THE ACCEPTABLE NOISE LEVEL:

Research findings and clinical implications and the hearing industry

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The Acceptable Noise Level (ANL) test is a measure of how much background noise a person is willing to "put up with" while listening to running speech (Nabelek, Tucker & Letowski, 1991). In recent years, it has gained interest among researchers and hearing healthcare professionals alike because of its ability to predict, with 85-percent accuracy, who will be successful with hearing aids (Nabelek, Freyaldenhoven, Tampas, Burchfield & Muenchen, 2006). This statistic is exciting because no other clinical test or measure has been able to accurately predict whether an individual will be successful with hearing aids. Knowing this information may help those who fit hearing aids provide better counselling to people with hearing loss. Additionally, if we can determine why certain people are less likely to be successful with hearing aids, then we may be able to create technology that addresses their objections to background noise and therefore improves their chances of success with hearing aids.

The ANL test only takes a few minutes to administer. With the listener seated in a sound booth, speech is presented over headphones or via sound field. Often the Arizona Travelogue is used (Cosmos Dist. Inc., nd). This passage consists of a male talker discussing his travels in Arizona. Using an adaptive procedure, the listener is instructed to adjust the level of the speech to a level that is "too loud" then "too soft" then "most comfortable to you." Next, background noise is added, multi-talker babble is usually used, and the listener is instructed to adjust its level to a level that is "too loud to understand the speech," then to a level that is "soft enough for the speech to be very clear" and finally to the highest level that he or she is "willing to put up with" while following the speech. The difference between the listener's most comfortable listening level (MCL) and his or her maximum tolerated background noise level (BNL) is his ANL.

A low ANL reflects a high tolerance for background noise, and a high ANL reflects a low tolerance for background noise. (One can think of this as meaning that someone with a low ANL is willing to listen at low (poor) signal-to-noise ratios (SNRs) whereas someone with a high ANL is only willing to listen at high (good) SNRs.) According to Nabelek et al. (2006) there are three categories of ANL: low (< 7dB), mid (7dB–13dB) and high (> 13dB). Those who have "low" ANLs are likely to be successful hearing aid wearers, whereas those who have "high" ANLs are unlikely to be successful hearing aid wearers. People with "mid" ANLs may or may not be successful with hearing aids. A wide range of ANLs has been observed in the literature, from -5 to 42dB (Rogers, Harkrider, Burchfield & Nabelek, 2003; Mueller, Weber & Hornsby, 2006; Nabelek et al., 2006; Tampas & Harkrider, 2006; Recker, McKinney & Edwards, 2011; Recker, McKinney & Edwards, in press). A typical distribution of ANLs, for hearing impaired listeners, is shown in Figure 1.

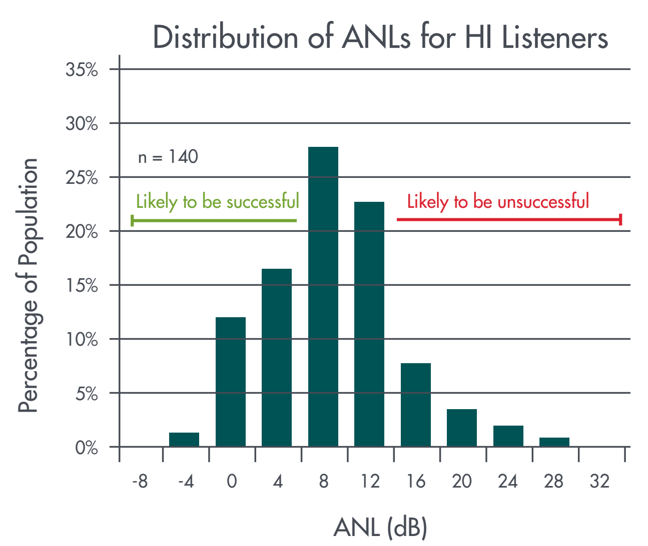

Figure 1: *ANLs for HI listeners. Arrows on the graph indicate whether the individuals would likely be successful or unsuccessful with hearing aids.*

ANLs are a unique measure that do not appear to be related to an individual's age, scores on the Abbreviated Profile of Hearing Aid Benefit questionnaire, the interest level of the speech material, an individual's auditory evoked potentials or his or her locus of control (Nabelek, Tucker & Letowski, 1991; Freyaldenhoven, Nabelek & Tampas, 2008; Plyler, Alworth, Rossini & Mapes, 2011; Brännström, Zunic, Borovac & Ibertsson, 2012; Nichols & Gordon-Hickey, 2012). For several other variables (e.g., speaker gender, listener gender, hearing sensitivity, type of background noise and hearing aid use), conflicting results are found in the literature, and additional research is necessary to determine how ANLs are impacted by these variables. A summary of the literature to date is provided in Table 1.

In order to know how to help people with high ANLs, it is first necessary to determine why they are unwilling to accept high levels of background noise. Once this is known, we can start to create and recommend technologies that address the underlying objections to the background noise.

In considering what cues listeners may be using to determine their ANLs, it is noteworthy that during the ANL test, listeners are not specifically asked to use any particular criterion when deciding how much noise they are "willing to put up with." Therefore, each individual is free to decide both how much noise he or she is willing to accept and the reason why he or she is willing to accept that amount of background noise. Because of this, it is perhaps not surprising both the large range of ANLs that has been observed in the literature and that several research studies have reported conflicting results.

There are several cues that listeners may be using to determine their ANLs. Some people may be choosing to listen at the lowest SNR that allows them to obtain good speech understanding. Others may become intolerant of the background noise when it becomes too loud, too annoying or too distracting. Some listeners may be trying to find the best compromise among a variety of factors.

Regardless of the strategy (or strategies) that a listener chooses, all listeners should choose an ANL that allows them to obtain a high level of speech understanding. This is true because the test instructions indicate that the listener should be able to "follow the story." To confirm that listeners are meeting this minimum requirement when performing the ANL test, it is worthwhile to consider the results of Sato, Morimoto and Ota (2011).

Sato and colleagues (2011) tested young normal-hearing listeners and elderly hearing-impaired listeners at 51 different SNRs to determine the minimum SNR that is required in order to maximize speech intelligibility and minimize listening effort. Their results showed that SNRs ≥ 0dB are required in order to maximize speech intelligibility, but higher SNRs (10dB–15dB) are required in order to minimize listening effort. Because the majority of people have an ANL ≥ 0dB (Rogers et al., 2003; Mueller et al., 2006; Nabelek et al., 2006; Tampas & Harkrider, 2006; Recker,

VARIABLE	DOESN'T MATTER	MATTERS
Speaker gender	Plyer et al., 2011	ANLs are lower with a female talker. (Gordon-Hickey, Moore & Estis, 2012)
Listener gender	Rogers et al., 2003	Males have lower ANLs than females do. (Gordon-Hickey et al., 2012)
Hearing sensitivity	Nabelek et al., 1991	Hearing impaired have lower ANLs than normal hearing. (Fredelake, Holube, Schlueter & Hansen, 2012)
Type of background noise	Lytle, 1994 Crowley & Nabelek, 1996	ANLs are different with music or different amounts of talkers. (Nabelek et al., 1991; Gordon-Hickey & Moore, 2007; Gordon-Hickey, 2012)
Hearing aid use	Nabelek, Tampas & Burchfield, 2014	ANLs are lower with hearing aids. (Ahlstrom, Horwitz & Dubno, 2009) It may depend on the type of signal processing. (Wu & Stangl, 2013)

Table 1: *Summary of the ANL literature showing which variables affect listeners' ANLs.*

McKinney & Edwards, 2011; Recker et al., in press), it is likely that most listeners are choosing an ANL that meets this minimum intelligibility requirement. As further evidence of this, data from Valentine (2009) suggest that hearing impaired listeners are choosing ANLs that, on average, should allow them to achieve approximately 80-percent speech intelligibility. For some listeners with low ANLs, this is likely the only cue that they are using (Recker, 2014).

For people with higher ANLs, speech intelligibility should be close to ceiling performance, and therefore other cues should be considered. When listeners performed a modified version of the ANL test — the speech was fixed at four different presentation levels (50dB–88dBA), and they adjusted the level of the background noise to the highest level that they were willing to put up with while listening to the speech — some listeners set the level of the background noise so that a constant level of speech intelligibility was obtained. However, they chose ANLs that were much higher in level than the minimum that would be required in order to obtain good speech intelligibility (Recker, 2014). For those who fell into this category, it is possible that they were trying to simultaneously optimize speech intelligibility and minimize listening effort. Support for this interpretation comes from Sato and colleagues (2011), who found that listening effort is minimized at an SNR of 10dB–15dB, which corresponds to a mid-to-high ANL.

Additional research suggests that some listeners with mid-to-high ANLs may be basing their decision about how much noise they are willing to accept on the loudness of the background noise (Recker et al., in press, 2014). When using the same modified version of the ANL test that was previously mentioned (with the speech fixed at one of four presentation levels between 50dB–88dB), a subset of listeners chose to set the level of the background noise to be equally loud across all of the test conditions. This indicates that for these listeners, it was the *loudness* of the background noise that was causing them to reject it.

Knowing the reason why different listeners are choosing different amounts of background noise for the ANL test provides insight into how the patient's hearing healthcare should be managed. For those who are basing their decision on the intelligibility of the speech, only technologies that can improve speech intelligibility (e.g., directional microphones and remote microphones) would be expected to provide benefit on the ANL test. For those who may be using other (or additional) cues such as listening effort or loudness, both directional microphones and noise reduction technology are likely to be helpful. Indeed, regardless of ANL, all people have been shown to receive about 3dB–5dB of benefit on the ANL test from directional microphones (Freyaldenhoven, Nabelek, Burchfield & Thelin, 2005; Peeters, Kuk, Lau & Keenan, 2009; Kim & Bryan, 2011; Wu & Stangl, 2013). This is similar to the approximately 4dB of improvement that has been observed on adaptive speech-in-noise tests using this same technology (Freyaldenhoven et al., 2005; Peeters et al., 2009; Kim & Bryan, 2011).

With digital noise-reduction technology, the amount of benefit is not the same across all ANLs. Specifically, several studies have shown that people with higher ANLs obtain greater benefit than people with lower ANLs (Mueller et al., 2006; Edwards et al., 2011; Eddins, Klein, Arnold & Ellison, 2013). This makes sense, because if the people with low ANLs are basing their decisions about how much noise they are willing to accept on the intelligibility of speech, then a technology such as digital noise reduction, which cannot improve speech intelligibility, would not be expected to provide any benefit. For those who are basing their decisions about how much noise they are willing to accept on the loudness of the background noise or the amount of listening effort that they are exerting during the test, they would be expected to see an improvement in ANL with digital noise reduction technology, because this technology has been shown to provide benefit in these areas (Sarampalis, Kalluri, Edwards & Hafter, 2009; Gustafson, McCreery, Hoover, Kopun & Stelmachowicz, 2014).

For those with higher ANLs, clinical recommendations may be especially important. This is because these individuals are least likely to be successful with hearing aids. Recommendations for directional microphones, digital noise reduction technology, streaming and remote microphone capabilities, like what is currently available with the Made for iPhone® hearing aid Halo,™ may be especially helpful. Future research should continue to investigate the special needs of each of the different ANL groups, paying particular attention to the high ANL group. The findings from such studies may lead to improved patient counselling, technology recommendations and patient outcomes.

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