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Deafness Drives Development of Attention to Change in the Visual Field

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Abstract

Deaf (n = 37) and hearing (n = 37) subjects ages 6-7, 9-10, and 18 + participated in a visual attention experiment designed to test the hypothesis that vision in the deaf becomes specialized over developmental time to detect change in the visual field. All children, regardless of hearing status, should attend to change in the visual field. However, the differing developmental experiences and sensory "tools" between deaf and hearing create different demands on their visual systems. Hearing individuals may become capable of ignoring many changes in the visual field because they can simultaneously monitor the world auditorially and attend to task-relevant information visually. If so, then deaf individuals may find it difficult to ignore change in the visual field because their visual system must both monitor the world and attend to task-relevant information without simultaneous auditory input. Subjects in this experiment completed two attentional capture tasks in which they searched for a uniquely shaped target in the presence of two irrelevant stimulus manipulations (color or motion). This manipulation was applied to the target on half the task trials and to a distractor on the other half. Attention to the irrelevant manipulations will create differential reaction times (RTs) when the target is manipulated versus when a distractor is manipulated. Results indicated divergent development between the two groups. Both deaf and hearing children produced differential RTs in the two tasks, while only deaf adults attended to the task-irrelevant changes. Further, while hearing subjects were more affected by motion than color, deaf subjects are more equally affected by both. Results are discussed as compensatory changes in visual processing as a result of auditory deprivation.

Introduction

There is a popular notion that unimodal sensory deprivation affects intersensory interaction by leading to the development of compensatory functioning in the other, intact modalities -- that deaf people see better and blind people hear better, for example. The fact, however, is that changes in intact modalities following unimodal sensory deprivation are not global, and can not necessarily be characterized as simply "better" or "worse." Rather, one has to consider the developing individual as a complex, changing system, adapting the configurations of its sensory systems to the specific task at hand. A close inspection of the roles of each modality in an intact system, of the ways each modality informs the others, as well as an analysis of the types of task problems the deprived system must solve are necessary in order to make precise, differential hypotheses about how intact modalities should function. In this research, we sought to understand these developmental processes in one domain: the role of audition in the development of visual attention.

Sensory systems do not develop independently. Research on altered sensory development in laboratory animals shows that manipulating the developmental timing of potentially competing, simultaneous sensory inputs can change the trajectory of development. For example, Turkewitz & Kenny (1985) found that introducing visual input to rat pups prior to its typical onset disrupted homing behavior, which is acquired very early and is dependent on olfactory information. Small (1978) showed that after removal of the olfactory bulb in neonate hamsters, a thermal preference continues to dominate homing behavior through the period when this preference is normally overtaken by olfaction. The manipulation of multimodal input also changes the organization of individual sensory systems at the neural level. For example, Krech, Rosenzweig, and Bennet (1963) reared rats in environments rich in opportunities for tactile and haptic stimulation. Those rats that had been reared in the dark developed heavier somatosensory cortical areas than did light-reared rats and dark-reared rats evidenced greater biochemical activity in nonvisual areas than did light-reared rats. Together, these results illustrate that behavioral and neural organization depends in part on the nature and developmental timing of correlated sensory input from multiple modalities (see also Stein & Meredith, 1993).

There is also evidence from human development in support of these ideas. Neville and her colleagues (Neville & Lawson, 1987a & b) reported enhanced processing of peripheral visual events in deaf subjects relative to hearing subjects. Deaf adults responded faster and more accurately than hearing adults to peripheral targets, while no group differences were found in responses to foveally presented targets (Neville & Lawson, 1987a & b; see also Loke & Song, 1991). Neville also found that deaf subjects' evoked responses to peripheral stimuli had higher amplitude and shorter latency than hearing adults'. Furthermore, deaf subjects produced activity in brain regions that are generally involved in the processing of auditory information in hearing adults (Neville & Lawson, 1987a & b). Additional study revealed that deaf individuals' enhanced sensitivity to peripheral information results somehow from a lack of auditory experience and not from the use of a visual language (Neville & Lawson, 1987c). Specifically, hearing adults who were raised by deaf parents and whose first language was American Sign Language performed like hearing subjects and not like deaf subjects.

While deaf adults show enhanced responding to peripheral visual information, research indicates that deaf children perform poorly in comparison to hearing children on tasks requiring sustained attention to centrally presented visual

information (Quittner, Smith, Osberger, Mitchell & Katz, 1994; Mitchell & Quittner, 1996). When asked to respond to a two-digit target sequence in a stream of individually presented stimuli, deaf children attend more to non-target information and produce lower d-prime and higher beta scores than hearing children. Together these results suggest that visual processing develops differently in the absence of audition, leading to enhanced attention to peripheral events and perhaps decreased vigilance to central events.

One way of understanding the differences between deaf and hearing individuals is in terms of a normally multimodal attentional system *adapting to* the lack of auditory input. In the hearing individual, audition provides information from both near and far environmental events. Thus, sound can be used to monitor the world for changing events and to reorient visual attention if necessary while the visual system is free to focus in on task-specific information. For deaf individuals, the absence of audition means that the visual system must become responsible for monitoring the world, both near and far, as well as picking up the relevant information for the task at hand. In brief, we predict that the differences between hearing and deaf individuals' experiences monitoring and orienting to events in the world, with and without the support of audition, leads to the emergence of differences in visual attention over developmental time. To test this idea, we track the development of visual attention in deaf and hearing individuals. This is the first study of this kind.

We tested the hypothesis that vision in deaf individuals become specialized over developmental time to detect change in the visual field. We predicted that development would <u>diverge</u> between deaf and hearing subjects. Young children, regardless of their hearing status, are poor selective attenders and should therefore attend to any change in the visual field. But, as these two groups age, their different sensory experiences should have cumulative effects. Hearing adults should be good at ignoring changes that are not task relevant. Deaf adults, because of the lack of accompanying auditory information, should need to attend to any change in the visual field, regardless of its task specificity. To test the hypothesis, deaf and hearing children and adults were presented with a task in which they searched for a target among distractors. We measured the degree to which performance was disrupted or helped by changes in the visual field.

Method

Subjects

Normally hearing subjects (n=37) were recruited from departmental subject files and from an undergraduate subject pool. Subjects were recruited from three age groups: 6-7, 9-10, adult. These age groups were chosen because of the degree to which attention changes in the early school years, and because we wanted to assess the cumulative effects of differing developmental experience.

Deaf subjects (n=37) were recruited from students and staff of two residential state schools for the deaf. These subjects were all prelingually deaf, were primary users of sign

language, had hearing losses above 90dB (average pure tone threshold in better ear), and had no additional handicapping conditions. Deaf subjects were recruited from the same age groups as hearing subjects.

Task and Procedure

We employed a computerized search task, modeled after the attentional capture paradigm (see Yantis, 1993), in which shape was the relevant stimulus dimension. A uniquely shaped target was embedded among one, three, or five homogeneously shaped distractors. Figure 1 presents the stimuli (1.62 degree visual angle each), which were arranged in a circular fashion (9.11 degree visual angle) in the center of the computer screen. Stimuli were presented with a 13 1/2" RGB color screen. Subjects sat approximately two feet from the screen with one hand on the mouse throughout the task. The experimenter sat behind and to the left of the subject, out of the line of vision, controlling stimulus presentations with the keyboard. All subjects were tested individually in a quiet, dimly lit room.
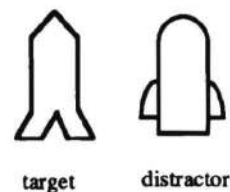

target   distractor

Figure 1. task stimuli

All subjects completed three versions of this task: a training task, a motion task, and a color task. Presentation of the motion and color tasks was counterbalanced across subjects. In the training task, all stimuli were in black outline and subjects were told to search for the oddly shaped target and respond by pressing the mouse button immediately upon detection of the target. They were told to work as quickly as they could without making mistakes. Reaction time was measured. Catch trials in which there was no target were embedded within each task. On these trials, subjects were told simply to indicate to the experimenter by speech, gesture, or sign that no target was present and reaction time (RT) was not measured. The experimenter then forwarded the task to the next trial. These "target absent" trials were included only as catch trials to check for subject compliance.

In the motion task, we introduced apparent motion as an irrelevant stimulus dimension. All stimuli were in black outline and on half of the trials, the target produced apparent motion (target trial), while on the other half of the trials, one of the distractors produced apparent motion (distractor trial). Subjects were told about the motion manipulation prior to the task and to ignore it as they searched for the target. If subjects could not ignore this irrelevant stimulus change, they would be fast on target trials, and slow on distractor trials. Similarly, the overall ratio of distractor trial RT to target trial RT will be large if subjects cannot ignore the stimulus manipulation.

Similarly in the color task, we introduced color as an irrelevant stimulus dimension. All stimuli were in green outline except for one stimulus, which was red. This red stimulus corresponded to the target on half of the trials and corresponded to a distractor on the other half of the trials. Subjects were told about the color manipulation prior to the task and to ignore it as they searched for the target. Again, if subjects could not ignore this irrelevant stimulus change, they would be fast on target trials, slow on distractor trials, and would produce large distractor to target RT ratios.

Results

Hearing subjects

Analyses of RT results included factors for age (3 levels), and trial type (target vs. distractor), while ratios were analyzed according to age. As shown in Table 1, hearing subjects' RT in the motion task decreased with age $(F(2) = 30.297, p < .001)$, subjects were slower on distractor trials than target trials $(F(1) = 121.893, p < .001)$, and the discrepancy in RT between distractor and target trials decreased with age $(F(2) = 6.939, p < .01)$. Significant change in the ratio of distractor trial RT to target trial RT, depicted in Figure 2, occurred between the ages of 9-10 and adult $(F(1) = 8.483, p < .01)$.

age group	target trials	distractor trials
6-7	RT = 668	RT = 761
	sd = 178	sd = 186
9-10	RT = 516	RT = 616
	sd = 56	sd = 83
adult	RT = 344	RT = 380
	sd = 40	sd = 53

Table 1: Motion task data, hearing subjects

As shown in Table 2, hearing subjects' RT in the color task decreased with age $(F(2) = 24.418, p < .001)$, all subjects were slower on distractor trials than target trials $(F(1) = 65.124, p < .001)$, and the discrepancy between target RT and distractor RT decreased with age $(F(2) = 7.909, p < .001)$. Both child groups produced similar ratios, which were larger than adults' (9-10 and adult: $F(1) = 4.523, p < .05)$, as depicted in Figure 2.

We directly compared hearing subjects' performance in the motion and color tasks to see if there was a qualitative difference in the way hearing subjects searched for the target in the face of dynamic information versus static information. Analysis of RT data indicated no task effects due to greater overall variability in the color task $(F(1) = 1.802, p > .05)$. Ratios were marginally larger in the motion task than in the color task $(F(1) = 3.067, p = .08)$: task irrelevant motion in the visual field is somewhat more difficult to ignore than color.

age group	target trials	distractor trials
6-7	RT = 699	RT = 804
	sd = 172	sd = 223
9-10	RT = 550	RT = 625
	sd = 58	sd = 92
adult	RT = 388	RT = 412
	sd = 109	sd = 116

Table 2: Color task data, hearing subjects

In summary, the major change with development is that hearing subjects become more able to ignore an irrelevant stimulus dimension as they search for a target, with the largest change occurring between the ages of 9-10 and adulthood. Dynamic change in the visual field affects target search somewhat more than static difference, across all age groups.
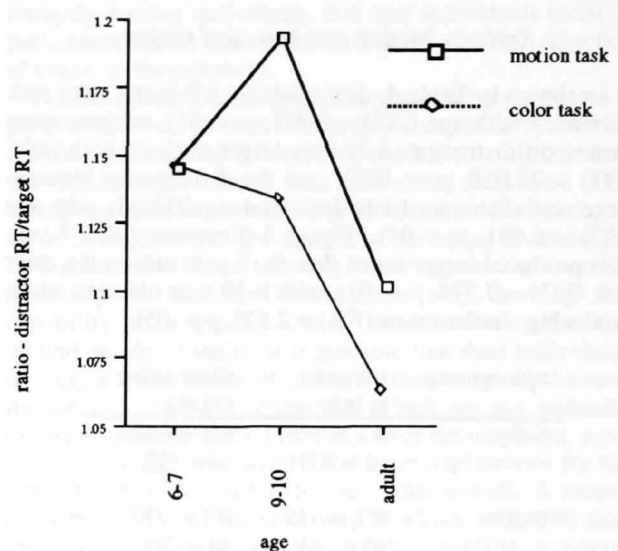

Figure 2. Hearing subjects, ratios - both tasks

Deaf subjects

In the motion task, deaf subjects' RT decreased with age ($F(2) = 9.573$, $p < .001$) and all subjects were slower on distractor trials than target trials ($F(1) = 76.459$, $p < .001$), as shown in Table 3. However, the discrepancy between target and distractor trials in the motion task decreased only marginally with age as shown by RT data ($F(2) = 3.152$, $p = .056$) and ratio data (9-10 and adult: $F(1) = 3.614$, $p = .06$; see Figure 3).

age group	target trials	distractor trials
6-7	RT = 663	RT = 778
	sd = 132	sd = 198
9-10	RT = 573	RT = 678
	sd = 163	sd = 195
adult	RT = 411	RT = 463
	sd = 66	sd = 87

Table 3: Motion task data, deaf subjects

As shown in Table 4, deaf subjects' RT in the color task decreased with age ($F(2) = 8.481$, $p < .01$), subjects were slower on distractor trials than target trials in both tasks ($F(1) = 75.010$, $p < .001$), and the discrepancy between target and distractor trials decreased significantly with age ($F(2) = 6.691$, $p < .01$). Figure 3 illustrates that 6-7 year olds produced larger ratios than 9-10 year olds in the color task ($F(1) = 7.374$, $p = .01$), with 9-10 year olds and adults producing similar ratios ($F(1) = 2.573$, $p > .05$).

age group	target trials	distractor trials
6-7	RT = 766	RT = 892
	sd = 203	sd = 233
9-10	RT = 675	RT = 730
	sd = 263	sd = 295
adult	RT = 428	RT = 481
	sd = 91	sd = 100

Table 4: Color task data, deaf subjects

Direct comparison of deaf subjects' RTs in the color and motion tasks showed that subjects were faster in the motion task ($F(1) = 10.253$, $p < .01$), and ratio data, shown in Figure 2, indicated that dynamic information was more difficult to ignore than color information ($F(1) = 4.468$, $p < .05$), but only for 9-10 year olds.

In summary, deaf subjects also develop the ability to ignore task-irrelevant information, but do so at a faster rate in the face of color information. By adulthood, deaf subjects are equally affected by static and dynamic information.
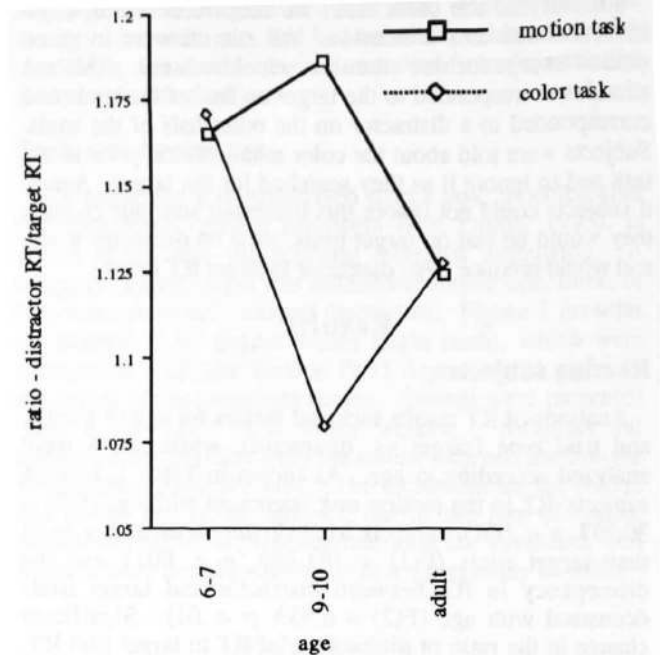

Figure 3. Deaf subjects, ratios - both tasks

Comparison of deaf and hearing performance

Direct comparison of deaf subjects to hearing subjects was done within each of the three age groups because of the high degree of variability between age groups. Analyses of RT results included factors for age (3 levels), group (2 levels), and trial type (target vs. distractor), while ratios were analyzed according to age and group. In the motion task, deaf and hearing 6-7 year olds performed similarly with regard to both RT ($F(1) = .0079$, $p > .10$) and ratio measures ($F(1) = .185$, $p > .05$), as did 9-10 year olds (RT: $F(1) = 1.167$, $p > .10$; ratio: $F(1) = .033$, $p > .10$). Adult hearing subjects were faster than adult deaf subjects ($F(1) = 9.563$, $p < .01$), but ratio scores were not different ($F(1) = .620$, $p > .05$).

In the color task, 6-7 year olds were again highly similar in RT ($F(1) = .575$, $p > .10$) and ratio scores ($F(1) = .192$, $p > .10$). Nine to ten year olds produced similar RTs ($F(1) = 2.085$, $p > .10$), but hearing subjects produced marginally larger ratios than deaf subjects ($F(1) = 3.519$, $p = .07$). Deaf adults were slower than hearing adults to respond, but only on distractor trials ($F(1) = 6.169$, $p < .001$), and produced marginally larger ratios than hearing adults ($F(1) = 3.946$, $p = .051$).

Thus, the two subject groups diverged in performance on our tasks. Six to seven year old children performed similarly in both tasks, while deaf adults were slower overall and were more affected by color than hearing adults were. Performance of the two groups was most similar in the face of apparent motion.

Discussion

The data we have presented support our hypothesis: early onset deafness produces greater attention to change in the visual field over developmental time. Deaf and hearing children performed similarly in both tasks, but by adulthood, deaf subjects were slower overall, and their search time increased when a distractor was manipulated while hearing subjects' search time did not.

The two groups also differed in their attention to dynamic and static information. Hearing subjects were more affected by dynamic information than static information as they searched for the target. This may be due to the correspondence between motion and sound in their normal experience. Deaf subjects, however, were affected strongly by both dynamic and static information. Any change in the visual field may become important for deaf individuals if their normal experience does not include auditory information that would differentiate between environmental events.

While this study revealed no differences in attention to irrelevant stimuli between deaf and hearing children, previous research has (Mitchell & Quittner, 1996; Quittner, Smith, Osberger & Katz, 1994). Differences in the experimental tasks are likely to have elicited different performance. First, stimulus presentation in this study was not speeded as it was in the previous studies. Subjects in this study were instructed to respond as quickly as possible, but stimuli were present until the response was made and natural saccades, blinks, and eye movements were not discouraged by the task. Second, previous research required subjects to attend to a two-digit sequence in a continuous stream of individually presented stimuli, which introduces both short-term and long-term memory constraints. No such constraints were introduced by the task in this study. It is possible, however, that a more sensitive measure than RT may reveal developmental differences earlier than those reported here.

The results of this study suggest that individuals develop a way of attending visually that is based on two things: the equipment they have and the input they receive. Hearing individuals receive multimodal, redundant information from their auditory and visual systems. This information leads to decreased attention to change in the visual field (or greater selectivity), and less responsivity to static information in comparison to dynamic information. Deaf individuals, on the other hand, rely primarily on visual information alone and therefore become more responsive to change in the visual field, regardless of whether it is static or dynamic information.

The finding that unimodal sensory deprivation produces greater attention to change in an intact modality is not unique. Studies using event-related potentials reveal enhanced, automatic processing of deviations in auditory stimulation in blind adults but not sighted adults (Kujala, et al, 1995). This is strong convergent evidence that attention functions like a gating mechanism, letting in information that is needed and selecting out that which is not as defined on-line by the organism, its sensory capabilities, and its developmental tasks. In this manner, the degree of attention to change or deviation shifts with the amount of information available to an organism. An organism that must rely on less information - either in real or developmental time - may become more attentive to changes or deviations in that information than an organism that has more available input. The alternative hypothesis, that a deprived system would become *more* selective and thereby ignore more information, has received no empirical support thus far. All of these results highlight the importance of a developmental analysis of attention and how it emerges over lifetime history to fit the configuration of abilities and task demands.

Recall that our larger hypothesis is that deafness affects visual processing in two ways: it makes vigilance to a restricted area of the visual field quite expensive to the system, and it makes vision specialize in detecting and attending to change. Evidence for each branch of this hypothesis has been reported in separate experiments. The strongest test of the larger hypothesis now will require giving subjects a dual attention task in which they must be vigilant to the center of the visual field, but also detect events in the periphery. We would expect to find, relative to normally hearing individuals, that deaf individuals sacrifice performance in the central task in order to maintain detection of events in the periphery.

The mechanism(s) that produces greater responsiveness to peripheral events in deaf adults, as documented by Neville and her colleagues, is currently unknown. First, deaf individuals might literally scan their visual field more often by moving their eyes or moving their heads. However, we know that individuals are capable of attending to nonfoveal information without moving their eyes: a second possibility is that deaf individuals may develop this capability to a greater extent than normally hearing individuals do. Finally, it is possible that deaf individuals develop a wider scope of attention than normally hearing individuals. These mechanisms, which are not mutually exclusive and are likely to change over development, have yet to be directly investigated and have implications for the development of attention to foveal events as well. A second experiment is currently underway in which we assess deaf and hearing subjects' attention to change using perpheral stimuli.

There is a great deal to be learned about the development of attention, about intersensory interaction, and the mechanisms of development itself by studying individuals with unimodal sensory deprivation. Understanding the manner in which the sensory systems interact under such perturbations will provide important, testable hypotheses regarding the way these systems interact in the intact organism.

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