

What can the pure-tone audiogram tell us about a patient's SNR loss?

By Mead C. Killion and Patricia A. Niquette

Although most of us know that you can't use a patient's audiogram to predict the amount of trouble he or she will have hearing in noise, many of us still enjoy guessing. In other words, many of us look at an audiogram and estimate the degree of signal-to-noise ratio (SNR) loss that our patient will have,^{1,2} and then act on our guess as if it were reality, i.e., as if we knew from our guess what difficulty the patient will have hearing in noise.

This article looks at hair cell microphotographs taken by Dunn and by Harrison, at histological evidence obtained by Schuknecht on 44 human ears,³ and at direct experimental evidence on the relationship between SNR loss and audiometric loss. All evidence suggests our guessing game won't (and probably can't) work very well.

BACKGROUND

Hearing loss has several components. Generally speaking, a mechanical difficulty in the middle ear causes conductive loss; loss of outer hair cells in the cochlea causes a loss of sensitivity that increases for weaker signals (recruitment); loss of inner hair cells causes a loss of clarity (especially in noise) as well as a loss of loudness; and a loss of neurons along the auditory pathway also causes a loss of clarity and a loss of loudness. (Neural loss—caused by eighth-nerve schwannoma or multiple sclerosis, for example—is rare.)

It is not surprising that inner hair cell loss and neural loss have similar consequences; both reduce the flow of information to the brain. So does *unaided* outer hair cell loss: The attendant loss of audibility also reduces the information to the brain.

Unfortunately, this picture is too simple. Problems in the stria vascularis can cause hearing loss even when the inner and outer hair cell populations are normal. The stria vascularis is the "battery" in the inner ear that powers both outer and inner hair cells.⁴ But when we look at Schuknecht's histological data, we see that some of the hearing losses were not accompanied by any visible abnormalities in hair cells *or* stria vascularis.

Recent studies suggest that problems in the transport of potassium ions may be an important factor in some hearing losses.⁵ The electrical current flow in the inner ear is dominated by potassium ions. The same potassium ions are apparently pumped around and around, passing through ion channels, any one of which can become blocked.⁵

The distinction between sensitivity (audiometric) loss and clarity (SNR) loss can be illustrated with a visual analogy, a modern version of the illustration used in the first audiology textbook.⁶ Imagine that each light bulb in the Times Square sign has its own cable that delivers the cur-

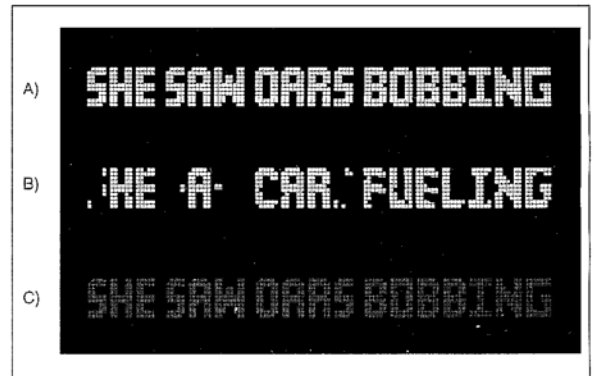


Figure 1. Visual analogy of normal hearing vs. loss of clarity or loss of sensitivity: electronic sign with (a) all lights lit normally, (b) approximately 35% of the bulbs burned out, and (c) all bulbs burning, but dimly.

rent when the master controller calls for that bulb to be turned on. In this analogy, a bulb that is out would correspond to either a dead inner hair cell (burned-out bulb) or a dead neuron (cut wire).

Figure 1a shows a segment of such a sign reproducing the sentence "She saw oars bobbing." If a third of the bulbs were burned out, or if someone cut a third of the wires, the remaining lights might spell "He a car fueling," as shown in Figure 1b. With half the bulbs out, the picture would become very grainy and details would be completely lost in some regions of the display. If enough bulbs were out, it would be impossible to read any of the smaller text, even though the remaining bulbs would be at full brilliance. Making things brighter wouldn't help the clarity.

A loss of outer hair cells might correspond to all the wires suddenly developing high resistance. In this case, the lights would go dim but would still work. Someone with good night vision (visual sensitivity) would see the picture

Cause	Number
Presbycusis (sensory, neural, stria, cochlear conductive)	20
Meniere's disease (endolymphatic hydrops)	8
Sudden, idiopathic sensorineural hearing loss	3
Ototoxic medications (kanamycin, neomycin, cisplatin)	5
Congenital loss—etiology unknown	2
Occupational noise-induced hearing loss	2
Progressive sensorineural hearing loss	1
Usher's syndrome	1
Mondini dysplasia	1
Hensen's cell cyst	1
TOTAL	44

Table 1: Etiology of hearing losses (data from Schuknecht³).

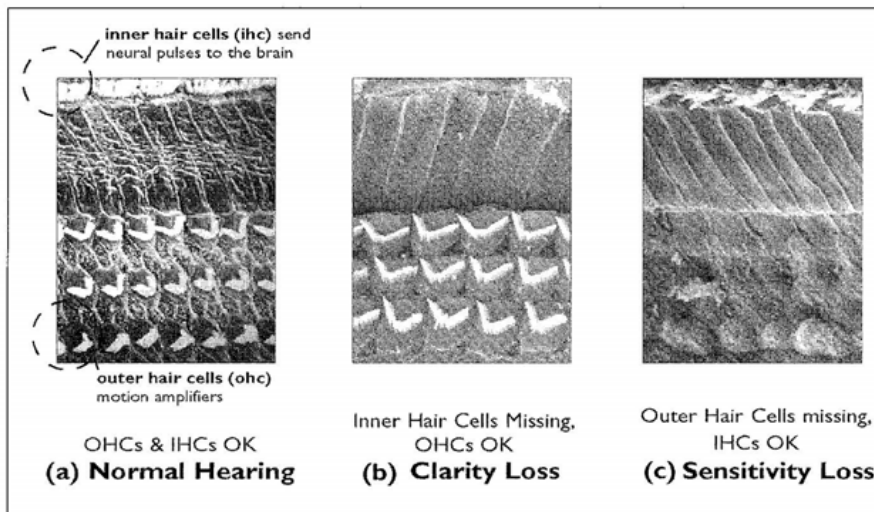


Figure 2. Electron microphotographs of a small section of the cochlea showing (a) normal inner and outer hair cells, (b) missing inner hair cells, and (c) missing outer hair cells. Photograph a is by Derek Dunn, used with permission of NHCA and NIOSH; photographs b and c were supplied by Robert Harrison, University of Toronto.

as dim but clear, as illustrated in Figure 1c. Someone without good night vision would need to use night-vision binoculars to make things brighter. The unaided picture would not be clear, but only because it was only partially visible. With amplification, the picture would be bright and clear. (The same amount of light amplification applied to day-bright objects would probably be uncomfortable or even painful. Night-vision goggles use electronic compression to reduce the light gain in bright light; it appears to be a form of wide dynamic range compression.)

In the same way, the amplification provided by good hearing aids may completely make up for the loss of sensitivity for quiet sounds (outer hair cell loss), but no amount of amplification can make up for the loss of detailed information that accompanies inner hair cell loss (or neural loss).

INNER AND OUTER HAIR CELL LOSS

As discussed above, there are several possible causes of hearing loss. However, our primary purpose in this article is to explore the relationship between the audiogram and SNR loss. For this purpose, the simple model illustrated in Figure 1 suggests a basis for predicting clarity loss from the audiogram. We thus assume that it is usually outer hair cell loss that causes loss of sensitivity for quiet sounds and inner hair cell loss that causes a loss of clarity—even for loud sounds—and thus a loss of ability to hear in noise. (As mentioned above, loss of sen-

sitivity for quiet sounds also causes a loss of clarity from lack of audibility.)

Figure 2 shows a portion of three cochleas with the condition of the hair cells representing normal hearing and the two extremes of hair cell loss—nearly total inner

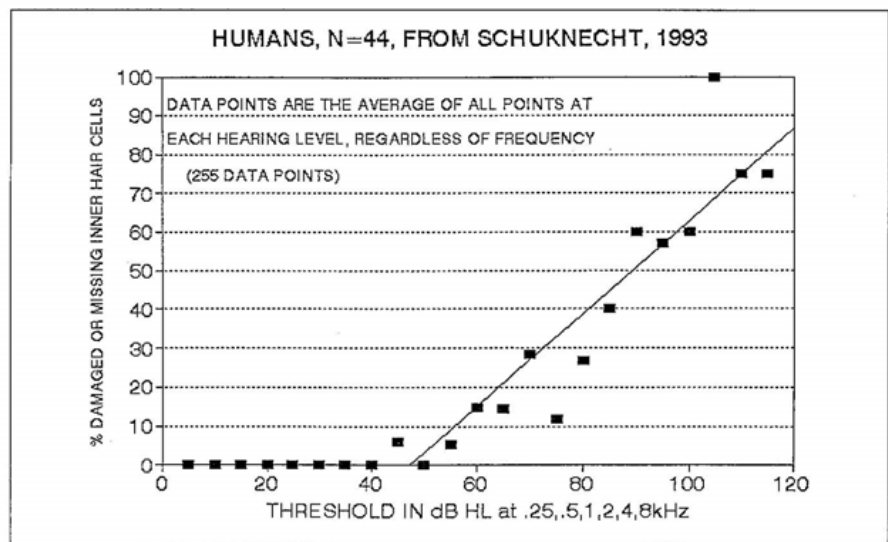


Figure 3. Inner hair cell loss vs. hearing loss. Data on 44 ears from Schuknecht.³

hair cell loss and nearly total outer hair cell loss. There is often a mixture of both types of loss at a given place on the basilar membrane, but in the case of noise-induced hearing loss, Borg and his colleagues concluded that high-intensity noise (gunshots, for example) produced mostly inner hair cell loss, while moderate noise levels for an extended period of time could produce extensive outer hair cell loss with relatively little inner hair cell loss.⁷

One of the authors (PAN) has studied the histological data on 44 of the 63 ears reported on by Schuknecht,³ after excluding 7 ears without audiograms, 9 ears with a conductive component to the hearing loss, and 3 with other disqualifications. Table 1 shows the stated etiology of the hearing loss.

The 44 ears were from patients who died 1 month to 19 years after their last audiogram. Their cochleas were preserved and subsequently studied under a microscope in order to count—at specific locations along the basilar membrane—the proportion of damaged or missing outer and inner hair cells, stria vascularis, and cochlear neurons. Since the place on the basilar membrane corresponding to each frequency is reasonably well known, it was possible to relate hair cell loss to hearing loss at each audiometric frequency.

Our compilation of data from Schuknecht produced the data in Figure 3, which shows the proportion of inner hair cells lost as a function of audiometric loss in HL (hearing level). The data at each frequency looked very similar, so the data were combined across fre-

quency to make the plot in Figure 3. For thresholds of 40 dB HL and below, no inner-hair-cell loss was evident in *any* of the cochleas examined by Schuknecht. (Below 60 dB HL, in fact, there were only two locations out of 113 examined showing any inner hair cell loss.) This is consistent with current theory, which suggests that outer hair cells provide the amplification for quiet sounds.

The problem with the graph in Figure 3 is that it suggests that a patient with an 85-

dB hearing loss would have lost 40% of his inner hair cells at that location. In actual fact, there were 15 locations corresponding to 85-dB loss in Schuknecht's data: 6 locations where the inner hair cells were *all* damaged or missing, and 9 locations where the inner hair cells looked normal. Based on Schuknecht's findings, the *probability* of inner hair cell damage with an 85-dB loss is 40%, but his data showed that a given individual will have either all-intact or all-missing inner hair cells at that location. This fascinating observation makes us wish we could look in on a few living cochleas to corroborate these findings. In any case, the data in Figure 3 represent an all-or-none phenomenon.

Part of the purpose in compiling the Schuknecht data was to see if it allowed a more accurate prediction of SNR loss. If we knew the relationship between the audiogram and the percentage of inner hair cells lost, and we assumed that a loss of half the inner hair cells would remove half of the speech cues at that frequency, we could calculate the expected articulation index and thus predict the SNR loss based on the audiogram.⁸ Even after observing that individual subjects usually had all or none of their inner hair cells in a given region, we thought such a calculation might improve the relationship between audiogram and SNR loss on the average.

Before discussing the results of such a prediction, we need to review some definitions.

PREDICTION OF SNR LOSS FROM AUDIOMETRIC HL

The commonly accepted definition of SNR loss is analogous to our definition of hearing loss; in both cases, normal performance is taken as the zero level. A normal-hearing subject requires about a 2-dB signal-to-noise ratio on the SIN (Speech In Noise) Test⁹ to achieve a 50% score (50% of the key words in each sentence repeated correctly). If it were possible to adjust the four-talker babble of the SIN test to 81 dB SPL and the target speech to 83 dB SPL, the typical normal-hearing subject would be able to repeat 50% of the five key words in sentences such as "The lawyer tried to lose his case," and "Adding fast leads to wrong sums."

Using the abbreviation "SNR-50" for "the signal-to-noise ratio required for 50% correct score," we would say a typical normal subject has an SNR-50 of 2 dB on the SIN Test.

If a hearing-impaired subject requires

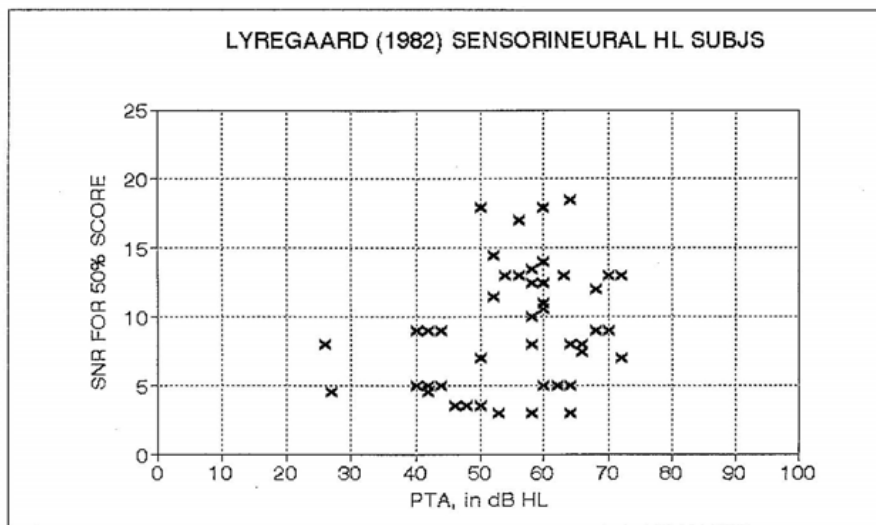


Figure 4. SNR-50 vs. hearing loss (three-frequency average). CVCVs in sentences against speech spectrum noise sensorineural-loss subjects (Lyregaard¹¹).

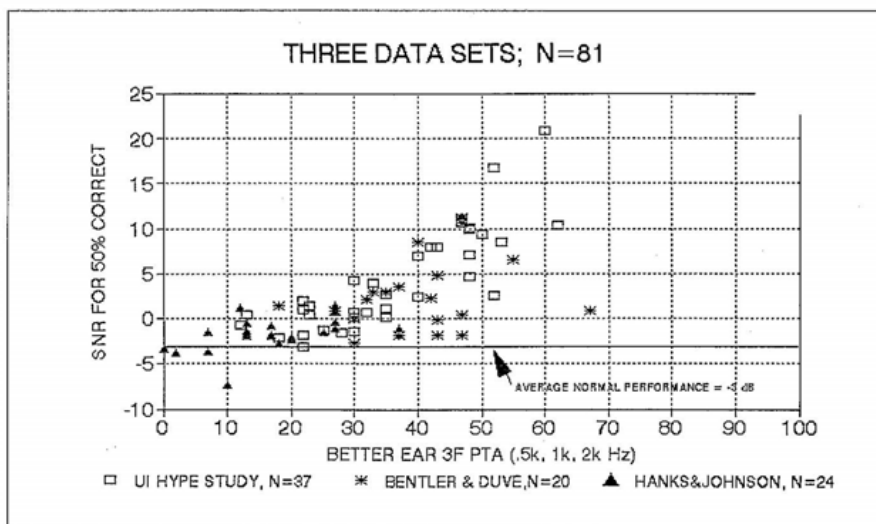


Figure 5. SNR-50 vs. hearing loss (three-frequency average). HINT test against 65-dB-SPL noise (Bentler and Duve,¹⁷ Hanks and Johnson¹³).

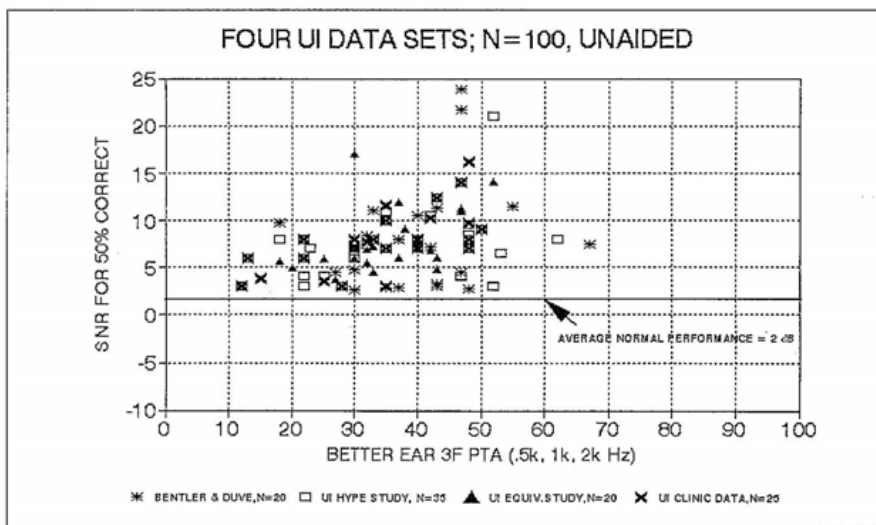


Figure 6. SNR-50 vs. hearing loss (three-frequency average). SIN test at 83 dB SPL.

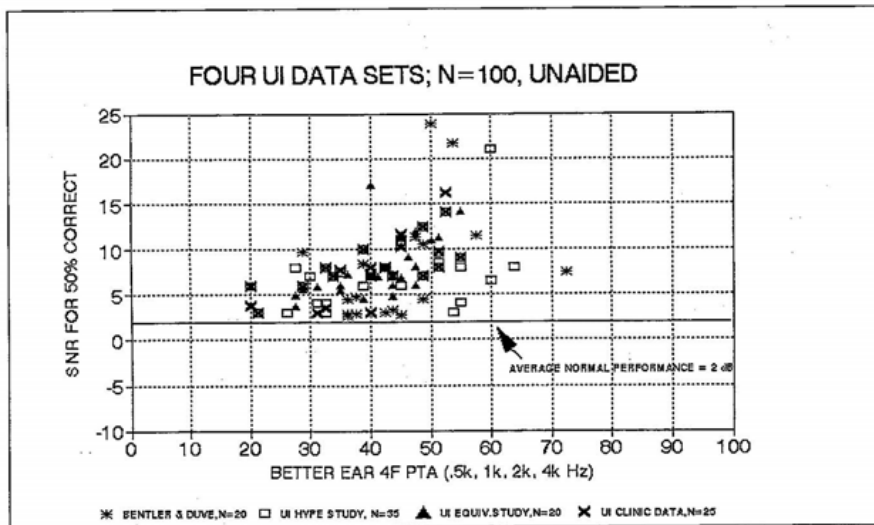


Figure 7. SNR-50 vs. hearing loss (four-frequency average). SIN test at 83 dB SPL

continued from page 48

the signal to be presented 12 dB above the noise to achieve a 50% correct score, that subject requires an SNR-50 of 12 dB, 10 dB greater than normal. We say that that subject has a 10-dB SNR loss.

In the case of the actual SIN test, five sentences each are presented at SNRs of 0 dB, 5 dB, 10 dB, and 15 dB. The SNR-50 is interpolated from the percent-correct scores at SNRs above and below SNR-50.¹⁰

There are three substantial data sets relating SNR loss to hearing loss: (1) Danish logatoms (CVCV words, noise = speech-spectrum noise¹¹), (2) the HINT (Hearing in Noise) Test (noise = speech-spectrum noise^{12,13}), and (3) the SIN Test (noise = four-talker babble¹⁴). Figures 4, 5, and 6 show these relationships. Note that in every case there is a spread of 15 dB to 20 dB in SNR loss for similar pure-tone average losses.

In order to improve the prediction of SNR loss from the audiogram, we calculate hearing loss in a different way. The three-frequency average used in Figures 4-6 ignores the hearing loss at 4000 Hz where there is a high density of information (see the count-the-dot AI audiogram, for example¹⁵). A three-frequency pure-tone average of 10 dB, for example, might correspond to 0-dB thresholds at 500 Hz and 1000 Hz, 30 dB HL at 2000 Hz, and 60 dB or 70 dB at 4000 Hz. We thus recalculated the pure-tone average as a four-frequency average including 4000 Hz. The results for the SIN test data are shown in Figure 7.

Use of the four-frequency average improves the prediction of SNR loss, but we are still faced with the fact that some

subjects with hearing losses of 40 dB PTA to 60 dB PTA have almost no SNR loss, while other subjects with mild-to-moder-

ate PTA losses have losses of 15 dB SNR to 20 dB SNR.

The SIN test results shown in Figures 6 and 7 were unaided tests presented at 70 dB HL, or 83 dB SPL sound field equivalent. For subjects with mild loss, this should leave all sounds audible, but that would not be true in the case of moderate-to-severe loss. Consider the case of a 65-dB-HL loss at each frequency. This would leave only the most intense 10 dB of speech cues audible with a 70-dB-HL presentation.¹⁶

Some indication of how the increased audibility provided by hearing aids improves intelligibility is seen in the Bentler and Duve SIN test data obtained with and without hearing aids.¹⁷ These data are shown in Figure 8. Note that even with the improvement for some subjects, there

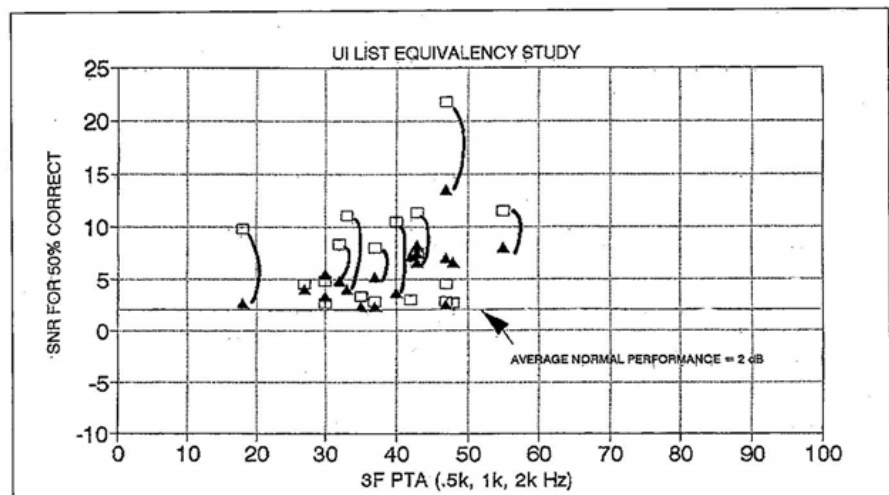


Figure 8. Aided vs. unaided SNR-50. SIN test at 83 dB SPL. Data from Bentler and Duve.¹⁷

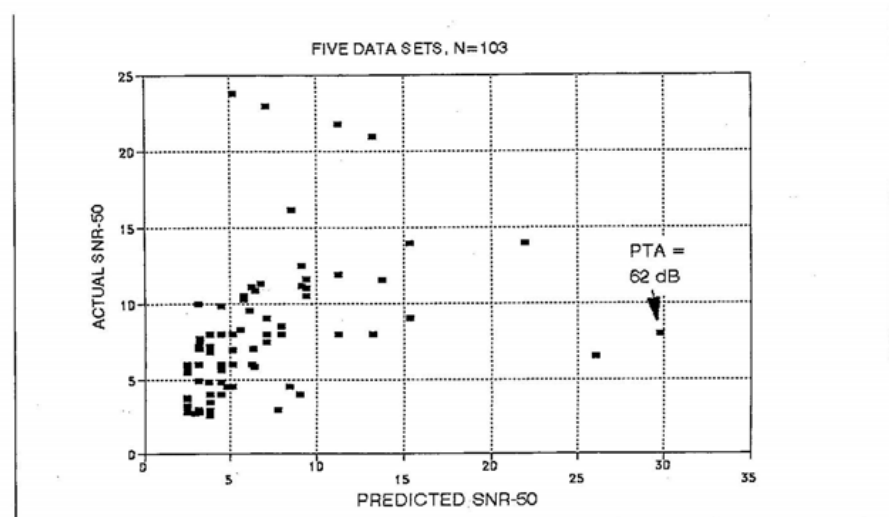


Figure 9. Correlation between measured SNR-50 and SNR-50 predicted from articulation index calculations taking audibility and estimated "missing dots" from inner hair cell loss into account.

remains a 10-dB difference between the better and poorer SNR performers with similar audiograms.

As a final step, we predicted the SNR-50 by (a) calculating the AI for each subject for the 70-dB-HL presentation, and (b) further refining the estimate by multiplying the number of speech-cue "dots" available above threshold by the estimate from Figure 3 of the average proportion of intact inner hair cells expected with that threshold. The resulting comparison between measured and predicted SNR-50 is shown in Figure 9.

Even after taking audibility *and* missing hair cells into account, there were differences as large as 15 dB to 20 dB between predicted and measured SNR-50 values. The point with a predicted SNR-50 of 29 dB is worthy of comment, because the subject did so much *better* than predicted. That subject had a PTA of 62 dB. A possible explanation would assume the subject's thresholds were 10 dB better on the day of SNR testing, in which case the predicted SNR-50 would have dropped to 14 dB.

We conclude that the only reliable way to determine a patient's ability to hear in noise is to measure it.¹⁸

Solutions for loss of sensitivity

It is important to remember that the sensitivity-loss component of hearing loss can be remedied quite well with appropriate hearing aids. Once the audibility problem has been solved, however, the remaining SNR loss cannot be solved with amplification.⁹ The only thing that can be done to help someone with moderate-to-severe SNR loss is to improve the signal-to-noise ratio.

The simplest approach for improving SNR in one-on-one conversations is the centuries-old speaking tube. Since the SPL at the talker's lips is typically 110 dB or so, an SNR improvement of 25 dB can be obtained at a typical 85-dB-SPL cocktail party. The modern version of the speaking tube is the remote microphone, wired into the listener's hearing aid and held at the talker's mouth.

Using modern technology, such as subminiature FM receivers and small wireless FM transmitters, can provide an improvement of 20 dB to 25 dB in SNR when the FM transmitter microphone is held or clipped near the talker's mouth.

Fortunately, perhaps one-quarter of hearing aid purchasers have only a mild SNR loss and can get by with good, low-distortion wide-band amplification.²⁰ Their problem is mostly one of audibility. One could argue, of course, that *everyone* needs SNR improvement sometimes, and, as long as you are going to wear hearing aids, you might as well add directional microphones to make listening easier.

Once a person reaches the moderate SNR loss category, he or she will sometimes be excluded from social conversations. In those cases, a good directional microphone with an improvement of 4 dB to 5 dB in SNR can produce substantial benefit.²⁰ Some of the more satisfied users of directional microphone hearing aids, however, have been those with severe SNR loss. Even though the increase of 4 dB to 5 dB in SNR only partially compensates for their SNR loss of 11 dB to 19 dB, it makes a significant improvement and listeners perceive it as very beneficial.

A better solution for those with severe loss is the use of array microphones, which can provide an improvement of 8 dB to 10 dB, depending on design. With some loss of convenience as the SNR loss increases, nearly everyone can now obtain enough improvement in SNR to enjoy relatively noisy social situations.

ADJECTIVE CATEGORIES FOR SNR LOSS

Although there is no accepted scale of adjectives for SNR loss, a loss of 20 dB in the ability to hear in noise excludes the patient from normal social conversation at parties. We might thus consider this a profound loss. Table 2 shows our suggested categories for SNR loss.

Category	SNR loss
Mild	0-4 dB
Moderate	5-10 dB
Severe	11-19 dB
Profound	20 dB

Table 2. Suggested categories for SNR loss.

SUMMARY

The evidence we have reviewed suggests that loss of one's ability to hear in noise can be more or less independent of the loss of one's ability to hear quiet sounds. We were unable to predict SNR loss from the audiogram.

If you have only enough time for one test, should it be an audiogram or an SNR-loss test? It is unlikely that an SNR test will pre-empt the audiogram anytime soon, but the lack of predictability of SNR loss may explain the disappointing level of satisfaction among hearing aid purchasers, the majority of whom have a mild-to-moderate hearing loss.

We suspect that experienced practitioners may intuitively assess patients' SNR loss and therefore provide realistic expectations during counseling. But, without information about each individual patient's SNR loss, it is possible that patients will be told that their aided hearing in noise will be better than it really will be.

Even hearing aids with high-performance directional microphones that have received the highest satisfaction ratings in consumer surveys¹⁹ can still leave some persons with an aided SNR loss of 5 dB to 10 dB, leaving them unable to hear well in noise. While the patient will notice improvement in the ability to hear in noise, he or she will still be left with a significant deficit. If the amount of SNR loss is known, then counseling for these persons can include the advantages of array microphones, hand-held microphones, and FM assistance.

In contrast, there are some persons with mild-to-moderate hearing loss who have so little SNR loss that well-fitted hearing aids will solve most of their hearing problems, and directional microphones will give them an extra edge in noisy situations. Knowing the degree of SNR loss is the key to better fittings and to appropriate counseling. The way to determine the SNR loss is to measure it. (HJ)

Mead C. Killion, PhD, is President of Etymotic Research, Adjunct Professor of Audiology at Northwestern University, and Visiting Professor

of Audiology at Rush University. **Patricia A. Niquette**, MA, is Research Audiologist at Etymotic Research. Correspondence to the authors at Etymotic Research, 61 Martin Lane, Elk Grove Village, IL 60007.

FOOTNOTES AND REFERENCES

1. Killion M: Hearing aids, past, present, future: Moving toward normal conversations in noise. *Brit J Audiol* 1997;31:141-148.
2. Killion M: The SIN report: Circuits haven't solved the hearing-in-noise problem. *Hear J* 1997; 50(10):28-32.
3. Schuknecht HF: *Pathology of the Ear* (2nd ed.). Baltimore: Lea Febiger, 1993.
4. Dallos P, Berlin CI: Outer hair cells: The inside story. Presented at the 1997 American Academy of Audiology convention, Fort Lauderdale, FL.
5. McKenna MJ, Adams JC: The biology of cochlear supporting cells and their critical role in hearing. Presented at the 13th annual Self-Help for Hard of Hearing People Convention, Boston, 1998.
6. Bunch CC: *Clinical Audiometry*. St. Louis: CV Mosby, 1943.
7. Borg E, Canlon B, Engstrom B: Noise-induced hearing loss: Literature review and experiments in rabbits. *Scand Audiol* 1995;24:40.
8. Killion MC, Christensen LA: The case of the missing dots: AI and SNR loss. *Hear J* 1998;51(5):32-47.
9. Killion MC, Vilchur E: Kessler was right—partly: But SIN test shows some aids improve hearing in noise. *Hear J* 1993;46(9):31-35.
10. A score of 20% correct response at 0 dB SNR and 70% correct at 5 dB SNR would correspond to a 2-dB SNR-50. The normal slope is about 12% per dB; the above example uses 10% per dB, which is not unusual.
11. Lyregaard PE: Frequency selectivity and speech intelligibility in noise. In Pedersen OJ, Poulsen T, eds. *Binaural Effects in Normal and Impaired Hearing*. *Scand Audiol* 1982;Suppl. 15. From the 10th Danavox Symposium, 1982, Denmark.
12. Nilsson M, Soli SD, Sullivan J: Development of the Hearing In Noise Test for the measurement of speech reception thresholds in quiet and in noise. *J Acoust Soc Amer* 1994;95:1085-1099.
13. Hanks WD, Johnson GD: HINT list equivalency using older listeners. *J Sp Lang Hear Res* 1998;41(12):1335-1340.
14. The SIN Test CD is available from Auditec of St. Louis, 2515 S. Big Bend Blvd., St. Louis, MO 63142, telephone 314/781-8890, fax 314/781-4946.
15. Mueller HG, Killion MC: An easy method for calculating the articulation index. *Hear J* 1990;43(9):14-17.
16. At 70 HL presentation level, a person with a 70-dB loss would hear *something*, and would be expected to repeat 50% of spondee words correctly. This occurs when the most intense 5 dB of the speech cues are audible. Thus, a 70-dB-HL presentation as we calibrate the speech circuit produces 75-dB-HL speech snippets. (In this case, 16% of the speech cues will be heard, which is sufficient for recognition of 50% of spondee words.)
17. Bentler RA, Duve M: Progression of hearing aid benefit over the 20th century. Poster presented at 1997 American Academy of Audiology Convention, Fort Lauderdale, FL.
18. We have been developing a "Quick SIN" CD recording that should permit a reasonable estimate of SNR-50 in 3 minutes or so. We have obtained a 16-subject average SNR-50 for 360 IEEE sentences.
19. Kochkin S: Customer satisfaction and subjective benefit with high performance hearing aids. *Hear Rev* 1996;3(12):16-26.
20. Killion MC, Niquette P: Hearing Aids—past, present, future: SNR loss comes of age. From the 18th Danavox Symposium, 1999, Denmark. In press.