Optimising Hearing Aid Settings to Maximise Speech Audibility

Pamela Souza, PhD, CCC-A,
The Roxelyn and Richard Pepper Department of Communication Sciences and Disorders,
School of Communication,
Northwestern University

Correspondence
Pamela Souza,
The Roxelyn and Richard Pepper Department of Communication Sciences and Disorders,
School of Communication,
Northwestern University,
Francis Searle Building 2-265, 2240 Campus Drive, Evanston, IL 60208, USA.
E: p-souza@northwestern.edu

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None declared.

What is severe hearing loss?

Historically, severe loss refers to auditory thresholds between 70 and 90dB HL. The obvious problem caused by severe loss is difficulty hearing soft sounds, and most individuals with severe loss can make out little if any conversation unless the speech is amplified. The problem is even worse if there is background noise, or if visual cues are not available. For example, many patients with unaided severe loss do not use the telephone, attend movies or enjoy meeting friends in restaurants. Unfortunately, amplifying speech offers only a partial solution to this problem. Patients with severe hearing loss complain that amplified speech is louder, but unclear. Recent studies of auditory physiology and perception suggest that these individuals have significant damage to both outer and inner auditory hair cells[1,2] which results in broadened auditory filters.[3] Simply put, the patient's auditory system cannot detect a difference between two sounds that differ in frequency (pitch). The ability to make that distinction is necessary for almost every aspect of hearing. Without good frequency selectivity, we cannot hear the difference between 'me' and 'knee'; distinguish speech from unwanted background noise; ignore interfering environmental sounds; or listen to music without distortion.

Severe hearing loss affects all aspects of everyday life. A patient with binaural severe loss recently commented to me that although he had worn hearing aids for 20 years, they had all failed to provide for adequate speech understanding, and he continued to feel isolated during any social gatherings. As a group, individuals with severe hearing loss report communication problems and feelings of isolation leading to decreased involvement in daily activities. Until human auditory hair cells can be regenerated or we develop a novel and completely successful treatment for sensorineural hearing loss, clinicians need to use the tools at their disposal to maximum advantage. For most patients with severe loss, the primary tool will be well-fitted hearing aids.

Once an innovation and now a standard feature, digital feedback suppression allows up to 35dB more gain than aids without digital feedback management

Improving audibility and loudness comfort, hopefully with minimal distortion

From decades of study, we know that improving audibility is the necessary foundation for improving speech understanding. Multichannel wide-dynamic range compression (WDRC) amplification offers us an excellent opportunity to improve audibility across a range of speech input levels. With this processing strategy, we can provide greater gain for low-level inputs than for high-level inputs and variable gain can be set within each compression channel to reflect the limitations of the listener's audiogram. Consider a simple example, a hypothetical listener with 60dB HL thresholds below 1kHz, 80dB HL thresholds above 1kHz, and loudness discomfort levels of 100dB HL at all frequencies. Gain is applied to bring lower intensity speech above threshold, while maintaining higher-level speech below the discomfort level. Above 1kHz, there is less energy in the conversational speech spectrum and the listener has a smaller dynamic range. In the high frequencies then, we need to further increase the gain for low-intensity speech. The end result will be a hearing aid fitted with compression at all frequencies, but with more compression applied to sounds above 1kHz.

In most digital aids, the amount of compression is controlled by adjusting compression ratio and compression threshold in combination with time constants. In theory, to achieve the best audibility for a severely-impaired listener with a small dynamic range we would use a low compression threshold, high compression ratio, and short attack and release times. Carried to an extreme this would provide perfect audibility of all speech cues. Such an effect is undesirable however when we remember that clear speech depends on spectrotemporal contrasts, as the unique frequency spectrum of each phoneme varies rapidly over time. More compression channels coupled with higher compression ratios

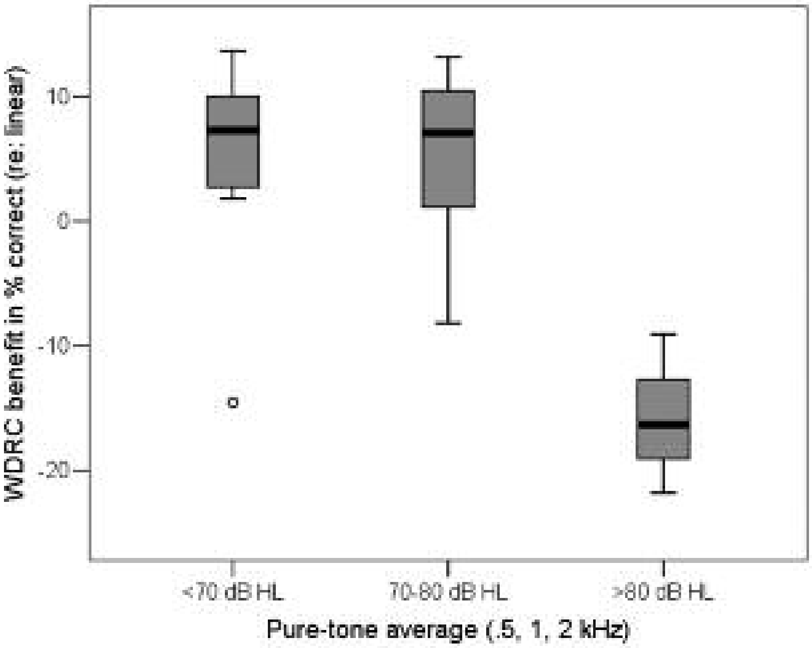

Figure 1: The benefit of multichannel WDRC hearing aids. Listeners are grouped according to their pure-tone average thresholds.

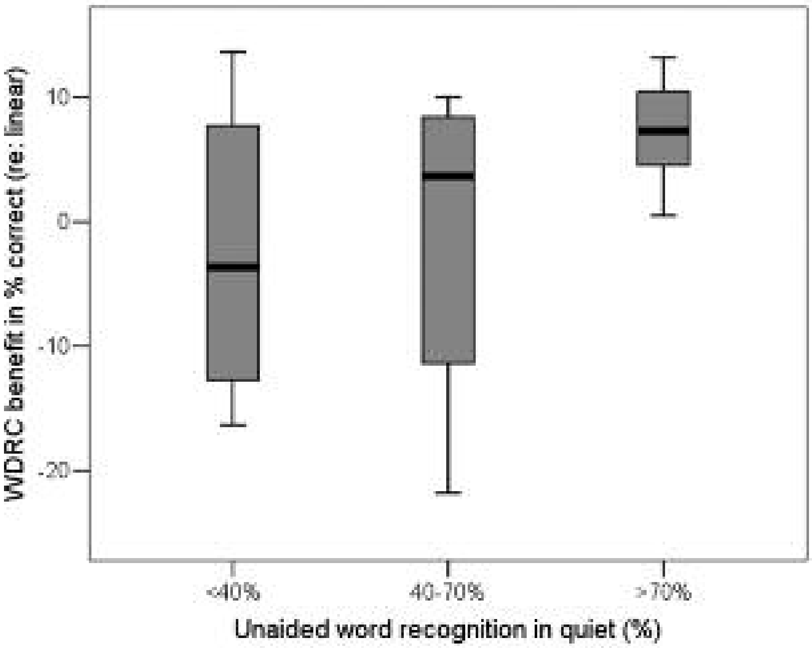

Figure 2: The benefit of multichannel WDRC hearing aids. Listeners are grouped according to their quiet speech recognition score.

will reduce spectral contrast, and short release times coupled with higher compression ratios will reduce temporal contrast. Our work shows that increasing compression beyond a certain point results in rapidly degraded intelligibility for vowels,[4] and consonants,[5] leading to poor perception of meaningful sentences.[6] This is not usually a problem for listeners with mild to moderate loss, where standard prescriptive methods rarely prescribe compression ratios greater than 2:1. However, target compression ratios for severely impaired listeners can be much higher. Achieving those compression ratios improves audibility, but at the expense of speech clarity. How then do we resolve this and pick the appropriate hearing aid settings for each individual with severe loss?

A complicating factor is the wide range of hearing aid benefit seen in this population, even with appropriately fitted hearing aids. Figures 1 and 2 illustrate the benefit of multichannel WDRC hearing aids (expressed as improvement in conversational speech recognition, compared to a linear hearing aid for the same listener) for 23 listeners with severe loss. Negative benefit scores indicate that listeners did worse with WDRC than with linear amplification. In Figure 1, listeners are grouped according to their pure-tone average thresholds; in Figure 2, according to their quiet speech recognition score (measured under headphones at 40dB above pure-tone average). On average, all listeners benefited from the multichannel WDRC processing except those individuals with the poorest thresholds and the worst speech recognition. Note also that these results are for conversational speech; benefit for low-intensity speech where multichannel WDRC drastically improved audibility was considerably greater. It would be helpful if we could use such data to make decisions about hearing aid choices for individuals. However, for clinical predictions, the variability is too large. An individual with a severe loss who has a pure-tone average of 75dB HL and unaided speech recognition scores of 55% might show speech recognition improvements as high as 10%, or decrements as low as 20%, when comparing WDRC processing to linear processing. Understanding the factors which determine individual benefit will aid clinical decision making.

One specific concern is that with broad auditory filters and poor frequency selectivity, a severely-impaired listener depends more on the temporal than on the spectral aspects of the signal thus we should avoid unnecessary distortion of temporal cues. Some hearing aid manufacturers have begun to take this position as well. The documentation for using slow-acting compression in one commonly fitted digital aid states that 'The big advantage of this [program] is that the time structure of speech signals is not changed… The time structure contains valuable information… to distinguish different phonemes'. In one recent study,[7] we reasoned that if listeners with severe loss depend heavily on temporal cues to speech recognition, they ought to perform more poorly with fast-acting WDRC that alters temporal cues. Listeners with less hearing loss, who have better access to spectral cues, ought to be unaffected by differing time constants. We fitted two groups of study volunteers: one with binaural mild-to-moderate loss and the other with binaural severe loss. All listeners received a hearing aid set as it would be in the clinic, with one exception: we created two different programs, a 'fast' WDRC program (short attack / release times) and a 'slow' WDRC program (long attack/release times). The listeners with severe loss had consonant recognition scores that were about 5% worse, on average, with the fast WDRC; the listeners with mild loss performed the same with both WDRC conditions. The data suggest that listeners with severe loss should be fitted with slow WDRC. However, it was of great interest to us that a minority of patients with severe loss did better with fast-acting than with slow-acting compression. They tended to be the listeners with the poorest thresholds, suggesting that their need for improved consonant audibility outweighed the distorting effects of the fast compressor. Alternatively, those individuals might have had better spectral discrimination than their peers, or used a listening strategy which placed less 'weight' on temporal cues. For now, it seems reasonable to use multichannel WDRC with the lowest possible distortion (that is, lowest compression ratio and longest time constants) that will achieve acceptable audibility. Audibility can be assessed using multilevel probe microphone measurements, aided speech recognition, and / or benefit questionnaires.

In the quest for improved speech audibility, acoustic feedback is the enemy. No patient will wear a squealing aid (or, at least, there may be strenuous objections from family members!). Once an innovation and now a standard feature, digital feedback suppression allows up to 35dB more gain than aids without digital feedback management.[8] This is a clear advantage over the 'old' method of using tighter fitting earmoulds and / or smaller vents to control feedback. Accordingly, some means of digital feedback suppression is a necessity in any hearing aid ordered for an individual with severe loss.

Severe high-frequency hearing loss

Some patients have relatively good (or, at least, relatively better) low-frequency thresholds sloping to a severe high-frequency loss. Brian Moore and his colleagues have proposed that such patients often demonstrate high-frequency auditory 'dead regions'. Presumably, in some portion of the basal cochlea auditory hair cells are sparse or absent, rendering the auditory system unable to faithfully transmit sound at that frequency range. One might conclude from this that making amplified speech audible within the dead region is not useful and hearing aids should be fitted with a more low-pass response,[9] but there are two issues which preclude universally implementing that strategy. First, the probability of a dead region in a region of severe loss is only about 60%.[10] A clinical test for dead regions is available[11] but in our laboratory, results were sometimes inconclusive when sufficiently high signal levels could not be achieved once audiometer limits were reached. Of course, completing a dead level test requires additional test time. Second, it is not clear that limiting high-frequency gain in regions of severe loss will be appropriate for all patients. For example, Mackersie *et al.*[12] found that in low and moderate noise backgrounds, patients with dead regions performed best with a wide-band amplification. In high levels of noise, patients did not improve with wide-band amplification, although fortunately scores did not decrease either. Clinically, this suggests that providing gain into the high-frequency dead region is at least as good, and often better, compared to a more low-pass hearing aid response. In the absence of definitive clinical guidelines, clinicians can also use objective measures including aided speech discrimination with and without limited high-frequency gain, as well as patient reports, to decide on the upper cut-off of the hearing aid response.

An interesting option for patients with severe high-frequency loss is frequency lowering. With frequency compression, some ratio is applied to the signal to compress the acoustic information into a lower frequency range. For example, a ratio of 2 means that an 8kHz signal is presented at 4kHz. In frequency transposition, only the high frequencies are altered and are superimposed over the retained lower frequencies. Kuk[13] reported that frequency lowering resulted in improved high-frequency aided thresholds, better perception of high-frequency environmental sounds and voiceless consonants, and improved production of voiceless fricatives for children. But, both in empirical studies and by clinical report, this is not an easy strategy to fit. Potential candidates should be considered carefully. It is necessary to have sufficiently good thresholds and resolution in the low-frequency range to extract usable information from the transposed signal. Even with careful selection, some patients may reject the frequency lowering aids due to sound quality issues. At minimum, patients should have extensive counselling to encourage realistic expectations for benefit of these aids.

Conclusions

As clinicians, we understand that the final outcome of any hearing aid fitting is constrained by the patient's auditory system. Few patients with severe sensorineural loss will achieve high levels of recognition in complex listening situations. However, modern devices which incorporate multichannel WDRC, digital noise reduction, frequency lowering, directional microphones and integrated FM receivers offer substantially improved speech recognition over traditional amplification for this population. At present, we can apply these features in a general sense, presuming they are beneficial for most patients. Clinicians should also be prepared for more frequent follow-up visits to adjust hearing aid parameters based on patient feedback, and for more extensive counselling to encourage realistic expectations of benefit. Work is underway in our laboratory and others to identify specific sources of variability across patients. It seems likely that individual auditory processing abilities, combined with cognitive ability to direct auditory attention and integrate contextual and visual cues will ultimately determine hearing aid benefit for an individual. Patients with severe hearing loss present unique challenges, but also unique rewards when they receive a hearing aid that allows them to hear conversation, participate in family events and enjoy daily activities. ■

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