subtest

On the face memory task, children with cochlear implants obtained a lower mean score, as shown in Figure 4, than predicted by the test norms provided for the Faces subtest. Although this difference was small, the difference reached statistical significance when a one-sample t-test was applied, testing the group mean against the standardized 50th percentile score of 30 points for normally-developing eight-year olds (*t*(30) = 2.167, *p* = .038). In contrast, the normal-hearing group's mean score on the Faces subtest did not differ significantly from the published 50th percentile score for eight-year olds (*p* = .70).

The distributions of scores obtained for the Face memory task were near-normally distributed between chance and ceiling performance, for both groups of children. Unlike the Dot Locations task, the Face memory task yielded few scores at ceiling for either group of children. The mean scores of the implanted group and the normal-hearing group also differed significantly from each other on the Faces subtest, with the normal-hearing group again scoring significantly higher (*t*(60) = 2.048, *p* = .045).

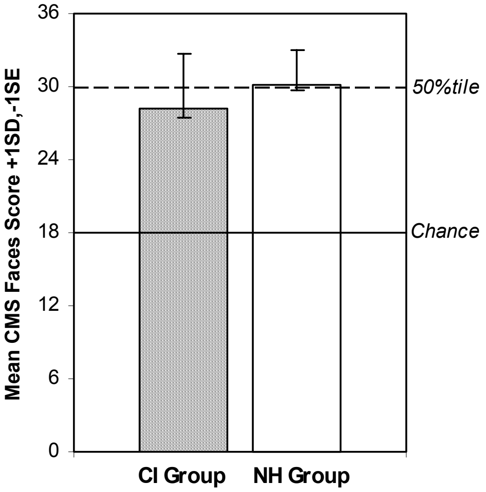

Figure 4. Mean performance for each group of children on the Faces task. Error bars in the positive direction indicate one standard deviation. Error bars in the negative direction indicate one standard error. The solid line shows the score predicted for chance performance (random guessing). The dashed line shows the 50th percentile score predicted for 8-year-old normally-developing children as provided by the Children's Memory Scale test manual (Cohen, 1997). The maximum score possible on this task was 36 points.

Correlational Analyses

Intercorrelations among the memory measures and a variety of demographic characteristics were also examined. Neither chronological age nor gender contributed significantly to the within-group variability in memory scores in either group of children. Characteristics of the CI users' hearing impairment were then examined in relation to memory performance. Although the group of pediatric cochlear implant users was relatively homogeneous with respect to age at onset of deafness, duration of deafness, and length of implant use, sufficient within-group variability existed in the last two variables to examine the degree to which these might be correlated with memory skill. A range of communication methods were also present within the CI group, such that it was possible to look for relationships between memory performance and degree of exposure to an auditory/oral educational setting.

As shown in Table 1, longer periods of auditory deprivation were weakly and nonsignificantly associated with lower scores on the dot locations task, whereas greater experience with an implant was weakly associated with higher scores on this same task. However, no such relationship was observed between these two demographic characteristics and face memory scores. In contrast, greater emphasis on auditory/oral methods of communication showed no relationship with dot location scores, but exhibited a correlation of +.40 with face memory scores. This last finding suggests that skills acquired through exposure to spoken language may be drawn upon by children with CIs during face encoding (see also Bergeson & Pisoni, 2004 for discussion). The data, however, are not consistent with some previous reports that greater exposure to manual language environments leads to enhanced face processing skills in non-implanted hearing-impaired populations (e.g., Arnold & Mills, 2001; Arnold & Murray, 1998; Bellugi et al. 1990).

N = 31	**Memory for Dot Locations**	**Memory for Faces**
Duration of Deafness	*r* = -.30, *p* = .11	*r* = +.06, *ns*
Duration of Implant Use	*r* = +.35, *p* = .06	*r* = -.01, *ns*
Communication Mode Score	*r* = +.11, *ns*	*r* = +.40, *p* = .03

Table 1. Correlations within the CI group between visual/visual-spatial measures and characteristics of the children's hearing impairment. Communication mode scores were assigned to each child based on the degree to which the child's educational environment emphasized auditory/oral methods. Higher scores correspond to a greater emphasis on auditory/oral methods of communication. P-values not adjusted for multiple comparisons.

Next, intercorrelations among the different memory measures were examined. Children's scores on the dot location and face memory tasks were not correlated with each other in either subject group. The restricted range of scores for the dot locations task may have contributed, in part, to this lack of correlation. It is also the case, however, that these two visual memory tasks differed considerably from each other, specifically in the complexity of the stimulus materials, and in the nature of the recall response required, and thus, strong correlations between the tasks were not necessarily expected.

Correlations between the list memory tasks and the two visual/visual-spatial memory measures were also examined. These values are shown for the CI group in Table 2. No relationship was observed in the CI group between any of the three list memory conditions and memory for dot locations. For the face memory task, however, a positive correlation (*r* = +.40) was observed with list memory scores in the auditory-only condition. When the list memory task included a visual component (i.e., in the lights-only and auditory-plus-lights conditions), no correlation was observed. This finding suggests that face recognition, unlike memory for dot configurations, may draw upon some skills that are better developed in hearing-impaired children who also do well on auditory list memory tasks.

N = 31	**Memory for Dot Locations**	**Memory for Faces**
List Memory, Lights-Only	*r* = +.02, *ns*	*r* = +.04, *ns*
List Memory, Auditory-Only	*r* = +.13, *ns*	*r* = +.40, *p* = .03
List Memory, Auditory-plus-Lights	*r* = +.09, *ns*	*r* = +.19, *ns*

Table 2. Correlations within the CI group between visual/visual-spatial measures and list memory performance tested under three different presentation conditions. P-values not adjusted for multiple comparisons.

Within the normal-hearing group of children, no relations were between either of the visual/visual-spatial memory measures and any of the list memory measures. This result is consistent with the hypothesis that memory for sequential order is a fundamentally different skill from memory for individual static items. The failure to find a correlation in the normal-hearing group between auditory-only list memory scores and face memory scores does not, however, correspond well with the results found in the implant group. More specifically, given that the hearing-impaired children who scored higher on the auditory-only list memory task (and thus, by extension, scored more similarly to normal-hearing children) also tended to score higher on the face memory task, one would predict a similar pattern of findings in the normal-hearing group. This was not observed, however, suggesting that the two groups of children may have encoded these images of static faces using different strategies. For the normal-hearing children, we did not find evidence that face encoding draws upon verbal-encoding resources used in the auditory-only list memory task.

General Discussion

The obtained pattern of results is not ideal for drawing firm conclusions and further investigation is clearly warranted. The most straightforward result from these data is the finding that the implanted children as a group did somewhat more poorly than expected on the Face recognition task, both as compared to the published norms for slightly younger children, and as compared to age-matched normal-hearing children. The CI group clearly did not show "enhanced" performance on this face processing task, relative to either the published norms or the NH comparison group.

On the Dot Locations task, the implanted children demonstrated levels of performance consistent with that expected from normally-developing children. Relative to published norms, no particular deficit or enhancement of spatial memory skill for simple stimulus patterns was observed. The slightly worse performance of the implanted children on the Dot Locations task as compared to the normal-hearing group must be considered relative to the fact that the normal-hearing children in this study did somewhat better on this task than the published subtest norms (albeit for slightly younger children) would predict.

Assuming that the norms for the CMS subtests are accurate, the present data also suggest that implanted children found the complex visual-spatial stimuli (i.e., faces) more difficult to process relative to the simpler visual-spatial stimulus configurations (i.e., dot patterns) than did normally-developing children. The source of this unexpected difference requires further investigation. The pediatric cochlear implant users may have attempted to encode the face stimuli (but not the dot patterns) using some form of verbal labeling, even though their verbal encoding and rehearsal skills are less well developed than those of age-matched normal-hearing children. The general pattern of correlations supports the notion that auditory/oral skills were associated with higher face memory scores. We observed this relationship even though some prior findings with non-implanted hearing-impaired populations suggest that use of verbal encoding strategies may actually negatively impact memory for unfamiliar faces under some testing situations (e.g., Arnold & Mills, 2001).

The present study also sought to examine the memory performance of pediatric cochlear implant users for static, non-sequenced visual-spatial stimulus configurations, with the aim of comparing these results to previous reports of memory difficulties for temporally ordered visual-spatial patterns (i.e., Cleary et al., 2001; Dawson et al., 2002). We found that neither CMS measure correlated significantly with scores on a list-memory task that used a lights-only stimulus presentation condition, in either group of children. Although this is a "null result," it is consistent with the hypothesis that memory for visual/visual-spatial sequences and memory for static individual items should be considered separately in studies of memory performance. Unexpectedly however, we also found that when the auditory component of the list-memory task was emphasized (i.e., in the auditory-only colornames condition), modest correlations with the CMS face memory task were observed, but only in the CI group. This apparent link between memory success for individual members of spatially complex visual categories and memory for temporally complex auditory verbal sequences should be examined further.

This line of research continues with the goal of further refining the experimental tasks used to examine non-sequential visual/visual-spatial memory in this clinical population. In the present study we assessed the feasibility of using two readily available standardized measures for this purpose, namely, the Dot Locations and Faces subtests from the Children's Memory Scale. Certain limitations and peculiarities of these two measures became apparent in the course of data collection. The dot locations task suffered from ceiling effects, particularly in the case of the normal-hearing children who participated in this study. This is probably due to our use of this subtest with some children who were too old for this form of the test. However, ceiling effect issues for this subtest have since been reported also by other researchers who followed the test directions regarding age more precisely. A critical review of the Children's Memory Scale by Vaupel (2001), for example, noted that although the CMS as a whole is "psychometrically sound" and "well-constructed," "significant floor and ceiling effects exist on several subtests," the dot locations subtest being among these.

Although the Faces subtest yielded more normally-distributed scores and appeared to be able to capture meaningful variability across both groups of children, one aspect of this test struck us as somewhat peculiar. Specifically, as previously described in the Method section, half of the familiarized studied faces are shown twice during testing. Presumably, this characteristic of the test arose due to time and attention constraints on total testing time, or to give the subtest score distribution better psychometric properties, however, the presence of repeated test items seems somewhat questionable.

Another potential drawback of the CMS is that its subtest norms may be overly "coarse" in the sense that norms are offered in 12-month increments—that is, for example, the same norms are provided for children ages 8;0 through 8;11. In contrast, some standardized tests are sensitive enough to offer norms in six-month or four-month increments. Collapsing across a 12-month age range may obscure important developmental changes in visual-spatial memory processing. If we are interested in studying such changes in pediatric cochlear implant users, a more age-sensitive test may be necessary.

The available evidence suggests however, that hearing-impaired children using cochlear implants perform somewhat more poorly than normal-hearing children on list memory tasks and on visual-spatial recognition memory tasks involving complex stimuli. One interesting question that remains is how well do implanted children do relative to hearing-impaired children who are receiving benefit from conventional hearing aids? A recent study by Surowiecki, Sarant, Maruff, Blamey, Busby, and Clark (2002) found that the performance of children with cochlear implants on a battery of visual memory tests did not differ measurably from that of age- and gender-matched children who were using conventional hearing aids to address moderate to profound hearing losses. Moreover, these authors also reported that visual memory scores in these groups of hearing-impaired children (all of whom were enrolled in oral educational settings) tended to positively correlate with individual differences in scores on some language processing tests. Comparisons with test norms for normal-hearing children were not included in Surowiecki et al.'s preliminary report, however, making it difficult to assess how well either group of hearing-impaired children was doing relative to normal-hearing children. Furthermore, as in the present study, ceiling effects were encountered for a number of the measures used.

In summary, the present study found that pediatric cochlear implant users perform at normal levels on memory for dot locations. Small, but statistically reliable differences were found, however, in recognition memory for briefly studied unfamiliar faces: children with cochlear implants did not perform as well as children with normal hearing. Interestingly, we also found a correlation in children with cochlear implants between recognition memory for briefly studied faces and individual variability in list memory for sequences of auditory stimuli. The present set of results suggests that memory difficulties in prelingually-deafened pediatric cochlear implant users may be more pronounced in behavioral tasks that require the processing of sequences of stimuli compared to isolated static stimuli, and for individually presented complex visual stimuli compared to simpler visual stimulus configurations.

References

Adams, A.M., & Gathercole, S.E. (2000). Limitations in working memory: implications for language development. *International Journal of Language and Communication Disorders, 35,* 95-116.

Arnold, P., & Mills, M. (2001). Memory for faces, shoes, and objects by deaf and hearing signers and hearing nonsigners. *Journal of Psycholinguistic Research, 30,* 185-195.

Arnold, P., & Murray, C. (1998). Memory for faces and objects by deaf and hearing signers and hearing nonsigners. *Journal of Psycholinguistics Research, 27,* 481-497.

Bavelier, D., Tomann, A., Hutton, C., Mitchell, T., Corina, D., Liu, G., & Neville, H. (2000). Visual attention to the periphery is enhanced in congenitally deaf individuals. *Journal of Neuroscience, 20-RC93,* 1-6.

Bebko, J.M. (1984). Memory and rehearsal characteristics of profoundly deaf children. *Journal of Experimental Child Psychology, 38,* 415-428.

Bellugi, U., O'Grady, L., Lillo-Martin, D., O'Grady, M., vanHoek, K., & Corina, D. (1990). Enhancement of spatial cognition in deaf children. In V. Volterra & C. Erting (Eds.), *From Gesture to Language in Hearing and Deaf Children, (pp. 278-298).* New York: Springer Verlag.

Bergeson, T.R. & Pisoni, D.B. (2004). Audiovisual speech perception in deaf adults and children following cochlear implantation. In G. Calvert, C. Spence & B.E. Stein (Eds.), *Handbook of Multisensory Processes (pp. 749-772).* MIT Press.

Brandimonte, M.A., Hitch, G.J., & Bishop, D.V. (1992). Verbal recoding of visual stimuli impairs mental image transformations. *Memory and Cognition, 20,* 449-455.

Carmichael, L., Hogan, H.P., & Walter, A.A. (1932). An experimental study of the effect of language on the reproduction of visually perceived forms. *Journal of Experimental Psychology, 15,* 73-86.

Carrow-Woolfolk, E. (1985). *Test for Auditory Comprehension of Language-Revised (TACL-R).* Austin, TX: Pro-Ed.

Cleary, M., Pisoni, D.B., & Geers, A.E. (2001). Some measures of verbal and spatial working memory in eight- and nine-year-old hearing-impaired children with cochlear implants. *Ear & Hearing, 22,* 395-411.

Cohen, M.J. (1997). *The Children's Memory Scale (CMS).* San Antonio, TX: The Psychological Corporation.

Conrad, R. (1972). Short-term memory in the deaf: A test for speech coding. *British Journal of Psychology, 63,* 173-80.

Conrad, R. (1979). *The Deaf Schoolchild.* London, England: Harper & Row.

Dawson, P.W., Busby, P.A., McKay, C.M., & Clark, G.M. (2002). Short-term auditory memory in children using cochlear implants and its relevance to receptive language. *Journal of Speech, Language, and Hearing Research, 45,* 789-801.

Dunn, L.M., & Dunn, L.M. (1997). *Peabody Picture Vocabulary Test, Third Edition.* Circle Pines, Minnesota: American Guidance Service.

Furth, H. (1966). *Thinking without language: Psychological implications of deafness.* New York: The Free Press.

Geers, A.E., Nicholas, J.G., & Sedey, A.L. (2003). Language skills of children with early cochlear implantation. *Ear & Hearing, 24(Suppl.),* 46S-58S.

Kelly, R.R., & Tomlinson, K.C. (1976). Information processing of visually presented picture and word stimuli by young hearing-impaired and normal hearing children. *Journal of Speech and Hearing Research, 19,* 628-638.

Mayberry, R.I. (1992). The cognitive development of deaf children: Recent insights. In S.J. Segalowitz & I. Rapin (Eds.), *Handbook of Neuropsychology, Vol. 7 (pp.51-68).* New York: Elsevier Science Publishers.

Montgomery, J.W. (2000). Verbal working memory and sentence comprehension in children with specific language impairment. *Journal of Speech, Language, & Hearing Research, 43,* 293-308.

Pintner, R., & Paterson, D.G. (1917). A comparison of deaf and hearing children in visual memory for digits. *Journal of Experimental Psychology, 2,* 76-88.

Pisoni, D.B. (2000). Cognitive factors and cochlear implants: some thoughts on perception, learning, and memory in speech perception. *Ear & Hearing, 21,* 70-78.

Pisoni, D.B., & Cleary, M. (2003). Measures of working memory span and verbal rehearsal speed in deaf children after cochlear implantation. *Ear & Hearing, 24(Suppl.),* 106S-120S.

Surowiecki, V.N., Sarant, J., Maruff, P., Blamey, P.J., Busby, P.A., & Clark, G.M. (2002). Cognitive processing in children using cochlear implants: the relationship between visual memory, attention, and executive functions and developing language skills. *Annals of Otology, Rhinology, & Laryngology, 189 (Supplement: VIII Symposium of Cochlear Implants in Children),* 119-126.

Tomlinson-Keasey, C., Smith-Winberry, C. (1990). Cognitive consequences of congenital deafness. *Journal of Genetic Psychology, 151,* 103-115.

Vaupel, C.A. (2001). Cohen, M.J. (1997). The Children's Memory Scale (CMS). San Antonio, TX: The Psychological Corporation (Review). *Journal of Psychoeducational Assessment, 19,* 392-400.

Waters, G.S., & Doehring, D.G. (1990). Reading acquisition in congenitally deaf children who communicate orally: Insights from an analysis of component reading, language, and memory skills. In T.H. Carr & B.A. Levy (Eds.), *Reading and its development (pp. 323-373).* San Diego: Academic Press.