

# The SIN report: Circuits haven't solved the hearing-in-noise problem

By Mead C. Killion

## THE PROBLEM

**RB** tests a patient with a mild loss: pure-tone average of only 30 dB HL. PN tests a patient with a moderate-severe sensorineural loss, with a pure-tone average of 60 dB HL. Based on averages, you would expect the patient with the greater loss to have greater trouble hearing in noise. You might be seriously wrong.

The first patient requires a 16-dB SNR (signal-to-noise ratio) to score 50% correct on the four-talker-babble SIN (Speech in Noise) test<sup>1</sup>; normals typically require 2 dB. For him to understand at a cocktail party, you would have to convince the crowd to drop its overall noise level from the typical 85 dB to 71 dB SPL, or else you would have to raise your voice from 86 dB to 100 dB! His SNR is one you would expect to find accompanying a severe-profound hearing loss of 80 dB to 90 dB.

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The second patient, on the other hand, comes within 2 dB of average normal performance in noise, requiring only a 4-dB SNR on the SIN test despite his 60-dB loss. His SNR is one you would expect with only a 30-dB loss.

Findings such as these will be more common as SNR tests like the SIN test come into common use. They bring up three

questions:

- (1) What explains these findings?
- (2) Is such information important for hearing aid fitting?
- (3) If so, should I be obtaining SNR data on all my hearing aid patients?

To save the impatient reader time, the writer's answers are:

- (1) Degree of inner hair cell loss
- (2) Yes
- (3) Yes

## OUTER AND INNER HAIR CELL LOSS

The cochlea has two types of hair cells: inner hair cells (one row) and outer hair cells (three rows). Outer hair cells appear to provide the ear's exquisite sensitivity to quiet sounds. Inner hair cells appear to provide all the information to the brain.<sup>2</sup> No one has ever found a neuron from an outer

hair cell sending information to the brain, although thousands of neural recordings have been made in laboratories around the world.

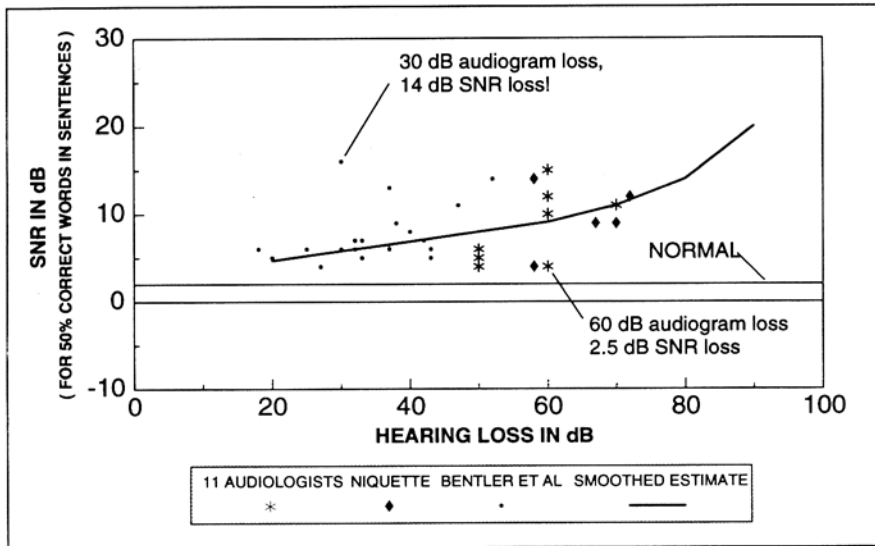
When you lose outer hair cells, you exhibit a threshold hearing loss; your ear is not as sensitive to quiet sounds any more. When you lose inner hair cells, you lose information. Even loud sounds lose clarity. An individual with extensive inner hair cell loss will have trouble understanding some speech in quiet and trouble with nearly all speech in noise.

Note: The once-popular term "nerve deafness" was almost always misapplied. Most cases of unexpectedly poor word (recognition) scores are a result of damage to the inner hair cells of the cochlea, caused by high-intensity noise, ototoxic drugs, or bad genes. "Sensorineural loss" is rarely neural, perhaps one time in 1000. True nerve deafness does occur, however. Unexpectedly poor word scores are one of the signs indicating possible eighth nerve lesions (most often unilateral when they occur), multiple sclerosis attacking the brainstem, or other neural damage in the auditory system.

Borg et al. suggest that high-intensity noise causes extensive damage to inner hair cells as well as to outer hair cells; long-term lower-level noise causing the same audiometric loss may show predominantly outer-cell loss.<sup>3</sup> Translation: If you shoot big loud guns a lot, you can expect a disproportionate loss of inner hair cells and a disproportionate loss of intelligibility in noise compared to someone with the same audiogram who has been exposed to long-term moderate, steady noise.

Figure 1 shows the data obtained by many audiologists around the country using the SIN test, which employs a female talker as signal and one male and three females as four-talker-babble noise. An important question about these data is: "How much of the differences are due to test variability?" The answer is virtually none. Each point represents at least two SIN-test blocks, so the 95% confidence interval is  $\pm 1.0$  dB, providing the subject remained awake. Data points labeled "11 audiologists" represent the average of five similar SIN-test blocks presented to each subject test and retest, giving a 95% confidence interval of  $\pm 0.4$  dB.<sup>4</sup> The large differences among subjects are real.

The subject with 30-dB loss, requiring 16-dB SNR (upper left point) was retested recently. The results were the same. Moreover, he does no better than 60% correct



**Figure 1.** Signal-to-noise required for 50% word-recognition scores as a function of hearing loss. SIN-test blocks 3, 4, 5, and occasionally 6 and 8 were used to obtain these data.

in quiet on W-22 words. Not surprisingly, he reports nearly every possible noise exposure, starting with military service. On the other hand, two different subjects in two different cities with 55-dB and 60-dB losses showed near-normal SNRs.

Clearly, some individuals have much more trouble hearing in noise than others. On the other hand, we can extract the average amount of difficulty as the smoothed mean result from Figure 1. This is shown in Figure 2. The typical individual with a mild-to-moderate loss will require a 5-dB to 6-dB increase in SNR, compared to the SNR required by someone with normal hearing, just to carry on a conversation.

### WHAT HEARING AIDS CAN('T) DO

Hearing aids can solve the problem of loss of sensitivity. Provided the hearing aids don't distort and don't have a bad frequency response, someone with only an outer hair cell loss can be expected to do quite well, even in noise.

But hearing aid circuits cannot solve the SNR problem caused by loss of inner hair cells, or actual nerve deafness. One is reminded of the old nursery rhyme: "All the king's horses, and all the king's men, couldn't put Humpty together again"—at least not with circuit improvements.

As argued elsewhere,<sup>5</sup> we have made substantial progress in eliminating the defects in hearing aids (distortion, limited band width, peaky frequency response, inappropriate frequency response, wrong AGC time constants). During this period,

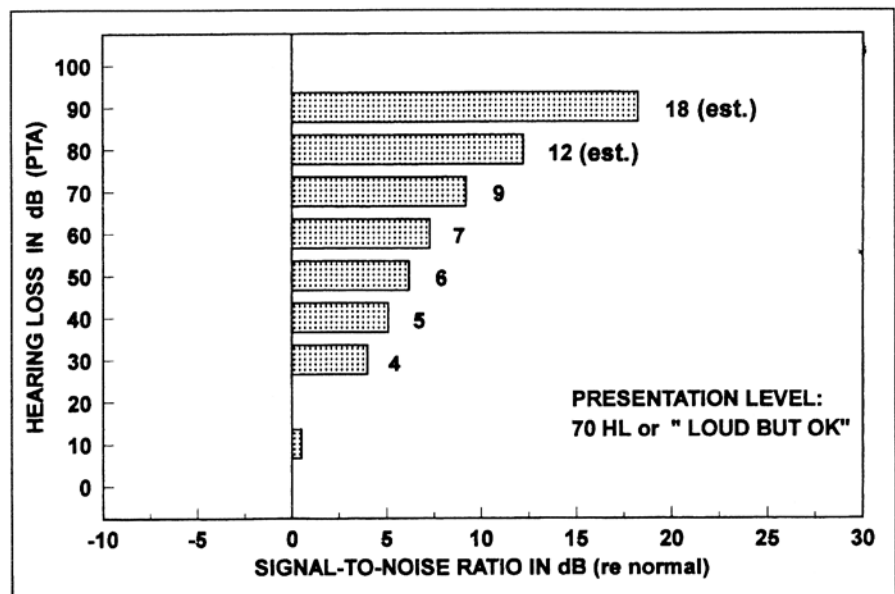
the aided word scores and the SNR for 50% correct scores steadily improved. We were making things better. And circuits will certainly continue to improve. However, the SNR problem remains.

The previous statement requires amplification to be believed, but the evidence is readily available. Thirty years ago, hearing aids made things much worse in high-level noise. You would be better off removing your hearing aid at a typical cocktail party (85 dBA after a few drinks), or at a party with a band playing (95 dBA), or at a country and western dance (up to 105 dBA).

In the 1970s, hearing aids made things worse even at the moderate levels Tillman, Olsen and Carhart used for their testing: The best hearing aid they could find introduced an SNR deficit of 12 dB for those with normal hearing.<sup>6</sup> This means that someone with normal hearing who was wearing such a hearing aid would find the edge of the party (about 5 dB better SNR) inadequate; the person would have to go outside the room to find adequate quiet. Those with typical levels of presbycusis hearing loss found their ability to hear in noise degraded by another 18 dB when they wore the hearing aid: They required 32 dB greater SNR than normal, meaning they could understand speech only when there was no noise.

Fortunately, we have eliminated most circuit problems in the better hearing aids, and hearing aids no longer have to be removed for their wearers to hear in high-level noise. When a person has a severe hearing loss, even loud sounds may not be clear without amplification. In this case, hearing aids can help even in high-level noise. Most of the data in Figure 1, for example, were obtained with an 83-dB SPL (70-dB HL) presentation level. Someone with a 70-dB hearing loss can barely hear a 70-dB HL signal, however, so subjects with a loss greater than 50 dB were tested at the level they chose as "Loud but OK."

With mild-moderate hearing loss, however, once cocktail-party levels of 85 dB (approximately 70 dB HL) are reached, the



**Figure 2.** Smoothed-average SNR vs. HL data from Figure 1.

best the hearing aid can do is become transparent. This is shown in the classic Skinner study, in which a flat frequency response provided about as good intelligibility at the highest input levels as treble emphasis.<sup>7</sup> Similarly Dirks<sup>8</sup> and van Buuren et al.<sup>9</sup> found that with hearing-impaired subjects, no amount of frequency-response shaping would significantly increase intelligibility compared to a flat response for high SPL presentations. (Note: van Buuren et al. found significant quality differences for different response shaping, judged on a scale of "Dull" to "Sharp," so the changes in frequency response were clearly *audible*.)

The three individuals reported on by Killion and Villchur, for example, did much better in low-level noise when wearing their low-distortion TILL-type hearing aids than when unaided, but did almost identically aided and unaided at an 85-dB SPL presentation level.<sup>10</sup> This is a good thing: We have finally eliminated virtually all of the defects in hearing aids.

### *How about digital aids?*

At one time, some people hoped that all-digital "digital signal processing" (DSP) hearing aids would solve the problem of hearing in noise. They don't.

At moderate cocktail party levels of 83 dB SPL, Bentler reported an 1800s speaking tube held out to the side of the ear provided an SNR for 50% correct scores on the SIN test, about equal to that of two recent all-digital hearing aid designs.<sup>11</sup> Lest the reader think this is an attack on digital hearing aids, she found the same results for two high-tech analog aids, one of them a K-AMP instrument. The average SNR scores from 20 subjects for the speaking tube, analog #1, analog #2, digital #1, and digital #2 were: 6.8, 6.0, 6.1, 6.8, and 5.2 dB, respectively. The statistically critical difference for these numbers is  $\pm 1$  dB, so none differs significantly from the average.

How can this be? The answer is simple. At these high levels, audibility is not a problem. The scores are determined by the ear itself. Indeed, the average unaided SIN-test SNR at 83 dB SPL in the above study was 6.5 dB, essentially the same as the various aided SNRs. The average subject had a deficit of 4.5 dB SNR compared to normal subjects; nothing the best circuits did could improve the situation.

As additional evidence: In Bentler's study, testing with CUNY sentences at 78

dB SPL gave average scores for the same circuits listed above of 81.5%, 78.9%, 76.0%, 80.9%, and 81.9%, respectively. The statistically critical difference for these averages was about 9%; none differed significantly in performance from an 1800s speaking tube, or from the average unaided score of 79.8%.

### *Hearing aids in low-level noise*

We have been concentrating on hearing in high-level noise. But what about amplification in low-level noise?

For the past 50 years and more, nearly all hearing aids have provided great benefit in low-level noise. Normal 65-dB SPL (50-dB HL) conversational speech would

*"...Hearing aids can increase the range of SPLs over which wearers can achieve a given SNR performance level, by amplifying low-SPL sounds until they are well above threshold..."*

have been largely inaudible to someone with a 55-dB loss, for example. In low-level noise, say 55 dBA SPL to 65 dBA SPL, such as sometimes occurs at a large family dinner at home or in some quiet restaurants, neither the speech *nor* the noise might have been audible without a hearing aid. Even a 1960s hearing aid would help hearing in noise under these circumstances; without the hearing aid neither the speech nor the noise would be audible. Even distorted or narrow-band-filtered speech is much more understandable than silence!

For several years, the Food and Drug Administration declined to understand this simple observation, insisting that *all* claims

that a hearing aid could help one hear better in noise were automatically misleading and subject to heavy federal sanctions. The only part of the problem the FDA appears to have understood was that filtering out the noise seldom helps. The noise can be filtered only at the expense of speech cues; as Villchur observed rhetorically: "Would you rather hear clear speech in clear noise or muffled speech in muffled noise?"<sup>12</sup>

### *The deficit remains*

For most individuals, hearing aid circuits can't reduce their SNR deficit for high-level sounds. Hearing aids can increase the *range* of SPLs over which wearers can achieve a given SNR performance level by amplifying low-SPL sounds until they are well above threshold. The individual with a 6-dB SNR deficit at high noise levels, however, will typically have at least a 6-dB SNR deficit at low levels, even with our best hearing aids. The deficit is not eliminated by circuitry.

The point is so often misunderstood that it bears repeating: *If an individual has an unaided SNR deficit of 8 dB for a 70-dB HL or 80-dB HL test presentation level, the available evidence suggests that the best the hearing aid can typically do is not make things worse for high-level noise and simply extend the same 8-dB SNR performance to include lower-SPL situations.* One can find exceptions, rollover phenomena, etc., but the statement provides a starting point for a clearer look at the problem. The SNR problem won't go away with circuitry.

### **THE ANSWER**

Fortunately, there is an answer. Indeed, the 1800s speaking tube had it: Increase the SNR! If you hold one of those speaking tubes to your mouth, you will generate 110-dB SPL signal levels. Even at a party with a band, the background noise will be only 95 dB, so you generate a 15-dB SNR into the mouthpiece. Providing the earpiece seals adequately, even someone with a 10-dB SNR deficit can hear fine. If you raise your voice, generating 115 dB to 120 dB at the mouthpiece, you can provide a 20-dB to 25-dB SNR, adequate even for someone with a severe-profound loss.

There are more modern solutions. Treated in more detail elsewhere,<sup>5, 13-17</sup> directional-microphone hearing aids can provide 3-dB to 5-dB SNR improvement even in difficult reverberant cases, and 5 or 10 more in special circumstances.

Array microphones will provide the next level of improvement, giving 8-dB to 10-dB SNR improvement in difficult reverberant conditions and more in special circumstances.<sup>18</sup> Their only disadvantage is the inconvenience of a wireless pencil microphone that needs to be held, or placed behind the ear, or set on the table.

For severe-profound cases, I expect that close-talking wireless microphones will become increasingly popular. They can provide 15-dB to 20-dB improvement in all circumstances.

By attacking the SNR problem directly, we will finally be able to achieve what circuits can't: help most of those with hearing impairment perform normally in noise. (H)

#### ACKNOWLEDGMENTS

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