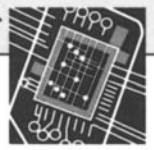
A Historical Perspective on Hearing Aid Selection

David B. Hawkins, Ph.D

No other area of audiology has intrigued and fascinated me as much as hearing aids. It is an area in which technical advancement is charging ahead, yet it is full of unresolved issues. Though we must be well versed in these technical areas, we must also deal with the human being in front of us, the psychology of which can be as complicated as any multi-band compression system. In making current decisions and deciding the directions in which we are moving, it is very useful to examine where we have been, and put into perspective our current notions. The purpose of this paper is to provide one person's perspective of where we have been and where we are heading. As the history teacher often says: "You don't know you are going if you don't know where you have been."

The hearing healthcare field is at a fascinating time in hearing aid and protocol development. It's evident that better circuitry is available today than even five years ago, and the rise of nonlinear circuitry is transforming the way in which we treat hearing loss. Unfortunately, the technology is outpacing our current fitting methods. The challenge ahead is to explore new optimal fitting parameters for nonlinear circuits.



What's Good and Bad About Now

There are lots of good things happening in hearing aid circuitry and selection. We have much better circuitry from which to select, such as Class D receivers, Adaptive Compression, two and three band compression, fixed ratio and variable ratio compression, and various combinations. We may not know what to do with all of these options yet and how to determine the optimal combinations and settings, but there is no doubt in my mind and from my clinical experience that we have much better products to offer to the hearing-impaired person than we did only several years ago. We also have better means of evaluating hearing aid performance. Probe-microphone measurements, paired-comparison capabilities on some of the programmable systems and new benefit assessment questionnaires are just a few of the tools.

David Hawkins, PhD, is head of the Audiology Section at the Mayo Clinic in Jacksonville, FL. This article was originally presented at the 1994 Jackson Hole Rendezvous in Jackson Hole, WY.

With all this optimism, what could be viewed as the down side? Basically, it is that many people dispensing hearing aids are not using methods available to them to provide a better product. Many dispensers apparently still allow the manufacturer to select the circuit and often opt for the least expensive unit, typically a linear peak clipping hearing aid. Unfortunately, this approach minimizes circuit sophistication and fidelity for the hearing aid user. In 1991, Hawkins and Naidoo[1] found that 82% of hearing aids sold utilized peak clipping. Hopefully, this trend has been reversed. The latest industry figures, however, still show that programmable hearing aids occupy a small percentage of the market. While there may be a variety of reasons for this low number, including price to the user, many dispensers seem reluctant to embrace the newer circuitry.

Another somewhat discouraging thought is that most of us seem to be functioning under the assumption that everyone with the same audiogram experiences the same perception of sound. The entire audiogram-based selection approach assumes this to be true. We know, however, from research completed years ago that there are many types of loudness growth curves. Hopefully, we will move more toward the concept of incorporating each individual's unique growth of loudness experience into the selection of amplification characteristics.

Finally, we do not seem to be using all the tools we have available to improve performance in noisy environments. Directional microphones, shown to improve speech understanding in noise,[2] are rarely used. FM systems, now available in

BTE units, continue to receive limited use in spite of the fact that they provide enormous improvement in the signal-to-noise ratio.[3]

Our Current Thinking—Is It So Current?

There is a resurgence of interest in loudness growth in the hearing impaired and factoring their perceptions into the selection of amplification characteristics. Consider the following quotes:

"The failure of these methods, based on the threshold of hearing curve alone, emphasizes the necessity, as stated above, of taking into account the convergence of equal loudness contours toward the threshold curve..."

and

"...the speech sounds must be placed within the auditory area to be heard. In determining the intensities, one must keep in mind that the equal loudness contours in ears with (sensorineural) impairments...usually converge toward the threshold curve at the higher frequencies..."

If you guessed that these quotations were written in 1994, you could be easily forgiven. The truth is that they were published in 1940 by Watson and Knudsen[4].

To further emphasize the full circle concept, consider the following quote from Lebel[5] in 1944:

"In the industry it has been common practice to measure the characteristics of a hearing aid...with a 2-cc closed coupler artificial ear. Our organization some years ago observed that instruments when fitted to a person did not behave exactly as uncorrected measurements and audiogram indicated."

In other words, "some years ago" (since 1944!) it was realized that real-ear performance can be quite different from 2cc coupler measurements. In this publication Lebel published a correction curve to convert from 2cc gain to real-ear gain that is quite close to those commonly accepted today.

What happened to the development of such ideas? Apparently they were "well before their time," as these concepts were dropped and not resurrected until years later. While hearing aid dealers and deaf educators were present in the 1940s, I doubt that they were reading the *Journal of the Acoustical Society of America* to expand their thinking regarding hearing aids. Perhaps it was the lack at that time of a profession with a scientific basis that claimed hearing instruments as its *raison d'etre*. Audiology as a discipline did not emerge until the late 1940s and did not really establish itself until the 1960s. Further, while the early audiologists were certainly interested in theories concerning amplification, they were not involved in day-to-day selection of hearing aids.

Assuming that these early progressive ideas were not pursued, how did hearing instrument selection evolve? It certainly has gone through some rather distinct eras, which will now be outlined.

Stage #1: The Carhart Era

To many people the "Carhart Evaluation" has a negative connotation. They view it as monosyllabic word lists presented in a quiet sound booth with three different hearing aids. The hearing aid with the highest score is selected.

As a former student of Carhart and one who has actually read all of his original works from the 1940s, let me state immediately that nothing could be further from the truth and proclaim that Carhart has gotten "a bum rap." For instance, consider this quote from the original 1946 Carhart article describing part of his procedure for selecting hearing aids:

"In the second stage the patient puts each of the fittings recommended for him to everyday use. He wears each hearing aid for 24 hours. At the end of this time he rates the instrument's performance in bringing him 13 different kinds of sounds. These items are controlled reproductions which are presented to the patient in a special session known as the 'listening hour.' When the patient has put all the recommended fittings through this procedure, the three hearing aid combinations which rate highest are designated for further study."[6]

Everyday use, rating scales, time for acclimatization. It all sounds very current to me. Of course, with time, the original ideas of Carhart were modified, the procedure shortened, and the second era began...

Stage #2: Let the Word Lists Select the Hearing Aid Era

This era can probably be said to have begun in the 1950s and continued into the 1980s. It is doubtful if it is currently being practiced in the United States. In this procedure, the clinician selected three (or four if they were conscientious) hearing aids from a pool of about 70 to 80 BTEs. The three hearing aids were selected somewhat at random, with a general guideline of high-frequency hearing loss equals a high-frequency emphasis aid, flat loss equals a flat response aid, etc.

I do not recall, nor do I think others did at the time, paying any attention to SSPL90 (then referred to as MPO). At the facility I worked, we used unvented receiver earmolds with snap-ring adapters on everyone. Word recognition scores were obtained in a sound booth with each instrument. The word lists were CID W-22 or NU-6 and were presented in quiet or in a background of noise. The hearing aid (notice singular, as rarely was binaural recommended) with the highest score, regardless of the magnitude of difference between the scores (Thornton and Raffin[7] had not come on the scene yet), was declared the "best hearing aid." The hearing-impaired person was sent to the hearing aid dealer—unvented receiver earmold in hand—to purchase the carefully selected hearing aid. They undoubtedly had their sintered filters, drill, and lamb's wool ready to be put to use. After purchase, the buyer was to return to the audiologist so that assurance could be made that no behind the scenes switch had occurred, or that the dealer had not pressured the unsuspecting person into trying *binaural* hearing aids.

Several events led to the demise of this era. In the mid-1970s, audiologists first became more directly involved in the dispensing of hearing aids (for a brief history of this, see p. 22 of the October *Hearing Review*). I believe they saw the futility of the speech discrimination based approach, both in its theory and its practicality. Could a score in a quiet sound booth with single words really reflect real-world performance? Was the lengthy evaluation time worth it? With the Thornton and Raffin publication in 1978, which showed that large differences were necessary before two scores could be considered statistically significant, the nails were starting to be put into the coffin. The coffin was sealed with the publication of the Walden et al[8] study which demonstrated that none of the critical assumptions that were underlying this approach could be upheld. It was during this time, the mid-1970s, that the next era could be said to have begun.

Stage #3: Let the Frequency Response Formula Select the Hearing Aid Era

Everyone is probably well familiar with this stage, as one might argue that we are still in it. NAL-R, Berger, POGO, Cox/MSU, 1/2 gain rule, Libby's 1/3 - 2/3 rule, and others have become household words in the hearing aid dispensing arena. While these various procedures yield rather similar results, assuming the user has a volume control wheel, their development often followed different pathways. Some were very pragmatic

in that they examined where the typical hearing aid user set their aid, then formulas were developed to give other users similar values. Other procedures started with a theory, such as to amplify the long-term spectrum of speech to most comfortable listening levels, and then developed formulas to make it happen. The focus was on frequency response selection for linear hearing aids.

Within this era, there are a number of various ways this formula approach has been, and still is being, implemented. The first I would call the "Stripped Down Approach." In this approach the dispenser functions as a pure technician. They do an audiogram, take impressions, let the manufacturer make all the decisions (who I will assume is using some type of formula) and fit the hearing aid with counselling only. All trust is placed in the manufacturer and the 2cc coupler response.

A second variation of the formula idea is the "Watered Down Approach." An audiogram, loudness discomfort levels (LDLs) and impressions are obtained. The manufacturer makes decisions regarding frequency response and SSPL90 and the dispenser fits the hearing aids without verification or with some form of limited verification such as "How does this sound?"

The final variation I will call "Select and Verify." The dispenser obtains an audiogram and LDLs, selects a formula-based approach, and determines the desired frequency response, SSPL90 and circuit. The dispenser tells the manufacturer what matrix or circuit is desired and the instrument is made and delivered. Some method, typically either sound-field thresholds or probe-microphone measurements, is employed to determine if the frequency response is acceptable and checks are made to verify that the SSPL90 is set so that the user does not experience uncomfortable loudness.

The best part of this era has been the emphasis placed by Skinner and colleagues at CID on packaging the speech signal within the dynamic range of the hearing-impaired individual. Skinner (1988) stated that amplification provides the greatest assistance if four basic goals are met:

1) Conversational speech in the 250 to 6000 Hz range is amplified to a comfortable listening level;

2) Overall level of speech can be adjusted so that it is comfortable for various listening situations;

3) Sound quality is acceptable;

4) Maximum output does not allow amplified sound to surpass the individual's discomfort level.[9]

If these four basic ideas are remembered and implemented, hearing aid fittings would be greatly improved. The emphasis by Skinner on the fact that hearing aids should not produce uncomfortably loud sounds has proven to be an important one. This is one area where the work of Carhart probably *did* have a negative influence, and unfortunately even today some view avoidance of extreme discomfort or even pain as the only real concern. Given that pain and extreme discomfort typically do not occur until 125-130 dB SPL, some dispensers seem to believe that loudness discomfort is a relatively unimportant aspect of hearing aid selection. Carhart considered it an important issue, as seen in this quotation from his 1946 paper:

"...the hearing aid selected should be the one with highest tolerance

limit...the tolerance limit may justifiably be made the primary criterion for selection."[6]

Although it was clearly important, the following instructions he used obviously converge on very high SPLs:

"The patient is asked to report the point at which he experiences some definite sensation such as pain, tickle, vibration or dizziness...is taken as the tolerance level, or psychological 'ceiling,' of a hearing aid. Care must be taken to insure that the patient is not reporting as his tolerance limit the point where the instrument becomes unpleasantly loud."[6]

The use of the word "tolerance" and instructions such as these led many to believe that hearing aid fittings were acceptable as long as the user could tolerate the sound. This resulted in many hearing aids being fit on mild and moderate sensorineural hearing losses with maximum outputs well above 120-125 dB SPL. The user might well "tolerate" the hearing aid, but it would be very uncomfortable on a daily basis and the volume control wheel would be manipulated constantly to prevent moderate to loud sounds from being unbearable.

When ITEs came on the market, the output was lower simply because of circuit limitations, the by-product of which has been more comfortable hearing aids for many users. The trend today is to attempt to ensure that loud sounds are perceived as loud, but not uncomfortable. Judicious attention to this aspect of hearing aid fitting will lead to users better accepting their hearing aids.

Stage #4: The Nonlinear Era

This is the stage that I believe we are just entering. Indeed, the latest market survey indicates that 43% of hearing aids being dispensed are nonlinear.[10] This is truly astounding given the survey of several years ago by Hawkins and Naidoo (1993), which was mentioned earlier, showing that 82% of hearing aids sold used peak clipping, typically employed in linear circuits.

I see several subcategories emerging in this era. One could be called the "Modify the Old Idea Slightly" category. Here I would include output limiting compression and single channel input compression circuits that have relatively high kneepoints (e.g., 70 dB SPL) and high compression ratios (e.g., 8:1 or greater). Compared to the traditional linear peak clipping instrument these circuits represent an improvement, but one could hardly call them revolutionary developments.

A second category might be called "Something Really New, and One Size Fits All." A good example of this approach might be the K-Amp. It represents something truly new and is a good idea based on solid theory. The unique input-output function (linear, 2:1, unity gain, limiting) and level-dependent frequency response are indicative of a nonlinear approach that is new, different, and promising. While the developer, Mead Killion, is quick to point out that it is not for everybody, variations of the K-Amp circuit are being made to accommodate virtually all but severe and profound hearing losses.

The final category of the nonlinear era could be called the "Something Really New, And We'll Tell You How to Fit It" method. This approach can be easily seen in some of the programmable hearing aids. The manufacturers have done some homework, maybe some research and certainly some field trials, and have "proprietary algorithms" to program the hearing aids. The dispenser is often provided little in the way of explanation and is expected to follow the saying "Trust Me, It'll Work."

So at present it appears to me that the field is diving into nonlinear instruments, sometimes trying variations of circuitry with which we are still familiar, other times embracing new technology that might apply to a range of people, and still other times experimenting with nonlinear programmable hearing aids, some of which clearly fall in the "Something Really New" category. There is certainly more concern with loudness growth and restoring normal loudness contours, making the circle back to the 1940s.

Conclusions

In analyzing the history of hearing aid selection and the current trends, I would offer the following conclusions: 1) We are at a fascinating time in hearing aid development: a period of rapid change and new technology; 2) Better circuitry is clearly available today than even five years ago; however, it is only better if it is used; 3) Nonlinear circuitry will eventually prove superior for most hearing-impaired persons; 4) Current fitting methods tell us little about how to fit nonlinear hearing aids; and 5) We must start exploring new ways of determining optimal fitting parameters for nonlinear circuitry. ◆

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