SOME ISSUES AFFECTING AIDED SPEECH UNDERSTANDING

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When adjusted appropriately, hearing aids have been shown to be both efficacious and effective (e.g., Chisolm et al., 2007). Despite this, only 20-25% of adults that could potentially benefit from hearing aids actually obtain amplification (Kochkin, 2007). In addition, many adults with hearing loss that do obtain hearing aids use them only rarely or not at all. There are multiple reasons for the limited use and nonuse of hearing aids by adults with hearing loss. However, one of the most common issues reported is limited benefit, in terms of improved speech understanding, particularly when listening in background noise (Franks and Beckman, 1985; Kochkin, 2000; Lupsako et al., 2005). In other words, despite the substantial technological advances in hearing aid design, signal processing algorithms and hearing aid fitting methods, many people with hearing loss continue to report limited aided benefit, in terms of improved speech understanding. This paper addresses three specific factors that may limit the benefit provided by hearing aids.

1. Limited Audibility Even When Aided

Decades of research have shown that, when listening without hearing aids, the speech recognition difficulties of people with hearing loss are due primarily to reduced audibility. In general, as hearing loss increases, speech audibility in a given condition decreases, resulting in increased difficulty understanding speech. This is true both when listening in quiet and in noise (Humes, 1991). Providing well fit hearing aids, for example ones that have been adjusted to match targets based on a generic prescriptive formula (e.g., NAL-NL1 or DSL 5.0), will improve audibility and in many cases improve understanding. However, it is important to note that matching a prescriptive target does NOT mean that audibility has been fully restored. In fact, it's likely that audibility has not been fully restored since this is not the goal of the majority of popular prescriptive fitting methods.

Fortunately for the clinician, information regarding residual deficits in audibility when aided and its potential impact on the patient is readily available. Probe microphone systems routinely use mathematical formula, such as the Speech Intelligibility Index (SII: ANSI S3.5 1997) to quantify how much audibility has, or has not, been restored by a given hearing aid fitting. The SII, and its predecessor the Articulation Index (AI), is a measure that can range between 0.0 and 1.0 which is highly correlated with speech intelligibility.

The SII is calculated by quantifying the proportion of speech information that is audible across a specific number of frequency bands. To do this the level of speech peaks are compared to either (1) auditory threshold and/or (2) the level of the noise (if present), in frequency-specific bands. The proportion of audible speech in a frequency region is then multiplied by the relative importance of that frequency band. Finally, the resulting band values are summed to give you an SII. The basic information used to calculate an SII is graphically illustrated in Figure 1 for a hypothetical person with mild to moderate (20-60 dB HL) hearing loss.

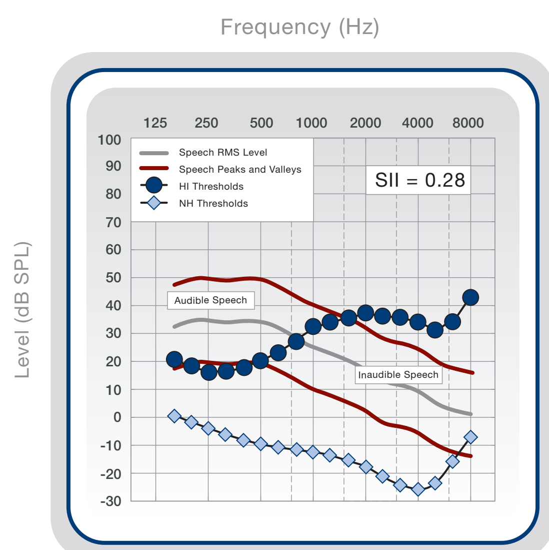

Figure 1. Speech levels in relation to auditory threshold used for calculation of residual audibility using an SII or AI method.

The light blue diamonds and dark blue circles represent threshold at various frequencies for someone with normal and impaired hearing, respectively. Thresholds are plotted in dB SPL rather than HL so that lower on the graph reflects better hearing. The gray line represents the rms level of average conversational speech at various frequencies while the red lines represent the higher and lower levels of the speech peaks and valleys. The area between the red lines shows the assumed 30 dB dynamic range of speech. This figure shows the limited audibility of conversational speech for our hypothetical person with sloping high-frequency hearing loss. In fact if we use the SII to quantify the area and importance of speech available to this person only about 28% (SII = 0.28) of speech is available. Given this limited audibility, reports of difficulties in communication, at least in some conditions, would clearly be expected.

Since we can readily quantify this deficit, it might be reasonable to expect that it could be entirely resolved through the provision of well fit hearing aids. Unfortunately, while hearing aids help, they do not fully restore audibility. Figure 2 shows the spectra of speech amplified to approximate NAL-NL1 targets for conversational speech for this degree of loss.

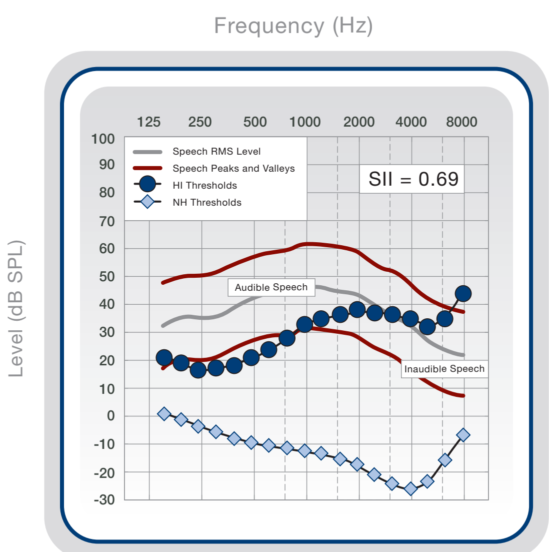

Figure 2. Aided speech levels in relation to auditory threshold.

SII calculations confirm that appropriate amplification substantially increases audibility (SII = 0.69). However, in this case even when aided appropriately, about 30% of primarily high-frequency speech information remains inaudible. As mentioned above this residual deficit in audibility is not surprising or uncommon.

Restoring complete audibility to individuals with more than a mild loss is often not possible or even desirable. Issues such as feedback, loudness recruitment and sound quality make restoration of complete audibility difficult. The use of compression can reduce some issues related to loudness. However, significant compression can lead to distortion of speech cues, potentially reducing or eliminating any advantage from increased audibility (e.g., Souza et al., 2007).

Validated hearing aid fitting algorithms, such as NAL-NL1 and DSL 5.0, attempt to balance the competing demands for increased audibility to improve speech recognition with the need for loudness comfort and good sound quality. These algorithms have substantial research support to show they provide a good starting point in the fitting process for the majority of persons with hearing loss (e.g., Mueller, 2005). However, the fact that a potentially large portion of the speech spectrum will, by design, remain inaudible can be expected to limit hearing aid benefit in a wide range of listening situations.

2. Negative Effects of High Presentation Levels

In addition to reduced audibility, aided speech understanding may remain poorer than normal due simply to the fact that sound levels are increased in the aided condition. Attempting to squeeze the normal dynamic range of speech into the residual dynamic range of someone with hearing loss may lead to complaints of excessive loudness and/or distortion of sound quality. In addition, substantial research suggests that speech understanding actually decreases when presented at levels commonly associated with aided listening (e.g., Rankovic, 1991; Studebaker et al., 1999).

Studebaker and colleagues (1999) found that, at a fixed signal-to-noise ratio (SNR), speech understanding systematically decreased as the level of the speech and noise increased from 69 to 99 dB SPL. In other words, even though audibility remained unchanged (i.e., the SNR was constant) as level increased, speech recognition decreased. The authors noted that magnitude of performance decreases with level varied with SNR. Negative effects were minimal in quiet but quite substantial at some SNRs (e.g., about 30% at a +5 dB SNR). Importantly their work suggested that these negative effects were similar for persons with and without hearing loss.

This is a real conundrum for hearing aid designers and users. In order for hearing aids to be effective they must amplify speech to increase audibility, however, by increasing the level of the speech performance may actually be degraded. Thus the need for increased audibility; to improve understanding must be balanced with the negative effects of high presentation levels. However, because persons with hearing loss must listen to aided speech at higher-than-normal levels, their aided speech understanding will likely be degraded, particularly in noise, compared to persons without.

3. Suprathreshold Deficits

Even when the effects of reduced audibility and high presentation levels are taken into account, persons with hearing loss may have poorer speech understanding than persons without hearing loss. Deficits in frequency and temporal processing are often cited as potential contributors to degraded speech understanding in persons with hearing loss. The literature examining the impact of frequency and temporal processing deficits on speech understanding is much too large to discuss in this brief paper. There is ample evidence to suggest, however, that frequency resolution abilities are degraded in the presence of severe hearing loss and that these deficits can impact speech understanding. The evidence relating hearing loss to deficits in temporal processing is less clear (Reed et al., 2009). However, temporal processing abilities have been shown to deteriorate in the elderly and to negatively impact speech processing (Gifford et al., 2007).

In addition to deficits in peripheral processing, age related declines in higher level cognitive processing (e.g., attention, working memory, inhibition) have also been shown to negatively impact speech processing in the elderly. Disentangling the contribution of these deficits from those due to high presentation levels and reduced audibility is challenging. However, regardless of the relative contribution it is clear that peripheral, and central, processing deficits may add to the communication difficulties experienced by many older adults with hearing loss and potentially limit benefit provided by hearing aids.

So Where Do We Go From Here?

Of the three factors discussed in this paper, the only one we have significant control over is residual audibility. Fortunately, knowledge regarding the potential impact of audibility is readily available with the use of probe microphone measures. It is important to remember that matching a prescriptive target likely will not restore full audibility. As discussed above, depending on the overall speech and noise levels increasing gain may not improve, and could potentially decrease, speech understanding. Therefore, the need for increased audibility must be balanced with the need for loudness comfort and good sound quality when making clinical decisions regarding amplification. For example, suppose real-ear measures reveal a good match to target but a residual deficit in audibility and the subjective complaints are primarily related to poor understanding, as opposed to loudness tolerance or poor sound quality. In this case close attention should be given to aided speech levels and residual audibility when deciding on modifications to hearing aid gain. This highlights the importance of probe microphone measures in the hearing aid fitting process (Palmer, 2010).

Although patient age and processing ability are beyond our control, an understanding of how these factors may affect benefit from hearing aids can help us appropriately counsel individuals regarding the potential need for additional signal processing or rehabilitation options. For example, since level effects are reduced at good SNRs, directional processing or FM systems that improve the SNR may also be beneficial for reducing the negative effects of high presentation levels. Likewise, methods for improving SNR may result in increased access to speech information across a wide frequency range which could limit the impact of poor frequency or temporal processing in any one frequency region (e.g., Thibodeau and Van Tasell, 1987). Recent work by Sarampalis et al. (2009) suggests that, in some situations, digital noise reduction (DNR) algorithms may help reduce cognitive processing demands thus easing listening effort, even in the absence of improvements in speech understanding. There are no easy solutions to resolve these issues, but by improving our understanding of factors that limit aided speech understanding, how they interact with each other and external variables (e.g., noise) to impact aided performance, we may better understand and respond to the residual communication difficulties experienced by hearing aid users.

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