Hearing Aid Features: Do Older People Need Different Things?

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Setting Clinical Goals

What is the best choice of hearing device for an older patient? For decades, researchers have approached this problem by comparing aided speech recognition results for younger and older groups of listeners. To focus on the effects of age, well-controlled studies recruit either older and younger listeners with similar amounts of hearing loss, or older and younger listeners with normal hearing. An alternative approach is to use statistical corrections to separate the effects of age from the effects of high-frequency hearing loss. Our collective goal as researchers is to determine whether older listeners are "different" and, ultimately, to find a hearing aid solution that compensates for age-specific problems. We ask practical questions: do older adults need longer release times? Less low-frequency gain? ITEs instead of BTEs? Longer acclimatization periods? Although some generalities have emerged from the literature, it also highlights a number of ambiguities. Simply put, older adults sometimes, but not always, perform worse than younger adults.

Over time, our view of the "older" audiology patient has shifted. We now acknowledge that older patients are heterogeneous in every respect: age, cognitive capacity, personality, motivation, physical capabilities. Clinically, our goal is to make the best possible choice for each patient. This goal emcompasses all aspects of audiology treatment, from parameters of the amplification device to appropriate aural rehabilitation and counseling. Accordingly, this article considers hearing aid decisions for the older patient in the context of a larger treatment plan. We describe two areas of recent research (one applicable to hearing aids, and one to cochlear implants) where older adults respond in unique ways.

Older Adults, Hearing Aids and Low-Rate Envelope Distortions

One generality that has emerged from the literature is that older adults lose the ability to respond to the temporal aspects of a signal (Pichora-Fuller & Souza, 2003). This loss of temporal resolution begins as early as age 40 (Helfer & Vargo, 2009). To understand temporal deficits, we first consider what cues are important to speech recognition. Speech can be thought of as a composite of time-varying signals that overlap in frequency, ranging from slow to rapid variations in amplitude. Rosen (1992) divides these into three rate categories, each of which conveys different information. Fast rates, referred to here as fine structure, cue place of articulation ("cut" vs "cup"). Moderate rates, referred to here as high-rate envelope fluctuations, provide cues for consonant voicing and manner, speaker identity, and prosodic cues to stress and intonation. The slowest variations in amplitude, referred to here as low-rate envelope, provide cues to vowel identity and consonant manner ("say" vs "stay") and voicing ("fuss" vs "fuzz").

All devices, including hearing aids and cochlear implants, distort the low-rate envelope to some extent. Some of this distortion is beneficial, as when consonant amplitude is increased to improve audibility. More ex-

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tensive distortions, however, can be problematic. Even before considering listener age, we know that greater envelope distortion occurs with more extreme compression parameters, including short release times and/or high compression ratios (Jenstad & Souza, 2005). Any listener that uses envelope cues for speech recognition may be susceptible to such distortions.

There are reasons to think that such distortions may affect older listeners differently than younger listeners. Use of the envelope for speech recognition can be thought of as requiring the listener to discriminate changes in sound duration, modulation, and gaps (Figure 1). Older listeners show deficits in all of these abilities. For example, they require longer gaps (Snell & Frisina, 2000), larger differences in duration (Abel, Krever, & Alberti, 1990; Fitzgibbons & Gordon-Salant, 1994), and greater modulation depth (Takahashi & Bacon, 1992) than younger listeners with similar hearing thresholds.

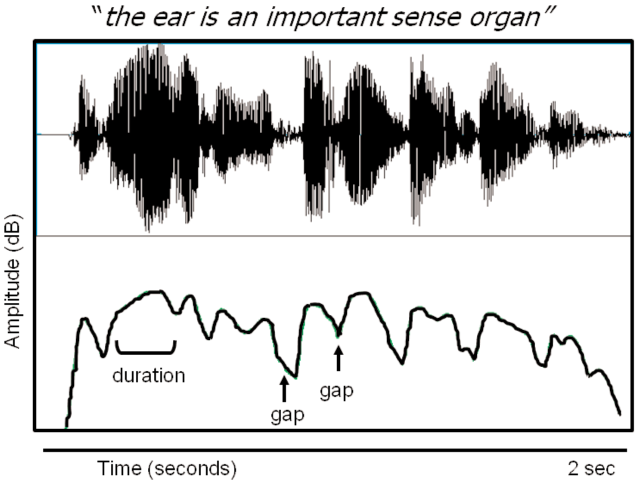

Figure 1: Time waveform of the sentence "The ear is an important sense organ". Contour in lower panel is the broad-band speech envelope, with examples of duration and gaps.

To understand how such deficits translate to speech recognition, we examined older listeners' ability to use envelope cues in quiet situations (Souza, 2000; Souza & Kitch, 2001; Souza and Boike 2006). In unprocessed speech, the envelope is redundant with other cues, including speech fine structure. If we want to understand how altering the envelope affects older listeners, we can digitally process the speech so that both low-rate and high-rate envelope cues are preserved, but fine structure is removed (Schroeder, 1968). We can also control the acoustic information that is available to the listener by varying the number of envelope channels in the signal. When many channels are presented, the speech will be quite intelligible (Shannon, 1995; Souza & Rosen, 2009) but sounds harsh and atonal. In the extreme case where only one channel is presented, the carrier is a broad-band noise with no spectral shape information. Such "envelope-only" signals are quite difficult to understand, although one can still obtain considerable information from amplitude and duration. For example, even in a single-channel signal, the difference between an "s" sound and a "t" sound is very distinct.

When single- or multi-channel envelope signals are presented in a processed but unamplified form (i.e., without frequency shaping or amplitude compression), older listeners always perform more poorly than younger listeners (Souza, 2000; Souza & Kitch, 2001; Jenstad & Souza, 2007). This holds true whether the older and younger groups have normal hearing, or have hearing loss; and whether the speech utterances were longer sentences or shorter syllables. So, we can conclude that older listeners have more difficulty perceiving cues contained in the speech envelope.

We know that hearing aid compression alters low-rate envelope cues (Souza & Gallun, in press). Wide-dynamic range compression amplification has only a very small effect (a few percent) on speech recognition when applied using the compression ratios that are usually prescribed for a listener with mild or moderate hearing loss. If compression ratios above 2:1 must be used to improve audibility, the advantage of that improved audibility will be partially offset by a decrease in recognition due to envelope distortion.

Fortunately, most clinical implementations of compression produce tolerable amounts of envelope distortion. Also fortunately, our data indicate that altering envelope with compression does not have a greater effect on older listeners for speech in quiet (Souza & Kitch, 2001). Although older listeners have poorer overall scores, distorting the envelope offers the same small decrement for all listeners. Even for rapidly spoken speech which has lower acoustic redundancy, older listener's scores parallel that of younger listeners (Jenstad & Souza, 2007). This means that we can apply the same constraints on envelope distortion for older patients. The specific clinical translation of this work is that compression ratios up to 2:1 can be used with short release times with little downside for amplifying quiet speech.

Of course, clinical decisions also require that we consider use of hearing aid compression in the listening environment older hearing aid wearers complain about: background noise. When compression is applied to speech in noise, some older listeners perform quite differently from younger listeners with the same hearing loss. Gatehouse et al. (2006) found that listeners with lower cognitive performance performed better with slow-acting than with fast-acting WDRC. The authors propose that this effect is directly related to alteration of the temporal envelope, in that listeners with greater cognitive capacity could tolerate loss of temporal (and spectral) contrast and enjoy maximum benefit from improved consonant audibility, whereas listeners with lower cognitive capacity cannot tolerate the contrast reduction. Because cognitive capacity is also correlated with age, a large number of older listeners performed worse with the fast-acting WDRC. However, this does not mean that older listeners should only be fit with fast-acting WDRC. The Gatehouse et al. data predict that an older listener with high-cognitive capacity would perform worse with fast-acting WDRC.

There are other aspects of applying WDRC to speech in noise that should be considered for older listeners. We already know that older individuals require more favorable signal-to-noise ratios than do younger individuals. Compression implemented with a small number of compression channels and without digital noise reduction can cause an increase in noise level that occurs when compression increases gain during low-intensity portions of the target signal (Naylor & Johannesson, 2009; Souza, Jenstad & Boike, 2006). Recently, Stone and Moore (2007) introduced another potential problem, when they demonstrated that compression can make it more difficult to separate speech from noise because applying the same gain function to both the target and masker makes their envelopes more similar to one another. Because spectral cues including fine structure are believed to be important for signal separation (e.g., Strelcyk & Dau, 2009), one could argue that older listeners who have less access to fine structure cues (Pichora-Fuller, Schneider, Macdonald, Pass & Brown, 2007) are more susceptible to envelope comodulation. In the next section, we consider use of temporal cues to signal separation by older listeners.

Older Adults and Cochlear Implants (or: What Good is Fine Structure, Anyway?)

In a conventional cochlear implant, the input signal is filtered and the low- and high-rate envelope for each channel is extracted and compressed to suit the electrical dynamic range. The compressed envelope modulates a series of rapid electrical pulses delivered through the implant. Speech fine structure is not transmitted. Thus, the implant is transmitting low-rate and high-rate envelope cues to the listener. In a “hybrid” implant, the electrode array protrudes only part-way into the cochlea. This partial insertion is appropriate for some individuals with residual low-frequency hearing, and allows for presentation of acoustic fine-structure information via the base of the cochlea, accompanying the delivery of envelope cues via electrical stimulation. That low-frequency acoustic information can substantially improve speech recognition, particularly in background noise, over what can be achieved with a conventional implant (Brown & Bacon, 2009; Li & Loizou, 2008; Kong & Carlyon, 2007).

We posed several questions related to older adults’ use of such devices. First, how do older listeners, who as a group have poorer perception of envelope cues, compare to younger implant wearers? Second, it has been suggested that some older adults may have impaired fine structure perception (Pichora-Fuller et al., 2007). To what extent will older adults benefit from a hybrid implant which assumes use of fine structure?

Clinical observations suggest that older implant patients perform more poorly than younger implant patients with conventional and hybrid devices (Ganz, Hansen, Turner, Oleson, Reiss & Parkinson, 2009; Luetje, Thedinger, Buckler, Dawson & Lisbona, 2007). The reasons are difficult to assess in the clinic, because age *per se* is not the only difference between older and younger persons who receive implants. Younger implant recipients often have congenital or early-onset profound loss which is identified and remediated (with the implant) in early childhood. Older implant recipients may acquire their hearing loss later in life or, depending on the etiology, over a period of many years. Often, they have a period of extensive auditory deprivation and/or a long period of hearing aid use prior to implantation. How then do we distinguish the effects of age from other factors?

One approach to studying issues related to aging is to measure the effects of age on listening with simulated cochlear implant situations; that is, to present listeners with normal hearing with processed signals that mimic the information conveyed by a traditional or hybrid implant. This controlled approach minimizes subject differences other than age. We used this approach to ask whether older adults perform more poorly, or more variably, compared to younger listeners when presented with conventional-implant (low- and high-rate envelope) and hybrid-implant (low- and high-rate envelope, plus fine structure) simulations. To focus on the effects of age, we recruited older and younger listeners with normal to near-normal hearing (at worst, the older listeners had slight high-frequency loss).

In designing these studies, we considered that everyday listening situations vary widely, from speech in quiet to speech in a competing (background noise) situation. In each of these environments, listeners must recognize cues that vary over time (dynamic) as well as cues that are relatively constant (static). We selected specific tasks to assess four different listening aspects (Table 1). Ultimately, we were interested in use of fine structure and/or envelope cues to segregate competing signals, but we also measured baseline ability to perceive pitch differences and to track those differences over time (Souza et al., submitted).

Each task shown in Table 1 was presented in three conditions. In the conventional cochlear implant simulation, noise vocoding was applied to retain low- and high-rate envelope information in 8 channels but fine structure was removed. In the hybrid implant simulation, speech was low-pass filtered at approximately 660 Hz (representing residual low-frequency hearing) and combined with five noise-vocoded channels above 660 Hz. Finally, we included an unprocessed (control) condition.

The first task assesses the ability to detect pitch differences. Here, older and younger listeners are presented with two sequential synthetic vowel sounds that differed in fundamental frequency. If the listener can detect a difference, the fundamental frequency difference is adaptively reduced until the individual's detection threshold was reached. For the unprocessed and hybrid conditions, older and younger listeners can detect a difference of about 3 Hz on average, and there is no difference in performance between age groups. The detectable difference in pitch is much larger for the conventional implant condition (as expected for a device simulation that does not convey fine structure); and in that condition, older listeners perform more poorly. Finally, within the older group, the ability to detect pitch differences is worse with increasing age.

In the second task, we ask listeners to track pitch changes over time by presenting synthetic diphthongs where fundamental frequency varied through the duration of the sound in either a rising or falling intonation. The extent of the intonation change varies, from distinctly rising (low fundamental frequency at utterance onset and high fundamental frequency at utterance end) through ambiguous (same fundamental frequency from start to end of the utterance) to distinctly falling (high fundamental frequency at utterance onset and low fundamental frequency at utterance end). A real-life correlate of this task might be the ability to follow the pitch of the talker's voice to extract meaning from intonation (question or statement) or simply to attend to the rise and fall of one talker's voice in the presence of other background talkers.

For the unprocessed and hybrid implant conditions, the older listeners perform slightly worse than the younger listeners. For the conventional implant condition, the older listeners perform substantially worse than the younger listeners. We also noted considerable variability among the older group. The variability can be described as three distinct patterns: a few could not perform the task at all, in any condition; roughly half performed as well as the younger listeners; and the remainder could do the task, but required a large pitch change before they could correctly perceive a rising or falling utterance. When both pitch tasks were considered, those individuals who had poor perception of pitch differences always had poor perception of intonation. Individuals with good perception of pitch differences sometimes had poor perception of intonation; that is, the ability to track dynamic changes in fundamental frequency over time require some ability beyond static pitch detection.

Although we are interested in the effects of age, we also wish to identify reasons for poorer performance in

Table 1. Division of everyday listening demands into specific abilities.

	Quiet	**Competing**
Static	Detect a difference in pitch (F0)	Recognize simultaneous vowel sounds
Dynamic	Rising or falling intonation	Recognize simultaneous sentences

some older individuals. We expect that those older adults who had more difficulty perceiving pitch in quiet will have difficulty using pitch cues to separate competing signals (Arehart et al., submitted). We measured older and younger listeners' ability to identify two simultaneously presented synthetic vowels, where each vowel is produced at a different fundamental frequency (representing two different talkers) and the difference in fundamental frequency between the two vowels was varied. The real-life correlate might be a situation where listening to a male speaker while another male with similar voice pitch is talking in the background (small fundamental frequency difference) versus listening to one deep-voiced male with a high-pitched female speaker in the background. In the conventional implant simulation, with no fine structure available, all listeners have difficulty identifying both vowels. When fine structure is provided in the hybrid simulation, as the fundamental frequency difference between the vowels was increased, vowel identification improves – but much more so for the younger listeners. That is older listeners are less able to make use of pitch differences between talkers conveyed by fine structure.

Finally, we asked the same individuals to report on their perceived difficulties in background noise. Older adults report more difficulty understanding than younger adults on items associated with speech-in-speech situations (Miller et al., submitted). We did not expect that poor performance on the pitch detection tasks would directly dictate perceived speech-in-speech ability, because so many other factors beyond pitch differences are present in real-life environments. However, the poorer and variable performance by older adults at detecting and using pitch differences for signal separation under controlled situations coupled with the age effect for perceived listening in multi-talker situations suggest that the laboratory tests can help us understand broader issues of speech understanding in realistic situations.

Making Clinical Decisions

Although we have a greater understanding of the complex and multi-dimensional nature of age-related changes, we still need specific guidelines for hearing aid processing parameters. We cannot view patient age alone as dictating our hearing aid choices. For example, we know that specific signal processing strategies can be beneficial to some older adults while detrimental to others. There is emerging consensus that clinicians must consider not just individual audiometric factors but also take cognitive status into account. Taken as a whole, the work described in this paper represents a commitment to identifying the factors that underlie variability among older listeners. It seems probable that once these factors are identified, we can develop screening tests to identify individuals unlikely to benefit from «standard» treatment. On the basis of such tests, we can select appropriate device/signal processing strategies for each person. Finally, we can fit the device as part of a comprehensive rehabilitation plan which considers peripheral and cognitive abilities.

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