AZIMUTH EFFECTS WITH EAR LEVEL HEARING AIDS[a]

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The existence of the head shadow and head baffle has long been recognized by workers in the field of audition. Individuals with unilateral hearing losses are being counseled concerning the many drawbacks of one-eared listening. The difficulty most often discussed is the problem that results from having the one good ear frequently located within the azimuth range that includes the acoustic shadow cast by the head. When this situation occurs, the one-eared listener is told that he can expect added difficulties in his communicative tasks. Sounds coming from the side of the bad ear would be reduced in intensity before they could reach the good ear. Thus, any time the desired signals emanate from the side of the head contralateral to the good ear, an undesirable decrease in signal strength occurs. At the same time, it is also anticipated that messages originating on the side of the head homolateral to the good ear would receive some signal enhancement as a result of the head baffle and resonant characteristics of the ear canal.

With the advent of ear level hearing aids, the considerations of these azimuth effects became even more important. Under these circumstances, the aided ear was one that was already impaired and the added decrement in performance introduced by the head shadow served to sharply limit the efficiency of the amplifying device.

Experimental attempts to quantify these azimuth effects and their influence over both aided and unaided signal reception were first reported almost 35 years ago. The early work of Sivian and White (1) dealt with the effects exerted by the shadow and baffle upon pure-tone thresholds. With the subject's test ear located within the acoustic shadow cast by the head, thresholds were depressed in a fairly systematic manner, the effect reaching its maximum in the azimuth range

[a] Based on work performed for the Prosthetic and Sensory Aids Service under the Intra-VA Prosthetics Research Program.

in which the head was fully interposed between the sound source and the test ear. Conversely, a systematic enhancement of threshold was seen when the test ear was located homolateral to the sound source. Both shadow and baffle effects tended to increase in magnitude with an increase in frequency.

Using an artificial head with calibrated microphones at the positions of the tympanic membranes, Nordlund and Liden (2) noted similar irregularities in interaural intensity differences as a function of azimuth.

Nordlund and Fritzell (3) employed the same artificial head to examine the influence that azimuth effects exerted upon speech intelligibility in the presence of competing noise. Relative to performance with the head facing the sound source, the head baffle effect tended to provide a slight improvement in intelligibility, while the head shadow yielded a relative decrement in performance of 21 to 23 percent.

Tillman, Kasten, and Horner (4) found that the shadow effect served to attenuate the sound field spondee threshold by 6.4 dB for normal listeners positioned between two loudspeakers located at 45 deg. on either side of the midline of the head.

The influence of azimuth upon aided speech intelligibility was examined by Kasten and Tillman (5) using speech materials recorded through hearing aids mounted on an artificial head. They found the head shadow produced a decrement in performance of 29 percent for hearing-impaired listeners when compared to their performance on materials recorded with the aid positioned at the ear favorably located with respect to the loudspeaker. In contrast to Nordlund and Fritzell (3), Kasten and Tillman (5) did not observe a head baffle effect as evidenced by a systematic improvement in intelligibility scores.

Both Temby (6) and Lybarger and Barron (7) used hearing-aid microphones attached directly to the skin of their subjects' heads to examine azimuth effects. Their findings, although differing in absolute magnitude, revealed similar patterns. The head baffle effect tended to increase the output of the hearing-aid microphones from 2 to 6 dB in the speech frequencies, while the shadow effect attenuated the outputs at frequencies above 1000 Hz.

The present study was designed as an attempt to clarify the discrepancies noted in the previous investigations. It was felt that a further evaluation of the effects of the head shadow and head baffle was warranted using actual ear level hearing aids rather than hearing aid microphones alone.

PROCEDURES

An artificial head was constructed by Mr. Joseph Coppolino, Restorations Service, Veterans Administration Prosthetics, New York, Center in New York. The head, shown in Figure 1, was made from a life mask and consisted of a hard plastic core covered by a layer of vinyl plastisol which reasonably simulates the acoustic properties of a human head, coupled to 2 cc coupler, and tested in positions representing imbedded at each ear so that the outer face of the coupler approximated the position of the outer face of an earmold as worn by a hearing aid user. Thus, ear level hearing aids could be placed on the head, coupled to the 2 cc coupler, and tested in positions representing those encountered in actual use.

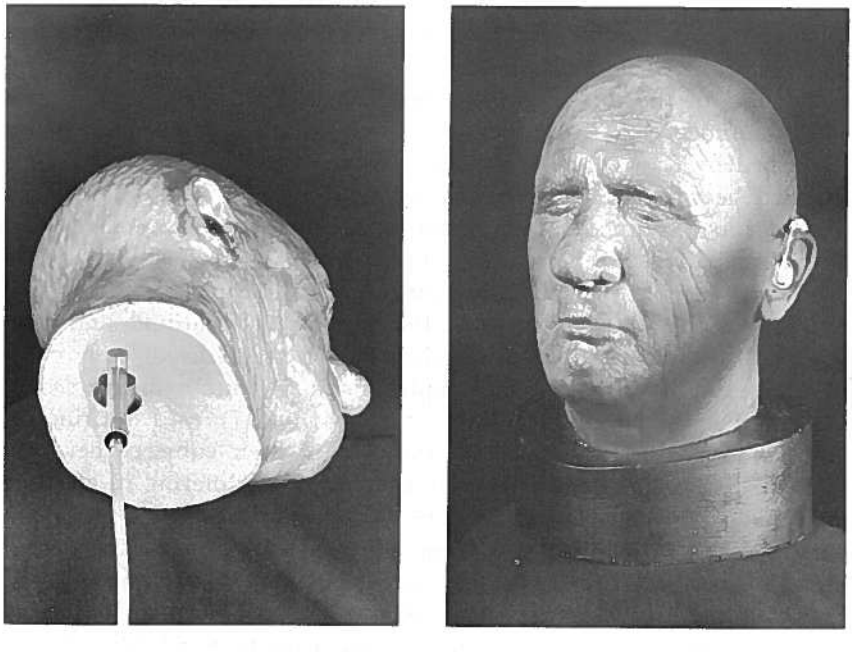

FIGURE 1.—Artificial head showing hearing aid in place for measurement and interior connections leading from 2 cc coupler.

The interior connections necessary to complete the coupler assembly are also shown in Figure 1. These connections included the 2 cc coupler, a 1 in. to ½ in. adapter, a ½ in. condenser microphone, a T-connector, and a ½-in. cathode follower. The cable of the cathode follower dropped through the base of the head and led to an audio frequency

spectrometer, the output of which drove a level recorder equipped with 360 deg. polar paper. The artificial head was positioned on a polar turntable which moved in synchrony with the level recorder and the polar paper. In this way, as the head was moved through 360 deg., the hearing-aid output was traced while a true relationship was maintained between the azimuth angle of the head and the tracing position of the polar paper. The entire head assembly was placed in a 4-ft.-cube anechoic chamber with the head positioned 39 in. from the sound source.

The pure-tone signals were fed from a beat frequency oscillator, through appropriate amplifiers and attenuators, to a loudspeaker located within the anechoic chamber. The input signals were maintained at 60 dB SPL [sound pressure level], initially measured at the point in space occupied by the head but with the head absent from the field.

Four different hearing aids were examined. Aid #1 was an eyeglass instrument with the microphone located in front of the ear and oriented downward. Aid #2 was an over-the-ear instrument with the microphone on the back of the aid and oriented toward the rear of the head. An over-the-ear instrument with the microphone located on the top of the aid and oriented directly forward was designated aid #3. Finally, #4 was an eyeglass aid with the microphone located behind the pinna but oriented in a forward direction. The gain of each aid was set well below maximum in order to preclude reaching saturation sound pressure level.

Measurements were initiated at the lowest frequency at which a stable response could be obtained from the aid. The next test frequency was 500 Hz, and subsequent measurements were obtained at 250 Hz intervals until the high frequency cutoff of the aid was reached. Each measurement at a discrete frequency consisted of one continuous 360 deg. rotation of the head with the accompanying tracing of the hearing aid output on the polar paper.

In all cases, the rotation began with the head facing directly toward the sound source, a condition designated 0 deg. azimuth. At the condition designated 90 deg. azimuth, the head was fully interposed between the sound source and the hearing aid. At 180 deg. the head was facing directly away from the sound source, while at 270 deg. the hearing aid was positioned on the side of the head adjacent to the loudspeaker.

RESULTS

The azimuth effects introduced by the head can be seen in the series of tracings shown in Figures 2a and 2b. These tracings, showing hearing-aid output as a function of azimuth, were made using aid #1.

The polar paper had a 50 dB range, and for each frequency, 0 deg. azimuth is located at the top of the tracing. The 90 deg. azimuth is found on the right side of each tracing, and between 0 and 180 deg., which is located at the bottom of the tracing, the head was interposed, at least in part, between the sound source and the aid. It is in this half of each tracing that the head shadow effects are revealed. Conversely, on the left side of the tracing the aid was more favorably positioned relative to the sound source, so the head baffle effects are apparent.

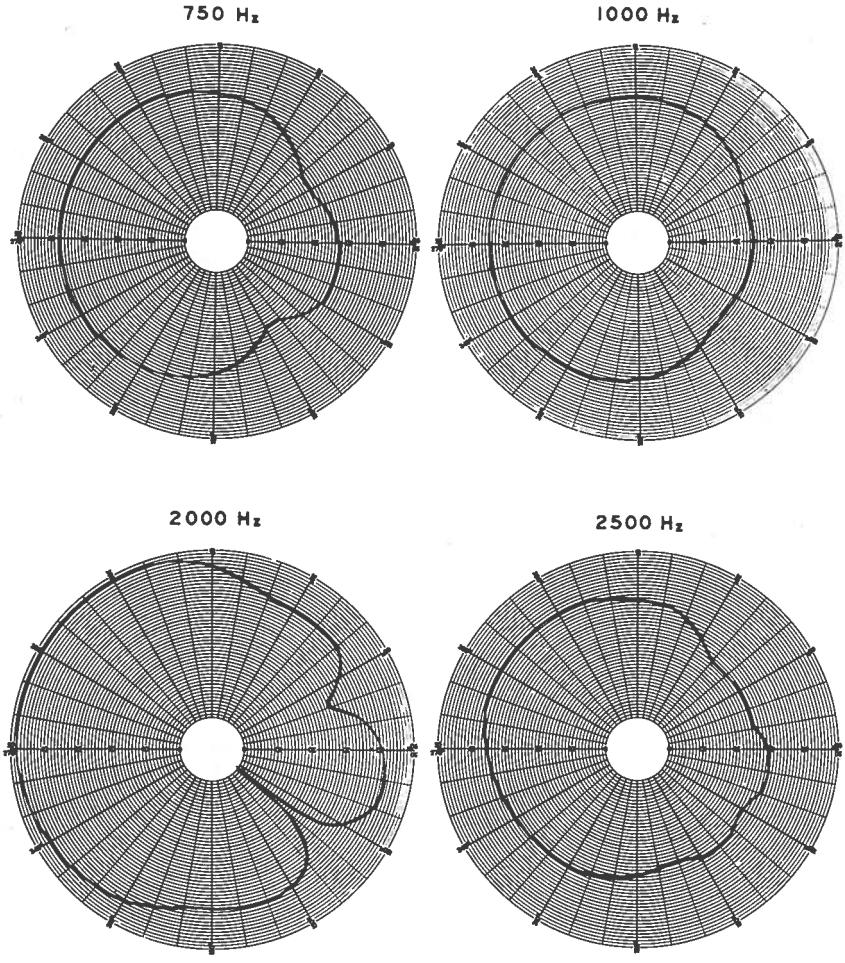

FIGURE 2a.—Polar tracings of hearing-aid output. IN EACH TRACING: Top—0 deg., head facing sound source; right—90 deg., head fully interposed between aid and sound source; bottom—180 deg., head facing directly away from sound source; left—270 deg., aid on same side of head as sound source.

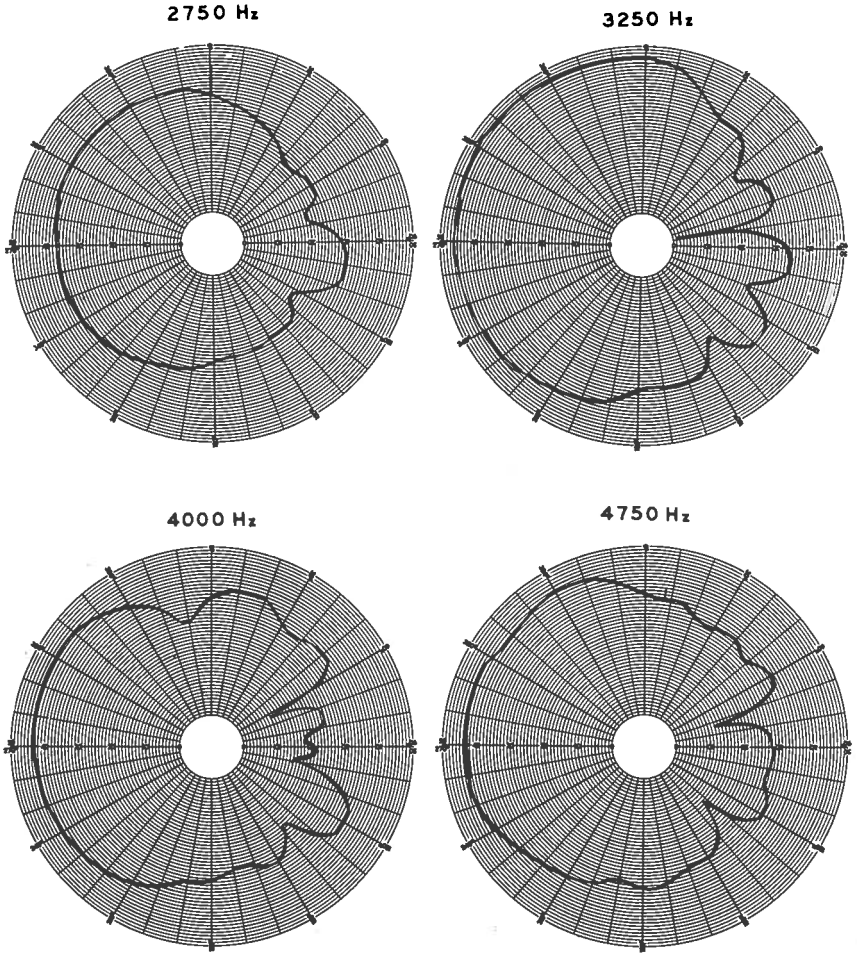

FIGURE 2b.—Polar tracings of hearing-aid output. IN EACH TRACING: Top—0 deg., head facing sound source; right—90 deg., head fully interposed between aid and sound source; bottom—180 deg., head facing directly away from sound source; left—270 deg., aid on same side of head as sound source.

The influence of the head shadow on the output of this aid is readily apparent. The signal erosion evident on the right side of the tracings indicates the magnitude of the shadow effect. Note that as frequency increases, the output of the aid showed multiple sharp dips as a function of azimuth. These tended to be most pronounced in the azimuth range from 60 to 150 deg. In addition, the magnitude of the overall deterioration in the hearing-aid output tended to increase with an increase in frequency.

When the head had turned sufficiently so that the aid was located

on the side homolateral to the loudspeaker, i.e., in the range from 210 to 330 deg., the output became relatively flat and uniform. The output tended to be quite stable between 180 and 360 deg. at frequencies below 2500 Hz.

Figure 3 gives the relationship between the sound pressure level developed at the microphones of the four aids (as reflected by output) and the sound field SPL at four azimuth settings. When the head faced directly toward the sound source, the 0 deg. azimuth condition, the general tendency was toward a sound pressure level at the face of the microphones which was slightly lower than the sound field SPL. Below 1250 Hz, the output of aid #1 was greater than that of the others and throughout most of this range equaled or exceeded the sound field SPL. Beyond 3250 Hz, aid #3, with the forward facing microphone located above the ear, tended to show the highest output. In this frequency region a spread of as much as 14 dB existed between instruments.

At the 60 deg. azimuth setting, where the head shadow effects were greatest, all four aids showed a deterioration in output as a function of frequency. Below 1000 Hz, the mean attenuation from the head shadow was 4.7 dB, and this progressively increased to 14.5 dB between 3000 and 4000 Hz. Beyond this frequency band, the mean effect was 10.5 dB. While the magnitude of this deterioration varied considerably among the aids, the general trend remained the same. Aid #2 tended to maintain the highest output beyond 1500 Hz although aid #3 also performed highly beyond 3500 Hz. In this high-frequency region, the outputs of aids #1 and #4 generally fell well below those of the other two aids.

The 180 deg. azimuth showed a more predictable set of relationships. Beyond 1500 Hz, the output of aid #1 was clearly lower than that of the others. Considering the placement of the microphone, however, you would anticipate this response. Aids #3 and #4 were similar in their outputs and the overall response of these two aids was slightly lower than that obtained in the sound field. Clearly, the highest output was found with aid #2. This also would be anticipated since, at 180 deg., the microphone of this instrument pointed directly toward the sound source.

At the 270 deg. azimuth the four aids again displayed slight differences. Aids #1 and #2 were quite similar and showed some mild enhancement of SPL at the microphone face over the sound field. Aid #4 tended to show the lowest overall performance at this azimuth. Beyond 1000 Hz, the SPL at the microphone face was generally lower than that measured in the sound field. Aid #3, the over-the-ear instrument with the forward facing microphone, tended to show the highest response relative to the sound field, particularly above 3500 Hz. At this

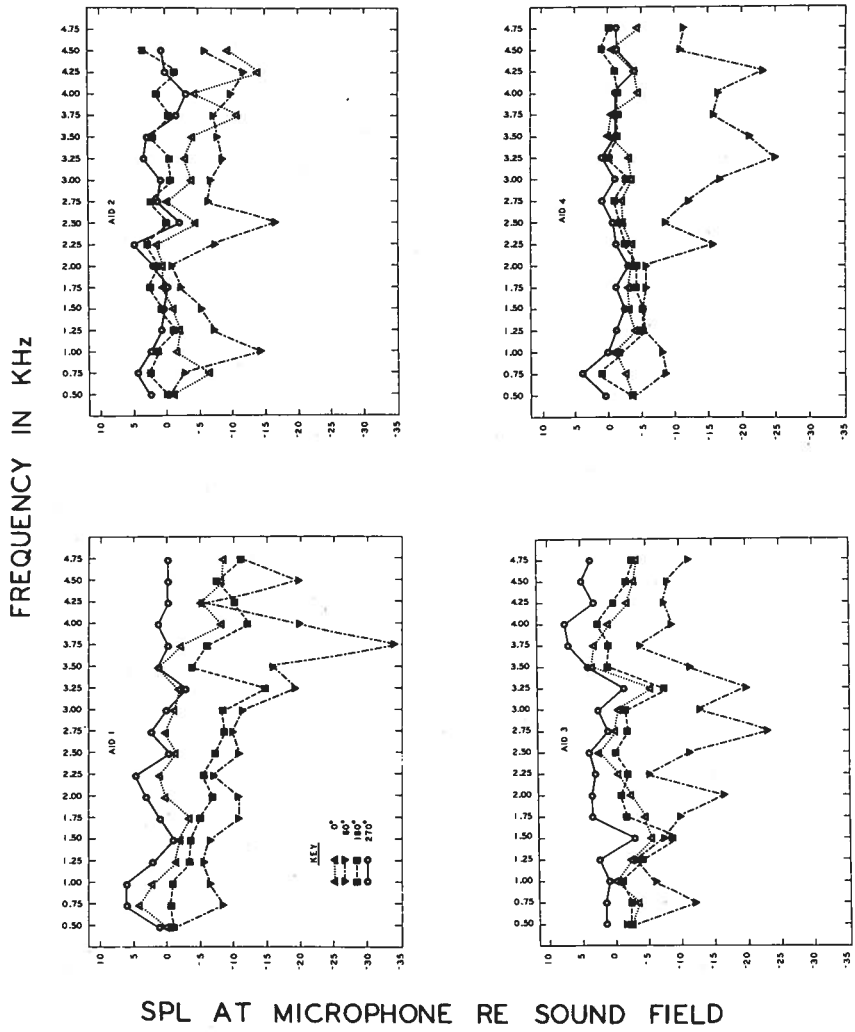

FIGURE 3.—SPL at microphone faces at four azimuth settings plotted relative to sound field SPL.

azimuth, the SPL developed at the faces of the hearing aid microphones generally equaled or slightly exceeded the sound field SPL.

To obtain a more meaningful set of azimuth relationships for each aid, a replot of the response data was accomplished using the 0 deg. azimuth position as a reference. In so doing, the aids have been equated arbitrarily in the way in which a user would equate them, i.e., adjusting them to some criterion of equality suitable for face-to-face (our 0 deg. azimuth condition) communication. Plotting the data in this

way permits direct examination of the differences between the aids under conditions in which they might be worn.

Figure 4 shows the hearing-aid outputs at three azimuth settings as a function of frequency relative to the output at 0 deg. azimuth. The differences among the four instruments are immediately more apparent. At the 60 deg. setting, for example, the over-the-ear aid with the rearward facing microphone, aid #2, had markedly greater output than the others beyond 2750 Hz. This increase in output, seen at each azimuth setting, is the direct result of the response of this aid at the 0 deg. setting (Fig. 3). At 0 deg., this aid showed slightly less output beyond 3000 Hz than the others. Therefore, when its response was plotted at different azimuths relative to 0 deg., an apparent increase in output was noted within this frequency range. At this same azimuth, the other three clearly differed across the frequency range, but tended to show the same pattern of output. Significantly, these three instruments had microphones that were located either in front of the ear or were oriented toward the front of the head.

An even more clearly defined set of output relationships can be seen at the 180 deg. azimuth. Again, aid #2, with the microphone oriented rearward, delivered a consistently higher output than the others. At the same time, aid #1, the eyeglass with the microphone located in the temple in front of the ear, produced a uniformly lower output across the frequency range. Between these two extremes, aids #3 and #4 tended to show the same pattern of response, both closely approximating the 0 deg. reference level.

At the 270 deg. azimuth, a clear differentiation among the aids was difficult. Once again, aid #2 developed a higher output beyond 2750 Hz. The remaining three instruments tended to display approximately equivalent response patterns. Between 500 and 3500 Hz, they showed a mean baffle effect of 2 to 4 dB. Beyond this point, aids #1 and #3 increased to approximately 7.5 dB while aid #4 varied between —1 and 4 dB.

DISCUSSION

In the fitting of monaural ear level hearing aids, the head shadow, and to a lesser degree the head baffle, should be considered in the clinical management of each patient. These phenomena will be present in virtually all acoustic environments and a more complete understanding of their influences will assist the hearing-aid user in his rehabilitative regimen.

The present results tend to support those findings from previous psychoacoustic investigations that the head shadow will degrade aided performance on speech acuity and speech intelligibility tasks. It is also

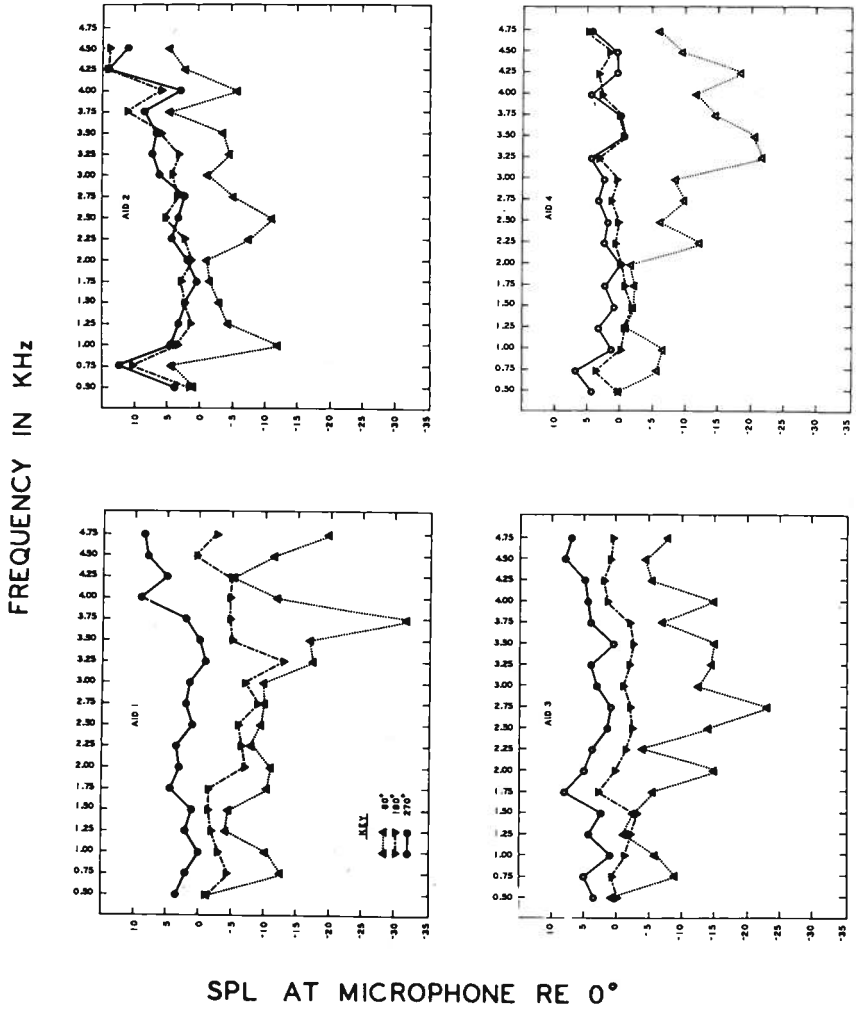

FIGURE 4.—SPL at microphone faces at three azimuth settings plotted relative to the SPL values at 0 deg.

apparent that similar patterns appeared among the four aids while they were within the acoustic shadow cast by the head. The magnitude of the signal degradation varied from instrument to instrument, though the patterns were similar. When computed at the azimuth angles, representative of the speech frequencies, the overall shadow effect was in close agreement with the 6.4 dB reported by Tillman, Kasten, and Horner (4). Additionally, when the mean shadow effect is considered throughout the full range of amplification, the overall influence that it can exert upon speech signals becomes obvious. The 29 percent

decrement in aided speech intelligibility reported by Kasten and Tillman (5) can be readily appreciated when the magnitudes of the shadow effects are examined, the effects being particularly marked in the higher frequencies.

The head baffle effect, as evidenced by a signal enhancement when the aid was located on the side of the head homolateral to the sound source, did not reach the magnitudes anticipated on the basis of real ear measurements. In fact, when the sound field sound pressure levels were compared with the SPL developed at the face of the hearing-aid microphones, the difference was generally less than 5 dB and often approximated 0 dB. This general trend toward a minimal signal enhancement would also tend to support the findings of Kasten and Tillman who noted that, under conditions simulating aided listening, the baffle effect does not provide systematic improvement for speech intelligibility as a function of azimuth. It would appear, on the basis of the instruments used in this investigation, that the conventional sound field measurements of response characteristics closely approximate the maximum responses obtainable with the aids in a baffled position. Instruments with a forward located or forward oriented microphone received some mild help from the baffle effect but all others tended to show near maximum response in the sound field situation.

The specific role to be played by microphone placement or orientation remains to be resolved. Examination of Figures 3 and 4 reveals that those instruments with the forward located or oriented microphones were clearly superior in reducing the transmission of unwanted sound emanating from the rear of the head. At the same time, however, these aids were most severely affected by the head shadow. Aid #2, the instrument with the microphone located in the rear and oriented toward the rear, tended to show an opposite pattern of performance. With this aid, the shadow effect tended to be less pronounced than with the others, but the sounds originating at the rear of the head were transmitted at a higher relative intensity than found with any other aid. The question of microphone placement or orientation, therefore, will have to remain one for individual consideration during any hearing-aid evaluation or fitting. The communicative needs and the acoustic surroundings of each potential hearing-aid user should be evaluated in order to provide that individual with an instrument having a microphone construction appropriate for his requirements.

SUMMARY

An artificial head with 2 cc couplers imbedded at the ear canals was constructed to measure the effects of the head shadow and head

baffle on the output of ear level hearing aids. Four aids, each with a different microphone position and orientation, were mounted on the artificial head and tested. Comparisons were made between the sound pressure level developed at the face of the hearing-aid microphones and the sound field SPL measured at the point in space occupied by the head but with the head absent from the field. The head shadow tended to produce a systematic deterioration of hearing-aid output, particularly above 1000 Hz. The head baffle was present but appeared to have only minimal effect. The influence of hearing-aid microphone position and orientation appears to require consideration in any discussion of the shadow and baffle effects.

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