Improving Hearing Aid Design and Performance

By Mark Ross

In the January and February 2004 issues of The Hearing Review *(a magazine for professionals in the hearing health care industry), Dr. Mead Killion discusses how certain prevalent myths have been discouraging improvements in hearing aid design. In this article, Mark Ross discusses these myths and some research results that bear on them, while adding a few personal observations of his own.*

Mad Killion, Ph.D., began his—January 2004 article in *The Hearing review* saying that as he approaches his 40th year in the hearing aid industiy it seems like a good time for him to reflect on how we got to where we are today. Dr. Killion is an audiologist, engineer, and president of Entymotic Research, Inc., in Elk Grove, Illinois. He holds patents relating to hearing aids and amplification devices.

Figuring out how we got to where we are today is a worthy objective, and since I can spot Dr. Killion a few years in the profession, I'm not only going to comment on his "myths," but try to put his observations into a historical perspective.

The most important myth he cites concerns hearing aid fidelity~ a belief that "fidelity doesn't matter to those with hearing loss because they can't hear the difference anyway." A related myth holds that fidelity has to be sacrificed to a certain extent in order to obtain maximum intelligibility through a hearing aid; i.e., the belief that fidelity and intelligibility may be conflicting goals.

1957: Hearing Aids are "Low-Fidelity Devices'

If we go back to the time I first entered the profession (1957), it was understood that hearing aids were "low-fidelity" devices. Nobody called them that, of course, but all one had to do was look at their electroacoustic performance and this fact would be quite obvious. Even at that time (which may appear to be in the dim, dark ages to some), audiophiles were demanding and receiving high-fidelity audio amplification through phonographs and other devices. They wanted, and received, a smooth amplification pattern (the "frequency response") from about 50 Hz to around 16 kHz, with total distortion of less than one or two percent.

This is still the goal of audiophiles, with the difference being that this response is now quite common and can be obtained through many relatively inexpensive audio devices.

The frequency response of hearing aids in the 1950s, however, was usu

ally between about 300 Hz to 3 kHz and looked like a profile of the Rocky Mountains — it was that jagged and peaked. (As evidenced from the first published book on hearing aids in 1947, the situation was even worse ten years earlier).

Total distortion was considered acceptable by the hearing aid industry if it did not exceed 10 percent. After various techniques were employed to eliminate the most egregious peaks (e.g., insertion of lamb's wool into the nub of the button receiver), the performance of these aids could be improved, at least compared to the unaided condition.

But their benefit was mainly limited to aiding speech comprehension in quiet situations, or at times when the hearing aid could be physically located close to a talker's mouth. Speech comprehension in noisy environments was difficult, if not impossible (still a major issue and a theme that is intertwined with Killion's myths).

It was undoubtedly the poor fidelity of hearing aids at the time that was responsible for another common myth: the belief that hearing aids could not help anyone with a sensorineural hearing loss.

Initially, this belief may not have been a myth at all, but had a solid foundation in fact. When the distorted amplification product of these early hearing aids interacted with the distortion inherent in sensorineural hearing losses, speech comprehension was often poorer than that obtainable without a hearing aid.

People could, indeed, hear better in noisy situations without a hearing aid than with one. The problem is that this belief held on long after hearing aids improved sufficiently so that most people with sensorineural hearing loss could receive significant benefit from hearing aids (but not enough, which is the theme of this paper). This myth was quite common among many physicians until well into the 1970s; indeed, speaking personally, some of my earliest professional articles dealt with this topic.

But how did the original hearing aid designers arrive at the limited frequency range they designed into the early generations of hearing aids? As near as I can determine, hearing aid designers used as their design goals the same range as that found in telephones at the time; i.e., around 300 Hz to 3 kHz. Influencing this decision, no doubt, was the cost factor; the more *"hi-fl"* the hearing aids, the more difficult it would be to design quality miniature components and the more expensive the hearing aids.

Since people could understand on the telephone with a frequency range of 300 Hz to 3 kHz, it was felt that people with hearing loss would be able to understand speech through hearing aids that embodied the same frequency range. At least that appears to have been the reasoning. Of course, the fact that a phone is placed against the ear while hearing aids are worn some distance from a source, and are thus more susceptible to poor environmental acoustics, was simply ignored.

Evidently, the fact that young children would also be using hearing aids did not influence these early design decisions. Even though adults with a normal history of language development can understand speech through a relatively narrow bandwidth (actually, even narrower than 300 Hz to 3 kHz), this is not necessarily true for young children who are in the process of learning an auditory-based language. Because of their knowledge of the language, adults are able to predict and fill in missing acoustic elements (often, quite unconsciously). This is not possible for children who are still learning language; they need all the acoustic information they can get.

There is a big difference, in other words, between *developing* an initial auditory-verbal language and *recognizing* one already mastered. And, for those children with residual hearing through the high frequencies, a hearing aid with a frequency range from 300 Hz to 3 kHz was simply inadequate.

The Killion Studies

Nevertheless, over the years, hearing aids did gradually improve in quality and complexity compared to these early days. Better fidelity is one of the improvements.

Now, instead of a frequency range of 300 Hz to 3 kHz, we have hearing aids that can significantly amplify speech signals up to and beyond 6 kHz. But, according to Dr. Killion, this still provides insufficient fidelity (not "hi-fl" enough) and he conducted several studies in order to evaluate directly the validity of the myths.

In his first study, he compared an experimental hearing aid with six modem digital hearing aids. The bandwidth of the experimental hearing aid, at 16 kHz, far exceeded the bandwidth of the commercially available digital aids. In addition to the increased bandwidth, the experimental aid could tolerate inputs exceeding 110 dB Sound Pressure Level (SPL) without producing measurable distortion. In brief, the experimental aid was a high-fidelity instrument comparable to a high-quality audio reproduction system.

Using live (and loud) music as the input, recordings were made through the hearing aids while they were placed on a head maniken. This maniken (the KEMAR) is commonly employed in acoustic research. Instead of an eardrum, it uses a microphone that connects to various acoustic analyzers and recording devices. The control condition was a recording made directly through the maniken’s open “ears” (no hearing aids and thus no processing distortion of any kind).

The subjects (16 with moderate, sloping losses, and 11 with moderate, flat hearing losses) compared the quality of the sound reproduced through each of the hearing aids, including the experimental hearing aid, to the open ear condition. Thus, the aids were not compared directly to each other; rather, each aid was compared to the condition that would produce the highest fidelity ratings: the open ear condition. In addition to the subjects with hearing loss, some 60 normally hearing audiologists also listened through the hearing aids and compared their quality to the control condition.

The results showed that the subjects with hearing loss gave fidelity ratings almost identical to that of the normally hearing controls. All subjects, both with hearing loss and with normal hearing, rated the experimental hearing aid as sounding closest to the fidelity occurring in the control condition. The ratings of the six digital hearing aids all fell below that of the experimental aid, with several rather far below.

When asked to put a dollar value on the ratings, the subjects with hearing loss judged that the extra quality of sound reproduction offered by the experimental hearing aid would have been worth approximately $1,000 more than the best digital hearing aid. Consequently, the notion that people with hearing loss were not sensitive to, and could not appreciate, “high-fidelity sound” was found to be just a “myth.” They enjoyed “high-fidelity” sound as much as the people with normal hearing did.

Signal-to-Noise Ratio Studies

In another study, the fidelity of the various aids was compared with respect to the speech-to-noise ratio (SNR) at which 50 percent of sentence scores could be identified. In this type of test, the lower numbers are actually more advantageous, since they indicate that a person can understand speech in the presence of higher levels of noise (a lower speech-to-noise ratio).

The results of this study show a direct relationship between the judged fidelity ratings and the SNR scores, with higher fidelity associated with the lower SNRs (remember, this is good). According to this study, therefore, the myth that fidelity and intelligibility are somehow in conflict was not supported.

One difference between the two aforementioned studies should be noted. In the first one, the input sound signal was loud instrumental music. In the second one, it was speech signals. In a personal correspondence between Dr. Killion and me, he points out that the SNR scores in the second study actually clustered pretty closely for all the hearing aids with the highest fidelity, including both the commercial and experimental aids.

What we can conclude is: 1) higher fidelity signals may be required when listening to and appreciating acoustically complex musical signals; and, 2) perhaps understanding of speech does not require the same high fidelity that music appreciation does. However, it doesn’t hurt either.

The Ability to Hear in Noise Myth

In a follow-up article in *The Hearing Review* in February 2004, Dr. Killion challenges another hearing aid myth, this one regarding the ability to hear in noisy situations with directional microphones.

He begins by pointing out that directional microphones "provide the only verified method of improving the ability of hearing aid users to understand speech in noise. Noise-reduction circuits do not." (Note: this does *not* apply when a microphone is placed close to a talker's lips, as in a personal FM system.) He then states that only 20 percent to 30 percent of all hearing aids include this feature and wonders why.

He ascribes this problem in part to the fact that the vast majority of dispensing professionals do not actually measure their clients' speech perception ability in noise through the use of appropriate, standardized tests. Without this information, they cannot have an informed, quantitative understanding of their clients' difficulty in comprehending speech in noisy situations. This difficulty would not be apparent when dispensers counsel their clients in the quiet of their office. Obviously, therefore, dispensing professionals have an obligation to include measures of SNR during the hearing aid selection process.

In my opinion, consumers should ask for this test if it is not automatically provided. It offers direct information on how a person can understand speech in noise. Several are now available, including the hearing in noise (HINT) test, and the speech in noise (SIN) test. (But please don't go into your hearing aid dispenser's office and ask for "sin! ")

But even when directional microphone hearing aids are recommended, they may be of little practical assistance. Beyond the fact that hearing aid users must understand the basic social dynamics in using directional microphones (i.e., they need to ensure that the desired signals are at their front, and unwanted signals [noise] at the rear or sides), the directional performance of the microphones may themselves be inadequate. That is, they simply may not be providing sufficient directional benefit.

This benefit is given as the Directivity Index (DI). This is the metric most often used to describe the performance of directional microphone hearing aids. Killion points out that there is a vast difference between a *measurable* DI and one that is actually *noticeable.* Dl's of 2 dB or less will, under carefully controlled test conditions, increase sentence identification scores by about 10 percent for every 1 dB improvement in the DI. Therefore, under these conditions, the effect of the directional microphones will be measurable.

In a real-life situation, however, with unpredictable and sometimes large changes in the nature, level and location of the noise, and with speech signals often varying from moment to moment, a DI of 2 dB or less is simply not noticeable. It is easy to attribute momentary improvements or decrements in comprehension to changes in the environmental situation, such as somebody talking louder or softer or the noise suddenly waning or waxing. It is only when the DI reaches about 4 dB that the contribution of directional microphone hearing aids is both measurable and noticeable in spite of the changing acoustic circumstances.

Confounding this concept is the fact that the DI is lower when actually measured on a human being (or, in this case, a simulated human being: the manikin KEMAR), compared to the value obtained when the aid is simply mounted on a stand in a test chamber. Thus, the DI specifications given by a hearing aid manufacturer may not accurately predict real-life performance.

A good rule of the thumb for hearing aid users would be to obtain directional microphone hearing aids that provide the highest possible DI. There are hearing aids with KEMAR-measured Dl’s of 5 and 6 dB. This degree of directionality would be not only measurable, but noticeable as well. It’s not enough, therefore, for consumers to simply request hearing aids with directional microphones; rather, they should be asking for those with the *best* directional performance. It can make a big difference.

According to Killion, the extent of this difference could actually permit *some* hearing aid users to hear *better* than people with normal hearing in

certain noisy situations. For many audiologists, including me, this is a heretical concept. We know of the mountains of evidence that point to the greater relative difficulty that people with hearing loss have understanding speech in the presence of noise.

His point is that the signal processing of directional microphone technology can more than compensate for the signal distortions caused by impaired hearing. However, he made this statement on a theoretical basis only, after taking into consideration a person’s SNR loss and the DI of some directional microphone hearing aids.

In March 2004, three respected audiological researchers (Bentler, Palmer and Dittbemer) published an article in the *Journal of the American Academy of Audiology* that did examine whether some people with hearing loss using directional microphone hearing aids could understand speech in noise as well as a group of normally hearing college students.

The 46 subjects with hearing loss had a mild-to-moderate sensorineural hearing loss with an average age of 62. As did Killion, these researchers also used a test that provided an SNR. (To review: an SNR is the intensity level of speech relative to noise at which a subject can achieve a 50 percent sentence identification score. The lower the better, with negative numbers being the best and each 1 dB change in the SNR can increase or decrease sentence intelligibility scores by about 10 percent.)

The 48 normally hearing subjects were directly tested in a sound-treated room. Their performance was the goal to which the scores of the group with hearing loss were compared. The examiners tested the subjects with hearing loss under a number of conditions. These included a hearing aid set in the omnidirectional mode, and two and three directional microphone hearing aids in both fixed and adaptive directional modes. In an adaptive mode, the hearing aid “tracks” the maximum noise source and changes its directional characteristics accordingly. All tests were conducted using

both stationary and moving noise delivered from loudspeakers behind and to the sides of the subjects.

There are several points that should be noted in evaluating this study:

- First, do directional microphones work as well as reputed?
- Second, is there a difference between two and three directional microphones?
- Third, is there a difference in efficacy between aids with fixed and those with adaptive directional microphone characteristics?
- Fourth, are these differences affected by the nature of the competing noise source (stationary or moving)?
- And fifth, do directional microphones permit people with hearing loss to comprehend speech in noise as well as normally hearing college students do?

Findings

There are lots of permutations here, but we'll just cover the major findings.

The very first general conclusion we can come to regarding this study is that directional microphones do work and can work very well. They provide better understanding of speech in noise with both two and three microphones, in either the adaptive or fixed directional mode and with both stationary and moving noise sources. In all of these conditions, the SNR obtained is three to four dB less than that obtained with omnidirectional microphone hearing aids.

With respect to the third point, the scores were slightly better with the adaptive directional microphones compared to the aids set in the fixed directional mode. This, of course, is only relevant in a moving noise situation. These differences, however, are slight and may not even be noticeable (though they are measurable!).

In terms of the last point, directional microphones do work well enough in stationary noise conditions so that the SNR scores of the group of people with hearing loss were very similar to those obtained by the normally hearing subjects using either the two- or three-directional microphone system.

In a moving background noise situation, which is a more challenging listening situation, only the results obtained with the three-directional adaptive microphone were statistically indistinguishable from those achieved by the normally hearing college students.

Still, these are pretty impressive results. Does this mean that all people with hearing loss need to do is use a hearing aid with good directional microphones and that they will hear as well as people with normal hearing?

Hardly Let's consider the subjects used in the three studies reviewed above. All of them had mild-to-moderate hearing losses, with measurable thresholds extending to the limits of the audiogram. These people had what Dr. Bentler called "plain vanilla" hearing losses. We do not know how much we can generalize these findings beyond the specific type of subjects and noise conditions of the three studies.

It is true that most people with hearing loss fall into the mild-to-moderate category. For these people, I think that "high-fidelity" hearing aids would be of undeniable and immediate benefit. If technology can provide these people with hearing aids that sound like an upscale audio system, why not? Just because their hearing loss is rated as "mild-to-moderate" does not mean that it does not produce problems for them. Of course, it does. These people, also, could undoubtedly realize great benefits from directional microphone hearing aids that incorporate real-life Dl's in excess of 6 dB. This is not an unreasonable figure.

However, there is one major qualification here. Directional microphones, of any type, do not work as well in highly reverberant conditions as they do in noise. In the Bentler, Palmer, and Dittberner study, the competing noise did not include reverberation. Since many real-life conversations take place in reverberant settings, it is unlikely that people with hearing loss will be able to understand speech as well as those with normal hearing. The normal ear feeding to the normal brain is still a lot more sophisticated than even the most advanced technology. And it is the brain more than the ears that enables people with normal hearing to focus in on the direct sound in a reverberant location while suppressing its reflections.

How about the people with severe hearing losses or those with little or no residual hearing in the higher *fre*quencies? How would the results of this research relate to them? We don't really know, but one conclusion is immediately apparent. It is unlikely that these people can appreciate a high-fidelity signal when they have only "low-fidelity" hearing.

For example, if a person has little or no residual hearing past three or four kHz, then can he or she appreciate an amplified signal that extends to 16 kHz? Probably not, in my judgment. We also do not know the degree to which people with more severe hearing losses can benefit from directional microphone hearing aids. The ear operates differently with hearing losses up to about 60 or 70 dB than it does to hearing losses greater than that. I do believe that some benefit is possible with this population — I've experienced it myself— but the degree of benefit may be less than that realized by people with less severe hearing losses.

Whatever one's degree or type of hearing loss, what this research suggests is that better hearing in noise is attainable through the use of high-fidelity amplification coupled to excellent directional microphones. At the most pessimistic, it can only help and won't hurt.

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