Recovery of Speech Perception Performance after Prolonged Auditory Deprivation: Case Study

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Abstract

The case reported here, a 26-year-old woman, has a bilaterally symmetric, severe-to-profound, sensorineural hearing loss, acquired early in life. Phoneme recognition scores were essentially symmetric at the onset of the investigation. She was basically monaurally aided from age 4 to age 24, at which time a loss of function in the aided ear prompted the change to binaural amplification. When monaurally aided, this subject had consistently given phoneme recognition scores around 80 percent and 40 percent in the aided and unaided ears, respectively, even though the pure-tone thresholds were almost identical. After several months of hearing aid use, phoneme recognition in the previously unaided ear rose to 75 percent. At the time of writing, this subject is able to hold unstructured telephone conversations via this ear. These data suggest that the earlier poor performance of the unaided ear was due, not to an irreversible loss of peripheral function, but to a lack of experience in interpreting the patterns of neural stimulation generated by that ear.

Key Words: Auditory deprivation, binaural amplification, hearing aids, monaural amplification, progression of hearing loss, speech perception

There is overwhelming evidence to support the conclusion that speech perception performance via an impaired ear is a function of use. More specifically, sensorineurally impaired subjects with symmetric bilateral losses, who wear a hearing aid in one ear only, demonstrate better phoneme, syllable, or word recognition when tested via that ear than when tested via the unaided ear (Silman et al, 1984, 1992; Gelfand et al, 1987; Gatehouse, 1989; Hattori, 1993). It could be argued that an initial performance difference was responsible for the original choice of ear to be fitted. In the study reported by Hattori (1993) in this issue, however, the cause–effect question is well addressed by comparing monaurally aided subjects with binaurally aided subjects and with subjects who have used a single aid alternated between ears. The fact that a performance asymmetry is not observed in either control group strongly supports the conclusion that the asymmetry observed in the monaurally aided subjects is a consequence of auditory deprivation in the unaided ear.

Decisions about phoneme, syllable, or word identity are made centrally, and are based partly on sensory evidence generated by the ears and partly on prior knowledge acquired as a result of auditory and linguistic development (Boothroyd, 1993). There is no reason to assume that the prior knowledge, or the skills needed to evaluate sensory evidence in relation to that knowledge, are ear specific. It is, after all, the same brain that is interpreting the acoustic input, regardless of the ear to which that input is delivered. It is tempting to conclude, therefore, that the diminished speech perception performance in an unused ear is due to the reception of limited sensory evidence from that ear—a conclusion that carries the implication of irreversible physical or physiologic changes resulting from lack of auditory stimulation. It could also be argued, however, that the two ears of a symmetrically impaired subject generate patterns of neural activity that are different qualit-
tatively but not quantitatively. If this were the case, then the performance asymmetry observed in a monaurally aided subject could be the result of inexperience rather than atrophy. In other words, the unaided ear may be delivering an adequate amount of sensory evidence, but in a form that the subject has not learned to interpret.

To distinguish between these two interpretations would require an experiment in which amplification was fitted to a previously unaided ear and adequate opportunity provided for learning. Unfortunately, long-standing users of monaural amplification are seldom receptive to the addition of a second aid and may well lack the motivation or persistence that would be required to ensure adequate learning. Silverman and Silman (1990), however, have reported two cases who were fitted with binaural aids after 3 and 8 years, respectively, of monaural amplification. Both showed considerable recovery of speech perception performance in the previously unaided ear, arguing against the notion of irreversible changes in peripheral structures. In neither case, however, was the hearing loss in the deprived ear very severe. Based on the published pure-tone data, one of the subjects would have had good audibility of unamplified conversational speech via the unaided ear. The other would have had partial audibility of the speech of others and good audibility of self-generated speech. The auditory deprivation of the unaided ears was, therefore, far from complete.

The purpose of the present report is to describe a case with a borderline severe-to-profound hearing loss in an ear that was unaided for almost two decades. Subsequent amplification for this ear became necessary following a sudden deterioration of the previously dominant ear.

CASE HISTORY

The case described is a 26-year-old woman, whom I will call Joan. She has a long-standing bilateral sensorineural hearing loss. Joan's mother claims to have been aware that "something" was wrong during the first few months of life. During the second year, she reached the decision that the "something" was a hearing loss. Unfortunately, the child was over 3 years old before professional confirmation was forthcoming. At that time, behavioral testing showed thresholds of around 65 dB in the right ear and 40 dB in the left. The finding of a loss of only 40 dB in the better ear was in keeping with the observed speech and language development. Although some delays of speech and language were noted, both were progressing nicely. During the next few months, however, audiometric test results showed increasingly more elevated thresholds. Joan was fitted with a hearing aid in the better, left, ear at around age 4 years. It should be noted that her only sibling, a younger brother, has an almost identical hearing loss.

My own contact with Joan began when she was 5 years of age. By this time the thresholds were in the region of 80 dB in the right ear and 90 dB in the left. The loss remained stable during the 10 years over which I provided audioligic management and educational support. Joan's education took place completely in the mainstream. A typical audiogram from this period is shown in the upper portion of Figure 1. The stability of the 3-frequency average pure-tone thresholds over time is illustrated in the upper left panel of Figure 2.

In light of the symmetry of the two ears, and the better pure-tone thresholds in the right, an obvious first step in management was to provide
amplification for the right ear. Joan steadfastly objected to a second aid, however, claiming that it sounded funny and was confusing. Between ages 9 and 10 she did wear a second aid on a fairly consistent basis. She still didn’t like the second aid, however, and there were serious tolerance problems with the right ear. After several months of audiologist and parental insistence, the attempt was discontinued and Joan remained monaurally aided. Between ages 6 and 8, Joan had also been supplied with a binaural FM amplification system for use in school. She also objected to this, saying that it gave her headaches, and sometimes picked up music (at that time, classroom amplification systems shared the commercial wireless bands). After 2 years of intermittent use and frustration, use of the wireless system was discontinued. From age 10, Joan used her monaural behind-the-ear aid for all face-to-face communication and the right ear, therefore, received little or no acoustic input for the next 14 years.

Between ages 5 and 18 years, Joan’s speech perception performance was measured periodically in terms of the recognition of phonemes in consonant-vowel-consonant words. The results are shown in the bottom left panel of Figure 2. The AB isophonemic word lists were used (Boothroyd, 1968). There are 15 lists, each containing 10 words constructed from the same 10 vowels and 20 consonants. These lists are very similar in structure, content, and difficulty to the more familiar NU6 materials. Note, however, that the scores reported here represent the percentage of phonemes correct in the subject’s repetition of these words, not the percentage of whole words correct. The phoneme recognition scores in Figure 2 are those obtained at the peak of the Performance versus Intensity function, as shown in the lower portion of Figure 1, and each was usually based on the data from 2 or 3 lists, containing a total of 60 or 90 phonemes. The 95 percent confidence limits for a single score are in the region of ±10 percentage points. Figure 2 demonstrates that, until about 7 and 1/2 years of age, Joan’s phoneme recognition scores were similar for the two ears. Scores for the left, aided, ear rose steadily until around age 10, but scores for the right, unaided, ear fell dramatically until binaural amplification was intro-
duced at age 9. There was an improvement of right ear performance during the binaural experiment, but a return to low scores after this was abandoned. After age 11, Joan's phoneme recognition score was approximately 80 percent in the left ear, but only 40 percent in the right. Note that a phoneme recognition score of 80 percent is equivalent to a whole word score in the region of 60 percent (Walker, 1975) and is sufficient to permit unstructured telephone conversation.

Shortly before her 24th birthday, Joan suffered a sudden “event” in the left ear. This event involved tinnitus and a loss of speech clarity, but not a loss of sensitivity. Several months of testing and attempted steroid treatment followed. During this time, the thresholds in both ears deteriorated, the right ear by about 10 dB and the left by about 15 dB. Speech perception performance continued to deteriorate in the left ear. Soon after the onset of deterioration, however, Joan started using an aid on the right ear. At first, she found this of limited assistance. In face-to-face conversation, she relied almost entirely on speechreading and she was no longer able to hold unstructured conversations over the telephone. Performance improved over the following months, however, and the right ear has come to play the dominant role previously enjoyed by the left, including telephone use.

Pure-tone threshold data obtained during the period following the onset of deterioration are shown in the upper right panel of Figure 2. Threshold deterioration in the left ear was not immediate but took several months. The 10-dB shift in the right ear, 1 year after the event is also apparent.

Speech perception data are also available for this period. Unfortunately, uncertainties about the test materials, presentation, scoring methods, and scoring criteria make it difficult to evaluate these data. For the purposes of the present report, however, it was possible to arrange a full audiologic evaluation including phoneme recognition measures obtained with the AB isophonemic word lists. The results are shown in Figure 3. Note that these data were obtained some 2 years after the onset of deterioration in the left ear and initiation of hearing aid use on the right ear.

Careful examination of the pure-tone threshold data in Figures 1 and 3 suggests that the changes in the right ear were greater in the low frequencies than in the highs. Further, the phoneme recognition score for the left ear fell from 80 percent (Fig. 1) to around 30 percent (see Fig. 3). Note that a 30 percent phoneme recognition score is equivalent to a whole word recognition score in the region of only 6 percent. What is remarkable, however, are the phoneme recognition data for the right ear. As seen in Figures 1 and 3, the phoneme recognition score improved from around 40 percent to around 75 percent. Moreover the 75 percent score was obtained both under headphones at comfortable listening levels, and via the right hearing aid. The phoneme recognition data are also shown in the lower right panel of Figure 2, where they demonstrate the reversal of the status of the two ears in terms of speech perception performance.

**COMMENTS**

If the earliest pure-tone data truly reflect Joan's hearing status during the first few years of life, it can be concluded that she must have relied almost entirely on the left ear for initial acquisition of spoken language skills (see Fig. 2). This reliance could account for her continued preference for the left ear, and monaural amplification, even after the left ear thresholds became poorer than those of the right ear.
At first sight, the presence of good speech perception scores in the right ear until age 7 1/2 is out of keeping with the comments made in the previous paragraph. Note, however, that the early pure-tone data suggest the right threshold was in the region of 65 dB. Such a threshold would permit audibility of self-generated speech without amplification. It seems probable, therefore, that Joan would have had some auditory experience via the right ear during the early years. Note, also, that there was some use of binaural classroom amplification during this time, albeit on an intermittent basis. When binaural personal amplification was attempted, at around age 10, the right ear phoneme recognition scores returned to the earlier values. Indeed, the "recovery" of right ear speech perception performance at that time was similar to that observed at age 26 years.

The data obtained up to the age of 17 years are in keeping with published results that show development of speech perception asymmetry after prolonged use of monaural amplification. The "recovery" of performance in the right ear, however, argues strongly against the conclusion that the previously poor performance was the result of irreversible physical or physiologic changes in the right ear. Note that there is evidence for such recovery both around age 10, when binaural amplification was attempted, and after age 24, when it was adopted. These findings make a strong case for the conclusion that Joan's poor speech perception performance via the right ear, when it was not being aided, was due to a lack of experience in interpreting the specific patterns of neural stimulation generated by the right ear in response to sound.

This evidence of continuing brain plasticity in adult life is encouraging (see, also, in this issue, Moore, 1993). Exactly how long it took, however, for speech perception performance via Joan's right ear to reach its present level is not clear. There are indications from the clinical data that the process was rapid, but these data are difficult to interpret because of uncertainties about test material and scoring strategies. Joan's anecdotal account of this period suggests that the process of adaptation to the new aid took between 2 and 6 months. This observation cannot, however, be used to draw inferences about the time needed for adaptation to binaural aids after many years of monaural amplification. Joan's motivation to take full advantage of the right ear was considerable once she had lost the excellent hearing in the left. She was fighting for communicative survival.

The nature of the "event" that marked the onset of deterioration in the left ear is not clear. Tests for perilymph fistula were negative and radiography offered no insights. Blood tests gave some evidence of autoimmune activity and it was on the strength of this that a course of steroid treatment was initiated. This was discontinued after a few months, however, because of negative side effects. An intracochlear vascular accident is also a possibility, but that would not explain the eventual threshold shift in the right ear. For present purposes, however, the nature and causes of the changes in hearing are not important because they do not bear directly on issues of deprivation, atrophy, and perceptual learning.

CONCLUSION

The data reported here support the conclusion that there is an ear-specific relationship between speech perception performance and listening experience. They do not, however, support the conclusion that such a relationship occurs because of reduced peripheral function resulting from auditory deprivation. In fact, Joan's data suggest that the process of learning to interpret the neural patterns generated by a defective cochlea must take place for each ear separately and that such learning can be effective even after many years of nonuse.

Because there are uncertainties about Joan's hearing status during the first 2 or 3 years of life, one cannot use these data to draw conclusions about the effects of very early auditory deprivation. In addition, the dangers of generalization from a single case are self-evident. Nevertheless, this case provides existence proof of the possibility of survival of speech perception capacity after one and a half decades of virtually complete auditory deprivation. It also highlights the need for caution when interpreting group performance data collected during a short period of clinical evaluation, and without adequate provision for learning.

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REFERENCES


COMMENTARY

This is an encouraging case report for the hearing handicapped and for those working with them.

Joan refused to use binaural aids in spite of rather remarkable improvement in speech perception ability in her right ear and it was not before loss of function in the monaurally aided ear that she positively accepted the right ear amplification. In our long-term study we also have experienced many cases in which the patients would not accept binaural amplification when they had already distinct “dominance” in the monaurally aided ear, and we have as yet not confirmed whether the speech discrimination in the “recessive” ear can be improved, if possible, to what extent, and by what strategy. The “recovery” of the right ear speech perception ability in this case could be explained as follows.

1. As is described in the Comments of Boothroyd’s report, Joan’s hearing loss was slight to moderate until 3 to 4 years of age. During this period, her auditory path from the right ear to auditory cortex and speech center to the processing mechanism of speech sound developed somehow and she showed nearly as good speech perception scores in her right ear until 7.5 years old, despite her hearing deteriorating at 5 years of age, and monaural amplification in the left ear was continued.

2. The development of the central nervous system depends on both the genetic program and stimuli from the environment. Because the human brain is immature when a baby is born, the postnatal development of the neuron networks are largely influenced by the latter, and the plasticity of synapse development by sprouting is greatest before 1 to 2 years of age, declining rather rapidly thereafter, but not abolished completely in adulthood. This morphologic synapse network is a necessary condition for the acquisition of complex neural function. Myelination, which is one measure of maturation of the developing nervous system, begins already in intrauterine life from the lower auditory path-way, and is completed in acoustic radiation by about 3 to 4 years after birth. Therefore, it is assumed that in her right auditory pathway, such synapse networks were developed morphologically, which has potential to process acoustic stimuli when needed.

3. Motivation is indispensable for the success of rehabilitation. It was the most powerful factor in this case. Of course, her intelligence, character, education, familial and social environment, and other factors must have had a positive effect on her success.

As to the notion that the earlier poor performance of the unaided ear was due, not to an irreversible loss of peripheral function but to a lack of experience in interpreting the patterns of neural stimulation generated by that ear, I want to make some comments.

The processing of speech sounds is performed by the interaction between the central and the peripheral auditory system. It is a well-documented fact that centrifugal pathways including efferent olivocochlear bundle from cortex to hair cells in cochlea have some control.
over the periphery, for example, facilitating and inhibitory effect on afferent impulse, control of filter bandwidth (critical band), which facilitates hearing in noise, frequency resolution in the cochlea, and ascending auditory pathway. That is, the auditory center with its associated field and auditory periphery act as one unit in the processing of speech sounds. Therefore, “recovery” in this case should not be interpreted solely as the results of learning in the auditory cortex. Because her auditory cortex had been largely adapted to substantially distorted information from her aided ear for almost 20 years, when the amplification in her right ear was started at 24 years of age, the period needed for recovery and the grade of recovery must be assumed to depend largely on the functional recovery in the neuron-network in the auditory pathway under control of auditory cortex with associated fields.

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REFERENCE