Apparent Auditory Deprivation in Children:
Implications of Monaural versus Binaural Amplification

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Abstract
This study investigated the effects of monaural versus binaural amplification upon the speech recognition scores (SRSs) of children with bilateral moderate sensorineural hearing loss after more than 4 years of hearing aid use. There was a significant decrease in SRSs for the unaided ears of the monaural hearing aid users, but there were no significant differences between initial and retest SRSs for their aided ears, or for both ears of those using binaural amplification. The SRS reduction was found to be large enough to be significant on an individual ear basis (by exceeding 95% confidence limits of the binomial model) in five of the ten unaided ears of the monaurally fitted children, but this did not occur for any of the initial–retest SRS differences in the aided ears of either group. These findings demonstrate that the auditory deprivation effect, which has been reported for adults using monaural hearing aids, is also found in children.

Key Words: Auditory deprivation, binaural amplification, hearing aids, monaural amplification, sensorineural hearing loss, speech perception, speech recognition

In the most general terms, apparent late-onset auditory deprivation in adults occurs when one of an individual’s ears receives regular auditory stimulation but the other ear is deprived of adequate input for a period of time. The result is a decrement in the speech recognition ability of the under-stimulated ear, and this phenomenon has been the focus of increasing investigation since it was first described by Silman, Gelfand, and Silverman (1984). Using veterans with essentially symmetric bilateral sensorineural losses whose thresholds did not change over the course of the study, they found that those using monaural amplification for 4 to 5 years experienced a significant reduction in the speech recognition scores (SRSs) of their unaided ears. In contrast, SRSs did not change in their aided ears or in either ear of a group using binaural hearing aids for the same period of time.

In a subsequent study using a different sample from the same clinic population, Gelfand, Silman, and Ross (1987) corroborated this effect for adults using monaural or binaural amplification for 4 to 17 years; and also demonstrated that there was no hearing-aid related progression of hearing loss in these subjects.

Since its original description and confirmation in a population of adult male veterans, the phenomenon of reduced speech recognition ability in the unaided ears of adults with bilateral hearing impairment has been corroborated by several studies (Gatehouse, 1989a, b; Silverman, 1989; Stubblefield and Nye, 1989; Emmer, 1990; Silverman and Silman, 1990) and supported by analogous findings in patients with unilateral and bilateral hearing loss due to Meniere’s disease (Hood, 1984, 1990).

In spite of the accelerating interest in late-onset auditory deprivation and its relationship to monaural versus binaural hearing aid use,
there have been no studies of this effect to date in children with sensorineural hearing loss. This lack is in sharp contrast to the extensive attention given to the somewhat related, but quite different issue of whether conductive impairments relate to central auditory and language deficits in children (Katz, 1978; Ventry, 1980; Allen and Robinson, 1984; Downs, 1988).

The lack of attention to the topic of monaural auditory deprivation in children with sensorineural hearing loss is more likely a result of the difficulties and ethical complexities of obtaining an adequate study sample rather than to any lack of interest. Specifically, there is a sparsity of clinical material available on children (1) with bilateral moderate sensorineural hearing losses, (2) who have been fitted with monaural amplification, and (3) for whom speech recognition scores are available both before (or at least soon after) the initial hearing-aid fitting and also after several years of use. This paper reports on the findings of a retrospective study of 10 such children and 10 others with similar hearing losses using binaural hearing aids. It demonstrates the presence of an auditory deprivation effect in the unaided ears of children using monaural amplification.

**METHOD**

The procedure, which involved a retrospective search of clinical records to find cases meeting the selection criteria, and the comparison of initial test and follow-up test SRSs, essentially replicates the approach used in our prior studies with adults (Silman et al., 1984; Gelfand et al., 1987). As anticipated, the sample was limited to a small number of subjects because of two factors. The first is a paradox pertaining to what constituted desirable subjects: these would be children (as young as possible at the initial test) who had enough hearing loss to interfere with auditory input; at the same time, these children would have to have developed sufficient speech and language skills in spite of their hearing losses so that they could be tested with an open-set monosyllabic word test (e.g., W-22, NU-6, or PBK-50) at the time of the initial test. The second factor is that there are very few records of this type available, especially for children who received monaural hearing aids. Requiring a sensorineural loss with an initial test SRT of 35 dB HL in both ears enabled us to obtain 10 usable subjects in each group.

Several thousand clinical records from several facilities were reviewed to find cases of children meeting the following criteria: (1) bilateral sensorineural hearing losses of presumably congenital (or early postnatal) origin; (2) speech reception thresholds (SRTs) of ≥35 dB HL (re: ANSI, 1969) in both ears; (3) audiologic evaluations composed of at least air- and bone-conduction pure-tone thresholds, SRTs, and speech recognition test scores obtained with open-set monosyllabic word tests for both ears (a) within 6 months of the hearing-aid fitting (initial test), and (b) at least 4 years after the initial test (retest); (4) retest SRSs done within 5 dB of the sensation level (SL) used during the initial test; (5) no significant air–bone gaps (Studebaker, 1962) during either the initial or retests; (6) use of a monaural ear-level hearing aid in the same ear for more than 4 years between the initial and retests for the monaurally aided group; (7) use of binaural ear-level hearing aids for more than 4 years between the initial and retests for the binaurally aided group; (8) aided SRTs (and/or at least two aided narrow band thresholds between 500–2000 Hz) of ≤25 dB HL; and (9) no erratic threshold shifts or SRSs that changed positively or negatively during any tests done between the initial and retests used for the study. Temporary conductive components attributable to, for example, ear infections, which occurred during any intervening tests were ignored as long as they were completely resolved by the retest used for the study.

Most of the SRSs were obtained at 35 dB SL. Most of the acceptable records found were for children with binaural hearing aids, and there was no apparent reason why monaural hearing aids were chosen in the cases where this occurred. The records search continued until 10 monaurally fitted children meeting the selection criteria were found. The binaural group was composed of the records of the 10 children using binaural hearing aids that most closely approximated those of the monaural group in

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Several children had WIPI tests (Ross and Lerman, 1971) before or very close in time after their hearing-aid fittings. These tests were not used because this would have led to a problematic comparison with the open-set test results at time of the retest. Thus, the results of a later open-set test were used if the measure was obtained within 6 months of the hearing-aid fitting, and its results were at least as good as on the WIPI. It was assumed that any decrease in speech recognition within the first few months of hearing-aid use would reduce any eventual deprivation effect rather than enhance it. In practice, the scores on the later open-set tests were always higher than the WIPI scores obtained several months earlier.
RESULTS

The subjects ranged in age from 5.1 to 7.5 years at the time of the initial speech recognition tests used in this study, and from 10.4 to 14.5 years at retests. There were seven boys and three girls in the monaurally aided group, and five boys and five girls among those with binaural hearing aids.

Table 1 summarizes the ages of the subjects at the times of the initial and retests, as well as the number of years between the two tests. The binaurally fitted children were about half a year younger than the monaurally fitted subjects at the time of their initial tests, which was statistically significant \( t(18) = 2.5, p < .05 \). However, there were no significant differences between the two groups for either their ages at the retests \( t(18) = 1.2, p > .05 \) or for the number of years between the initial and retests \( t(18) = 0.35, p > .05 \). That the two groups did not differ in terms of the number of years between their initial and retests is important from the standpoint of comparing the effects of monaural versus binaural amplification over time, which averaged 6 years in this sample.

The mean initial and re-evaluation pure-tone thresholds and SRTs for both ears of the two groups, with their respective standard deviations and ranges, are shown in Table 2. These data are shown separately for the aided and unaided ears of the monaurally fitted children, and separately for the right and left ears of those who were fitted binaurally. The subjects had moderate sensorineural hearing losses, with SRTs ranging from 35 to 65 dB HL; with an assortment of audiometric configurations for both groups, as revealed by the ranges of the pure-tone thresholds. While the groups were not composed of subjects with exactly symmetric hearing losses, both groups had no significant differences \( p > .05 \) between the two ears in terms of either pure-tone averages (PTAs) or SRTs.

The significance of the differences between the initial and retest thresholds shown in Table 2 was assessed using t-tests for repeated measures (Winer, 1971). This was done separately for each of the four groups of ears (monaurally fitted: aided and unaided ears; binaurally fitted: right ear and left ears). None of the SRTs or pure-tone threshold differences between the initial and retests were statistically significant \( p > .05 \) except at 2000 Hz for the monaural/aided ears at 2000 Hz \( t(9) = 2.75, p < .05 \). The single significant change was mainly due to a 15-dB threshold shift from 35 to 50 dB HL at 2000 Hz in one subject. Thus, hearing sensitivity overall remained stable over the period of time between the initial and retests for both ears of both groups.

Table 3 shows the mean initial and retest percentage correct speech recognition scores (SRSs), standard deviations and ranges for each condition. The initial and retest means for each condition are shown graphically in Figure 1. The initial and retest mean SRSs were within 5 percent of one another for both ears of the binaurally fitted children and for the aided ears of those using monaural hearing aids. In contrast, there was a mean decrease of 18.6 percent for the unaided ears of the monaural hearing aid users.

The significance of the differences between the initial and retest SRSs was evaluated using repeated measures t-tests. The SRSs were arcsine transformed in order to stabilize the error variance associated with proportional data (Winer, 1971); and all statistical analyses involving these scores were accomplished using the arcsine transformed values. The results revealed a significant difference only for the unaided ears of the monaurally fitted children \( t(9) = 2.69, p < .03 \). However, there were no significant differences between the initial and retests for the aided ears of the monaural hearing aid users \( t(9) = 0.61, p > .05 \), or for the binaurally aided subjects’ right \( t(9) = -1.37, p > .05 \) or left \( t(9) = -1.72, p > .05 \) ears.

It was of some interest to determine whether the significant decrease in SRSs for the unaided ears of the monaurally amplified group might be related to the degree of hearing loss or to the duration of monaural hearing aid use. Thus, the
Table 2 Initial and Retest Pure-Tone Thresholds and Speech Reception Thresholds

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Initial Test Thresholds (dB HL)</th>
<th>Retest Thresholds (dB HL)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SRT</td>
<td>250</td>
</tr>
<tr>
<td>250</td>
<td>50</td>
<td>35.00</td>
</tr>
<tr>
<td>2000</td>
<td>41.00</td>
<td>32.50</td>
</tr>
</tbody>
</table>

Table 3 Initial and Retest Speech Recognition Scores (Percent)

<table>
<thead>
<tr>
<th>SRT (%)</th>
<th>Initial Test</th>
<th>Retest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>82.20</td>
<td>81.40</td>
</tr>
<tr>
<td>SD</td>
<td>10.14</td>
<td>8.00</td>
</tr>
<tr>
<td>Range</td>
<td>64-96</td>
<td>66-92</td>
</tr>
<tr>
<td>Mean</td>
<td>76.40</td>
<td>57.80</td>
</tr>
<tr>
<td>SD</td>
<td>9.11</td>
<td>25.40</td>
</tr>
<tr>
<td>Range</td>
<td>60-90</td>
<td>28-92</td>
</tr>
<tr>
<td>Mean</td>
<td>77.40</td>
<td>81.80</td>
</tr>
<tr>
<td>SD</td>
<td>8.39</td>
<td>7.77</td>
</tr>
<tr>
<td>Range</td>
<td>66-94</td>
<td>68-96</td>
</tr>
<tr>
<td>Mean</td>
<td>78.60</td>
<td>83.20</td>
</tr>
<tr>
<td>SD</td>
<td>6.99</td>
<td>4.75</td>
</tr>
<tr>
<td>Range</td>
<td>66-92</td>
<td>72-88</td>
</tr>
</tbody>
</table>

difference between the initial and retest SRSs was correlated with the initial test SRT (r = 0.148), retest SRT (r = 0.312), and with the time between the initial and retests (r = 0.149). All of these correlations were nonsignificant (p > .05).

The variability of SRSs may be described in terms of a binomial model, on the basis of which 95 percent confidence intervals have been developed (Thornton and Raffin, 1978; Raffin and Schafer, 1980; Raffin and Thornton, 1980). One may assess the significance of the difference between two SRSs obtained by the same subject by comparing these scores to the appropriate 95 percent confidence interval. The initial and retest SRSs were compared to the appropriate 95 percent confidence intervals in order to determine if a given SRS change was significant in each case.2

The results of this analysis were in agreement with the group findings just described. There were no individually significant drops in SRSs for either ear in any of the binaural hearing aid users, or for any of the fitted ears of those using monaural amplification. In contrast, scores fell by individually significant amounts in five of the ten unaided ears of the monaural hearing aid users. Three of the five ears with individually significant declines in their SRSs had SRTs of ≥ 55 dB, whereas the other two ears had SRTs of 40 dB and 45 dB, respectively. On the other hand, all five of the monaural/unaided ears that did not have individually significant changes in SRSs over time had SRTs of ≤ 45 dB.

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2One could not be certain, retrospectively, whether a given SRS was based on a 50- or 25-word list unless the percentage itself could not be obtained using 25 words (e.g., scores of 90% or 58% are possible with 50 words, but not with 25 words). Therefore, the stricter 95 percent confidence limits for 25-word lists were used unless the percentages of both the scores in a given pair could only be obtained with 50-word lists. Also, there may have been some deviation from the binomial model's assumption of equal difficulty because a few of the cases had different initial and retests (e.g., PBK-50 for one and W-22 for the other). This situation was unavoidable, but should be acknowledged. In any case, it is unlikely that this affected the outcome of the study because one ear effectively served as the control for the other ear of each subject.
DISCUSSION

The principal finding of this study is the demonstration, for the first time, of a significant decrement in word recognition performance in the unaided ears of bilaterally hearing-impaired children using monaural amplification for more than 4 years. These observations confirm those of prior reports (Silman et al., 1984; Gelfand et al., 1987; Silverman, 1989; Stubblefield and Nye, 1989), and expand the findings to include children with moderate bilateral sensorineural hearing losses of presumably congenital (or at least very early) origin.

The unaided ear effect in this sample is revealed in two ways: it is observed on a group basis as a significant decrease in the mean SRSs for the unaided ears of those wearing monaural hearing aids, but not in the aided ears of these children or in either ear of those using binaural amplification. It is also demonstrated on an individual patient basis by the presence of individually significant decreases in SRS in five out of ten of the monaural/unaided ears; but in none of the aided ears of either group.

This phenomenon is interpreted as reflecting an auditory deprivation effect as the result of inadequate auditory stimulation of an impaired ear. The current findings suggest that this effect occurs not only in adults, but also in moderately hearing-impaired children who have developed sufficient speech and language skills to the point that they are able to participate in open set monosyllabic word recognition testing. Thus, the late onset concept of auditory deprivation that occurs after a critical period of auditory development (Silman et al., 1984), may be expanded to include children as young as those in the current sample.3 This deficit may still be considered to be of the late onset type, which has been described in adults, because it does not occur until after the child has begun using monaural amplification.

Individuals with moderate hearing losses are certainly not deprived of all auditory input. Consequently, one might suggest that the specifically lacking input to the unaided ear of monaural hearing aid users is speech at readily audible levels and on a regular basis. Although the underlying mechanism of the auditory deprivation effect is not yet apparent, it is clear that inadequate speech stimulation to an impaired ear can and often does lead to this effect, at least when the opposite ear is receiving adequate speech input. While this may not apply in all cases, the findings of this study clearly support the use of binaural amplification in children who have aidable residual hearing in both ears.

The findings of this study indicate that considerable research is needed on auditory deprivation and related phenomena in hearing-impaired children. Several lines of study are apparent, although this list is certainly not exhaustive: there is a need to know how these effects are related to the child's age, the magnitude and/or symmetry of the hearing loss, when amplification is introduced, and whether changes in hearing-aid configurations (between ears and binaurally) relate to changes in speech intelligibility performance. Studies are needed to address such issues as (1) what is the time course over which auditory deprivation effects emerge among children; and (2) whether a child's deteriorated speech recognition performance is recoverable (or permanent) if a previously unaided ear is provided with amplification. Almost certainly, such studies will be complicated by the fact that speech perception performance must be measured at a time when even normal-hearing children are undergoing a development-

3These points are by no means meant to imply that speech and language development is a completed process in these children. Rather, it is meant to point out that an auditory deprivation effect can be measured in children as long as they are able to be tested.
tal emergence of speech and language skills, and will be confounded by the impaired (or at least delayed) development of these competencies due to the very existence of the hearing loss. For this reason, investigating the physiologic correlates of auditory deprivation and/or using psychoacoustic tasks requiring simple (and nonverbally mediated) responses should be particularly relevant to the study of this phenomenon in children.

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REFERENCES


