▶ ***FITTING TIPS***

SNR Loss: "I Can *Hear* What People Say, but I Can't *Understand* Them."

By Mead C. Killion, PhD

Hearing aids can provide a dramatic improvement in intelligibility when the problem is a loss of speech clarity caused by lack of audibility of certain elements of the speech. They are less successful when the loss of clarity is caused by inner hair cell damage. Knowing which problem is dominant in the individual case can lead to better hearing aid fittings.

The distinctions in this paper were first introduced to the author by a) Olsen and Tillman[1], who provided early data illustrating these distinctions, b) Plomp[2], who made well-reasoned arguments at a time when adequate supporting data were not available, and c) Dirks, Morgan and Dubno[3], who supplied much of the data that were needed to give a solid foundation to the distinctions. A special debt goes to Edgar Villchur, whose ability to see and state these matters clearly has been invaluable. Finally, the perspective presented in this paper came into being as a result of discussions with, and the research of, Ruth Bentler.

> When fitting and counseling patients, it is important to know that sensitivity loss and Signal-to-Noise Ratio (SNR) loss can be relatively independent qualities. As shown by examples in this article, one person may report incredible results after being fit with hearing instruments, while another person may be keenly disappointed. Discussion of how SNR loss may relate to these outcomes is presented here.

The Distinctions

Hearing-impaired listeners often experience two problems: 1) loss of sensitivity, which is the loss of ability to hear quiet sounds, and 2) loss of clarity, which results in a loss of ability to understand speech, especially in noise.

We use pure tones to measure loss of sensitivity, which we plot in dB relative to normal threshold on the audiogram. We use a speech test or a speech-in-noise test to quantify loss of clarity. Plomp[2] used the terms A (Audibility) and D (Distortion in the cochlea) to distinguish the two manifestations of hearing impairment. Dubno et al[4] used the Articulation Index (basically the proportion of speech cues that are audible) to help distinguish between the audibility problem and the clarity problem: "I can hear what people say, but I can't *understand* them."[1]

"Percent correct" was once the most common report from speech tests, but after Dirks et al.[3] it has been increas-

Definitions

- ▶ **SNR**: Signal-to-noise ratio.
- ▶ **SNR loss**: Loss in ability to understand speech at the SNR used by those with normal hearing.

Author's Note: *In this paper, the shorthand term "SNR loss" will be used to mean the dB increase in SNR (signal-to-noise ratio) required for 50% correct word recognition, over the average SNR required by those with normal hearing, to achieve a 50% correct score. This is analogous to our use of "hearing loss" to mean the number of dB increase in SPL required for audibility, over the average SPL required by those with normal hearing sensitivity. Thus, loss of clarity is measured as an SNR loss; loss of sensitivity is measured as a (threshold) hearing loss. ("Hearing loss" has traditionally meant the loss shown on an audiogram, and there seems to be no reason to change this usage.)* ◆

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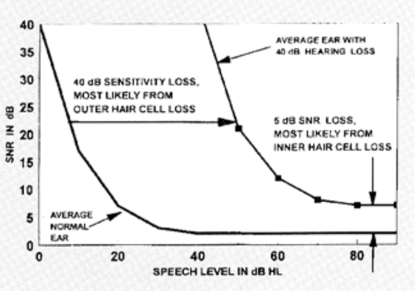

Fig. 1. *The two consequences of hearing loss: a) Loss of ability to hear quiet sounds (audibility loss), and b) Loss of ability to understand speech in noise (SNR loss).*

ingly common to report the signal-to-noise ratio (SNR) in dB required for 50% correct recognition of words. Tests such as the HINT[5] (Hearing-in-Noise Test) and SIN[6] (Speech In Noise) test were expressly designed to facilitate such reporting. SNR reporting permits a direct comparison between the SNR improvement of a proposed remedy (move 3 feet closer to the talker, for example, or use an FM pickup near the talker's mouth) and the degree of SNR impairment.

Clarity Loss vs. Audibility Loss: Average Results

A recent paper[7] contained SIN-test data on the SNR required by hearing-impaired subjects to recognize 50% of words in sentences. These data showed that even a mild hearing loss is usually accompanied by some increase in difficulty understanding speech in noise. In other words, a mild sensitivity loss is typically accompanied by a mild SNR loss, not only when the speech is not completely audible, but even when the speech is intense enough that all speech cues are audible.

The relationship between average SNR loss and audiometric loss, shown in Table 1, is taken from the combined SIN-test data of 14 audiologists.[7] The data in Table 1 were obtained at sufficiently intense levels that only a lack of clarity should have produced difficulty hearing in noise, because all speech cues were audible at those presentation levels. Subjects with a 40 dB pure-tone-average loss typically showed a 5 dB SNR loss; those with a 60 dB loss typically showed a 7 dB SNR loss.

Fig. 1 shows the hypothetical SNR required for 50% correct recognition for a subject with normal hearing and a subject with a 40 dB pure-tone-average hearing loss. Even with normal hearing, the required SNR starts to increase once the speech level drops below 30 dB HL (45 dB SPL), simply because the quieter speech cues become inaudible. Under those circumstances, the remaining audible cues need to be clearer (more free of noise contamination) in order to maintain intelligibility. By the time a presentation level of 0 dB HL is reached, we would expect someone with normal hearing to achieve 50% correct recognition on spondees in quiet (the definition of 0 dB HL for speech), so the graph shown is probably a bit optimistic (i.e., 50% correct for words in sentences may not be possible at any SNR at 0 dB HL). The normal-performance curve shown in Fig. 1 is also optimistic at high levels, since the ear overloads and the SNR required for a 50% correct score increases by a few dB (Dirks et al.[3]). For present purposes, however, we will take the simplified view shown in the figure.

An individual with a 40 dB hearing loss will require an increased SNR once the speech level drops below 70 dB HL for the same reason that someone with normal hearing will require increased SNR once the speech drops below 30 dB HL. Of present interest, however, is the fact that at high presentation levels the typical subject with a 40 dB loss will require 5 dB greater SNR than someone with normal hearing.

Table 1. Average relationship between SNR loss and hearing (pure tone average) loss, when testing is done at high intensities (83 dB SPL or higher) .

HL Pure Tone Average (0.5, 1, 2 kHz)	SNR Loss
30 dB	4 dB
40 dB	5 dB
50 dB	6 dB
60 dB	7 dB
70 dB	9 dB
80 dB	12 dB*
90 dB	18 dB*

* estimated

Individual Differences

As shown by Dirks et al.[3], some individuals have a much greater loss of ability to understand speech in noise than would be predicted from their audiogram; others have less. In other words, sensitivity loss and SNR loss are independent characteristics.

Fig. 2 illustrates a case we have seen in which a relatively mild 30 dB pure-tone-average loss is accompanied by a very large (14 dB) SNR loss. This person scored only 60% correct on NU-6 in quiet[7], and has trouble hearing in nearly all social conditions. Extensive noise exposure of every kind, starting with military service, appears to be the cause of his bilateral hearing problem, rather than any neural involvement.

Fig. 3 illustrates the opposite case, in which a moderate-severe pure-tone-average loss of 60 dB is accompanied by only 2 dB SNR loss at high levels. Indeed, +/-2 dB is within the range of normal performance, so it would be correct to say that his SNR performance is normal at high levels.

An attempt to display the distinc-

Two Unusual and Contrasting Cases

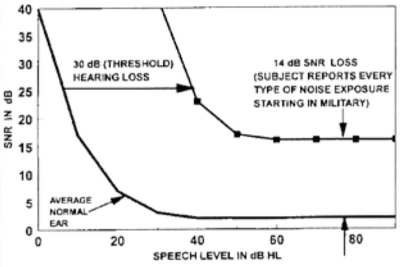

Fig. 2. *A 30 dB hearing loss with 14 dB SNR loss. This person has trouble hearing in most social situations.*

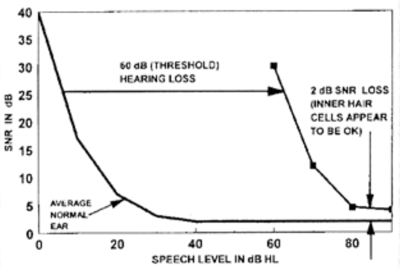

Fig. 3. *A 60 dB hearing loss with near-normal ability to hear in noise at high levels.*

Figs. 2 and 3 display dramatically different hearing losses. Plomp[2] attributed these differences to the degree of cochlear distortion. We now have more knowledge about the operation of the cochlea, so it is possible to speculate with some confidence that the controlling factor is the degree of inner hair cell loss: Inner hair cells provide all of the information to the brain[13], so a loss of inner hair cells means a loss of information flow to the brain.

tion between audibility and clarity on the count-the-dots audiogram form[8] is shown in Fig. 4. Even though the speech has been amplified so that 99% of speech cues are audible to this individual, the high-frequency dots are damaged, incapable of sending the full flow of information the brain needs to separate speech from noise. Those dots represent speech cues that are completely *audible*, but *not clear*.

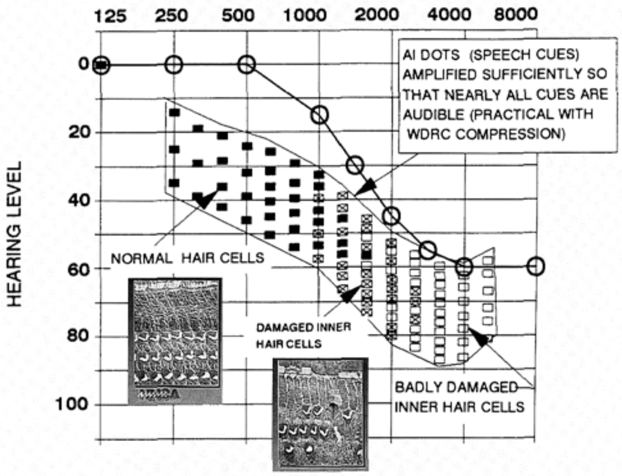

Fig. 4. *Count-the-dots figure used to illustrate amplified speech that is still not clear. The high frequency dots represent speech cues that are audible but poorly represented in signals to the brain because inner hair cells are damaged. (Hair cell electron microphotograph by Derek Dunn, used with permission of NHCA and NIOSH.)*

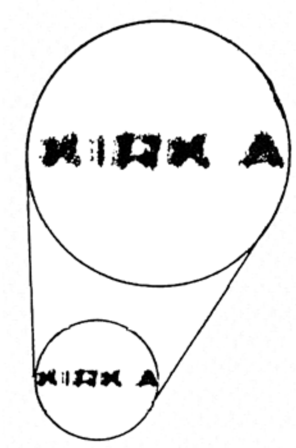

Fig. 5. *Visual illustration of a clarity problem that is not helped by additional magnification. Fuzzy images (or sounds) remain fuzzy upon magnification (or amplification).*

Fig. 5 shows an illustration similar to one Herb McCollom has used in his dispensing practice for years to make the same distinction. Once a picture is large enough to be completely visible, magnifying a fuzzy image will only produce a *larger image that is just as fuzzy*. In our terms, the SNR loss remains.

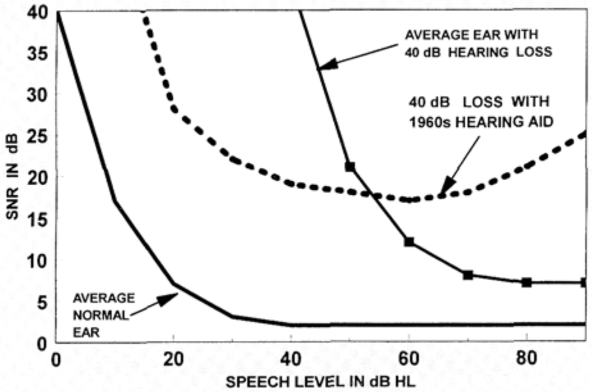

Fig. 6. *In the 1960's, hearing aids improved the clarity of quiet and normal speech, but degraded the clarity of loud speech.*

Benefit of Hearing Aids

Shortly after Plomp's paper appeared, the author wrote a paper[9] challenging Plomp's conclusion that hearing aids had "essentially limited applicability." Plomp's conclusion appeared unnecessarily pessimistic since it was based on data obtained on narrow-band, high-distortion hearing aids. (As indicated by Plomp's own data, those 1970s hearing aids, like the 1960s aids studied by Tillman, Carhart and Olson[10], increased the SNR over the unaided condition.)

The estimated performance of someone wearing a 1960s hearing aid is shown in Fig. 6. The hand-drawn estimate is based on the Tillman et al.[10] data showing that the aid introduced an SNR deficit of 12 dB even for those with *normal* hearing. It also takes into consideration the known high-level-input overload characteristics of hearing aids of that era.

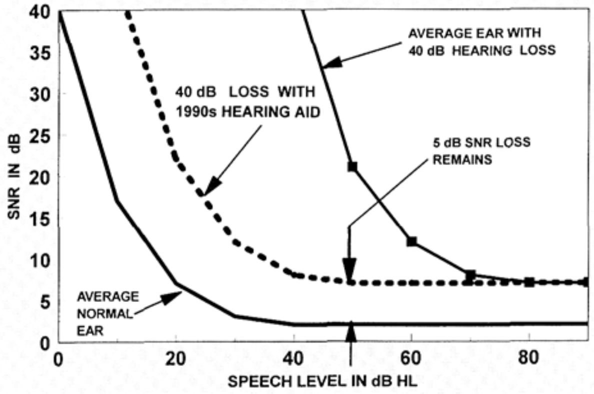

Fig. 7. *In the 1990's, hearing aid circuits dramatically improve speech clarity over a wide range of input levels, extending the region of best SNR performance down to low input levels and not degrading SNR performance at high levels. The residual SNR deficit remains, however.*

Fig. 7 shows the result of using more sophisticated hearing aids. The audibility problem can be readily solved with properly fitted modern hearing aids. If the volume control is turned up another 20 dB, the curve in Fig. 7 can be extended to approximately 0 dB, although it is unlikely anyone would want to wear hearing aids adjusted for that much amplification.

We now have extensive data, however, that indicate the audibility part of the hearing-in-noise problem is the only part we can solve with hearing aid circuits.[11] No hearing aid circuit known to the author—analog or digital—has decreased the SNR loss below that exhibited for high-intensity speech. In this sense, Plomp's pessimism proved correct.

What hearing aids *can* do extremely well, however, is to improve the audibility of speech cues in those more-common situations when all the cues are *not* audible. In a very real (and real-world) sense, the signal processing in modern hearing aids (selective amplification, compression, etc.) *will solve* much of the perceived clarity problem by making previously inaudible speech cues audible. In doing so, hearing aids extend the range over which "best SNR performance" can be obtained, from a limited range near discomfort to a wider range including most daily speech and many speech-in-noise experiences. In many daily situations, the use of modern hearing aids can make the difference between a 20 dB or 30 dB SNR loss unaided and a 5 dB SNR loss aided.

The person with the hearing loss shown in Fig. 3, moreover, may report that the hearing aid worked a miracle, providing nearly normal hearing in noise. Such an individual makes dispensers feel good about their abilities (especially if they don't realize the individual has almost no SNR loss at high levels). Similarly, the author took some of the early glowing testimonials about the K-AMP circuit ("Now I can stand in the back of the room and still understand the [square dance] caller," and "For the first time I can hear clearly at a baseball game") as proof that we had done the "right thing" for those people. Indeed we had, but the circuit probably didn't improve their ability to hear in noise at high levels; in all probability, it was simply the first time they had heard a circuit that didn't *degrade* their high-level abilities.

The type of person with the hearing loss shown in Fig. 2, on the other hand, needs to be counseled carefully. Even with counseling, such persons will almost certainly report disappointment in their hearing aid experience, regardless of how carefully dispensers fit them or how much they spend on the circuits. Even though they may receive significant benefit in many normal situations, their inability to hear better in noise dominates their perception.

The good news is that the residual SNR deficit that many individuals experience can be compensated for by the use of one of the many options suggested by Plomp: move the microphone closer to the talker(s) and use directional-microphone hearing aids, to name two. The best directional-microphone hearing aids can now provide a 4-5 dB improvement in difficult situations, more in special circumstances; array microphones nearing production can provide 8-10 dB improvements; tiny FM transmitters are already practical for one-on-one situations, providing a 15-20 dB improvement.[12]

Summary

When counseling patients, it is important to know that sensitivity loss and SNR loss can be relatively independent quantities. When we measure SNR loss in the individual case, we can guide patients to more realistic expectations than we might be inclined to do based on average data or our accumulated experience. We also have a better basis for deciding how much SNR assistance we need to provide in hearing aids or their accessories. Fortunately, the non-audibility part of SNR loss *is* being solved. ◆

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