Unsuccessful Use of Binaural Amplification by an Elderly Person

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Abstract

An elderly person who preferred and performed better with monaural than with binaural amplification was extensively studied, both audiologically and neuropsychologically, in search of an explanation for the phenomenon. Particular emphasis was placed on the study of dichotic speech perception, both behaviorally and electrophysiologically. Results suggest that age-related changes in interhemispheric transfer of auditory input via corpus callosum may underlie the preference for monaural amplification. Implications for the evaluation of amplification potential in elderly persons are discussed.

Key Words: Aging, amplification, binaural, corpus callosum, elderly, hearing aids, presbyacusis

Abbreviations: ABR = auditory brainstem response; ALD = assistive listening device; BTE = behind-the-ear hearing aid; DPOAE = distortion-product otoacoustic emissions; DSI = dichotic sentence identification test; LVR = late vertex response; MCR = message-to-competition ratio; MLR = middle latency response; NAL = National Acoustic Laboratory of Australia; SBR = signal-to-babble ratio; SSI = Synthetic Sentence Identification Test

Despite the theoretical superiority of binaural hearing (Haggard and Hall, 1982; Brooks, 1984; Balfour and Hawkins, 1992), some hearing-impaired persons prefer monaural to binaural amplification (Erdman and Sedge, 1981; Schreurs and Olsen, 1985; Stephens et al, 1991; Dempsey, 1994). Economic considerations are undoubtedly the pivotal factor in many such cases; the cost of two hearing aids is often beyond the user’s means. There are, however, other individuals, especially in the elderly sector, who actually appear to function more effectively with one hearing aid than with two. The present paper reports the results of intensive testing of one such individual. We sought a better understanding of the basis for the phenomenon.

CASE HISTORY

The subject of this report, AK, is a 90-year-old woman with a 13-year history of gradual decline in the hearing of both ears following aspirin therapy for shoulder pain. There is no history or obvious evidence of stroke, dementia, neurologic or other systemic disease. She has received hormone therapy for osteoporosis, but otherwise has a negative medical history. AK is active and in good general health. She was first evaluated by our audiology service at the age of 87. She had been fitted with binaural aids at another center and complained that they were not satisfactory, especially in the presence of background noise.

In the following sections, we present (1) basic audiometric data; (2) monaural auditory evoked potential results; (3) behavioral and electrophysiologic results on a battery of dichotic speech tests; (4) performance on a battery of neuropsychological tests; and (5) the evaluation of hearing aid performance in both monaural and binaural modes.

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BASIC AUDIOMETRIC DATA

In this section, we present data relating to the degree, configuration, and symmetry of peripheral auditory function. Measures include conventional pure-tone and speech audiometry, distortion-product otoacoustic emissions (DPOAEs), and monaural auditory evoked potentials.

Pure-Tone and Speech Audiometry

Figure 1 shows conventional air-conduction thresholds obtained at the first evaluation, at the age of 87. Bone-conduction thresholds, tympanograms, and acoustic reflex thresholds were all consistent with sensorineural loss. These data are omitted for the sake of clarity. In the low-frequency region, the air-conducted threshold configuration rose from about 60 dB at 250 Hz to about 30 dB at 2000 Hz and the right ear was slightly poorer than the left ear. In the high-frequency region, there was a steep decline in both ears and slightly greater loss in the left ear. The average of the HTLs at 500, 1000, and 2000 Hz (pure-tone average [PTA]) was 47 dB for the right ear and 43 dB for the left ear. At a presentation level of 80 dB HL, phonemically balanced (PB) word recognition scores were 96 percent for the right ear and 76 percent for the left ear. At the same presentation level, Synthetic Sentence Identification (SSI) scores (Jerger et al, 1968) at 0 dB message-to-competition ratio (MCR) were 20 percent for the right ear and 10 percent for the left ear. At the +10 dB MCR, SSI scores were 100 percent in both ears.

Otoacoustic Emissions

DPOAEs were measured by means of a commercially available system (Etymotic Research, CUBeDIS,™ version 2.40). Probe tone SPLs were 65 dB, the f2/f1 ratio was 1.2, and the amplitude of the 2f1−f2 distortion product was plotted as a function of the f1 frequency. Figure 2 shows the results for right and left ears. Interestingly, distortion products are relatively robust in both ears relative to the sensitivity loss. At 2000 Hz, for example, where the threshold hearing level was 30 dB in both ears, DPOAEs were still 15 to 20 dB above the noise floor. At 4000 Hz, where the threshold hearing levels were 40 dB in the right ear and 50 dB in the left ear, DPOAEs were still 6 to 12 dB above the noise floor. These results suggest that at least part of the threshold sensitivity loss in both ears is on a retrocochlear basis. Of particular interest, moreover, is the observation that, in the frequency region above 3000 Hz, the left ear shows consistently stronger emissions than the right ear, in spite of the poorer left-ear behavioral thresholds. This result is not consistent with a greater cochlear deficit in the left ear than in the right ear in this high-frequency region.

Monaural Auditory Evoked Potentials

This series of measures evaluates the status of monaural processing at various levels of the ascending auditory pathways. Auditory evoked potentials were measured in the early (auditory brainstem response [ABR]), middle (middle latency response [MLR]), and late (late
vertex response (LVR) latency ranges. For ABR, conventional clinical recording techniques were employed. Activity at the vertex electrode (C.) was referred to right and left earlobes with forehead as ground. For all later potentials, activity was recorded at 18 active electrodes arranged on the scalp according to the international 10-20 system and referred to a common average reference.

ABR waveforms were unremarkable. The wave V latency was 5.6 msec on each ear and amplitudes were approximately equal. A similar situation held for the MLR and the LVR waveforms. Latency of the positive peak P₀, measured at electrode F., was about 40 msec for each ear and amplitudes were similar. Latencies of the negative peak N₀ and the positive peak P₂, measured at electrode C., were approximately 120 and 180 msec, respectively, in each ear. Again, amplitudes were similar.

**DICHOTIC SPEECH TESTING**

Dichotically presented speech signals challenge the central auditory processing mechanisms of the binaural system. To determine the status of AK's binaural processing capabilities, we administered three different dichotic measures: the Dichotic Sentence Identification (DSI) Test (Fifer et al, 1983); the Cued Listening Test (Jerger and Jordan, 1992); and a newly devised dichotic PB word test procedure (Jerger et al, 1995) designed to elicit P₃₀₀ event-related potentials separately for right-ear and left-ear verbal and nonverbal targets.

Figure 3 shows individual ear scores on the DSI test under a variety of experimental conditions. When single sentences were presented monaurally (lowest bars), scores were 100 percent for both right and left ears. When a sequence of two sentences was presented monaurally, scores were 90 percent in the right ear and 75 percent in the left ear. When pairs of sentences were presented dichotically in a divided attention mode (respond to both ears), the right ear score remained at 90 percent but the left ear score dropped to 15 percent, indicating a striking right-ear advantage, or left-ear disadvantage, in the dichotic listening mode. The remaining three dichotic conditions represent systematic manipulation of the dichotic sentence task in order to determine the extent to which the apparent left-ear disadvantage in the divided attention mode can be attenuated by lessening the cognitive load. In the focused attention mode, AK was required to respond only to one cued ear. The right ear was cued for a block of 10 trials, then the left ear was cued for another block of 10 trials. Here, performance on the cued right ear increased to 100 percent, but performance on the cued left ear, instead of improving due to lessening of the cognitive demand, actually declined to 10 percent. In the precued condition, each trial was cued immediately before its presentation rather than in blocked fashion. In the postcued condition, each trial was cued immediately after its presentation. In both of these individually cued conditions, left ear performance remained at the same level as in the blocked divided and focused attention modes.

Figure 4 shows performance on the cued listening task (Jerger and Jordan, 1992). In the sound field, AK listened for a speech target (the personal pronoun “I”) embedded in a continuous narrative. The same narrative was presented from speakers located to the right and to the left of AK but there was a 60-second time delay between speakers. The to-be-attended speaker was precued (“listen right” or “listen left”) in blocks of five targets each. Successive blocks were presented in random order. A total of five blocks was presented to each side. Multitalker babble was presented from a loudspeaker mounted directly above AK in the sound-treated chamber. Correct target identification as a function of signal-to-babble ratio (SBR) is shown separately for target-right and target-left conditions. At the most favorable SBR (+10 dB), there was little difference between sides. But as the SBR became more unfavorable, performance was substantially poorer for the target-left than for the target-right condition.

To explore further the nature of AK's marked left-ear disadvantage on the dichotic sentence task, we constructed two additional dichotic measures, one verbal and one nonverbal. Both
were based on the dichotic presentation of pairs of PB words. In addition, both were cast in the "oddball" paradigm useful for recording event-related potentials from electroencephalographic activity. In both the verbal and nonverbal versions of the oddball paradigm, the "frequent" event was the simultaneous presentation of two randomly selected PB words spoken by the same male talker. For the verbal task, the "rare" event was the occurrence of a target word rhyming with "book" (e.g., "look," "took," "cook," etc.), also recorded by the same male talker. For the nonverbal task, the rare event was a change in gender of the talker from male to female. In each mode, verbal and nonverbal, a total of 300 word pairs was presented in succession. There were 90 rare or target events and 210 frequent or nontarget events (a priori probability 30%). Rare events were randomly interspersed among frequent events with the single constraint that a rare event could not occur more than twice in succession. Both verbal and nonverbal targets were presented to the right ear on half of the rare trials and to the left ear on the other half. In each mode, responses to nontargets (frequent events) to right- and to left-ear targets (rare events) were averaged separately. Electroencephalographic activity was recorded from gold-cup scalp electrodes affixed according to the international 10–20 system. Ocular activity was monitored by electrodes above and below the left eye. Individual epochs were rejected automatically whenever electrical activity exceeded 30μV.

After the presentation of each word pair, AK responded by pushing one of two buttons arranged vertically on a response board. The upper button indicated that a target word had been heard in either ear. The lower button signaled that a nontarget word pair had been heard. Reaction times (elapsed time from word-pair onset to button push) were automatically recorded.

Figure 5 shows reaction times for the right and left ears for both verbal and nonverbal targets. The expected left-ear disadvantage in the verbal mode is evident. Interestingly, moreover, the nonverbal targets show a right-ear, rather than a left-ear, disadvantage. Correct responses were faster for right-ear verbal targets and for left-ear nonverbal targets.

Figure 6 shows averaged waveforms recorded at the P3 electrode (left of Pz) for right-ear and left-ear targets in both the verbal and nonverbal tasks in our experimental subject (S: AK). Each waveform is the subtraction of the frequent (nontarget) waveform from the rare (target) waveform. The event-related potential, usually referred to as the P3 or P300 response because of positivity in the post-stimulus interval beyond 300 msec, is clearly evident in the right-ear response to verbal targets and in the left-ear response to nonverbal targets. There was virtually no P300 response to verbal targets presented to the left ear, and a greatly attenuated response to nonverbal targets presented to the right ear. For comparative purposes, we present, in Figure 7, analogous data obtained from a 78-year-old man with a similar degree of loss but without behavioral evidence of a large dichotic asymmetry. In this control subject (S: Control), there was a slightly larger right-ear response in the verbal mode, and a slightly larger left-ear response in the nonverbal mode, but the amplitude differences were much smaller.
Figure 6  $P_{300}$ waveforms at electrode $P_3$ for right and left ears of subject AK on dichotic PB word pairs presented as verbal (phonemic target) or nonverbal (voice gender target) dichotic tasks.

Figure 7  $P_{300}$ waveforms at electrode $P_3$ for right and left ears of elderly subject without dichotic deficit on dichotic PB word pairs presented as verbal (phonemic target) or nonverbal (voice gender target) dichotic tasks.

Figure 8  Comparison of ear difference scores of $P_{300}$ amplitude for subject AK and elderly control subject without dichotic deficit.

Figure 9  Comparison of ear difference scores of $P_{300}$ amplitude for subject AK and elderly control subject without dichotic deficit.
right and left hands. The right hand was superior in all cases. Memory evaluation revealed expected age-related difficulties. No psychological or adjustment problems were revealed by the evaluation.

The Telephone Dialing Test requires the recollection of digits in the presence of auditory distraction. Here, results were consistent with the audiologic findings of processing difficulty in the presence of competing continuous discourse (e.g., SSI).

The results of two tests, the Traffic Reaction Time test and the Haptic Naming Test, showed results consistent with a deficit in interhemispheric communication. On the Haptic Naming Test, AK had considerable difficulty naming objects out of view with her left hand. On the Traffic Reaction Time Test, she had faster reaction times when information was presented to the ipsilateral visual field (i.e., when she attempted to stop a car with her ipsilateral foot) than when it was presented to the contralateral field.

EVALUATION OF HEARING AID PERFORMANCE

In order to determine the extent to which AK's central auditory processing abilities impacted the use of amplification, we measured sentence identification in the presence of competing continuous discourse under four conditions of conventional hearing aid amplification: (1) unaided, (2) aided in the right ear only, (3) aided in the left ear only, and (4) aided in both ears.

Table 1  Summary of Neuropsychological Test Results

<table>
<thead>
<tr>
<th>Measure</th>
<th>Score</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raven Progressive Matrices</td>
<td>65th percentile</td>
<td>WNL*</td>
</tr>
<tr>
<td>Boston Naming Test</td>
<td>70th percentile</td>
<td>WNL</td>
</tr>
<tr>
<td>Multi-Score</td>
<td>WNL</td>
<td></td>
</tr>
<tr>
<td>Depression Inventory</td>
<td>WNL</td>
<td></td>
</tr>
<tr>
<td>ITPA Visual Closure</td>
<td>WNL</td>
<td></td>
</tr>
<tr>
<td>Western Aphasia Battery</td>
<td>WNL</td>
<td></td>
</tr>
<tr>
<td>NEO Five Factor Inventory</td>
<td>WNL</td>
<td></td>
</tr>
<tr>
<td>Brief Symptom Index</td>
<td>WNL</td>
<td></td>
</tr>
<tr>
<td>Selective Reminding Test</td>
<td>WNL</td>
<td></td>
</tr>
<tr>
<td>Grooved Pegboard Test</td>
<td>WNL</td>
<td></td>
</tr>
<tr>
<td>Finger Tapping Test</td>
<td>WNL</td>
<td></td>
</tr>
<tr>
<td>Delayed Non-Matching to Sample</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Haptic Naming - right hand</td>
<td>8/8</td>
<td>WNL</td>
</tr>
<tr>
<td>Haptic Naming - left hand</td>
<td>5/8</td>
<td>SI*</td>
</tr>
<tr>
<td>Telephone Dialing Test</td>
<td>20th percentile</td>
<td>SI</td>
</tr>
<tr>
<td>Traffic Reaction Time Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Left field - left foot</td>
<td>780 msec</td>
<td>WNL</td>
</tr>
<tr>
<td>Left field - right foot</td>
<td>912 msec</td>
<td>SI</td>
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<tr>
<td>Right field - right foot</td>
<td>696 msec</td>
<td>WNL</td>
</tr>
<tr>
<td>Right field - left foot</td>
<td>1040 msec</td>
<td>SI</td>
</tr>
</tbody>
</table>

*WNL = within normal limits; SI = significant impairment.
left ear only, and (4) aided binaurally. In addition, we compared right-ear aided and left-ear aided amplification through an assistive listening device (ALD).

Conventional hearing aids were fit using a Fonix 6500-C Real-Ear Measurement System. From the pure-tone audiometric data, the desired frequency response of the hearing aid was determined using the National Acoustic Laboratories' (NAL) procedure (Byrne and Dillon, 1986). Real-ear insertion gain measurements were obtained unaided and with the hearing aid coupled to the system. Then, a computer algorithm was initiated, which provided an estimate of the best fit of the gain and frequency response of the hearing aid to the NAL target. The hearing aid was adjusted until the frequency response matched as closely as possible the NAL target response.

Figure 10 shows the result of soundfield testing of a programmable behind-the-ear (BTE) aid fitted either to the right ear, the left ear, or both ears (binaural). Test materials were SSI sentences presented from a loudspeaker at 0 degrees azimuth either in quiet (no competition) or while competing continuous discourse was presented from a loudspeaker at 180 degrees azimuth at varying MCR ratios. Results show that performance was best when the right ear was aided, poorest when the left ear was aided, and intermediate when both ears were aided. Figure 11 shows the result when the ALD was tested with the same materials. Performance was almost within normal limits when the right ear was aided, but poorer when the left ear was aided.

**DISCUSSION**

Our subject, AK, is typical of many elderly hearing-impaired persons who, in spite of relatively symmetric sensitivity loss, appear to function better with monaural than with binaural amplification. She was initially fitted with binaural aids but never found this arrangement satisfactory. She is a satisfied user of right monaural amplification but does badly when any amplification is attempted on the left ear. Subject AK illustrates the binaural interference phenomenon described by Jerger et al (1993). The presentation of verbal information to the left ear appears to interfere with verbal processing by the right ear.

At least three possible explanations suggest themselves: (1) a greater peripheral deficit on the left ear leading to imbalance in, or asynchrony of, binaural input, (2) a cognitive deficit limiting successful use of binaural input, or (3) an auditory processing deficit limiting successful use of binaural input.

The possibility of a greater peripheral (i.e., cochlear) deficit on the left side must be considered since audiometric threshold HTLs were slightly poorer at frequencies above 2000 Hz on the left ear. The difference was 20 dB in favor of the right ear at 3000 Hz, 10 dB at 4000 Hz, and 10 dB at 6000 Hz. In further support of a peripheral asymmetry is the fact that there was a 20 percent difference in PB word recognition scores—a significant difference by the Thornton and Raffin (1978) test.

Arguing against peripheral asymmetry as the basis for the apparent binaural interference effect, however, are the DPOAEs (see Fig. 2). If emission amplitude indexes hair cell status (Kemp, 1978; Probst et al, 1987), then we must conclude that, in the region above 3000 Hz, the
left ear has better, not worse, cochlear reserve than the right ear.

Further argument against the left peripheral hypothesis lies in the dichotic data for verbal and nonverbal tasks (see Figs. 5–9). Here, it is clear that asymmetries in reaction time and P300 amplitude can be reversed, from a left-ear deficit to a right-ear deficit, by simply changing the to-be-attended speech feature, of the same monosyllabic words, from phonemic to voice gender. It is difficult to reconcile this result with a left-sided cochlear effect.

The possibility of a cognitive deficit that limits the successful use of binaural input must certainly be considered in anyone in the 87- to 90-year range. Arguing for such a deficit are the monotic data for identifying two sentences in sequence (see Fig. 3). Here, two randomly selected DSI sentences are presented sequentially to one ear. The subject's task is simply to identify which 2 sentences, from a closed list of 10, were heard. In the absence of cognitive deficit, this task is ordinarily executed without difficulty, even by persons with substantial peripheral sensitivity loss. Individual ear accuracy scores are usually 100 percent. But AK's performance fell to 90 percent, for the right ear, and to 75 percent, for the left ear, indicating some difficulty in immediate memory. Since memory for two sentences is critical to adequate dichotic performance in the divided-attention mode, the left-ear deficit in this condition might be explained by a memory problem. The interaction of such a memory deficit with problems in attention and speed of mental processing might conceivably result in more sensory overload when both ears are amplified than when only one ear is amplified.

Arguing against cognitive deficit, however, as an explanation for the left-ear dichotic deficit are the results of the remaining dichotic conditions of Figure 3. If cognitive dysfunction is the basis for the left-ear deficit in the divided attention mode, then the deficit should be attenuated by switching to the focused attention mode. Here, only one ear must be attended. The other can be ignored, thus lessening the memory load. The precued and postcued modes represent further manipulation of the cognitive demands of the task. In the case of a dichotic asymmetry due to cognitive deficit, the ear difference should be greatest in the divided attention mode, less in the focused attention mode, then progressively greater in the precued and postcued modes. But AK showed virtually no effect from this cognitive manipulation. The ear asymmetry noted in the divided attention mode remained constant across all dichotic conditions. Thus, while cognitive deficits in memory, attention, and speed of processing may certainly be present, they do not appear to explain the left dichotic deficit. Further argument against the cognitive deficit hypothesis is the fact that the general results of the neuropsychological evaluation were within normal limits.

The third possibility, an auditory processing deficit impacting binaural input, seems more consistent with the available data. The most persuasive argument comes from the dichotic results illustrated in Figures 5 to 9. They demonstrate a pattern not unlike that of patients who have undergone commissural section (Milner et al, 1968; Sparks and Geschwind, 1968). When the dichotic task is verbal, the left ear performs poorly, but when the dichotic task is nonverbal, the pattern reverses and the right ear performs less well than the left ear. Further support for this view is provided by the neuropsychological evaluation. Results achieved by experimental manipulation of the neuropsychological tests revealed a pattern of performance much like that seen in callosal agenesis patients (Ferris and Dorsen, 1975) and in some callosectomy patients (Sperry, 1974).

The important role of the corpus callosum in mediating verbal responses to left-ear input has been extensively studied (Milner et al, 1968; Sparks and Geschwind, 1968; Lindeboom and Horst, 1988; Rao et al, 1989; Kaga et al, 1990). That there is age-related change in the human corpus callosum is also well documented (Byne et al, 1988; Witelson, 1989; Yoshii and Duara, 1989; Allen et al, 1991; Doraiswamy et al, 1991; Weis et al, 1991; Laissy et al, 1993). That such change can affect the efficiency of interhemispheric transfer has also been documented (Goldstein and Shelly, 1974). Thus, the necessary conditions can be marshaled to support the hypothesis that, in aging, there may be a significant loss of efficiency of interhemispheric transfer of auditory information through the corpus callosum. As a result, the left ear is at an increased disadvantage for the processing of verbal tasks. The present results on subject AK demonstrate this effect both behaviorally and electrophysiologically.

We suggest that AK's difficulty with binaural amplification may be explained by age-related progressive atrophy and/or demyelination of corpus callosal fibers, resulting in delay or other loss of the efficiency of interhemispheric transfer of auditory information in a manner similar
to that recently suggested by Jerger et al. (1995). Such loss could explain the deficits in left-ear performance when AK responded to dichotic presentation of verbal materials, and the deficits in right-ear performance for the nonverbal task. To the extent that such faulty interhemispheric transfer affects the utilization of subtle binaural cues, elderly persons like AK may experience a variety of problems involving sound localization, auditory space, and the effective use of binaural hearing aids.

**AN IMPORTANT CLINICAL IMPLICATION**

In recent years, we have seen a major paradigm shift, among audiologists, away from speech audiometric assessment of hearing aid performance and toward real-ear measurement of frequency response. The case for this shift was stated most eloquently by Hawkins et al. (1987):

> Recent data concerning the test–retest variability of word recognition scores...and the lack of support for the underlying assumptions of the comparative hearing aid evaluation that uses word recognition scores...have cast doubt on both the reliability and the validity of this approach. A popular alternative in hearing aid selection utilizes audiogram-based prescriptions of appropriate amplification and the measurement of unaided and aided sound-field thresholds. (p. 56)

The present case illustrates the hazards of such a narrow approach to hearing-aid evaluation and fitting, especially as it applies to elderly persons and binaural amplification. In the case of AK, neither the pure-tone audiogram nor prescriptions of appropriate amplification based on real-ear measures revealed, or even hinted at, the fact that binaural amplification was inappropriate for this individual. In point of fact, it was *speech audiometry* that highlighted the problem. Beginning with the PB word scores, followed by the DSI scores, then progressing through the cued listening test scores and ending with the dichotic verbal and nonverbal tasks, there was a consistent left-ear deficit for verbal tasks. The consequence of this unilateral deficit was well illustrated in the evaluation of hearing aid performance and in AK’s reaction to monaural versus binaural amplification.

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**REFERENCES**


