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COMMENTARY

Clinical implications of a damaged cochlea: Pure tone thresholds vs information-carrying capacity

Chris Halpin, PhD, and **Steven D. Rauch, MD,** Boston, MA

The pure tone audiogram is an accurate measure of auditory threshold as a function of stimulus frequency. However, it does not provide the complete picture in patients with sensorineural hearing loss (SNHL) because it is not a direct measure of damage to the cochlear epithelium or of the associated limits on information-carrying capacity that restrict word recognition. Diagnostic use of the audiogram leads to the error of viewing SNHL as "dB of hearing loss," which may seem reversible by gain. Cochlear disorders, on the other hand, often give rise to abnormal thresholds because regions are damaged and may best be thought of more in terms of intractable sensory limitations, comparable to vision loss in retinal disease. We argue that word recognition testing at low vs high presentation levels provides a quantification of the cochlea's information-carrying capacity and is a useful predictor of word recognition limits with hearing aids.

In daily practice, the disorder known as sensorineural "hearing loss" (SNHL) is portrayed on an audiogram. It is common to think of the hearing problem in terms of the associated change along the vertical axis on the audiogram (dB HL). Equating cochlear dysfunction with the pure tone audiogram is tempting but leads to some faulty assumptions about the actual pathology and its management—most importantly, the notion that a threshold shift can be "reversed" using hearing aid gain. In this commentary we argue that this assumption leads clinicians to treat the audiogram rather than the cochlea. They try to reverse "loss" (threshold shift) with gain when they often actually face a different condition: intractable damage to cochlear epithelium and loss of information-carrying capacity. One might compare this situation to a case where a patient has low vision due to retinal disease. In such a case, no treatment, such as brighter light or new eyeglasses, will overcome the limits on the information sent to the brain. A damaged cochlea imposes limits (mild or severe) on the amount of speech information that can pass, and this pathophysiologic reality, not the pure tone audiometric thresholds, limits function in remediation of SNHL. The best representation of this limit on information-carrying capacity is speech audiometry (word recognition score). Word performance can vary from zero, in inaudible or noisy conditions, up to whatever limit is imposed by the patient's cochlear damage. We propose that these upper limits can be evaluated using standard audiometric tests and can explain the different performance of patients, even when they have similar audiograms (Fig 1).

EVALUATING EACH DAMAGED COCHLEA

In Figure 1, two very different cochleae give rise to similar audiograms and we suggest a word recognition framework in the bottom graphs for how the two cochlear conditions could be analyzed. The black "S" curves are the best possible scores, as if all sensory cells remain useful, calculated using the Speech Intelligibility Index.[1] The white vertical bars represent measured scores and levels, where the height of each bar corresponds to the 95 percent critical difference.[2] Speech at 55 and 95 dB HL are used to highlight regional differences for these temporal bones. At the lower level, both examples show scores (~50%) that match the calculated expectation. Thus, the low-frequency regions stimulated by the speech are not heavily damaged. When either the level is raised, or the high frequencies are emphasized, the two cases diverge. In the first case, the cytocochleogram shows an intact hair cell population (stria and neurons, not shown, were normal). Many cells remain and the score may improve (to 98% in this example), including with hearing aids. In the second case, the "hearing loss" is similar to the first, but there are no hair cells in higher-frequency regions and the score cannot rise. The patient's responses to high-frequency tones are due to powerful remote stimulation spreading to healthy regions.[3] While there are no aided results from this temporal bone case, we feel this cochlear base cannot add meaningfully to performance with hearing aids. Also, when word recognition scores plateau, as in this example, this is evidence that the effect is not due to a central disorder that would affect both low and high levels. Word recognition analysis does not yield a diagnosis for specific cell types, but does show whether affected frequency regions contribute to performance. The tradi-

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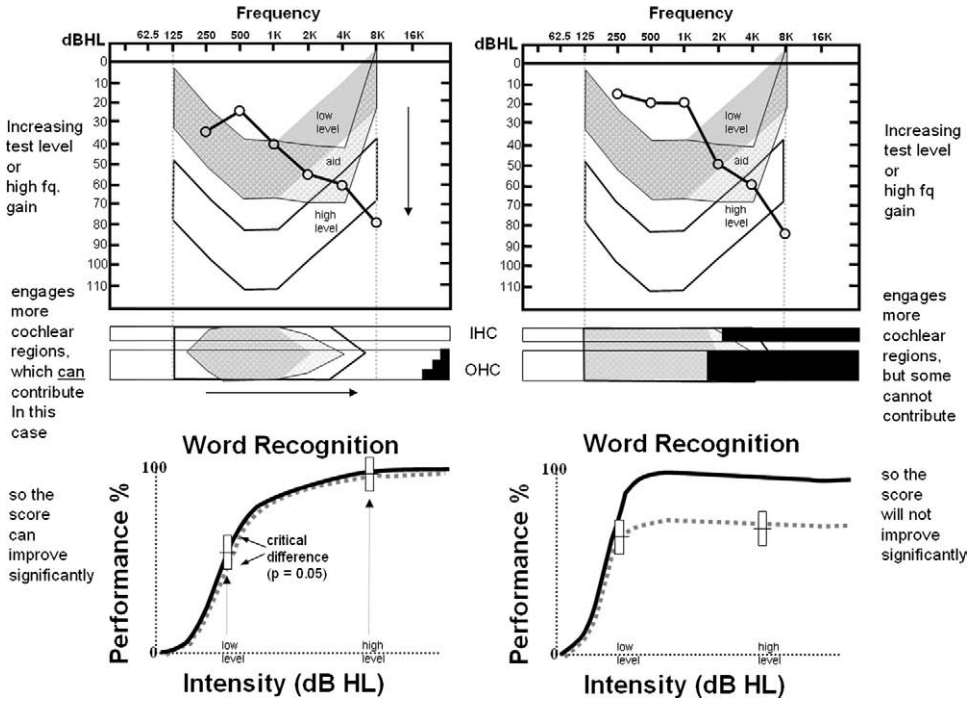

Figure 1 Two temporal bone cases. Audiograms appear above bars showing residual inner and outer hair cells, with black denoting missing cells.[8] Three shaded areas on both audiograms and cytocochleograms show speech for low-level, high-level, and aided conditions. The bottom graphs show a proposed analysis using word recognition.

tional approach to hearing aid fitting is based on a scenario like the first case, with a relatively intact population of sensory cells but inadequate audibility. Unfortunately, the improvement in word recognition with increasing level is seen in a minority of our sloping SNHL cases.

HOW OFTEN DOES THIS HAPPEN?

The presence of noncontributory cochlear regions is common in cases with sloping audiograms. We performed a survey of 255 sequential cases with audiograms similar to those in Figure 1, and where the word lists were presented at both low and high levels. In 81 percent of these cases, increased presentation level failed to achieve statistically significant increase in word recognition.[4] Across a wider variety of affected frequencies and shallower slopes, the proportion of cases showing dead regions has been reported at approximately 50 percent.[5] We conclude that word information limits imposed by the cochlea should not be assumed from the audiogram. They should be measured and factored into any discussion of hearing aid benefit.

ARE WORD RECOGNITION LIMITS EXCEEDED BY HEARING AIDS?

Standard speech audiometry reveals the upper limit of word recognition achievable by gain. If this ceiling is reduced due to missing cochlear epithelium, then frequency-gain compensation with a hearing aid is not predicted to yield any better word recognition than the standard headphone test. We tested this prediction by comparing results of clinical word recognition scores to scores obtained with formula-fit, digital hearing aids (CLARO; NAL-NL1, Phonak, Warrenville, OH) in a sound field. In Figure 2, audiogram-fit hearing aids approached, but did not exceed, clinical word recognition scores, and the standard clinical score is shown to predict over 90 percent of the variance in maximum performance with hearing aids (Pearson's $r = 0.958$; $r^2 = 0.92$). We performed these tests in quiet to ensure that the result is a measure of maximum cochlear

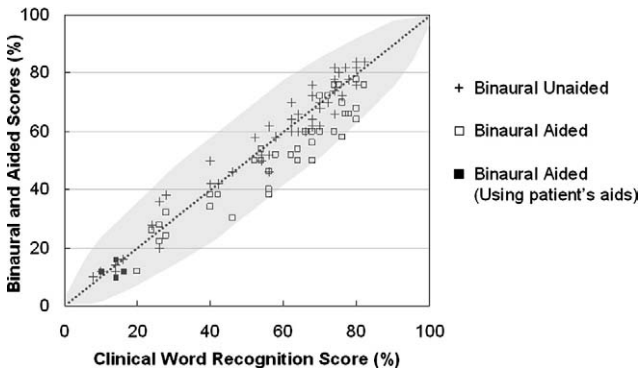

Figure 2 Fifty patients (mean age 70; SD 17) with symmetric sensory loss. Their best word recognition score (*horizontal axis*) is compared to binaural and aided scores, using the same test and levels. The *shaded oval* shows the 95 percent critical difference for these tests.[2]

performance, not confounded by effects of noise. Hearing aids clearly help these patients, but they do so by improving their word recognition only to the performance ceiling allowed by cochlear damage, which is reliably characterized by their word recognition score.

BEYOND "HEARING LOSS IN DB:" EVALUATING THE COCHLEA

In current practice, cochlear limits can be evaluated using standard tests. The high-level word list is the current standard of practice. The addition of a low-level word list demonstrates the potential for improvement. If the patient can perform a word list at 40 dB HL, that score may be compared to one obtained at 70 dB HL. Validity of this comparison requires use of full (50-item) recorded lists and application of the binomial table.[6] If a patient cannot hear words at 40 dB HL, the low-level score can be considered zero and speech audiometry at multiple levels is not required. Since this is an evaluation of the cochlea, it should be undertaken in quiet, just as with pure tone thresholds. If the word recognition score is significantly increased with level, then prognosis for hearing aid benefit is good. Conversely, if increased gain does not significantly improve word recognition, hearing aid benefit will be equally restricted. Alternate strategies and assistive devices should be pursued, but it is essential that the patient be informed that limits imposed by the damaged sensory organ cannot be overcome by amplification. Using this approach, fewer patients would receive a recommendation for hearing aids, but those who did would justifiably expect improvement in word recognition with higher sound level.

COCHLEAR DISORDER AS INFORMATION LIMIT: A CHANGE IN DISCOURSE

The discourse between clinicians and their patients is very different for cochlear vs retinal disease. Despite extensive testing, the nature of cochlear damage always remains somewhat speculative. A damaged retina is visible and much less open to speculation regarding rehabilitative options. Ophthalmologists do not suggest that shining bright light at damaged regions of the retina would restore function. Nor would a retina patient be told that the limits imposed by damage can be exceeded by buying a more expensive pair of eyeglasses. Neither would anyone suggest that these patients be abandoned once retinal damage is found. Not every aspect of the ophthalmic analogy applies but, if the maximum word recognition score is high, satisfaction with hearing aids should be possible. If the score is low, but nonetheless improves with level, then hearing aids will offer some benefit and should be worn. The inevitable complaints of such patients can legitimately be attributed to limited ears, as opposed to the programming or cost of the device. Despite the presence of "hearing loss," if there is no demonstrable word recognition benefit with increased level, hearing aids should generally not be recommended to address communication problems. The question is not whether thresholds are elevated, but whether the damaged cochlea will allow improved word recognition with increased presentation level. Improved signal-to-noise ratio will still be beneficial in specific situations, but prognosis for hearing aid use must reflect the reality of limits imposed by a damaged sensory organ. This is a very important message for the patient's family. In cases like the right panel in Figure 1, limited word recognition will persist whatever the patient does (or buys). The family will achieve greater success in communication when they vigorously follow suggestions for careful, face-to-face speech in quieter rooms than they will with a hearing aid.[7]

A change in discourse would be useful as clinicians interact with scientists and manufacturers. Studies of hearing aid benefit are confounded by using cohorts of subjects defined by their audiometric thresholds. Both cases in Figure 1 would be included as having equivalent "hearing loss." This results in groups with variable degrees of cochlear damage and, consequently, variable benefit from amplification. Imagine a study of a group with the same amount of fever ("degrees of sickness"). It is more useful to group by cochlear damage than by "hearing loss." As in Figure 2, it may be best not to group the subjects at all, but to consider their maximum word recognition along one axis. This would show the impact of cochlear damage, from mild to severe, on other study variables. In hearing research, the validity of "simulated loss" (where degraded information is given to normal cochleae) is a questionable model for the opposite, real-world situation in which good information fails to pass through a badly damaged cochlea.

We acknowledge that a great deal of data and discussion remain to be presented on this topic, and that higher parts of the auditory system must also be included as these sorts of clinical models are considered. Our object here was to articulate a different approach after many years of facing this disorder in the clinic, sometimes with disappointing results. We advocate the application of readily available word recognition testing for evaluation, device recommendation, and counseling, and for factoring cochlear limits into the development of hearing aids. We recommend treating the cochlea, not the audiogram.

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AUTHOR INFORMATION

From the Department of Audiology, Massachusetts Eye and Ear Infirmary (Dr Halpin), and the Department of Otology and Laryngology, Harvard Medical School (Drs Halpin and Rauch).

Corresponding author: Chris Halpin, PhD, Department of Audiology, Massachusetts Eye and Ear Infirmary, 243 Charles Street, Boston, MA 02114.

E-mail address: cfhalpin@meei.harvard.edu.

AUTHOR CONTRIBUTIONS

Chris Halpin, collected data, original text, and figures; **Steven D. Rauch**, structure and content of manuscript; significant editing of text and figures.

FINANCIAL DISCLOSURE

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