0196-0202/81/0205-0194$02.00/0
Ear and Hearing
Vol. 2, No. 5
Printed in U.S.A.

Demonstration of Binaural Advantage in Audiometric Test Rooms

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ABSTRACT

Binaural advantage was measured for 12 normally hearing subjects in a typical rectangular audiometric test room with a loudspeaker located in each corner. Four different loudspeaker configurations for presentation of signal and competition were evaluated. The results indicated that a configuration in which uncorrelated competition was delivered from both sides of the subject while the signal was presented from a 0° azimuth was the most resistant to interaural asymmetries resulting from the room geometry and produced the most consistent binaural advantages. Binaural advantage was then measured using this loudspeaker configuration for 15 hearing-impaired individuals wearing hearing aids. Although the group results indicated a mean unaided binaural advantage only slightly smaller than seen in the normal hearers, when hearing aids were worn an interaural asymmetry in a signal-to-competition ratio developed that reduced the clinical usefulness of the data for individuals. This outcome emphasizes that a valid clinical demonstration of binaural advantage is critically dependent on interaural symmetry in signal-to-competition ratios for both aided and unaided tests. Such symmetry may be difficult to achieve in a typical audiometric test room.

After it became feasible to wear hearing aids at ear level rather than on the body, many investigators addressed themselves to the question of whether speech could be better understood by persons wearing binaural hearing aids than by persons with monaural amplification. Twenty years later, it is evident that the answer to this question is critically dependent on the conditions prevailing for monaural and binaural listening. In recent years, numerous investigations have been reported which demonstrated that when test conditions include: (1) a relatively poor signal-to-competition ratio, and (2) signal and competition emanating from different azimuths; hearing-impaired individuals, taken as a group, perform better on speech intelligibility tests when wearing binaural ear-level hearing aids than with monaural head-worn amplification (5–7, 11, 13, 14, 20, 22). Little or no doubt currently exists on this issue.

Because speech is the most important signal to be processed by hearing aids, whether monaural or binaural, most investigators have used speech test material in attempts to demonstrate binaural advantages. However, it has been consistently found that only a modest binaural improvement is seen in group averages, and that the intrasubject test-retest variability of the measuring instrument, (usually a 25- or 50-item monosyllabic word list) is relatively large (18).

Because of the variability in repeated speech discrimination tests (6, 16), some investigators have suggested that insistence on a demonstrable binaural advantage in clinical hearing aid selections is unrealistic and that all hearing-impaired persons should be regarded as candidates for binaural amplification unless there is evidence to the contrary (1, 3, 15). However, this point of view has not been widely adopted in audiological management for various practical reasons. A need continues to exist for a procedure which can be used with some confidence in a clinical setting to test whether a binaural hearing aid fitting is more advantageous than a monaural fitting for a particular individual. This paper reports the results from two investigations that were performed to explore some of the issues involved in objective demonstration of binaural advantage in a typical clinical setting.

In these investigations, the term binaural advantage was defined as encompassing the effect labelled "binaural squelch factor" by Carhart (4). This binaural advantage is demonstrated when a binaural score is compared to a monaural score obtained with the path of the signal to the listening ear unperturbed by head shadow. Inasmuch as the head shadow effect has been repeatedly demonstrated (11, 12, 21) and is, consequently, fairly predictable, it seemed unnecessary to include a measure of this factor.

EXPERIMENT I

Dirks and Wilson (7) and MacKeith and Coles (10) have reported data showing the considerable effect of azimuths of signal and competing message on the measured binaural advantage for speech signals. The purpose of the first investigation, therefore, was to select which of several loudspeaker configurations resulted in the maximum consistent difference between binaural and monaural performance for normally hearing subjects in a sound-treated audiometric test room.

Method

Loudspeaker Configurations The investigation was conducted in a typical 7 ft × 9 ft double-walled, sound-treated room. (Industrial Acoustics Corp., 1200 series.) Four loudspeaker configurations were used for the presentation of test and competing signals. These are illustrated in Figure 1.

In the condition designated C1 both test signal and competition were presented from the same loudspeaker at a 0° azimuth to the subject.

In the C2 condition, the signal and competition were presented from opposite sides of the subject. For monaural testing in this condition, the test signal was always adjacent to the open or listening ear. Because the test signal was always presented from the same loudspeaker, it was necessary to orient the left ear monaural subjects as shown in C2a and the right ear monaural subjects as shown in C2b. Because the room was rectangular rather than square, this resulted in actual signal and competition azimuths of ±52° and ±41° for left monaural and right monaural subjects, respectively.

In the C3 condition the test signal was presented from the loudspeaker at a 0° azimuth to the subject and the competition was presented from the loudspeaker at 180° azimuth.

In the C4 condition the test signal was presented from the 0° azimuth loudspeaker and uncorrelated competition was presented from loudspeakers adjacent to each ear. The actual azimuths of these two loudspeakers were −75° and +105° for the left and right ears, respectively.

Subjects and Stimuli Twelve young adults with bilaterally-symmetrical normal hearing served as subjects.

The test stimuli were three prerecorded lists of Northwestern University auditory test no. 6 which had been shown to yield equivalent performance for normal hearers (17). Four randomizations of each list were used.

The competing message was a locally produced six-talker speech babble, the long term average spectrum of which closely resembled published speech spectra (2).

Calibration for test and competing stimuli was achieved in terms of the overall sound pressure level (SPL) of a speech-shaped noise recorded at the level of the average peaks as seen on a VU meter and measured at the presumed center of the subject's head with the subject absent.

Instrumentation A block diagram of the instrumentation is shown in Figure 2. The test words were replayed on channel I of a Revox A-77 tape recorder and routed to the signal loudspeaker via a Grason-Stadler 1701 audiometer and a power amplifier. Channel II of the Revox tape recorder and both channels of the Viking 433 tape recorder were used to present the competing message to the remaining three loudspeakers as needed in the various signal/competition configurations.

Electronic weighting was used to equalize the frequency responses of the four loudspeakers.

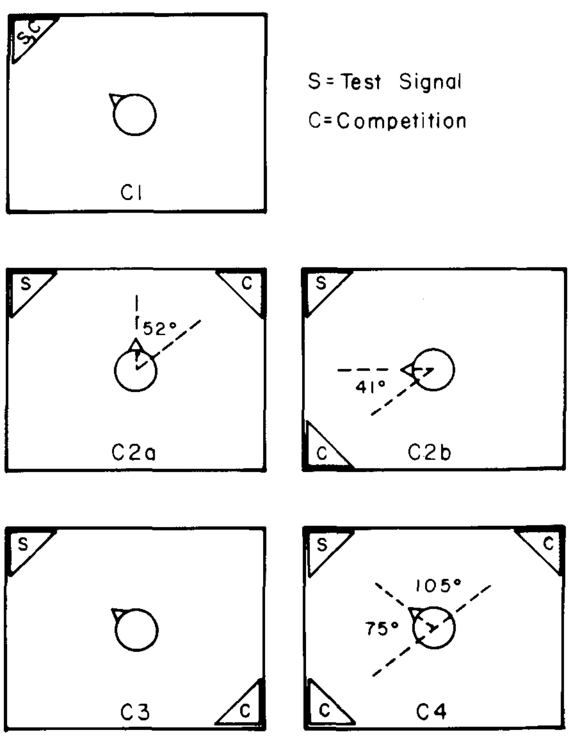

Figure 1. Arrangement of loudspeakers delivering signal (S) and competition (C) in the configurations used in the study.

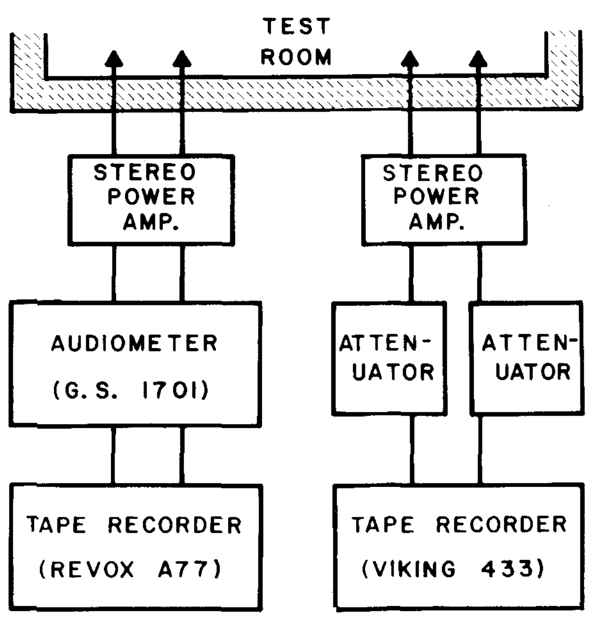

Figure 2. Diagram of instrumentation

Procedure Subjects were seated in the center of the room and oriented in the appropriate direction. No head restraint was employed, but the subjects were instructed not to move their heads.

Each subject responded to a 50-item word list in all four loudspeaker configurations at each of three signal-to-competition ratios. The test words were always presented at a level of 65 dB SPL. The three levels of the competing message were chosen for each loudspeaker configuration to produce a range of scores which would all fall on the linear portion of the performance-intensity function. Thus, for a given loudspeaker configuration, the same three signal-to-competition ratios were presented to all subjects. However, the three nominal signal-to-competition ratios differed across loudspeaker configurations. Subjects responded to all conditions both monaurally and binaurally. In the monaural condition six subjects listened with their left ears and six with their right ears.

Subjects were rendered monaural by the use of a circumaural earmuff covering an insert earphone (coupled to an earmold impression) which presented a broadband masking noise to the non-test ear at 30 dB effective level. A pilot study indicated that the masking noise had no significant effect on the word discrimination score obtained in the contralateral ear.

All experimental variables were counterbalanced or randomized. Written responses were obtained.

Results and Discussion

The subjects' responses were scored according to percentage of words correct and percentage of phonemes correct. Since the two methods of scoring yielded essentially identical results, only the results for word scoring will be reported.

Grouped Data To compare the results with those reported by other investigators, the average binaural "squelch" effect for each configuration was expressed in terms of the equivalent improvement in signal-to-competition ratio at the 50% discrimination score level as described by Carhart (4). The average binaural squelch effects were 1.9 dB, 4.5 dB, 4.0 dB, and 4.3 dB in the C1, C2, C3, and C4 configurations, respectively. These data are in good agreement with previously reported studies employing similar loudspeaker configurations in which signals were presented to subjects who were permitted minimal head movement (4, 10, 11, 13, 14). However, in the analysis of the results, it became obvious that there was a difference between monaural right ear and monaural left ear scores. In spite of the equalization of the loudspeaker responses, and the careful location of the subject in the center of the room, a subject's right ear was, evidently, placed less advantageously than his left ear. As a result, subjects who listened monaurally with the right ear obtained a poorer score, on the average, than subjects who listened monaurally with the left ear. This led to the outcome of an apparently greater binaural advantage for the right-monaural subjects.

Measurements on real ears and KEMAR of the actual signal-to-competition ratios at the two ears confirmed that there was a measurable interaural disparity in signal-to-competition ratios in the C2 and C3 configurations.

In the C2 conditions this outcome was seen to be due to a difference in the head shadow effect when the signal and competition were presented at azimuths of $\pm 41°$ compared to $\pm 52°$. (This change in head shadow effect is equivalent to that which would be observed if the subject's position were moved a total of 17 inches while listening to loudspeakers located seven feet apart.) The result was a difference in effective signal-to-competition ratio in the monaurally tested ear in the C2a and C2b conditions leading to a superior average score for the left monaural condition.

In the C3 configuration, the poorer signal-to-competition ratio for the right ear was attributable to the rectangular shape of the room and the placement of loudspeakers in the corners. In this arrangement, a subject seated in the center of the room and oriented on a diagonal between the two loudspeakers was placed 7° off axis to the right of the front loudspeaker and to the left of the back loudspeaker. Due to the directivity of the loudspeakers at higher frequencies, this slightly off-axis location resulted in a slight drop in level of the high frequency components of the signal to the right ear and a corresponding slight drop in level of the high frequency components of the competition to the left ear.

Measurements for the C4 configuration did not reveal measurable interaural difference in signal-to-competition ratio.

A four-way analysis of variance (right monaural versus left monaural $\times$ configurations $\times$ binaural/monaural listening $\times$ signal-to-competition ratios) with repeated measures on the last three factors (9, p. 298) was performed to test the significance of the binaural advantages measured for right monaural and left monaural subjects. Post hoc analyses were performed using tests of simple main effects (9, p. 263).

The binaural squelch obtained in the various conditions is shown in Table 1. Seven of the eight binaural squelch effects tested were statistically significant at ≤ 0.03 level regardless of the ear used for the monaural test.

Individual Data The data for the individual subjects were analyzed to determine whether the binaural/monaural differences observed in the various configurations exceeded the 95% critical differences for 50-item word tests applying a binomial model as described by Thornton and Raffin (18). This model is applicable in the evaluation of a binaural advantage which is expressed in terms of word discrimination score difference. When the binaural score exceeds the monaural score by more than the critical difference there is a 95% (or better) probability that the obtained difference represents a real effect due to the addition of the second ear. The four analyses are depicted in Figure 3. Any data point which falls below the shaded area represents a subject whose binaural advantage exceeded the 95% critical difference. Right-monaural and left-monaural subjects are shown using different symbols. In all four speaker/competition configurations, all 12 subjects obtained a measurable binaural advantage. However, in the C1 configuration eight subjects did not exceed the critical difference. In the C2 and C3 configurations three subjects did not exceed the critical difference; and in the C4 configuration one subject did not exceed the critical difference.

Table 1. Binaural squelch obtained in various conditions[a]

Loudspeaker Configuration	Monaurally Tested Ear	
	Right	Left
C1	1.6	2.1[b]
C2	6.0[c]	4.6[c]
C3	6.2[c]	1.8[b]
C4	5.5[c]	3.2[c]

[a] *Mean binaural squelch (equivalent improvement in signal-to-competition ratio) in dB for normally hearing subjects for four loudspeaker configurations. Results for right-ear monaural and left-ear monaural groups are shown separately.*

[b] $p \leq 0.03$.

[c] $p \leq 0.01$.

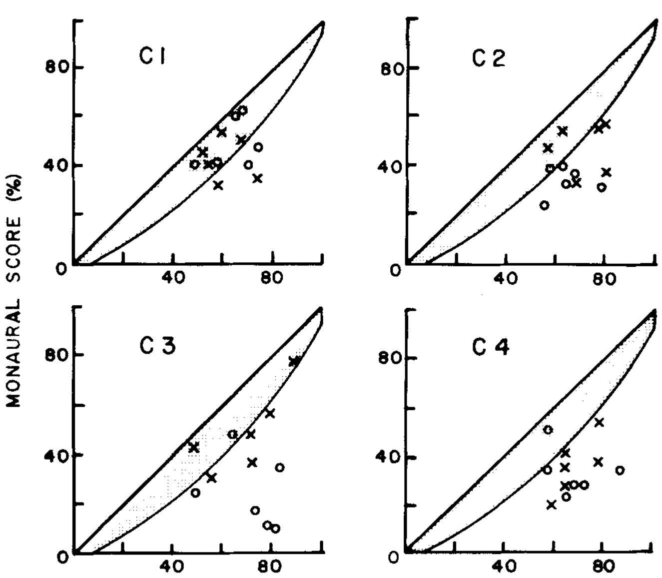

Figure 3. Fifty-item binaural and monaural discrimination scores for 12 normally hearing subjects in each of four loudspeaker configurations. *Data points* below the shaded area represent subjects demonstrating a significant binaural advantage ($p < 0.05$). ×, left ear monaural subject; O, right ear monaural subject.

Conclusion The most striking outcome of this investigation was the demonstration of the significant interaural disparity in signal-to-competition ratios which may result from quite small asymmetries (or changes) in the location of the subject with respect to the loudspeakers. Such disparities would invalidate a clinical comparison of monaural with binaural listening.

Of the four arrangements investigated, the one in which uncorrelated competition was presented simultaneously from two side loudspeakers (the C4 configuration) seemed to be the most resistant to the effects of slight deviations in interaural symmetry. With this test configuration, binaural performance was significantly superior to monaural performance on both a group and an individual basis regardless of which ear was used for the monaural test, and there was no measurable difference in signal-to-competition ratios at the two ears.

EXPERIMENT II

The purpose of the second experiment was to ascertain whether the binaural advantage observed for normal hearers in the C4 test configuration would also be displayed by hearing-impaired individuals during aided listening.

Method

Subjects Fifteen hearing-impaired subjects aged 25 to 80 years with a mean age of 57 served in the study. All subjects had a bilateral sensorineural hearing loss of mild-to-severe extent. In the frequency range from 500 to 4000 Hz, five subjects had flat audiometric configurations, three had gently sloping configurations (less than 10 dB/octave), five had sharply sloping configurations (10 to 20 dB/octave) and two had configurations which dropped 23 dB/octave. One subject had an asymmetric hearing loss with configurations for the two ears 15 to 20 dB apart. All other subjects had symmetric hearing losses.

None of the subjects had previously worn binaural hearing aids, but seven used monaural hearing aids for 4 or more hours a day.

Stimuli and Instrumentation The test signals, competing messages, and instrumentation were the same as used in the first experiment.

Procedure

Hearing Aid Fitting. Three pairs of over-the-ear hearing aids were used in the study. All had forward-facing, omni-directional microphones; adjustable gain and maximum output; and low frequency tone controls. Each subject was fitted with two different pairs of hearing aids for this study. All hearing aids were coupled to standard, unvented earmolds. Each pair of hearing aids was adjusted in the following way: initial gain and tone control adjustments were made on the basis of the pure tone thresholds; both hearing aids were then placed on the subject's ears and adjusted for preferred listening level and equal loudness while the subject listened to a recording of continuous discourse at 65 dB SPL in a sound-treated audiometric test room; the positions of the volume controls were noted; functional gain was then measured for each hearing aid with the opposite ear plugged and muffed. The objective was to provide functional gain equal to approximately one-half of the hearing loss at 1 kHz, 2 kHz, and 4 kHz. If the unaided hearing threshold at 500 Hz was 25 dB HL or better, no gain was intentionally provided at this frequency. If the unaided threshold was poorer than 25 dB HL an amount of gain up to half the hearing loss was permissible as long as the aided threshold was no better than 25 dB. No gain was intentionally provided at 250 Hz for any subject. In the final fittings, the mean functional gain across all subjects and hearing aids, expressed as a percentage of hearing loss was 26% at 500 Hz, 51% at 1000 Hz, 45% at 2000 Hz, and 39% at 4000 Hz. Maximum outputs of experimental hearing aids were not reduced unless the subjects expressed discomfort while listening in the sound treated room. All subjects judged both pairs of hearing aids to be subjectively acceptable in this environment.

Determination of Signal-to-Competition Ratio. Each subject's aided word discrimination score in quiet was estimated using a 50-item monosyllabic word list while the subject wore one pair of hearing aids. Preliminary tests were then performed to determine the signal-to-competition ratio to be used in administration of tests for binaural advantage. The signal-to-competition ratio was selected with the objective that the mean binaural and monaural word discrimination score would be approximately equal to half the binaural score obtained in quiet. The purpose of this procedure was to place both the binaural and monaural scores on the linear portion of that subject's performance-intensity function so as to obtain the maximum separation between them. The signal-to-competition ratios selected individually for each subject varied from +10dB to 0 dB.

Collection of Data. The adjustment and measurement of the hearing aids and the selection of signal-to-competition ratio consumed the initial test session. Each subject returned for at least four more sessions. On each occasion the subject responded to 50-item Northwestern University no. 6 word lists during both binaural and monaural listening against the selected level of the competing message while wearing each pair of hearing aids. During data collection, the performance of five subjects improved to such an extent that the signal-to-competition ratio had to be further reduced by 2 to 5 dB in order to keep the scores close to the desired levels.

The ear chosen for the monaural condition was either the ear currently being used for a monaural hearing aid or the ear the subject judged as "better." Six subjects listened monaurally with their right ears and nine listened monaurally with their left ears. Audiograms for test and non-test ears in the monaural conditions are summarized in Figure 4. During monaural testing, the unaided ear was always plugged and muffed to ensure true monaural listening: this was done to permit a direct comparison with the data from the first experiment.

All experimental variables were either counterbalanced or randomized.

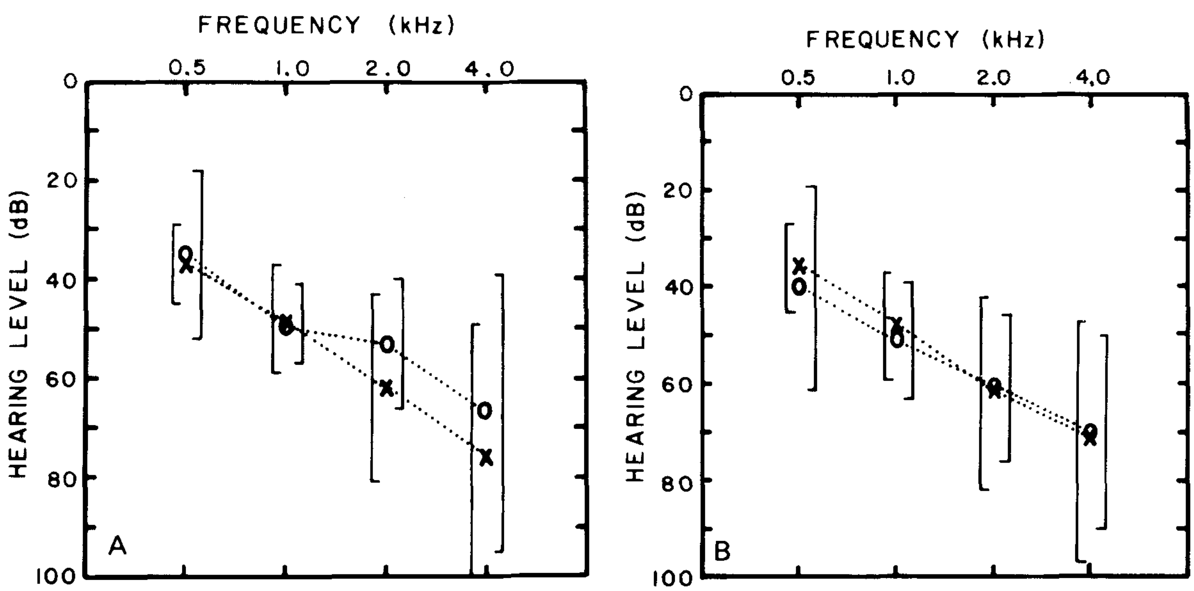

Figure 4. *A*, Mean thresholds for the monaurally tested ear for right ear monaural (O) and left ear monaural (×) subjects. *Brackets*, ± 1 S.D. *B*, Mean thresholds for the non-test ear in the monaural condition. O, right ear monaural subjects; ×, left ear monaural subjects. *Brackets*, ± 1 S.D.

Results and Discussion

Grouped Data Each subject responded to a total of 200 words (four 50-word lists) in both monaural and binaural listening conditions using each pair of hearing aids. The best estimate of the binaural advantage obtained with each pair of hearing aids was calculated as the difference between binaural and monaural word scores for the entire 200 words. For each subject the hearing aid pair showing the greatest binaural advantage was selected for statistical analysis.

The significance of the binaural advantage was tested using an analysis of variance for repeated measures with right monaural and left monaural subjects kept separate (9, p. 279). The results indicated that the binaural advantage was significant at ≤0.02 level for both right monaural and left monaural groups.

A mean binaural advantage of 19% was obtained for the hearing-impaired group compared to a mean advantage of 26% obtained for the normal hearing group in the first experiment. This 7% difference in mean binaural advantage may indicate that hearing-impaired subjects listening to speech processed through hearing aids cannot achieve as much benefit from binaural listening as can normal hearers responding to unprocessed speech. On the other hand, this finding would also be consistent with a decrease in the slope of the performance-intensity function for the hearing-impaired group as observed by Tillman and Carhart (19). This would have the consequence that an effective improvement in signal-to-competition ratio which was equal to that achieved by a normal hearing person would be translated, in the hearing impaired individual, into a smaller percentage difference between binaural and monaural discrimination scores. The ambiguity of this outcome suggests that it would be advisable to express binaural advantage for aided hearing-impaired individuals in terms of equivalent improvement in signal-to-competition ratio rather than as a percentage difference between binaural and monaural scores. This would avoid confounding with the effects of a flattened performance-intensity function and permit a more direct comparison with the binaural advantage achieved by normal hearers under the same test conditions.

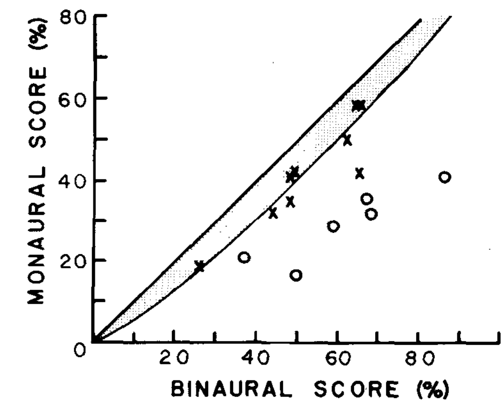

Figure 5. Two hundred-item binaural and monaural discrimination scores for 15 aided hearing-impaired subjects. *Data points* below the shaded area represent subjects demonstrating a significant binaural advantage ($p < 0.05$). ×, left ear monaural subjects; O, right ear monaural subjects.

Individual Data The monaural and binaural 200-word percentage scores for each subject for the better hearing aid pair are shown in Figure 5. The shaded area on this figure shows the 95% critical differences for a 200-item test (18). Any data point which falls below the shaded area represents a subject for whom there is a 95% (or better) probability that the addition of a second hearing aid produced a real improvement in word discrimination performance.

It is readily apparent in Figure 5 that the difference between right monaural and left monaural subjects that was seen in the C2 and C3 configurations for the normal hearing group was also displayed in the C4 configuration for the hearing-impaired subjects: all six right monaural subjects showed a significant binaural advantage compared to only four of the nine left monaural subjects. It seems that the acoustic conditions resulting from this test arrangement exacted a more severe penalty from the hearing-impaired subjects than from the normally hearing subjects in the first experiment.

To further explore this finding, aided signal-to-competition ratio measurements were made for each of KEMAR's ears. This had the effect of measuring the signal-to-competition ratio at the location of the hearing aid microphone opening rather than at the entrance to the ear canal. The result of the measurement is shown in Figure 6. These data show that in the aided condition there was a clear difference between the two ears in signal-to-competition ratio even though no measurable difference existed in the unaided condition. This difference was almost certainly responsible for the apparently greater binaural advantage experienced by the hearing-impaired subjects who were tested monaurally using the

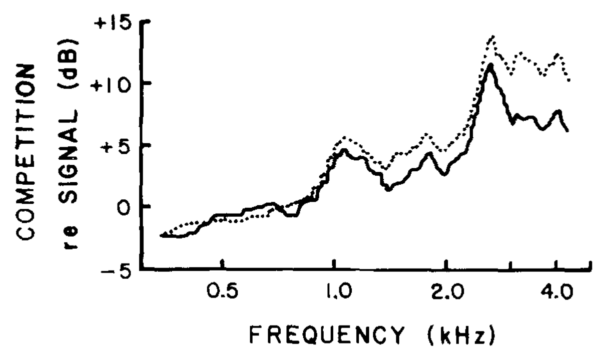

Figure 6. Spectrum of competition relative to spectrum of test signal (nominal signal-to-competition ratio = 0 dB) at the eardrum position of an aided KEMAR manikin. ····, Right ear; —, left ear.

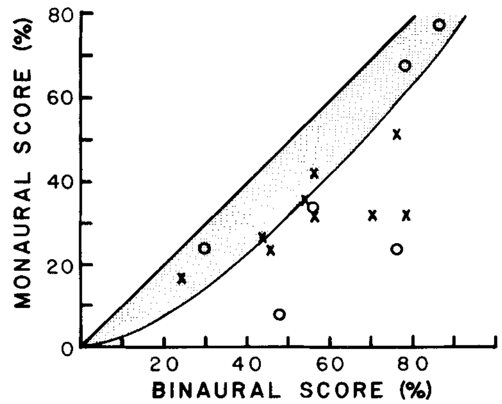

Figure 7. Initial 50-item binaural and monaural discrimination scores for 15 aided hearing-impaired subjects. *Data points* below the shaded area represent subjects demonstrating a significant binaural advantage ($p < 0.05$). ×, Left ear monaural subjects; ○, right ear monaural subjects.

right ear. Further analyses indicated that this interaural asymmetry in signal-to-competition ratio had a much more potent effect on the apparent binaural advantage than age of subjects, binaural discrimination score in quiet, functional gain in the added ear, greatest functional gain in either ear, binaural advantage for 50-item lists on the first day of testing, previous hearing aid experience, or any combinations of these factors.

If the significance of the individual binaural advantages had been judged on the basis of the first 50 items tested rather than the full 200 items; the results would have been much less clear-cut. Figure 7 shows the monaural and binaural percentage scores obtained by each subject with the better hearing aid pair for the initial binaural and monaural 50-item lists. These data indicate that approximately half the right monaural and half the left monaural subjects showed a significant binaural advantage on the first day of testing. A comparison of Figures 5 and 7 suggests that a period of experience with binaural and monaural listening produced considerable changes in performance for some subjects. This is substantiated by the observation that a figure showing the monaural and binaural scores for the last pair of 50-item lists has essentially the same appearance as Figure 5. This finding is consistent with the suggestions of Hedgecock and Sheets (8) and Nabelek and Pickett (13) concerning the possible effect of previous experience with binaural listening on the measured binaural advantage.

As noted earlier, each subject was tested with two pairs of hearing aids both fitted in the same way. This procedure allowed a check on possible interactions between hearing aids and binaural advantage. The results revealed that most subjects achieved similar binaural advantages with both pairs of hearing aids. However, four subjects achieved a significant binaural advantage with one pair of hearing aids, but not with the other pair. There was no obvious common factor across these subjects which would serve as a basis for a hypothesis to explain this result.

Conclusions The following conclusions were drawn on the basis of these results:

1. A valid test of binaural advantage cannot be performed unless the testing situation is configured in such a way that the signal-to-competition ratios at the two ears are virtually identical for both the aided and unaided conditions. Furthermore, demonstration of interaural equality in signal-to-competition ratio for one set of testing conditions (e.g., unaided listening) does not ensure that a similar equality will exist in other testing conditions (such as aided listening).
2. The physical test arrangement used in the second experiment could not be satisfactorily employed to test the advantages of binaural amplification for individual hearing-impaired subjects because of the interaural inequality of signal-to-competition ratios, which apparently resulted from the shape of the room and the corner placement of loudspeakers. This outcome seems to indicate that a typical rectangular audiometric room with corner loudspeakers is an inherently unsatisfactory acoustic environment for demonstration of binaural advantage.
3. It is important to provide potential candidates for binaural amplification with a period of time for adjustment to binaurally aided listening before testing the binaural advantage obtained.

References

1. Bentzen, O. 1980. Psychological aspects of patients with binaural hearing aids. Audiology **19,** 202–204.
2. Byrne, D. 1977. The speech spectrum—some aspects of its significance for hearing aid selection and evaluation. Br. J. Audiol. **11,** 40–46.
3. Byrne, D. 1980. Binaural hearing aid fitting: research findings and clinical application. in E. R. Libby, ed. *Binaural Hearing and Amplification.* Vol. II, Zenetron Inc., Chicago.
4. Carhart, R. 1965. Monaural and binaural discrimination against competing sentences. Int. Audiol. **4,** 5–10.
5. Causey, G. D., and D. R. Bender. 1980. Clinical studies in binaural amplification. in E. R. Libby, ed. *Binaural Hearing and Amplification.* Vol. II, Zenetron Inc., Chicago.
6. Dermody, P., and D. Byrne. 1975. Variability in speech test performance for binaural hearing aid valuations. National Acoustic Laboratories, Report No. 62.
7. Dirks, D. D., and R. H. Wilson. 1969. The effect of spacially separated sound sources on speech intelligibility. J. Speech Hear. Res. **11,** 5–38.
8. Hedgecock, L. D., and B. V. Sheets. 1958. A comparison of monaural and binaural hearing aids for listening to speech. Arch. Otolaryngol. **68,** 624–629.
9. Kirk, R. E. 1968. *Experimental Design: Procedures for the Behavioral Sciences.* Brooks/Cole, California.
10. MacKeith, N. W., and R. R. A. Coles. 1971. Binaural advantages in hearing of speech. J. Laryngol. **75,** 213–232.
11. Markides, A. 1977. *Binaural Hearing Aids.* Academic Press, New York.
12. Moncur, J. P., and D. D. Dirks. 1967. Binaural and monaural speech intelligibility in reverberation. J. Speech Hear. Res. **10,** 186–195.
13. Nabelek, A. K., and J. M. Pickett. 1974. Monaural and binaural speech perception through hearing aids under noise and reverberation with normal and hearing-impaired listeners. J. Speech Hear. Res. **17,** 724–739.
14. Olsen, W. O., and R. Carhart. 1967. Development of test procedures for

evaluation of binaural hearing aids. Bull. Prosthet. Res., Spring, 22–49.

15. Ross, M. 1977. Binaural versus monaural hearing aid amplification for hearing impaired individuals. in F. H. Bess, ed. *Childhood Deafness*. Grune and Stratton, New York.
16. Shore, I., R. C. Bilger, and I. J. Hirsh. 1960. Hearing aid evaluation: reliability of repeated measurements. J. Speech Hear. Dis. **25**, 152–170.
17. Sommerville, S. 1967. An investigation of the University of Oklahoma recordings of the modified N.U. auditory test #6. M. S. thesis, University of Oklahoma.
18. Thornton, A. R., and M. J. Raffin. 1978. Speech-discrimination scores modelled as a binomial variable. J. Speech Hear. Res. **21**, 507–518.
19. Tillman, T. W., and R. Carhart. 1966. An expanded test for speech discrimination utilizing CNC monosyllable words: Northwestern University test no. 6. USAF School of Aerospace Medicine SAM-TR-66-55.
20. Tillman, T. W., R. Carhart, and W. O. Olsen. 1970. Hearing aid efficiency in a competing speech situation. J. Speech Hear. Res. **13**, 789–811.
21. Tillman, T. W., R. N. Kasten, and J. S. Horner. 1963. Effect of head shadow on reception of speech. ASHA J. Am. Speech Hear. Assoc. **5**, 778–779.
22. Zelnick, E. 1970. Comparison of speech perception utilizing monotic and dichotic modes of listening. J. Aud. Res. **10**, 87–97.

Acknowledgments: The authors wish to thank Danavox, Inc., Siemens Hearing Instruments, Inc., and Widex Hearing Aid Company, Inc. for supplying the hearing aids used in experiment 2.

A portion of this work was presented at the annual meeting of the American Speech-Language-Hearing Association, November 1979.

This work was supported in part by the Memphis State University Faculty Research Grant fund and in part by the National Institute of Neurological and Communicative Disorders and Stroke of the National Institutes of Health (NS15996).

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