Can Acceptable Noise Levels Be Predicted from a Noise-Tolerance Questionnaire?

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 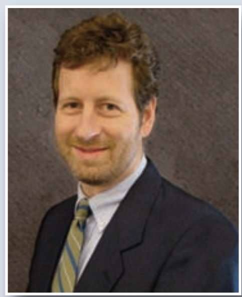 

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ABSTRACT

The Acceptable Noise Level (ANL) test is a measure of the amount of background noise that a person is willing to tolerate. In recent years it has gained interest among researchers and hearing care professionals because of its ability to predict, with 85% accuracy, who will be successful with hearing aids. This statistic is not only useful for counselling purposes, but it implies that if one could understand why different people are able to tolerate different amounts of background noise, then one could gain insight into what makes a patient successful (or unsuccessful) with hearing aids. This knowledge could be used to target hearing-aid solutions to the individual to improve her prognosis with hearing aids. However, several studies have been unsuccessful at correlating ANLs with audiological factors other than hearing-aid success. This article reviews some of the ANL literature, speculates on the potential future applications of the ANL test and reports the results of a questionnaire that was administered to 139 participants to gain insight into the potential mechanisms underlying individuals' ANLs.

CAN ACCEPTABLE NOISE LEVELS BE PREDICTED FROM A NOISE-TOLERANCE QUESTIONNAIRE?

The Acceptable Noise Level (ANL) test is a measure of the amount of background noise that a person is willing to tolerate.[1] In recent years it has gained interest among researchers and hearing-care professionals because of its ability to predict, with 85% accuracy, who will be successful with hearing aids.[2] This statistic is not only useful for counselling purposes, but it implies that if one could understand why different people are able to tolerate different amounts of background noise, then one could gain insight into what makes a patient successful (or unsuccessful) with hearing aids. This knowledge could be used to target hearing-aid solutions for an individual to improve her prognosis with hearing aids. However, several studies have been unsuccessful at correlating ANLs with audiological factors other than hearing-aid success. This article reviews some of the ANL literature, speculates on the potential future applications of the ANL test and reports the results of a questionnaire that we administered to gain insight into why different individuals are willing to tolerate different amounts of background noise.

Performing the ANL test is relatively quick and simple. First, running speech is presented to a listener over headphones or via sound field. Often the Arizona Travelogue is used as the speech stimulus (Cosmos, Inc.). This passage consists of continuous discourse by a male talker discussing his travels in Arizona. Using an adaptive procedure, the listener is first 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, usually multi-talker babble, and the listener is instructed to adjust its level, first 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 she is "willing to put up with" while following the speech. The difference between the listener's most comfortable listening level (MCL) and her maximum tolerated background noise level (BNL) is her ANL. The test takes about 2–3 minutes to administer.

A lower ANL score reflects a higher tolerance for background noise. According to Nabelek et al.,[2] there are three different ANL categories – low, mid, and high. Individuals who have "low" ANLs (less than 7 dB) are generally successful hearing-aid wearers, whereas individuals who have "high" ANLs (greater than 13 dB) are generally unsuccessful hearing-aid wearers. People with "mid" ANLs (7 to 13 dB) may or may not be successful with hearing aids. Nabelek et al. showed that most hearing-impaired people had ANLs between 0 and 25 dB; the most frequently-occurring ANLs were around 10–11 dB.

ANLs do not appear to be related to an individual's age[1,2] gender[2,3] hearing sensitivity[1,2] or preference for the existence of background sound.[4] At present, it is ambiguous whether ANLs are related to an individual's speech understanding abilities – some researchers[5,6] suggest that ANLs and speech intelligibility are uncorrelated while other researchers[7] suggest that people with better speech intelligibility skills also have lower ANLs. Similarly, studies examining aided and unaided ANLs have produced conflicting results, with Nabelek et al.[6] showing that ANLs are the same regardless of the test condition and Ahlstrom et al.[7] showing that aided ANLs are lower than unaided ANLs.

In addition to these findings, both directional microphones and noise reduction technology have been shown to improve (lower) listeners' ANLs by about 2.5–4 dB over the aided condition without these features active.[8–10] These results are exciting because they suggest that hearing-aid features and hearing-aid signal processing allow people to tolerate higher levels of background noise, which may in turn improve listeners' success rates with hearing aids. Moreover, if we could understand the cues that individuals are using to determine their tolerance of background noise, this information could offer insight into who is most likely to benefit from these technologies.

Because the ANL instructions request that listeners be able to follow the primary talker, it is possible that some individuals adjust the level of the background noise based on a speech-intelligibility criterion. If this is true, then we suspect that these individuals will be more likely to benefit from directionality, or other SNR-enhancing technology, than listeners who base their ANLs on some other criteria.

However, the ANL instructions do not require listeners to adjust the level of the background noise until a certain speech intelligibility criterion is reached. Because listeners are simply asked how much background noise they are "willing to put up with" while following the speech, they may be basing their decision on some other criterion such as how loud or how annoying the background noise is. If someone were basing her ANL on the loudness of the background noise, then she may be more likely to benefit from hearing-aid features that reduced the loudness of the noise, such as noise reduction.

Although each manufacturer's noise-reduction algorithm will function differently depending on the environment, generally, the smaller the temporal fluctuations are in a signal, the more likely the noise-reduction algorithm is to classify a signal as "noise" and reduce the gain of the hearing aid. Specifically with the ANL test, the background "noise" is 8-talker babble. With this many talkers, the temporal fluctuations in the signal are substantially less than what is observed with a single talker, and so the noise reduction algorithm may recognize it as noise and reduce the gain of the hearing aid. In real-world environments, such as restaurants or bars, there may be many more than 8 talkers, and much higher levels of reverberation than occur in a sound booth. Both of these factors will reduce the temporal fluctuations in the signal and increase the likelihood that a noise-reduction algorithm will classify "babble" as noise. Other factors that will affect whether a noise reduction algorithm activates include the overall level of the environment and an estimate of the SNR. Finally, once "noise" is detected, the time constants of the algorithm will determine whether the overall gain of the hearing aid is decreased or whether the gain is only decreased between the pauses of speech. This latter type of noise reduction technology may be especially useful for listeners who are basing their ANLs on loudness, because it will preserve the loudness of the speech signal while reducing the loudness of the "noise" between the pauses of speech. Listeners who base their ANLs on listening effort may also be good candidates for noise-reduction technology, because it has also been shown to reduce listening effort and free up cognitive resources for other tasks.[11]

Determining whether the cue underlying a listener's ANL is predictive of her success with different hearing-aid features is of interest because historically it has been very difficult to predict who would benefit from various features, as a listener's performance in the laboratory may not correlate well with her real-world benefit.[12–15] For example, in a double-blind study involving 94 hearing-aid wearers who were fitted for one month with directional technology and one month with omnidirectional technology, Gnewikow et al.[14] found that participants performed significantly better on all of the laboratory (speech-in-noise) tests with the directional settings than with the omnidirectional settings; however, similar ratings were obtained for the two microphone settings on almost all of the subjective measures of benefit (the Profile of Hearing Aid Benefit (PHAB) and the Satisfaction with Amplification in Daily Life (SADL) questionnaires). The authors concluded that, "self-perceived directional benefit is either limited in magnitude, not readily measured using general outcome measures, or both."[14]

If the cues that listeners are using to determine their ANLs are predictive of hearing-aid feature benefit, then knowledge of individuals' ANLs, and the cues that they are using to determine their ANLs, could be used to better counsel patients and to customize hearing solutions for them. Knowledge of this information could also benefit hearing-aid manufacturers, as it would allow them to predict when, where and for whom certain hearing-aid features would provide benefit. Ideally, this would result in a better first fit, less fine-tuning adjustments, and happier, more satisfied, hearing-aid wearers. As an initial step in determining the cues that listeners are using to determine their ANLs, we created a questionnaire to determine how listeners view their performance in noisy situations compared to quiet ones.

METHODS

As a first step in determining what cues listeners may be using to select their ANLs, we compared individuals' ANLs to their responses to a custom questionnaire (Appendix). The questionnaire investigated the perceived negative impact that background noise has on speech intelligibility, stress levels and concentration levels. Additionally, it asked participants about their own perceived tolerance for background noise and whether or not they typically avoid situations known to have high levels of background noise. Finally, hearing-aid wearers were asked to describe their hearing-aid use following the categories defined by Nabelek et al.[2]: (a) I wear my hearing aids whenever I need them, (b) I only wear my hearing aids occasionally, and (c) I do not wear my hearing aids.

The goals of this questionnaire and the ANL testing were threefold. First we wanted to determine whether participants' responses to these questions could provide insight into why some people are more tolerant of background noise than others. This information could help explain why some people are more successful hearing-aid wearers than others, and it could help guide future ANL research. Second, we wanted to determine whether a short questionnaire is sufficiently accurate at predicting individuals' ANLs that it could be used as an alternative method of predicting hearing-aid success. If so, the questionnaire could replace the ANL test, thereby eliminating the need for electronic equipment to produce and verify the levels of the test signals. Also, if the patient were to complete the questionnaire prior to her visit with the audiologist, the audiologist could save

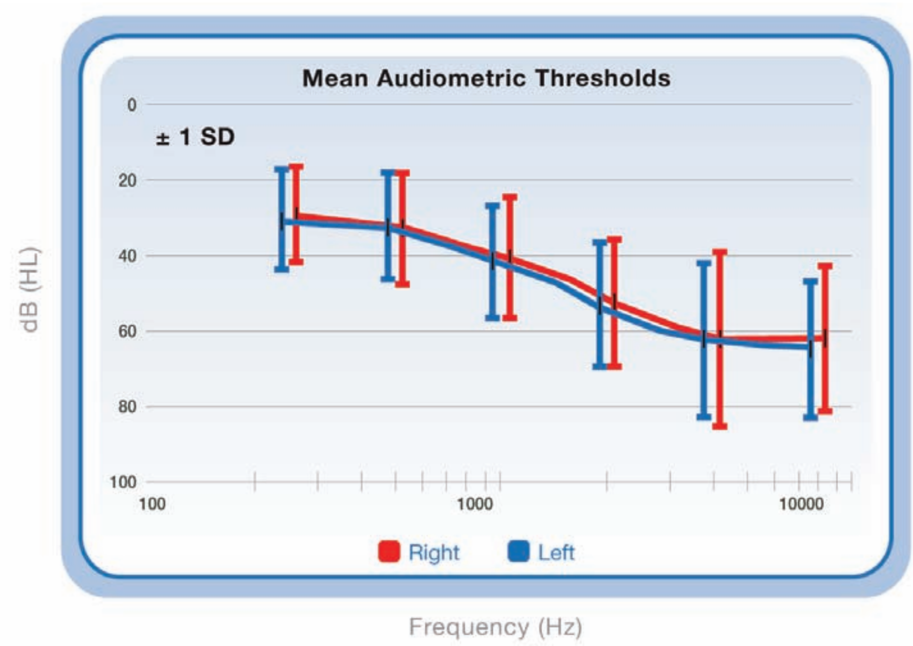

Figure 1. Mean audiometric thresholds ± 1 standard deviation (SD).

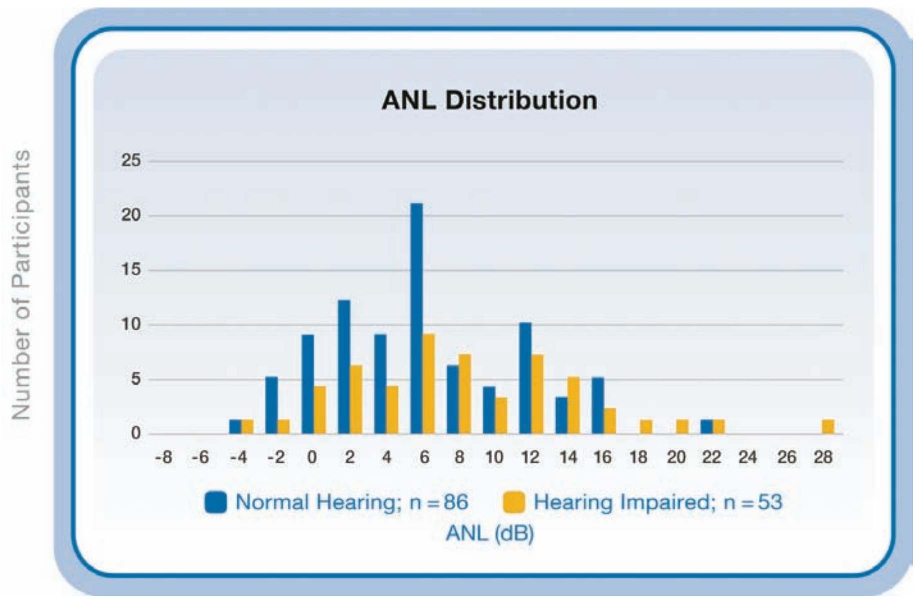

Figure 2. Distribution of ANLs for normal-hearing and hearing-impaired participants.

2–3 minutes of time that would otherwise be required to perform the ANL test. Third, we wanted to replicate the Nabelek et al.[2] study to determine whether ANLs are predictive of hearing-aid success for our test population.

In all, 86 normal-hearing and 53 hearing-impaired individuals participated in this study. Normal-hearing participants were Starkey employees who had volunteered to participate in research. Hearing-impaired participants were members of our research database; most had bilateral, mild-to-moderately severe sensorineural hearing loss (Figure 1). Forty-three of these participants were full-time hearing-aid wearers. All had digital hearing aids that were built between the years of 2000 and 2010 (median year built = 2007). All individuals signed a consent form before participating.

For each of the questions on the questionnaire, participants were asked to consider their performance in a "noisy" situation compared to a quiet one. A quiet situation was chosen as a reference so that participants would focus on the increased difficulty of the task caused by the background noise. Participants were asked to consider the "noisy" situation as being the equivalent to a crowded restaurant or bar. This reference was chosen because the type of background noise that one encounters in this situation is likely to be fairly similar to the multi-talker babble that was used during the ANL testing.

Using the standard ANL stimuli (the Arizona Travelogue (Cosmos, Inc.) and 8-talker babble), the ANL test was performed five times during a single session for each of the participants. The first iteration was practice; the remaining 4 iterations were averaged to obtain the listener's ANL. All participants were tested unaided. For the questionnaire, each question used a 4 or a 5-point scale.

RESULTS/DISCUSSION

ANL Distribution

Figure 2 shows the distribution of ANLs for the normal-hearing and hearing-impaired groups. Normal-hearing participants had a mean ANL of 5.1 dB, with a range of –4.4 to 21.6 dB, and hearing-impaired participants had a mean ANL of 7.3 dB, with a range of

−4.1 dB to 27.5 dB. A Mann Whitney Rank Sum test showed that ANLs were significantly lower for the normal-hearing group compared to the hearing-impaired group ($p < .05$).

For both groups, the mean ANLs were lower than the average ANLs of 10–11 dB reported by Nabelek et al.[2] The only potential explanation that we have for this is cultural differences. A majority of the normal-hearing people who participated in this study worked for a hearing-aid manufacturer. Many of these individuals have had past experiences that have led them to have a special interest in hearing or sound (e.g., personal experience with hearing loss, experience participating in psychoacoustic experiments, advanced musical training or audio engineering experience), and these experiences may have caused them to relate to sound differently than a random sampling of the population. Additionally, as previously stated, many of the hearing-impaired individuals were full-time hearing-aid wearers. Nabelek et al.[2] has shown that there is a moderate correlation between ANLs and amount of hearing-aid use, and so the fact that many of our hearing-impaired participants were full-time hearing-aid wearers may have biased our results toward lower ANLs.

Questionnaire Results

For analysis purposes, each multiple-choice response on the questionnaire was assigned a number 1–5. Low numbers indicate that background noise had minimal perceived negative impact on the listener's performance on that task and high numbers indicate that background noise had a large perceived negative impact on the listener's performance on that task.

What Factors Affect Listeners' ANLs?

To determine which question or combination of questions was best able to predict listeners' ANLs, a regression analysis was completed to investigate the relationship between an individual's ANL and her survey response scores. For both normal-hearing and hearing-impaired participants, results showed that concentration levels, perceived speech understanding abilities and tolerance for background noise were the primary factors influencing listeners' ANLs. Combining these three factors resulted in only slightly better predictive performance than using the single best factor. For the normal-hearing participants, the top three factors gave a coefficient of determination (R^2) of .1627 ($F_{4,81} = 5.3$, $p < .005$) whereas the single best factor – individuals' perceptions of their own noise tolerance – gave an R^2 of .1207 ($F_{2,83} = 11.5$, $p < .001$). For the hearing-impaired participants, the three top factors gave an R^2 of .1861 ($F_{4,48} = 3.7$, $p < .05$) whereas the best single factor – perceived speech understanding abilities – gave an R^2 of .1410 ($F_{2,50} = 8.4$, $p < .01$).

The low correlations between these variables and participants' ANLs suggest that none of these factors is singularly driving listeners' ANLs. Potentially, this could mean that different individuals are using different cues to determine their ANLs or that cues other than the ones that were investigated in this study are driving listeners' ANLs. Alternatively, it is possible that the questionnaire format did not sufficiently capture the variables of interest.

Can ANL Group Membership Be Predicted?

Because the ANL category to which an individual belongs should be predictive of her success with hearing aids, we wanted to determine whether we could predict individuals' ANL categories based on their responses to questions 1–6 of the questionnaire. To investigate this, we performed a quadratic discriminant analysis (QDA). This analysis tried to predict the ANL group (low/mid/high) to which an individual belonged based on her responses to the questions. The results of this analysis showed that the questions had poor predictive ability. At best the ANL category to which an individual belonged could be accurately predicted 54% of the time for normal-hearing participants and 49% of the time for hearing-impaired participants; chance performance was 33%. In general, there was too much overlap in participants' responses to the questions to accurately categorize them into the different ANL groups.

Can Success with Hearing Aids Be Predicted Based on Participants' Responses on the Questionnaire?

To determine whether any of the questions 1–6 on the questionnaire could be used to accurately predict success with hearing aids, we examined the responses of the 43 hearing-impaired participants in this study who reported owning hearing aids. Of these 43 people, 36 (84%) would be considered successful hearing-aid wearers according to Nabelek et al.'s[2] classification scheme, meaning they reported wearing their hearing aids whenever they needed them (question 8). Only 7 people (16%) would be considered "unsuccessful" hearing-aid wearers, meaning they only occasionally (5) or never (2) wore their hearing aids. Due to the small sample sizes, it was not possible to draw definitive conclusions regarding the ability of these questions to predict success with hearing aids. However, preliminary data showed that the mean participant responses on each of the questions were fairly similar

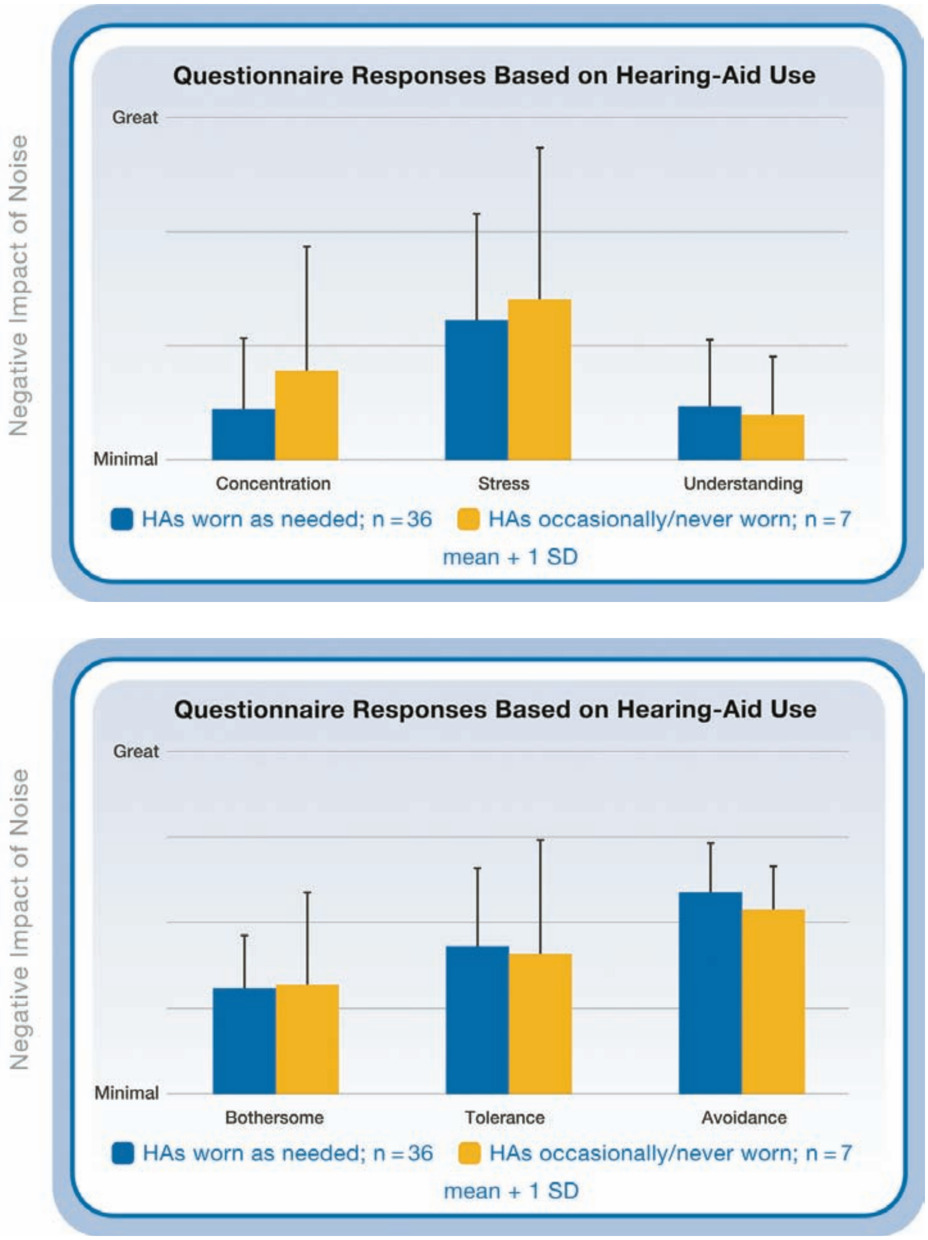

Figure 3. Hearing-aid wearers' mean responses (+ 1 SD) to the first six questions on the questionnaire. Questions that used a 4-point scale are on the top, and questions that used a 5-point scale are on the bottom. Participants' data were grouped according to their hearing-aid use.

across the different hearing-aid use groups, suggesting that participants' responses on this questionnaire are unlikely to be predictive of hearing-aid success (Figure 3).

Do ANLs Predict Success with Hearing Aids?

According to Nabelek et al.[2], people with low ANLs are likely to be successful with hearing aids, whereas people with high ANLs are likely to be unsuccessful with hearing aids. To determine whether this same trend occurred for our participants, we compared hearing-aid wearers' ANL groups to their responses to question 8 on the questionnaire (which classified them into successful and unsuccessful hearing-aid wearers, as discussed above). We found that 85% of our participants with low ANLs (17 of 20), 83% of our participants with mid ANLs (15 of 18) and 80% of our participants with high ANLs (4 of 5) would be considered successful hearing-aid wearers. These percentages are much higher than the 36% of individuals that Nabelek et al. suggested would be successful hearing-aid wearers. Additionally, they do not show the same strong trend for hearing-aid success to decrease with increasing ANL score. Again, differences between our results and those reported by Nabelek et al. may be due to biases in the way in which our participants were recruited.

CONCLUSION

Historically it has been very difficult to predict who would be successful with hearing aids. Research by Nabelek et al.[2] has offered hope that hearing-aid success may be predicted with a high degree of accuracy using a simple test investigating the amount of background noise that listeners are willing to accept while listening to running speech. The current questionnaire was administered to gain insight into the potential cues that listeners may be using to determine their ANLs, which may offer an explanation as to why some individuals are successful with hearing aids while others are not. The results of our study showed the following:

- The distribution of ANLs for our participants was much lower than what has been reported in the literature.[2] This would suggest that most of our participants should be successful with hearing aids. In fact, 84% of the hearing-aid wearers in this

study would be considered successful hearing-aid wearers based on Nabelek et al.'s definition of hearing-aid success. It is possible that our participant selection method may have biased the findings of the current study toward lower ANLs and therefore more successful hearing-aid wearers.
- For the normal-hearing and the hearing-impaired groups, there were mild, but significant, correlations between participants' ANLs and their responses to questions on concentration levels, perceived speech understanding abilities and tolerance for background noise. While these results suggest that these variables may play a role in listeners' ANLs, the low correlations suggest that none of these factors is singularly driving listeners' ANLs.
- The results of the questionnaire did not accurately predict the ANL category to which an individual belonged nor did they accurately predict whether or not someone was successful with hearing aids.
- For our population, ANLs were not predictive of hearing-aid success.

The results of this study suggest several areas in which additional research is necessary. First, existing research should be replicated to address the discrepancies between our results and those of other researchers to confirm that the observed differences in ANL distribution and hearing-aid success are, in fact, due to population differences and not some other variable. Second, future research should focus on determining the cues that individuals are using to select their ANLs. In particular, it may be useful to investigate the potential roles that concentration and speech intelligibility have on ANLs, given that significant correlations were observed between both of these variables and listeners' ANLs. Finally, research is necessary to determine whether the cues that individuals are using to determine their ANLs are in fact related to user benefit with various hearing-aid features. The results of these studies could have far-reaching implications for the treatment and rehabilitation of those with hearing loss.

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APPENDIX: QUESTIONNAIRE

For these questions, think about how your experiences in noisy environments compare to your experiences in quiet environments
Circle your response.

1. In noisy situations (e.g., a crowded restaurant or bar), I ________ more difficult to concentrate than when in quiet situations.

a. find it much
b. find it somewhat
c. find it slightly
d. rarely find it any

2. In noisy situations (e.g., a crowded restaurant or bar), I________ more stressed than when in quiet situations.

a. feel much
b. feel somewhat
c. feel slightly
d. rarely feel any

3. In noisy situations (e.g., a crowded restaurant or bar), I________ more difficult to understand the speech of those sitting next to me than when in quiet situations.

a. find it much
b. find it somewhat
c. find it slightly
d. rarely find it any

4. I usually find high levels of background noise, like those encountered in a crowded restaurant or bar, to be…

a. extremely bothersome
b. very bothersome
c. somewhat bothersome
d. slightly bothersome
e. rarely bothersome

5. I consider myself to be…

a. extremely intolerant of background noise
b. very intolerant of background noise
c. somewhat intolerant of background noise
d. slightly intolerant of background noise
e. very tolerant of background noise

6. I…

a. usually avoid situations that have high levels of background noise
b. frequently avoid situations that have high levels of background noise
c. sometimes avoid situations that have high levels of background noise
d. occasionally avoid situations that have high levels of background noise
e. rarely base my decision on whether to enter an environment on the level of the background noise

7. Do you have hearing aids?

a. Yes (go to question #8)
b. No (questionnaire is complete)

8. How often do you use your hearing aids?

a. I wear my hearing aids whenever I need them
  - Approximately how many hours? ________
b. I only wear my hearing aids occasionally
  - Approximately how many hours? ________
c. I do not wear my hearing aids
  - Why do you not wear them?

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