Effects of Interaural Speech-Recognition Differences on Binaural Advantage for Speech in Noise

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Abstract
The relationship between interaural differences in speech-recognition performance and binaural advantage for speech in noise was studied. Subjects were five hearing-impaired listeners with symmetrical pure-tone air-conduction audiograms and significant interaural differences in speech recognition. All subjects repeated nonsense syllables in the presence of competing noise in monaural and binaural conditions. Binaural advantage was calculated as the difference in signal-to-noise ratio that afforded 50 percent correct performance between the monaural and binaural conditions. The results were diverse. Although the majority of the subjects retained some degree of binaural advantage, a conclusive relationship between interaural differences in speech recognition and binaural advantage could not be established. The implications for binaural hearing aid fittings are discussed.

Key Words: Binaural advantage, binaural amplification, speech recognition, interaural difference, hearing loss

The binaural auditory system provides signal processing advantages for normal listeners in many communicative situations. Researchers have speculated, however, that certain aspects of sensorineural hearing loss may cause a reduction in the binaural advantage that normally would be anticipated from hearing-impaired listeners using amplification (see Byrne, 1980, for a review). Colburn and Hauser (1981), modeling binaural interactions in impaired auditory systems, suggested that binaural processing might be limited when a signal from one ear that is degraded or distorted in the frequency domain is compared to an “intact” signal from the other ear. This type of sensorineural loss, where differences in frequency processing exist interaurally, may manifest itself in the clinic as a symmetrical loss of hearing sensitivity accompanied by asymmetrical speech-recognition performance in the absence of retrocochlear pathology. No data are available to confirm that patients who exhibit this clinical profile do not receive binaural benefits, or to describe the extent of interaural differences that disrupt binaural processing. It is important to differentiate those hearing-impaired listeners who may or may not use binaural information effectively since the potential benefits of binaural amplification are great. The purpose of this study is to describe the relationship between interaural differences in speech-recognition performance and binaural advantage for nonsense syllables in noise for five hearing-impaired listeners with symmetrical pure-tone air-conduction audiograms and significant interaural differences in speech recognition.

METHOD

Subjects

Five hearing-impaired listeners, three males (S1, S4, and S5) and two females (S2 and S3) served as subjects. All had been previously evaluated in the audiology clinic and had exhibited symmetrical (±15 dB) pure-tone thresholds from 250 to 4000 Hz and significant interaural...
Figure 1. The pure-tone air-conduction audiograms of the five hearing-impaired listeners who served as subjects in this investigation.

Speech-recognition performance (in percent correct) for each of the subjects is given in Table 1. Although several of the subjects were tested with different speech stimuli representing different evaluative protocols on the original testing dates, the test procedures for both ears of an individual listener were identical with respect to signal presentation level or signal-to-noise (S/N) ratio, and each subject had a significant interaural difference. Three of the four subjects (S1, S4, and S5) had excellent-to-good word recognition in the better ear with fair word recognition in the poorer ear, whereas two of the subjects (S2 and S3) had fair-to-poor word recognition in the better ear and poor word recognition in the poorer ear. Four of the subjects (S1, S2, S4, and S5) exhibited better performance in the left ear, whereas the other subject (S3) had better word recognition ability in the right ear.

Differences in speech recognition (Thornton and Raffin, 1978). The pure-tone audiograms for the five subjects are shown in Figure 1. For all subjects, speech-recognition threshold (SRT) was in agreement with the pure-tone average (PTA), and acoustic impedance measurements revealed single-peaked tympanograms (±100 daPa), present acoustic reflexes (contralateral and ipsilateral) from 500 to 2000 Hz with no abnormal reflex adaptation. Medical follow-up was negative for retrocochlear pathology. Four of the subjects were elderly (aged 60–70 years) and the other subject (S2) was younger (aged 35 years). All subjects had mild-to-moderate or mild-to-severe sensorineural hearing losses throughout the frequency range except for S1, who had normal pure-tone thresholds below 2000 Hz.
Table 1  Speech-Recognition Scores for the Five Hearing-Impaired Subjects

<table>
<thead>
<tr>
<th>Subject</th>
<th>Most Comfortable Level (dB HL)</th>
<th>Percent Correct</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R</td>
<td>L</td>
</tr>
<tr>
<td>1</td>
<td>60</td>
<td>55</td>
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<tr>
<td>2</td>
<td>75</td>
<td>70</td>
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<tr>
<td>3</td>
<td>75</td>
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<tr>
<td>4</td>
<td>85</td>
<td>90</td>
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<tr>
<td>5</td>
<td>70</td>
<td>70</td>
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</table>

Finally, one subject (S1) had never worn a hearing aid, whereas four of the subjects (S2, S3, S4, and S5) were experienced (more than 1 year of regular hearing aid use) monaural hearing aid users. Interestingly, two of the subjects (S2 and S3) wore hearing aids in the poorer ear, whereas the other two subjects (S4 and S5) were fitted with hearing aids in the better ear.

Speech Materials

Twenty predominantly low-frequency (LF) items were selected from the original Non-sense-Syllable Test (NST) (Resnick et al, 1975) to serve as test materials. These LF items, chosen on the basis of the phonetic content of the consonants (stops, nasals, glides), are listed in Table 2. It was hoped that the selection of LF items would maximize binaural advantage by providing interaural time/phase difference cues. Each of the 20 items was randomized five times to form a longer list of 100 items. The individual nonsense syllables were converted from digital to analog form and recorded on reel-to-reel tape.

The LF NST items were re-recorded in a sound-treated classroom (T = 0.33 seconds, average of 500, 1000, and 2000 Hz) using the Knowles Electronics Manikin for Auditory Research (KEMAR). To deliver the test items, a loudspeaker (JBL, Model LE8T11) was positioned at a 45° azimuth at a distance of 15 feet from KEMAR, placing KEMAR in the reverberant field. Two microphones (1/2 inch condenser, B & K, Type 4131) situated in Zwislocki couplers were used to record the test materials. The output was amplified and recorded individually on separate tracks of a four-channel tape recorder (Sony, Model 200 CD).

For competition, a speech noise (Grason-Stadler, Model 162) similarly was delivered through the loudspeaker positioned at a 315° azimuth at a distance of 15 feet from KEMAR. The noise was recorded individually on the remaining two channels of the tape recorder. The KEMAR recording consisted of four channels with the speech and noise separated for both the near ear (the ear closest to the speech) and the far ear (the ear closest to the noise).

Procedures

Each subject was tested individually under earphones in a sound-treated room (IAC, Model 4). Initially, pure-tone air-conduction thresholds were re-established and most comfortable levels (MCLs) obtained for each ear (Ventry and Johnson, 1978). The complete NST (7-subtest, 62-item version) also was presented monaurally at MCL in each ear at a 20-dB S/N (speech-shaped noise) to determine the extent of interaural differences in speech recognition for the NST, to derive baseline interaural differences on the LF NST items (scored separately) prior to the experimental conditions, and to serve as practice for the experimental conditions. Prior to testing, the subjects were shown a list of the response foils and familiarized orally with them by the examiner. Test items were preceded by the phrase, “you will mark,” and the subjects responded by circling the item on the NST response form that was heard.

In the experimental conditions, the speech and noise recorded previously from the near ear and far ear of KEMAR were delivered from a four-channel tape recorder (Sony, Model 200 CD) into two channels of speech audiometers (Grason-Stadler, Model 162), and then combined to deliver the near ear stimuli (speech and noise) or the far ear stimuli (speech and noise) through TDH-39 earphones encased in MX-41/
AR cushions. Speech-recognition performance was obtained for the LF NST items in four experimental conditions (monaural direct vs binaural and monaural indirect vs binaural) presented in random order. In the monaural direct condition, the stimuli recorded at the near ear of KEMAR (speech and noise) were presented to the better ear of each subject, and the stimuli recorded at the far ear were added to the poorer ear in the binaural comparison condition. In the monaural indirect case, the stimuli recorded at the far ear were presented to the better ear and the stimuli recorded at the near ear were added to the poorer ear in the binaural comparison condition. For all conditions, a list of the 20 LF NST items was placed in front of the subjects for reference as needed and the subjects were instructed to respond orally.

During the monaural conditions, the speech stimuli were presented at MCL, whereas during the binaural conditions, the speech stimuli were presented at monaural MCL – 4 dB in each ear to minimize binaural loudness summation effects. Although the absolute level of the signal was decreased for the binaural conditions, Dirks et al (1982) demonstrated that once a signal is sufficiently above threshold, recognition performance in competition remains relatively stable.

The S/N that afforded 50 percent correct performance was obtained during each experimental condition using an adaptive procedure (Levitt, 1971). In this procedure, the level of the noise was decreased in 2-dB steps following each incorrect response and increased in 2-dB steps following each correct response. The level of the noise initially was 50-dB SPL and increased in 4-dB steps until the first incorrect response occurred. Test items were presented until eight to 12 reversals occurred, and the average of the final six reversals was calculated to be the 50 percent correct point. The large number of reversals in conjunction with averaging the final six sample points was designed to increase the reliability of the measurement without multiple replications. The S/N at the 50 percent point for the monaural conditions was subtracted from the S/N for the binaural comparison conditions to obtain a binaural advantage score.

RESULTS

Individual subject data for the five hearing-impaired listeners are presented in Table 3. Here, the subjects’ MCLs, complete 62-item NST scores, derived LF NST scores, and S/N for the monaural direct versus binaural and monaural indirect versus binaural conditions as well as binaural advantages are shown.

The MCLs were bilaterally symmetrical (±5 dB) and ranged from 55 dB to 90 dB HL for all listeners. Note that the monaural NST scores (obtained at MCL, +20 S/N) fell between 50 percent and 65 percent in both the better and poorer ears of each subject. The subsequent interaural differences in speech recognition on the NST, ranging from 8 percent to 12 percent, were considerably smaller for each subject than had been obtained during the initial audiologic evaluation with other speech materials (see Table 1; CCT, SPIN, and W-22s). The reduced range of scores for the NST, however, probably reflects both the increased difficulty of recognizing nonsense syllables as opposed to words, which would lower the ceiling, and the unlikelihood of confusing a particular phoneme with another outside its phoneme class, particularly in the closed-set response mode, which would create a floor. Other variables, including differences in signal presentation level, competing noise levels, and number of items in a list undoubtedly contributed to the differences in scores.

To further explore the effect of test materials on the magnitude of interaural difference, the interaural differences for low-frequency NST items were derived for each subject by calculating the percentage of correct responses to all of the low-frequency items in the 62-item version of the NST. Here, interaural differences were larger, ranging from 13 percent to 15 percent for these stimuli, even for S1, who had normal low-frequency thresholds bilaterally. Since one ear consistently achieved the better performance on each speech recognition task across all test materials for a particular subject, it is likely that some degree of interaural difference existed for each listener.

For the experimental conditions, the S/N that afforded 50 percent correct performance encompassed a wide range of values. In the monaural conditions, the S/N ranged from –2 dB to 12 dB and in the binaural conditions, the S/N ranged from –5 dB to 12 dB. The binaural advantages, calculated from the S/N data by subtracting the S/N obtained in the monaural conditions from the binaural comparison conditions, also were diverse. A binaural advantage occurred for two subjects, S1 and S2, both in the monaural direct versus binaural condition.
Table 3  Individual Subject Data for the Five Hearing-Impaired Subjects *

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<th>S1</th>
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<td>MCL (dB HL)</td>
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<td>75</td>
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<td>Full NST (% correct)</td>
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<td>65</td>
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<td>50</td>
<td>61</td>
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<td>61</td>
<td>52</td>
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<td>63</td>
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<tr>
<td>Derived LF NST (% correct)</td>
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<td>78</td>
<td></td>
<td>53</td>
<td>66</td>
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<td>74</td>
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<td>Monaural Direct (dB)</td>
<td>+6</td>
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<td>+10</td>
<td></td>
<td>+12</td>
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<td>+6</td>
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<td>+10</td>
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<td>Binaural Advantages (dB)</td>
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<td>-2</td>
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<tr>
<td>Monaural Indirect (dB)</td>
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<td></td>
<td>+10</td>
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<td>+12</td>
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<td>+2</td>
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<td>Binaural (dB)</td>
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<td>+2</td>
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<tr>
<td>Binaural Advantages (dB)</td>
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<td></td>
<td>12</td>
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<td>0</td>
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*Data includes most comfortable levels (MCL); monaural nonsense syllable test (NST) scores; low-frequency (LF) NST scores; and signal-to-noise (SN) ratios from the monaural direct, monaural indirect, and binaural comparison experimental conditions with subsequent binaural advantages.

(4 dB) and for the monaural indirect versus binaural condition (8 dB and 12 dB respectively). The magnitude of the binaural advantages for these subjects was comparable to those obtained by normal listeners under similar experimental conditions (Dirks and Wilson, 1969). A "normal" binaural advantage also occurred for S4 and S5 in the monaural direct versus binaural condition (4 dB and 2 dB respectively). However, a comparatively small binaural advantage occurred for these subjects in the monaural indirect versus binaural condition (2 dB and 4 dB). For S3, no binaural advantage occurred over either monaural condition (−2 dB and 0 dB for monaural direct vs binaural and monaural indirect vs binaural respectively). The diversity of the binaural advantage scores indicated that, for these listeners, binaural advantage could not be predicted on the basis of interaural difference in speech recognition alone.

**DISCUSSION**

As stated previously, the two binaural tasks (monaural direct vs binaural and monaural indirect vs binaural) have been shown to result in different degrees of binaural advantage. The binaural advantage over the monaural direct situation typically is small, perhaps 3 to 6 dB at best. The binaural advantage over the monaural direct conditions in this study ranged from 2 to 4 dB for four of the five subjects. Although these results are entirely consistent with the degree of binaural advantage usually achieved by normal listeners, it represents a small difference in performance between the monaural and binaural conditions. Therefore, the reliability of the results from the monaural direct versus binaural condition was explored.

Several procedural variables associated with reduced variability/increased reliability, including practice prior to testing, the use of highly reliable speech stimuli (the NST), a closed-set experimental paradigm, and the use of an adaptive procedure for approximating target criterion performance (50%), were employed in the investigation. With respect to the adaptive procedure, Dirks et al (1982) demonstrated that it is most effective when stimuli that are equally intelligible are used. According
to Dubno and Dirks (1982), the NST is highly reliable, not only across trials but also across specific syllable confusions, for hearing-impaired listeners. Since the experimental procedures were designed to reduce variability, it seems reasonable that the small binaural advantages over monaural direct are in fact reflective of a true difference in performance across monaural direct and binaural conditions and not measurement error.

The purpose of this investigation was to describe the relationship between interaural differences in speech-recognition performance and binaural advantage for speech in noise for five hearing-impaired listeners. Since no conclusive relationship could be established between interaural difference in speech recognition and binaural advantage, further analysis was performed to determine qualitatively if other audiologic characteristics, including low-frequency sensitivity (normal or impaired), speech-recognition ability in the poor ear (fair or poor), or hearing aid configuration history (better ear or poorer ear) could be related to binaural advantage. However, no trends between these characteristics and binaural advantage were revealed.

It was noted that two subjects (S4 and S5) had a "normal" binaural advantage in the monaural direct versus binaural condition (4 dB and 2 dB), but did not achieve a comparable degree of binaural advantage in the monaural indirect versus binaural condition. The two conditions for measuring binaural advantage may in fact test different aspects of the auditory system. That is, although both of the experimental conditions were designed to measure binaural advantage, the importance of monaural (peripheral) processing and binaural (central) processing to each condition probably was different. In a monaural direct versus binaural condition, binaural advantage results from a lessening of the masking effect of the competing noise (Koenig, 1950). Here, the binaural system must combine the inputs so that the signal and competition from each ear may be perceived as being spatially separate intracranially. In a monaural indirect versus binaural condition, binaural advantage primarily results from the increase in S/N at a "functioning" ear when the head shadow is eliminated. In this investigation, for the monaural direct condition, the speech and noise recorded at the near ear (which would result in a positive S/N) were presented to the better ear of the subjects. In the binaural comparison condition, the speech and noise from the far ear (resulting in a negative S/N) were added to the poorer ear. This condition may be conceptualized as presenting "audible" speech to the better ear (monaural direct) and adding "noisy" speech to the "noisy" ear (binaural). For these subjects, when the inputs from both ears were combined, even the "noisy" ear contributed to the squelching of the competing noise since binaural advantage was achieved. However, presenting "noisy" speech to the better ear (monaural indirect) and adding "audible" speech to the poorer ear (binaural) did not result in the binaural advantage typically occurring when the head shadow is eliminated, suggesting that the binaural advantage of adding "audible" speech may be discounted when processed through a poor peripheral system.

A primary goal of this investigation was to relate the results to hearing aid fitting strategies. Although the results from the subjects were diverse and no conclusive relationship between interaural difference and binaural advantage was seen, some binaural advantage was achieved for the majority of the subjects, ranging from 2 dB to 12 dB under various test conditions. The finding that some hearing-impaired listeners with interaural differences did retain some binaural advantage for speech in noise is significant because it is evident that even small improvements in the S/N may be of substantial benefit to hearing-impaired listeners, particularly in "typical" listening situations involving sentence material (Plomp, 1986). This would indicate that binaural hearing aids would provide an advantage for speech in noise for these patients. Additionally, other binaural advantages, such as loudness summation and localization, also may be retained as these tasks may be less dependent upon disruption in the frequency domain.

**SUMMARY**

The relationship between interaural difference in speech recognition and binaural advantage for speech in noise was studied for five subjects with symmetrical pure-tone thresholds and significant interaural differences in speech recognition. All subjects repeated nonsense syllables in noise in monaural direct, monaural indirect, and binaural comparison conditions, and binaural advantage was calculated as the difference in S/N that afforded 50 percent correct performance in the monaural and binaural conditions. Although the results were diverse and no conclusive relationship
between interaural difference and binaural advantage could be documented, a majority of the subjects were able to achieve some binaural advantage in various test conditions. This being the case, binaural amplification should prove beneficial for those patients in typical communicative situations. Since the number of subjects who participated in this study was small, further research is indicated to substantiate the findings with a larger group of hearing-impaired listeners exhibiting interaural differences in speech recognition.


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**REFERENCES**


