

The noise problem: There's hope

By Mead C. Killion, PhD

In an excellent paper published some years back, Plomp¹⁷ discussed the problems experienced by a hearing aid wearer listening in noise and concluded that hearing aids had an "essentially limited applicability." While holding both Plomp and that paper in high regard, this author respectfully disagrees with his essentially pessimistic conclusion. This review presents a more optimistic conclusion.

The problem

Anyone dealing with the hearing impaired has heard the common complaint "I can't understand when its noisy or when more than one person is talking at a time." Even people with normal hearing sometimes have that problem, of course, but in a series of studies in the 1960s, Olsen and Carhart¹² and Carhart and Tillman³ demonstrated that older people with sensorineural hearing loss required some 14 dB greater separation between the level of the desired talker's voice and the level of a competing talker's voice than did normal hearing subjects. Fig. 1 illustrates the average of the intelligibility functions they obtained for normal and impaired listeners, both of whom were listening to loudspeakers in a sound field. Similar findings were reported by Plomp and his colleagues. More recently, Dirks, Morgan and Dubno⁴ found that some hearing-impaired subjects required up to 30 dB greater signal to noise ratio even when the desired speech was very loud, as shown in Fig. 2.

NOTE: Throughout this paper, the term "signal to noise" ratio will be used, where "noise" is used in the generic sense to mean any unwanted sound including competing speech. The signal to noise ratio required to understand speech depends on both the type of speech (including talker characteristics) and the type of noise (spectrum shape, amplitude variations, etc.) but usually is greatest when the noise is competing speech.

What then is the practical importance of the finding that some hearing-impaired subjects require up to 30 dB greater signal to noise ratio even when the desired speech is very loud? It turns out that a lot of everyday conversation is carried on at a surprisingly small signal to noise ratio. Those with normal hearing seem to speak with just enough effort to be understood by the intended listener most of the time. The fact that not enough effort is used by most individuals to be understood *all* of the time

in noise can be realized when one counts the number of times a day that the word "what?" is used.

Pearsons, et al,¹⁶ studied the conversational speech levels used in homes, schools, stores, trains, etc., and reported the data shown in Fig. 3. A line has been added to their figure corresponding to a signal to noise ratio of -5 dB (the noise 5 dB greater than the wanted signal), about the minimum required for useful conversation between normals. Another line has been drawn 15 dB higher, corresponding to a signal to noise ratio of +10 dB, which is about the minimum required by many older hearing-impaired individuals listening without a hearing aid. Note that these individuals will be excluded totally from most normal conversations whenever the background noise exceeds 45 dB. Worse yet, they will not be able to hear the conversation without a hearing aid if their loss exceeds about 50 dB (corresponding to a speech level of about 65 dB SPL) unless the talker speaks loudly. The combined regions of "can't hear" and "can hear but can't understand" have been shaded.

The traditional view (and Plomp's) has been that the hearing aid can help the sensitivity problem but not the noise problem, leading to the complaint "I can hear, but I can't understand." With the hearing aids and fitting methods used years ago that often was true. Fig. 4 shows the dramatic improvement in bandwidth available in hearing aids designed in the 1980s compared with the typical aid of the 1960s. With the 1960s hearing aid used by Tillman, et al,¹⁹ for example, even normals required 9 to 12 dB greater signal to noise ratios in order to understand speech when listening through the hearing aid. Older subjects with sensorineural loss required 12 to 20 dB greater signal to noise ratio when they were wearing that aid than when they were aided by a reasonable fidelity amplifier and loudspeaker system.

Before discussing how and why the situation has changed, however, the reasons the problem exists need to be examined.

Causes of the problem

One of Plomp's contributions was to

define a factor "D," standing for the Distortion or Deficit of the impaired ear, and equal to the increase in signal to

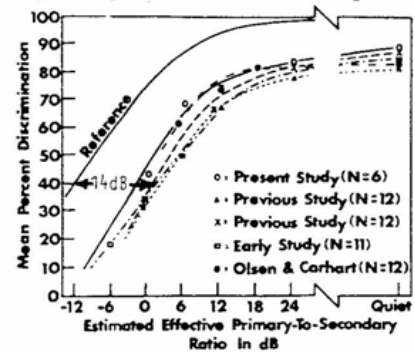


Fig. 1. Loss in ability of impaired listeners to hear against competing talker (Carhart and Tillman³ with permission), sound field listening. Results for normals shown as reference.

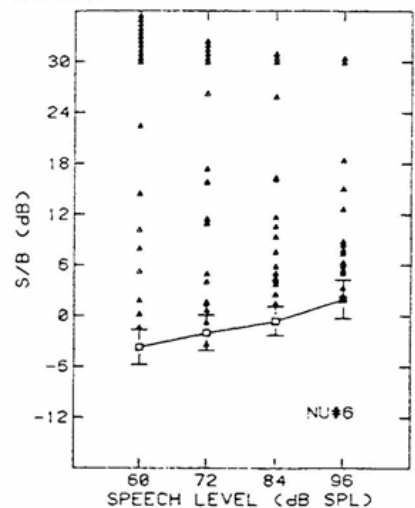


Fig. 2. Loss in ability of impaired listeners to hear in noise (Dirks, et al,⁴ with permission), earphone listening. Results for normals shown for comparison.

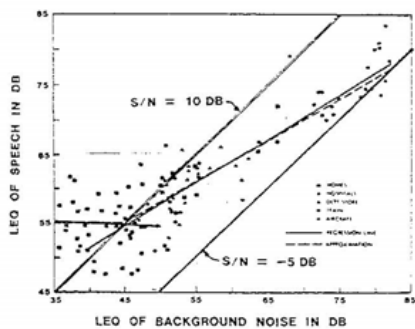


Fig. 3. Conversational speech levels as a function of background noise level (Pearsons, et al,¹⁶ with permission). Shaded area covers everyday speech that would be either inaudible or unintelligible to many older persons listening without a hearing aid.

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noise ratio required by someone with hearing loss over the acceptable ratio for someone with normal hearing. In general, $D = 0$ dB for someone with normal hearing, while D would equal 14 dB for the typical older subject with sensorineural loss described by Carhart and Tillman.³ There are several ways to break down the list of causes for the

1. Loss of audibility of speech cues
2. Cochlear distortions (freq, masking, etc.)
3. Loss of channel capacity (neural)
4. Loss of processing speed (brain)

Table 1. Factors determining "Distortion" D in impaired auditory system.

deficit D . One of these is given in Table 1.

Leaving consideration of the first factor for later, the other three will be reviewed first. Cochlear end-organ distortions often have been studied, but only in rare cases are they large enough to cause more than a fraction of the observed problems in noise.

The classic cases of loss of channel capacity are those of VIIIth nerve tumors (the schwannoma or maningeoma), which can pinch the nerve so individual neurons are blocked. In some cases, an individual with an VIIIth nerve lesion can exhibit normal thresholds in that ear but be completely unable to under-

stand speech, sometimes even in quiet. Fortunately, VIIIth nerve lesions are rare.

The fact that humans slow down as they get older is evidenced in that for runners 30 seconds per year is added to 10 km times for every year past 40 to thinkers where the brain does not process as fast. Dubno, et al.⁵ tested two groups of hearing-impaired subjects matched for audiograms, one 65 and older and one 44 and younger, and found that a few dB (but usually no more) greater signal to noise ratio was required for the older group to understand speech.

In summary, then, even the combination of factors 2 through 4 is usually far from sufficient to explain a deficit of 14 dB, to say nothing of a deficit of 30 dB.

This leaves the loss of audibility of speech clues as the primary explanation. Because of the redundancy in speech, individuals can tell which consonant is spoken in at least two ways: either from actually hearing its high frequency sounds or from the swoop of the low frequency vowel transitions ("cut" and "cup" spoken with no final plosive—the high frequency noise burst—are typical examples.) In his 1943 book on audiology, Bunch² gave an excellent visual analogy reproduced here as Fig. 5. All of the letters do not need to be seen in

order to read (with difficulty) the words, just as all the speech sounds do not need to be heard in order to understand the words.

More than that, all the words do not have to be heard to understand all the sentences. Fig. 6 illustrates the relationship between syllable, word and sentence intelligibility for subjects with normal hearing. Not surprisingly, individuals with severe high frequency hearing loss can do quite well in quiet because they can reconstruct the words or at least the sentences from the partial (low frequency only) information that they receive.

Background noise, especially competing speech, is usually variable; sometimes the high frequency components are loudest, sometimes the low frequency components are loudest. With normal hearing, listeners can use the high frequency information when the low frequency cues are masked and vice versa. Listeners with a severe high frequency hearing loss, however, find that all the information is wiped out when the low frequency cues are masked. Two interesting studies, one by Lacroix and Harris¹¹ and one by Bilger, et al.,¹ found that subjects with severe high frequency loss actually did better than normals in noise when the normals could not hear the high frequency speech cues either (because they were filtered or masked

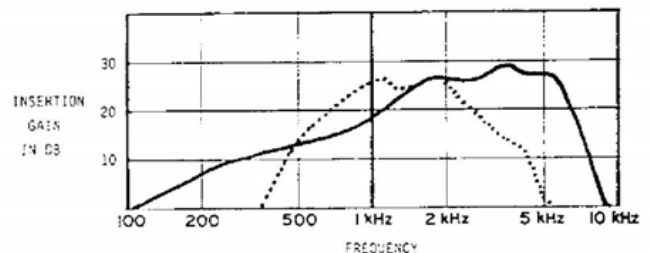


Fig. 4. Wideband response of 1980s hearing aid with "horn" earmold (—) compared to narrowband response of typical 1960s hearing aid with standard earmold (.....) (Killion¹⁰ with permission).

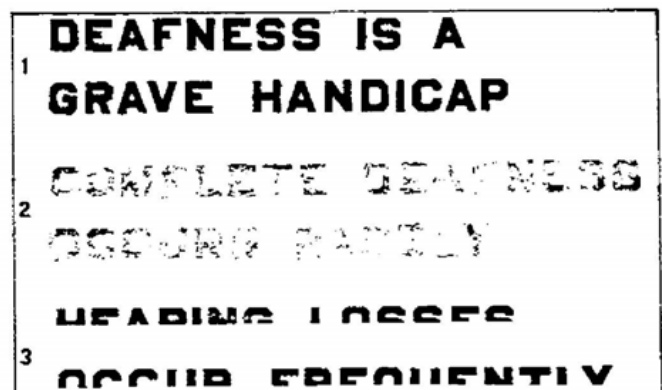


Fig. 5. Bunch's 1943 analogy:² loss of visual cues (with permission of publisher).

out). The apparent explanation is that the hearing-impaired subjects had learned to extract every possible bit of information from the low frequency speech sounds, whereas those with normal hearing had not developed this skill.

Further evidence was summarized in several papers at this year's Acoustical Society of America meeting, where Chas Pavlovic chaired a session¹⁵ that reviewed research using the Articulation Index. The consensus was that a significant portion of the problems traditionally experienced by hearing aid wearers is due to lack of audibility of many speech cues, a confirmation of the 1953 findings of Fletcher.⁶

This, then, may be the explanation for the Tillman, et al.¹⁹ finding that a 1960s vintage hearing aid could make things even worse: The hearing aid they used passed only the mid-frequency speech sounds, suppressing both low frequency and high frequency speech cues. This also helps explain the severity of the noise problem for the "unaided" listeners discovered in the studies discussed above.^{3,4,12,17} Because of their uncompensated high frequency hearing loss, they simply could not hear many of the high frequency speech cues.

This information, however, becomes a positive statement for a properly fitted modern hearing aid, for these aids can make a dramatic improvement in the audibility of all the speech sounds, not just the mid-frequency sounds. This is in sharp contrast to what could be achieved with the typical hearing aid of the 1960s as illustrated in Fig. 4.

How hearing aids can help

In an analogy with another of Plomp's formulae, the following formula is suggested: $AD = D - AHA$, where AD = Aided Deficit, D = Distortion of the auditory system and AHA = Assistance of Hearing Aid.

In the case of the narrow band hearing aid used by Tillman, et al.¹⁹ for example, AHA was a negative 12 to 18 dB for both normal hearing and hearing-impaired subjects (compared to the loudspeaker aided condition), with the result that the aided deficit AD might exceed 30 dB. (This may explain why it used to be said that "hearing aids can't help much with nerve deafness in noise.")

Therefore, there are two basic ap-

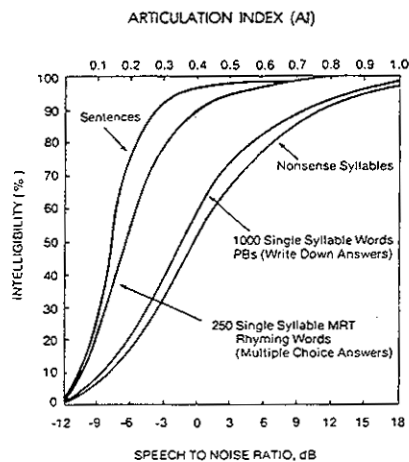


Fig. 6. The relationship between syllable, word and sentence intelligibility (Webster²⁰ with permission).

proaches to increasing the assistance of the hearing aid: 1) making more speech cues audible and 2) increasing the received signal to noise ratio.

Increasing the audibility of speech cues

Pascoe's now classic study¹⁴ showed that a properly fitted wideband hearing aid could produce substantial assistance, giving an 18% advantage in intelligibility in noise compared to a conventional hearing aid of the early 1970s. Assuming a typical slope for the graph of intelligibility versus signal to noise ratio of 3% per dB for sensorineural subjects, Pascoe's finding corresponds to an improvement of 6 dB ($AHA = 6$ dB). Skinner, et al.¹⁸ found an improvement of 22% in intelligibility when they compared a traditional bandwidth hearing aid (real ear response of 500 to 3000 Hz) with a properly fitted wideband master aid. The corresponding assistance in this case would be approximately 7 dB ($AHA = 7$ dB).

Another important factor is the use of both ears. Several studies have shown that in a diffuse sound field (sounds coming from all directions due to reflections, which represents the typical listening environment), the use of binaural aids can provide a 2 to 3 dB improvement in AHA . Examined in another way, a monaural fitting amounts to adding 2 to 3 dB to the deficit the hearing-impaired wearer already has.

Increasing the received signal to noise ratio

Several strategies for increasing the signal to noise ratio exist: 1) move closer to the talker, 2) move the hearing aid microphone closer to the talker, 3) ask the talker to speak up and 4) use well-designed directional microphone hearing aids. The last is a hearing aid choice. Here, again, available studies⁷ indicate that an improvement of 3 to 4 dB can be obtained with directional hearing aids

in a typical (diffuse-field) listening situation. (Up to 20 dB improvement can be obtained in carefully contrived listening situations.)

An untested conclusion

A properly fitted binaural pair of modern wideband directional aids thus should provide an assistance of 9 to 11 dB in the wearer's ability to understand speech in noise, compared to a conventional bandwidth binaural fitting, and an improvement of 11 to 14 dB compared to an old monaural fitting. Even in the 1970s, it was commonplace for the aided intelligibility score of a conventional bandwidth hearing aid to exceed the "unaided PBmax" (amplified TDH-39 headphones) score,⁸ leaving hope that a good portion of the typical deficit can be overcome with today's improvements in hearing aids and hearing aid fittings. That hope has yet to be tested directly, however. The closest test, using commercially available hearing aids, appears to be that of Hawkins and Yacullo,⁷ who chose two (binaural and directional) out of the four (binaural, directional, wideband and compensating selective amplification) requirements.

For the purposes of their study, Hawkins and Yacullo chose a 1970s design aid that could be switched easily between directional and non-directional modes of operation, but did not have a wide bandwidth and had an insertion gain frequency response that de-emphasized the highs. Even so, the results of their study are so encouraging it is worth further examination. The averaged audiogram for the 11 subjects used by Hawkins and Yacullo sloped from 25 dB HL at 500 Hz to 55 dB HL at 4 kHz. Based on the measured insertion gain of the hearing aid they chose and the reported listening levels used in the study, it is possible to calculate the aided hearing thresholds their subjects should have experienced. Those calculated thresholds are shown in the audiogram of Fig. 7, to which has been added the speech spectrum region of normal speech sounds as estimated by Olsen.¹³ Assuming Fig. 7 is correct, note that essentially none of the speech sounds at 4 kHz and above were probably audible to Hawkins and Yacullo's subjects, and only about half of the speech sounds between 2 and 4 kHz were audible. It is perhaps not surprising, therefore, that their subjects still showed approximately a 14 dB deficit in the signal to noise ratio required to understand speech, compared to normals under the same listening conditions.

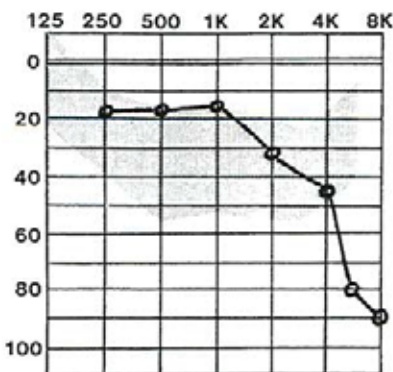
The encouraging results were that their hearing-impaired subjects showed an 8 dB improvement under binaural plus directional aided listening compared to monaural omnidirectional listening, as shown in Fig. 8.

The future

This review was started by taking issue with an old statement of Plomp's. It can be aptly finished by reconsidering one of the author's own strongly argued and embarrassingly recent positions taken against speech-discrimination-only research which stated that "...the excellent speech discrimination research of the last decade has provided sufficient information so that... further improvements can be obtained only at the expense of a very large additional effort."¹³ It would appear that the most exciting hearing aid research going on right now is speech-discrimination-only research spurred by considerations such as those above. This research is aimed at discovering just how much of a reduction in deficit can be obtained with properly fitted modern hearing aids or with experimental laboratory designs and how to achieve that reduction on a regular basis. The results of such research are eagerly awaited. □

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Fig. 7. Estimate of aided sound field thresholds achieved by the subjects in the Hawkins and Yacullo study.⁷

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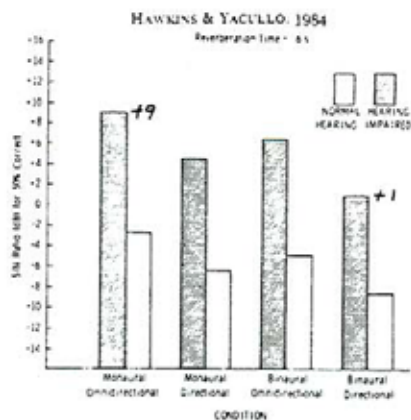


Fig. 8. Mean signal to noise ratio required for 50% intelligibility with the different aided conditions (Hawkins and Yacullo⁷ with permission).

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