Department of Veterans Affairs

Journal of Rehabilitation Research
and Development Vol. 27 No. 1
Pages 33–42

The effects of hearing aids on speech discrimination in noise by normal-hearing listeners

Phillip V. McAlister, BE (Elec)
National Acoustic Laboratories, Chatswood, NSW 2067, Australia

Abstract—This investigation measured the degree to which hearing aids degrade speech discrimination in noise. Ten normal-hearing subjects were tested for speech reception thresholds (SRT) in noise. The tests were repeated under two aided conditions: one used binaural behind-the-ear (BTE) aids, the other an experimental binaural high-fidelity aid fitted with in-the-ear transducers. To assess the loss of any directional cues under aided conditions, a test environment producing directional cues in both horizontal and vertical planes was employed. Results indicated a 3 dB deterioration of speech-to-noise ratio for frontal speech with the BTE aids. Despite this, mean SRTs, when averaged over several listening directions, differed by less than 1 dB from unaided levels under both aided conditions. This suggests that improvements in hearing aid fidelity and directional performance beyond that available in current BTE aids will do little to improve speech discrimination in noise, although other benefits may accrue.

Key words: *aided speech discrimination, speech reception threshold (SRT), directional hearing, localization, high-fidelity hearing aids.*

INTRODUCTION

Probably the most commonly stated difficulty with hearing aids is understanding speech in a background of noise. Most people with sensorineural losses require a better speech-to-noise ratio than normal hearers to communicate in a noisy environment (11), so it is vital that a hearing aid does not degrade the prevailing signal-to-noise ratio of the environment and make communication even more difficult.

Early work by Tillman, *et al.,* (14) suggested that the effect on normal-hearing individuals of wearing a hearing aid was equivalent to increasing the masking efficiency of background noise by about 10 dB. Hearing aids have improved considerably since then, but still suffer from internal noise, distortion, uneven frequency response, and reduced bandwidth. Another factor which is harder to quantify, but may degrade the reception of speech for a hearing aid wearer, is reduced discrimination of spatially separate sources. In a typically noisy environment, the speech, and particularly the noise, may come from any direction or combination of directions. If we assume that the normal unaided ear takes full advantage of the spatial distribution of the speech and noise sources to discriminate (13), it is reasonable to ask to what degree a hearing aid degrades directional cues required for this task.

Plomp (11) placed a figure of about 3 dB on the combined effect of non-directional factors (e.g., internal noise and distortion) on speech reception in noise, but more recent work by Duquesnoy and Plomp (3) suggests that a figure less than 1 dB can be expected from a high-quality aid operating at low to moderate gain levels. The effects resulting from directional factors have not been as well-documented in the literature, although several researchers

Address all correspondence and reprint requests to: Phillip V. McAlister, Research Section, National Acoustic Laboratories, 126 Greville Street, Chatswood, NSW 2067 Australia.

DOI: 10.1682/JRRD.1990.01.0033

Journal of Rehabilitation Research and Development Vol 27 No 1 Winter 1990

have investigated the influence of hearing aids on the ability to discriminate spatially separate signals located in the horizontal plane: e.g., Festen and Plomp (4), and Hawkins and Yacullo (6). Their results indicate that hearing aids do little to lessen the advantage offered the unaided ear by spatially separate signals. However, the question of whether this advantage remains for signals spatially separated in the vertical plane seems to have been ignored.

The purpose of this study was twofold. The first objective was to establish the degree to which currently available hearing aids reduce speech discrimination ability in noise for normal-hearing listeners. The protocol adopted for this was to explore aided speech reception in an environment which generated strong directional cues in both horizontal and vertical planes. The results obtained thus reflect any deficiencies hearing aids may have in dealing with directional information, as well as the more commonly considered technical limitations associated with hearing aids (noise, distortion, etc.).

The second objective was to monitor any improvement in aided speech reception resulting from use of an experimental hearing aid designed to minimize the effects of the factors referred to above. The experimental aid, configured from wideband hearing aid transducers connected to a stereo Hi-Fi amplifier, was designed to provide improved fidelity and localization.

Unless the aided and unaided test material is delivered to hearing-impaired subjects at the same level with identical frequency response, speech discrimination results may reflect suitability of frequency response rather than indicate any inherent inadequacy with the hearing aid in question (16). For this reason, it was decided to use normal-hearing adults as subjects in order to isolate with some certainty the extent to which the hearing aid alone is responsible for any decrease in aided discrimination. It was decided that any significant improvement obtained with the experimental Hi-Fi aid would warrant further investigation with hearing-impaired subjects.

METHOD

Subjects

Ten adults with pure tone thresholds below 25 dB sound pressure level (SPL) at audiometric test frequencies between 250 Hz and 8,000 Hz were selected as subjects. The subjects comprised seven males and three females; ages ranged from 23 to 49 years, with a median of 33 years.

Technique and materials

Speech reception threshold (SRT) defines the level at which speech is 50 percent intelligible. SRT in noise, therefore, provides a measure of how well a person performs in a competing environment. For obtaining SRTs in this experiment, it was decided to use an intelligibility estimation technique described by Walker and Byrne (17). Traditional methods, e.g., Plomp and Mimpen (12), and Dubno, *et al.*, (2), rely on the experimenter adjusting the level of speech (presented as meaningful sentences) until the subject performs at the 50 percent level. In contrast, the estimation technique used in this study requires the subject to adjust the level of speech (connected discourse) to the point at which he/she judges half of what is being said is recognizable. The technique is highly reliable, producing test-retest differences with a standard deviation of less than 1 dB, which are similar to those reported for conventional adaptive procedures (17).

Three types of test material were used: speech, noise, and babble. The speech material consisted of a short passage read by a male speaker and frequency-shaped to the long-term spectral characteristics of average speech, as reported by Byrne (1). The competing signals were white noise, shaped to the same spectrum as the speech material, and four-talker babble.

Equipment

A block diagram of the equipment used is shown in **Figure 1**. A small test room was employed. The room was quiet (< 15 dB SPL A-weighted) but displayed some low frequency reverberation. Three loudspeakers were positioned within the room approximately one meter equidistant from the subject's head at different positions in horizontal and vertical planes. This arrangement provided directional cues in three dimensions, rather than two as is usual. It did not aim to provide a basis for detailed analysis of the directional performance of subjects. For convenience, the three loudspeakers are referred to as "front," "side," and "rear," although **Figure 1** reveals their exact position. At any given time one of the loudspeakers produced speech while the other

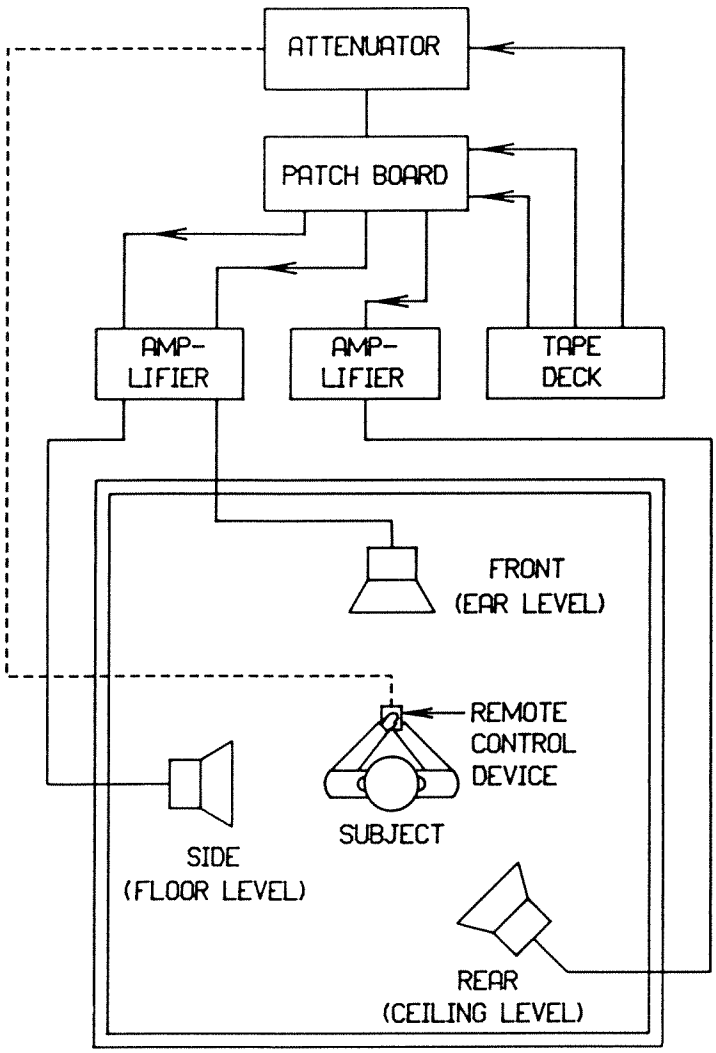

Figure 1.
Block diagram of test arrangement. Note elevation of loudspeakers.

two simultaneously provided independent, competing, signals. Three directional combinations were considered (**Table 1**). During testing, only the presentation level of the speech channel was allowed to vary. This was done by the subject through the use of a remotely controlled custom-built attenuator. The level of the two competing channels was fixed so that the combined SPL at the subject's head remained at a long-term RMS value of 70 dB. All materials were played on a TASCAM 4-track recorder connected to two stereo Hi-Fi amplifiers through a patchboard.

Hearing aids

Binaural, omnidirectional BTE aids were selected for the reference-aided condition. This type of aid, a standard *naso-auricular line* National Acoustic Laboratories' issue for mild to moderate losses, provides a low-noise, low-distortion output within a bandwidth of about 4 kHz and can be considered representative of the range of better quality BTE hearing aids available in the marketplace. It features output-limiting compression, but the relatively low gain used in this experiment (20 dB peak at 3,500 Hz) ensured operation was in the linear region. The tone controls were set in the minimum bass cut position and maximum power output (MPO) control was adjusted for maximum output.

The other aided condition entailed use of an experimental high fidelity binaural aid. Each channel was comprised of a Knowles EA 1934 microphone and ED 1912 receiver connected to one channel of a Leak 20 Watt stereo Hi-Fi amplifier. The aid was found to have a level of internal noise

Journal of Rehabilitation Research and Development Vol 27 No 1 Winter 1990

Table 1.
Distribution of competing program material for the three speech directions under test.

Speech direction	Front speaker	Side speaker	Rear speaker
Front	Speech	Noise	Babble
Side	Babble	Speech	Noise
Rear	Noise	Babble	Speech

and distortion governed only by the transducer limits, as well as a bandwidth extending beyond 12 kHz. The microphone and receiver for each channel, along with a Macrae acoustic horn, were located in a small impedance tip inserted as far as possible into the ear canal of each subject (**Figure 2**). The depth of insertion varied among subjects, but in all cases the microphone was located well within the concha, near the ear canal entrance. A family of gain curves, derived from the coupler response of the aid, allowed calibration of peak gain to that of the BTE reference aids.

The frequency responses of the two aided conditions differed from one another and from the unaided condition. However, as the speech and noise sources all shared the same frequency spectrum shape, it was expected that differences between frequency response alone would have no significant effect upon SRT scores in noise for normal hearers (12). As a checking procedure, three subjects were tested for the condition of the Hi-Fi aid equalized to the BTE frequency response. No significant difference could be measured.

Procedure

At the start of each test session, subjects were asked to adjust the level of speech during each trial

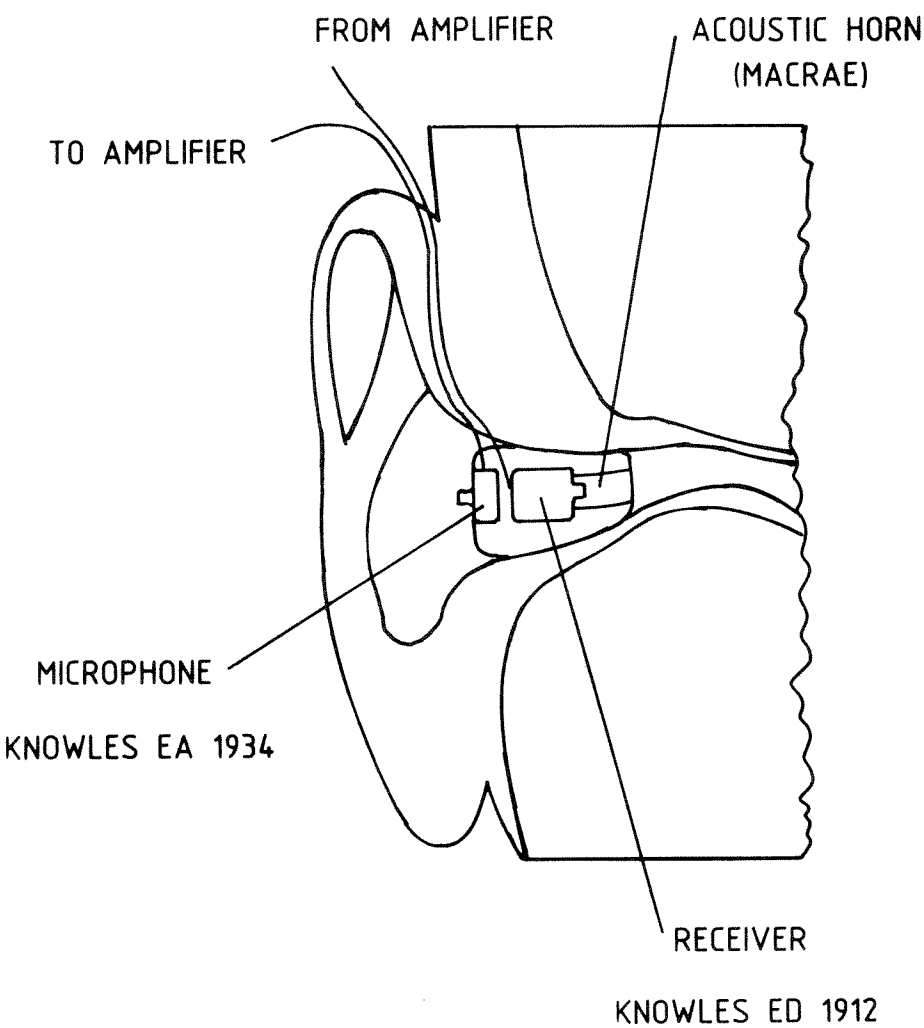

Figure 2.
Transducer arrangement for Hi-Fi aid.

until they could understand about half of what was being said. Each of the ten normally-hearing subjects was tested four times for each of the three speech directions shown in **Table 1**. The procedure was then repeated for the two aided conditions. The first measurement in each direction for each session was discarded, as a slight learning effect was anticipated (17).

RESULTS

An examination of test-retest differences (between replications of the same trial) confirms the repeatability of the SRT estimation technique used in this experiment. The median test-retest difference was measured at 1.2 dB, in exact agreement with the Walker and Byrne (17) data.

Figure 3 provides a summary of the main experimental results. **Figures 4 and 5** present a detailed picture of performance for individual subjects. An analysis of variance (ANOVA) was performed on the complete data. Each factor (listening condition, speech direction, and measurement number) was treated as a repeated measures factor. As each factor supported three levels, a 3 × 3 × 3 analysis was performed.

Main effects

The only factor to provide a main effect was listening condition. As expected, both aided conditions produced higher average SRTs than the unaided condition but the only significant difference ($p<0.05$) to emerge from planned comparisons was a difference of 0.8 dB between the unaided and reference aid conditions. No significant difference could be measured between the Hi-Fi aid and the BTE reference aids or between the Hi-Fi aid and the unaided condition.

Interactive effects

The only significant interactive effect of the ANOVA occurred between listening condition and

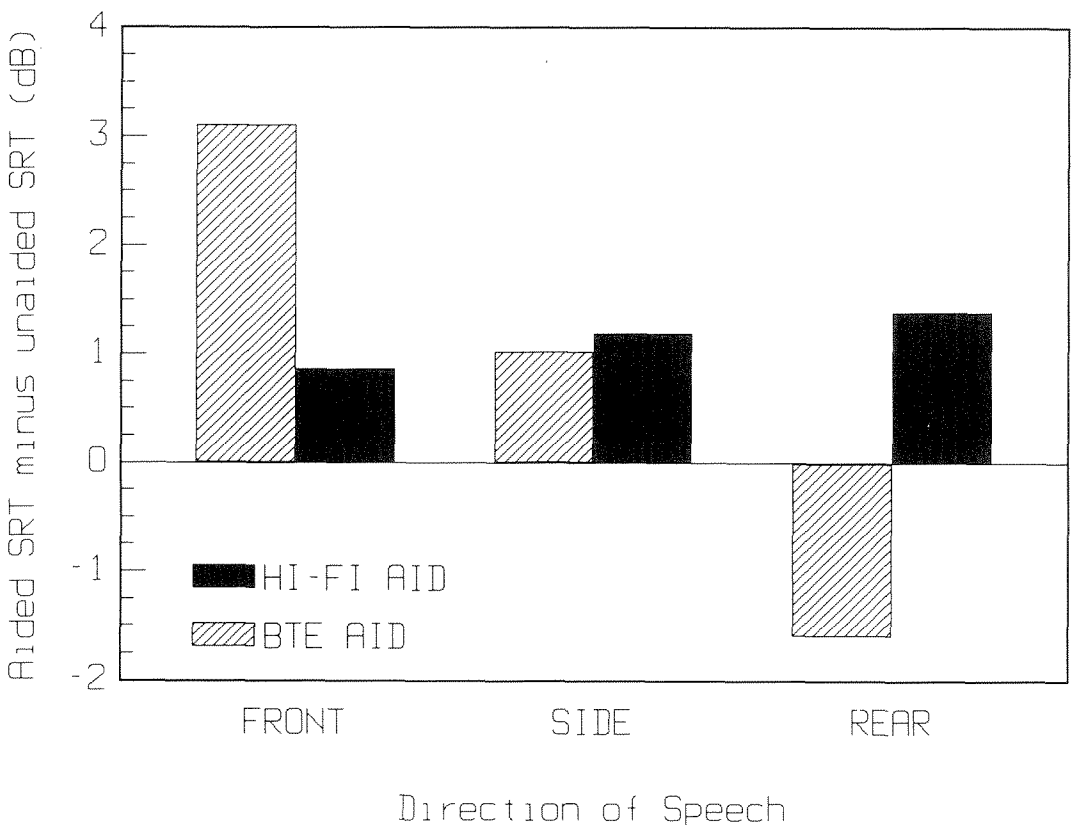

Figure 3.
Changes in SRT for each aided condition. Results pooled across all subjects.

Journal of Rehabilitation Research and Development Vol 27 No 1 Winter 1990

direction ($p<0.00001$). This important result is discussed separately for each aided condition.

Although subjects wearing the reference aids required an average of only 0.8 dB more signal than for the unaided case, the strong dependence on direction is evident from **Figure 3**. In planned comparisons, the standard aids produced statistically significant departures from the unaided scores in all three test directions. With speech coming from the front (the most commonly occurring situation in conversation), the average listener required 3.1 dB more signal to achieve SRT. **Figure 4** shows that all ten subjects recorded higher SRTs for this direction ($p<0.0002$). The situation was reversed for speech coming from the rear. On average, subjects recorded 1.6 dB lower (better) SRTs than the unaided condition. Although not as pronounced as the difference for frontal speech, nine out of ten subjects supported this trend of slightly lower SRT for speech from the rear.

In contrast, the shift in SRT for the Hi-Fi aid is about 1 dB for each of the three directions measured. In planned comparisons, the only statistically significant difference between aided and unaided SRTs for this aid occurred with speech coming from the rear ($p<0.02$).

DISCUSSION

In a strict sense, discussion of the above results should be confined to the three directional combinations investigated. Even the data pooled across directions are misleading because they do not give primary weight to the arrangement most commonly encountered by listeners in conversation, that of speech from the front. Nevertheless, sufficient data have been collected to offer the following comments.

Reference aids

Significant degradation of the speech-to-noise ratio has occurred for frontal speech. This result is predictable from the findings of Kuhn (9) and

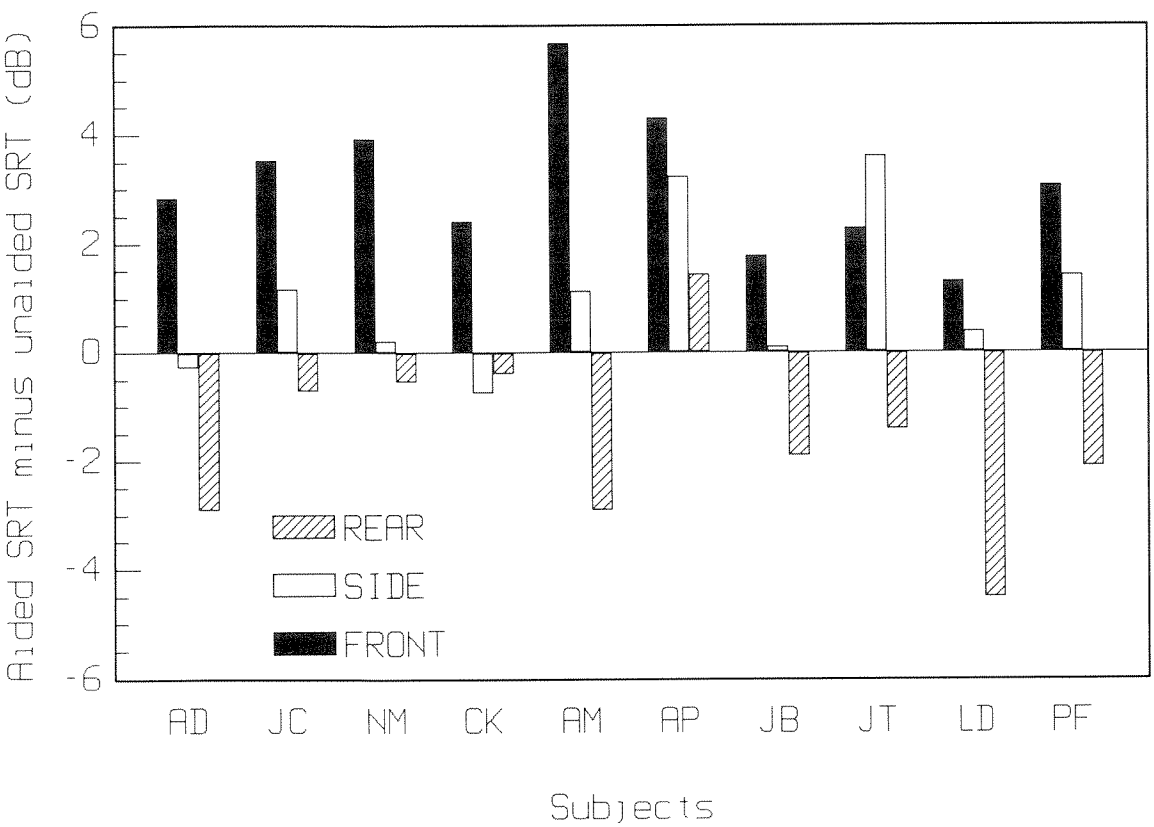

Figure 4.
Changes in SRT for BTE reference aids. Individual subjects shown.

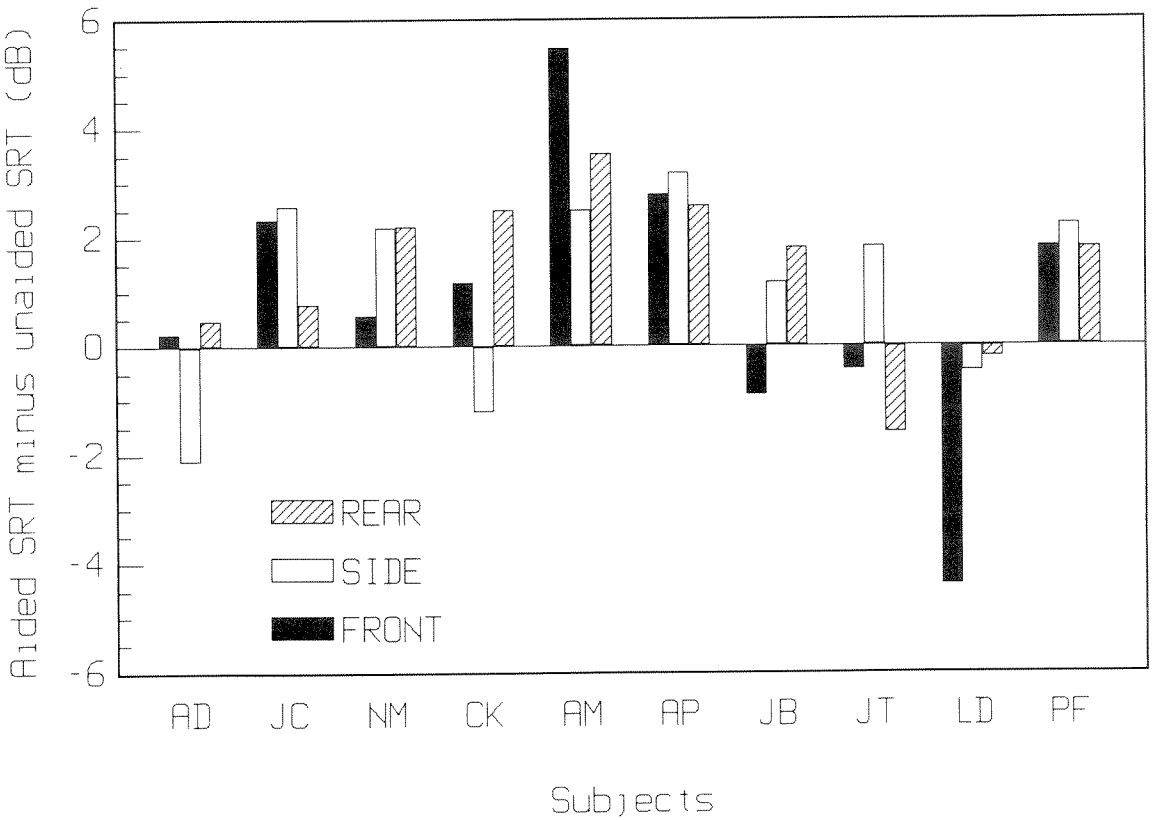

Figure 5.
Changes in SRT for Hi-Fi hearing aid. Individual subjects shown.

others. Physical measurements conducted by Festen and Plomp (4) found that for the condition of frontal speech and lateral noise, moving the microphone from the entrance of the ear canal to the standard BTE position weakened the relative strength of the speech signal by 2 to 3 dB, due to head baffle effects. It is almost certain, therefore, that the elevation of SRT, observed in the current experiment, for frontally incident speech results mainly from the particular microphone placement common to BTE aids. However, when dealing with sentence material, 3 dB may translate to a loss in intelligibility of 35 percent or more in a critical listening situation.

It is likely that subjects experienced impaired localization while wearing the reference aids. This supposition is supported by studies such as Turk (15), Westermann and Topholm (19), and Orton and Preves (10), which report reduced capacity to localize sounds in the horizontal plane (mainly front-rear confusions) when wearing BTE aids. While similar studies do not seem to exist regarding aided localization in the vertical plane, it is known that the cues critical for vertical plane localization reside in the frequency region of 4 to 16 kHz (7,18). As the reference aids used for this study possess negligible gain in this frequency band and BTE microphones are not positioned to take advantage of external ear filtering, it is very unlikely that subjects were able to localize in the vertical plane. Further evidence of impaired localization with the BTE reference aids was provided by comments from listeners participating in this study. Most subjects remarked that when wearing the standard aids, their perception of elevation was absent.

Despite apparently poor localization, subjects lost very little of the advantage gained by spatial separation of sources. Gelfand, *et al.,* (5), found that normal hearers derive about 6 dB advantage from optimal spatial separation of speech and noise sources. If the reference hearing aids used in this current investigation had negated this advantage, one would expect the average SRT scores in the aided condition to be substantially higher than the

Journal of Rehabilitation Research and Development Vol 27 No 1 Winter 1990

unaided condition, and not just a fraction of a decibel higher, as was recorded.

It was expected that the effects of noise, distortion, and restricted frequency response on SRT would be minimal in a well-designed aid. However, it was not anticipated that normally-hearing listeners would perform almost as well with conventional BTE hearing aids, as without them in an environment rich in directional cues. One may argue that only redundant cues have been lost or degraded, but it should be remembered that the SRTs obtained reflect a marginal listening situation. Presumably any redundant cues have been exhausted in reaching a point of 50 percent intelligibility, whether in the aided or unaided condition.

The likely explanation for why SRTs have remained essentially unaltered is that even without vertical plane localization, the reference BTE aids reproduce sufficient directional cues to maintain an adequate perception of spatial separation. These cues, which mainly comprise interaural time and intensity differences, do not require extended bandwidth amplification or concha microphone location to be reproduced.

Hi-Fi aid

An examination of the Hi-Fi aid results in **Figure 3** reveals a small elevation of SRT approximately independent of direction. This is highlighted by the compact appearance of data in the individual results of **Figure 5** when compared to the individual results obtained with the reference aids shown in **Figure 4**. The more balanced pattern of directional sensitivity seen here results from placing the microphone of the Hi-Fi aid in the vicinity of the ear canal entrance. This has ensured that the aided listener receives the same signal-to-noise ratio as the unaided listener, regardless of signal or noise direction.

Indications are that subjects wearing the Hi-Fi aid experienced good localization. The conditions thought to be necessary for accurate horizontal and vertical plane localization (interaural time and amplitude differences, pinna filtering, and wideband amplification) were certainly present and, unlike the BTE aided condition, most subjects were unaware of any disparity between their perceived location of the test loudspeakers and their actual position. Turk (15) found that normally-hearing subjects displayed significantly better directional hearing with a BTE aid when the microphone was externally located near the canal entrance, although it should be noted that his investigation was confined to localization in the horizontal plane.

Comparative performance of Hi-Fi aid and reference aids

Overall results indicate that the combined effect of directional and non-directional factors on SRT in noise amounts to no more than 1 dB for both aided conditions. From this, two conclusions can be drawn.

First, despite the superior amplifier performance of the Hi-Fi aid, the difference between the unaided SRT results and those obtained with the reference BTE aids are so small that any improvement in fidelity is unlikely to be measurable.

Second, although the directional performance of the reference aids may be less than ideal, subjects lost very little of the advantage gained by spatial separation of sources while wearing them, even when sources were located in the vertical plane. Thus any improvement in directional characteristics obtained with the Hi-Fi aid may improve localization but, similarly, will be too small to produce any effect on discrimination performance.

Although this investigation was restricted to normal-hearing subjects, the findings of other studies suggest similar results would be found for hearing-impaired individuals. Festen and Plomp (4) showed that SRT differences (in directional noise) between unaided and binaurally-aided hearing-impaired subjects could be accounted for by BTE microphone placement alone. Hawkins and Yacullo (6) found that, although SRT in noise scores were higher for hearing-impaired subjects, the advantage they derived from binaural aids in listening to spatially separate sources was the same as that for normal hearers. Given that normal hearers were unable to extract any benefit in a marginal listening environment from the improved fidelity and localization offered by the Hi-Fi aid, it is unlikely that hearing-impaired individuals could.

Implications for hearing aid design

The results obtained with the reference aids for frontally-incident speech underscore the need for BTE hearing aid design to focus on improving sensitivity for signals from this direction. This can be achieved by external microphone placement near

the ear canal entrance or by the use of directional microphones. It is difficult to quote a figure on the typical benefit obtainable from directional microphones, but 3 to 4 dB improvement can be expected from binaural aids in low and moderately reverberant environments (6). This advantage, however, barely outweighs the inherent disadvantage that results from positioning the microphone in the orthodox BTE location above the pinna. It would be more useful, if not practical, to employ an omnidirectional microphone near the canal entrance and offer the wearer the benefits of pinna filtering. Low-profile in-the-ear (ITE) aids and canal aids represent a practical attempt in this direction, but performance in other areas is compromised (15). As well as improving sensitivity to frontal speech, correct microphone placement restores a more balanced pattern of directional sensitivity. While such an improvement carries no guarantee of improved discrimination other than for frontal speech, it may significantly improve the overall utility of a hearing aid in everyday life (8).

On the surface, the results of the Hi-Fi aid indicate that little is to be gained from improving the fidelity of the hearing aid signal. This conclusion should be tempered by several considerations. First, at higher drive levels, fidelity becomes an important factor in speech discrimination as conventional hearing aid amplifiers, even those with compression circuitry, develop distortion. Second, high fidelity, wide bandwidth amplification is necessary for transmission of directional cues originating in the vertical plane. Third, the improved quality of the signal can contribute to increased user satisfaction.

SUMMARY AND CONCLUSIONS

Based on the results of speech reception thresholds in noise for normal hearers, there is no evidence that improving the fidelity of amplification beyond that offered in a current BTE aid will improve speech discrimination in noise although other benefits may be realized. Currently available high-quality hearing aids essentially reproduce the signal-to-noise ratio of the environment in which they are placed. Inappropriate microphone placement may prejudice the amplification of signals in certain directions, but overall, hearing aids do not impede the processing of spatially separate signals. It is the inability of the hearing aid to correct for the effects of sensorineural loss that causes so much user dissatisfaction in a noisy environment.

ACKNOWLEDGMENTS

Thanks are due to Denis Byrne and John Macrae for helpful comments on an earlier draft of this manuscript.

REFERENCES

1. **Byrne D:** The speech spectrum: Some aspects of its significance for hearing aid selection and evaluation. *Br J Audiol* 11:44-46, 1977.
2. **Dubno JR, Dirks DD, Morgan DE:** Effects of age and mild hearing loss on speech recognition in noise. *J Acoust Soc Am* 76(1):87-96, 1984.
3. **Duquesnoy AJ, Plomp R:** The effect of a hearing aid on the speech-reception threshold of hearing-impaired listeners in quiet and noise. *J Acoust Soc Am* 73(6):2166-2173, 1983.
4. **Festen JM, Plomp R:** Speech-reception threshold in noise with one and two hearing aids. *J Acoust Soc Am* 79(2):465-471, 1986.
5. **Gelfand SA, Ross L, Miller S:** Sentence reception in noise from one versus two sources: Effects of aging and hearing loss. *J Acoust Soc Am* 83(1):248-256, 1988.
6. **Hawkins DB, Yacullo WS:** Signal-to-noise ratio advantage of binaural hearing aids and directional microphones under different levels of reverberation. *J Speech Hear Disord* 49(3):278-286, 1984.
7. **Hebrank J, Wright D:** Spectral cues used in the localization of sound sources on the median plane? *J Acoust Soc Am* 56:1829-1834, 1974.
8. **Killion MC:** Transducers, earmolds and sound quality considerations. In *The Vanderbilt Hearing-Aid Report,* G.A. Studebaker and F.H. Bess (Eds.), 104-111. Upper Darby, PA: Monographs in Contemporary Audiology, 1982.
9. **Kuhn GF:** Some effects of microphone location, signal bandwidth, and incident wave field on the hearing aid input signal. In *Acoustical Factors Affecting Hearing Aid Performance (Perspectives in Audiology series),* G.A. Studebaker and I. Hochberg (Eds.), Baltimore, MD: University Park Press, 1980.
10. **Orton JF, Preves DA:** Localization ability as a function of hearing aid microphone placement. *Hear Instr* 30(1):1821, 1979.
11. **Plomp R:** Auditory handicap of hearing impairment and the limited benefits of hearing aids. *J Acoust Soc Am* 63(2):533-549, 1978.
12. **Plomp R, Mimpen AM:** Improving the reliability of testing the speech reception threshold for sentences. *Audiology* 18:43-52, 1979.
13. **Plomp R, Mimpen AM:** Effect of the orientation of the

speaker's head and the azimuth of a noise source on the speech-reception threshold for sentences. *Acustica* 48:325-328, 1981.

14. **Tillman TW, Carhart R, Olsen WO:** Hearing aid efficiency in a competing speech situation. *J Speech Hear Res* 13:789-811, 1970.
15. **Turk R:** A new hearing aid variant; Preliminary evaluation. *Scand Audiol* 16:179-85, 1987.
16. **Van Tasell DJ, Yanz JL:** Speech recognition threshold in noise: Effects of hearing loss, frequency response, and speech materials. *J Speech Hear Res* 30:377-386, 1987.
17. **Walker G, Byrne D:** Reliability of speech intelligibility estimation for measuring speech reception thresholds in quiet and in noise. *Aust J Audiol* 7(1):23-31, 1985.
18. **Watkins AJ:** Psychoacoustical aspects of synthesized vertical locale cues. *J Acoust Soc Am* 63(4):1152-1165, 1978.
19. **Westermann S, Topholm J:** Comparing BTEs and ITEs for localizing speech. *Hear Instr* 36(2):20-24, 36, 1985.