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Acceptable Noise Level as a Predictor of Hearing Aid Use

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Abstract

Acceptable noise level (ANL) measures a listener's reaction to background noise while listening to speech. Relations among hearing aid use and ANL, speech in noise (SPIN) scores, and listener characteristics (age, gender, pure-tone average) were investigated in 191 listeners with hearing impairment. Listeners were assigned to one of three groups based on patterns of hearing aid use: full-time use (whenever hearing aids are needed), part-time use (occasional use), or nonuse. Results showed that SPIN scores and listener characteristics were not related to ANL or hearing aid use. However, ANLs were related to hearing aid use. Specifically, full-time hearing aid users accepted more background noise than part-time users or nonusers, yet part-time users and nonusers could not be differentiated. Thus, a prediction of hearing aid use was examined by comparing part-time users and nonusers (unsuccessful hearing aid users) with full-time users (successful hearing aid users). Regression analysis determined that unaided ANLs could predict a listener's success of hearing aids with 85% accuracy.

Key Words: Acceptable noise level, background noise, hearing aids, hearing aid use, speech perception in noise

Abbreviations: ANL = acceptable noise level; BNL = background noise level; MCL = most comfortable level; PTA = pure tone average, mean of HLs at 0.5, 1, and 2 kHz; SPIN = Speech Perception in Noise; TRT = tinnitus retraining therapy

Sumario

El nivel aceptable de ruido (ANL) mide la reacción del sujeto ante el ruido de fondo mientras se encuentra escuchando lenguaje. Se investigaron las relaciones entre el auxiliar auditivo y el ANL, los puntajes de la prueba de audición en ruido (SPIN), y las características del oyente (edad, género, promedio tonal puro) en 191 sujetos con trastornos auditivos. Los sujetos fueron asignados a uno de tres grupos con base en los patrones de uso del auxiliar auditivo: uso de tiempo completo (siempre que se necesite el audífono), uso de tiempo parcial (uso ocasional), o ausencia de uso. Los resultados mostraron que los puntajes del SPIN y las características del oyente no se relacionaron con el ANL o el uso de auxiliar auditivo. Sin embargo, los ANL sí se relacionaron con el uso del auxiliar auditivo. Específicamente, los usuarios de tiempo completo aceptaban más ruido ambiente que los no usuarios, aunque no se pudo diferenciar entre los usuarios de tiempo parcial y los que no usaban audífono del todo. Así, se estableció una predicción en el uso de auxiliar,

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Data from this research has previously been presented at the International Hearing Aid Research Conference 2002 and 2004 (Lake Tahoe, CA); the 145th Acoustical Society of America Convention, 2003 (Nashville, TN); the American Academy of Audiology's 16th Annual Convention, 2004 (Salt Lake City, UT); and the 11th Annual Sol Alder Conference, 2004 (Knoxville, TN).

comparando los usuarios de tiempo parcial y los que no lo usaban (usuarios no exitosos de auxiliar auditivo), con los usuarios de tiempo completo. El análisis de regresión determinó que los ANL sin amplificación servían para predecir, con un 85% de exactitud, el éxito en el uso de los auxiliares auditivos.

Palabras Clave: Nivel aceptable de ruido, ruido de fondo, auxiliares auditivos, uso de auxiliares auditivos, percepción en ruido

Abreviaturas: ANL = nivel aceptable de ruido; BNL = nivel de ruido de fondo; MCL = nivel más confortable; PTA = promedio tonal puro, media de los niveles HL a 0.5, 1 y 2 kHz; SPIN = Percepción del Lenguaje en Ruido; TRT = terapia de re-entrenamiento en acúfeno

Difficulty understanding speech in background noise is the most frequent complaint of adults who use hearing aids (Kochkin, 2002a, 2002b; Cord et al, 2004; Killion et al, 2004; Wilson, 2004). Paradoxically, speech perception scores obtained in background noise do not predict success with hearing aid use (Bentler et al, 1993; Humes et al, 1996). Nabelek et al (1991) hypothesized that the willingness to listen to speech in background noise may be more indicative of hearing aid use than speech perception scores obtained in background noise. This hypothesis led to the development of a procedure to quantify the amount of background noise that listeners are willing to accept when listening to speech, called the "acceptable noise level" (ANL). The ANL was defined as the difference between the most comfortable listening level (MCL) for running speech and the maximum background noise level (BNL) that a listener is willing to accept.

Nabelek et al (1991) investigated ANLs, called in this study "tolerated speech-to-noise ratios (S/N)," in three groups of hearing-impaired elderly listeners (N = 15/group) who differed in their pattern of hearing aid use. Full-time users wore their hearing aids whenever they needed them; part-time users wore their hearing aids only occasionally; and nonusers had completely stopped wearing their hearing aids. The stimuli were delivered monaurally through an earphone with the frequency response modified to each individual's hearing loss, simulating the hearing aid frequency response. The effects of the following five different noises were determined: multitalker babble, speech spectrum noise, traffic noise, pneumatic drill noise, and "elevator" type music. The results showed that mean ANLs were similar for the five noises; however, mean ANLs for the full-time users were significantly lower than mean ANLs for part-time users and nonusers. There was no ANL difference between part-time users and nonusers.

Crowley (1994) investigated the relationship between ANLs (then called "tolerated S/Ns") and several other audiometric variables (i.e., audiometric thresholds, audiometric slope, and speech perception in background noise) in an attempt to predict satisfaction and hours of daily hearing aid use in 46 listeners with hearing impairment who had been recently fit with binaural hearing aids. Speech perception was assessed using the Speech Perception in Noise (SPIN) test (Bilger et al, 1984). The ANL was obtained monaurally through earphones with the frequency response shaped to simulate an appropriate hearing aid fitting as described by Nabelek et al (1991). Two background noises were used in measuring ANL: speech babble and speech spectrum noise. These noises were chosen because they are readily available in clinical settings. Four to six weeks postfitting, listeners were asked to complete the Profile of Hearing Aid Benefit (PHAB; Cox and Gilmore, 1990). No significant correlations were found between ANLs, SPIN scores, and individual subject variables; however, ANLs collected using speech spectrum and speech babble noises were significantly correlated. In subsequent data analysis, Crowley and Nabelek (1996) conducted regression analyses to determine the contribution of ANL as a predictive measure of PHAB outcome. Results showed that ANLs were predictive of the familiar talkers subscale of the PHAB only.

Lytle (1994) compared ANLs (then called "tolerated S/Ns") in two groups of elderly listeners that were matched for hearing sensitivity and speech perception. The groups were selected on the basis of their hearing aid use. One group, the successful hearing aid users, contained ten listeners who used their hearing aids full-time, which was defined as using them when "needed." The other group, ten unsuccessful hearing aid users, rarely or never wore their hearing aids. Lytle (1994) compared ANLs with and without monaural linear hearing aids in two background noises, speech spectrum and multitalker speech babble. In order to compare ANLs in the sound field with those obtained by frequency-shaped earphone delivery (Nabelek et al, 1991), Lytle (1994) tested listeners with signals delivered from a loudspeaker located at 0° azimuth. Comparison of ANLs between the groups revealed that the difference between aided and unaided ANLs and the difference between speech-spectrum and babble noise were not significant. These results suggest that ANL may be a predictive variable that can differentiate successful and unsuccessful hearing aid users prior to individual hearing aid fittings.

By definition, a prediction is based on variables that are obtained prior to the hearing aid fitting, and an outcome measure is based on measures obtained after hearing aids have been worn. To date, the proposed predictions have been based on multiple listener characteristics such as age, gender, or pure-tone audiometric average (PTA), and outcome measures have attempted to document hearing aid benefit/satisfaction using questionnaires. For example, Crowley and Nabelek (1996) used the PHAB (Cox and Gilmore, 1990); Hosford-Dunn and Halpern (2000, 2001) used the Satisfaction with Amplification in Daily Life (SADL) (Cox and Alexander, 1999); and Walden and Walden (2004) used the International Outcome Inventory for Hearing Aids (IOI-HA) (Cox and Alexander, 2002). Furthermore, Schum (1999) reported no predictive value of prefitting ratings assessed by the Hearing Aid Needs Assessment. This research has provided valuable insight into subjective satisfaction and benefit but has not produced an accurate method of predicting success with hearing aids.

Nabelek et al (2004) compared the effect of two perceptual measures of moderate levels of background noise: speech perception and willingness to listen to speech in the presence of background noise. Speech perception was determined with SPIN scores, and willingness to listen to speech was determined with ANLs. The new term “acceptable noise level” (ANL) avoids possible confusion with “tolerated noise level,” which is sometimes associated with Loudness Discomfort Level (e.g., Formby and Gold, 2002). Data were collected with and without hearing aids, and the results indicated that both measures were reliable and did not change during a three-month acclimatization period to hearing aids. Because the listeners in the Nabelek et al (2004) study were predominately full-time hearing aid users (41 of 50), the ANL and SPIN score contributions to the prediction of hearing aid use and benefit could not be fully explored. These contributions are determined in the present study, in which large groups of full-time users, part-time users, and nonusers of hearing aids were tested.

Therefore, the primary aim of the present study was to determine if ANL can be used to predict hearing aid use for listeners fit with a variety of hearing aids. ANL was incorporated with other traditionally used predictive data such as age, gender, PTA, and SPIN scores. Outcome was assessed using an adapted questionnaire originally developed by Nabelek et al (1991), which classifies listeners based on pattern of hearing aid use (Appendix 1). The questionnaire defined the patterns as follows: full-time use (hearing aids used whenever needed), part-time use (hearing aids used occasionally), and nonuse (hearing aids no longer used). Hours of daily hearing aid use also were determined.

Secondary aims of the present study were to determine (1) the relationship between ANLs and both predictive and outcome data, (2) the reliability of the questionnaire responses, (3) the differences in mean ANLs, predictive data, SPIN scores, and hours of daily hearing aid use among the three groups of listeners, and (4) the effect of hearing aids on ANLs and SPIN scores for the three groups.

METHODS

Listeners

Adults with hearing impairment were recruited from the Audiology Clinic at the University of Tennessee, Knoxville, and the greater Knoxville area. The criteria for inclusion were as follows: (1) binaural hearing aids, which were obtained within the last three years, and (2) no known neurological or cognitive listener deficits. Listeners were excluded from the study if the rationale for not using hearing aids was due to cost, cosmetics, or complaints such as comfort, which are not related to hearing aid performance. To avoid bias, all listeners (N = 191) were fitted with hearing aids by audiologists independent of the study. Therefore, based on the individual needs of the listener, various hearing aids ranging from analog to digital technology were included.

The first 58 listeners in this study were tested during three sessions: at the initial hearing aid fitting, one month postfitting, and three months postfitting. Nabelek et al (2004) reported ANL and SPIN reliability for 50 of these 58 listeners, 31 of whom were first-time hearing aid users. Only 50 listeners were included in the publication, because data from Session 3 for the remaining eight listeners were unavailable at the time of manuscript submission. Results indicated that the mean ANLs and SPIN scores did not change over a three-month acclimatization period and test-retest data were significantly correlated (Nabelek et al, 2004). Based on this information, the remaining data for the present study were collected in a single session with experienced listeners who had worn hearing aids for at least three months but no longer than three years. An additional 133 listeners were tested, resulting in 191 total listeners. Therefore, the 191 included 50 listeners who participated in the reliability study (Nabelek et al, 2004), eight listeners who completed three sessions after the reliability study was published, and 133 listeners who had between three months and three years experience with hearing aids.

The 191 listeners were assigned to one of three groups based on the questionnaire: full-time users, part-time users, and nonusers. Table 1 shows the listener characteristics of each of the three groups. Mean binaural hearing thresholds (in dB HL) and standard deviations (in dB) for the three groups are displayed in Figure 1. Individual right and left thresholds, measured under earphones, were averaged for each listener, and thresholds were then averaged across listeners to obtain mean audiometric thresholds.

Test Materials

ANL was determined using running speech recorded by a male talker as the primary stimulus (Arizona Travelogue, Cosmos, Inc.) and 12-talker speech babble (Revised SPIN recorded by Cosmos, Inc.; Bilger et al, 1984) as the competing background noise. Speech babble was selected as the only competing background noise to be consistent with the noise used in the SPIN test and because previous studies revealed that type of background noise did not affect ANLs (Lytle, 1994; Crowley and Nabelek, 1996). Speech perception in noise was assessed using the revised SPIN test (Bilger et al, 1984). Pattern and hours of daily hearing aid use were assessed using the questionnaire (Appendix 1).

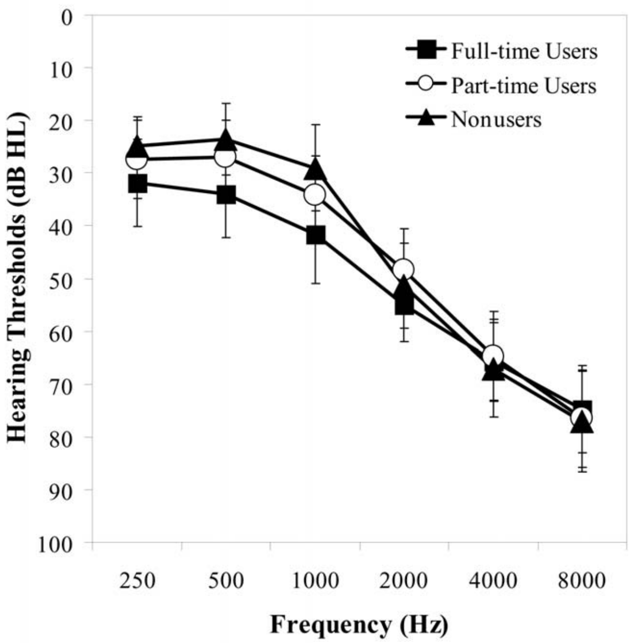

Figure 1. Mean audiometric thresholds (in dB HL) and standard deviations (in dB) for the three groups as a function of audiometric frequency.

Table 1. Listener Characteristics of Three Groups

		Group		
		Full-time users (N = 69)	Part-time users (N = 69)	Nonusers (N = 53)
Gender	(F, M)	19, 50	18, 51	13, 40
Age (yrs.)	Mean	72	71	70
	SD	10.3	11.8	11.4
	Range	42–89	32–94	42–91
PTA (dB HL)	Mean	43.7	36.4	34.3
	SD	14.0	12.5	12.1
	Range	16.7–80.0	5.0–67.5	9.2–63.3

Equipment and Procedures

Audiometric thresholds, age, gender, ANLs, SPIN scores, hours of daily hearing aid use, and pattern of use were collected for each listener. Unaided (binaurally without hearing aids) testing was performed for all 191 listeners. Aided (with binaural hearing aids) testing was performed for 164 of 191 listeners, because 27 nonusers did not retain their hearing aids. The order of testing was counterbalanced across listeners. For the listeners who were seen only one time, all testing was conducted during this session. For the listeners who took part in three sessions, ANLs and SPIN scores were obtained in all three sessions, and the questionnaire was completed in Sessions 2 and 3.

The equipment and procedures used in the present study were described by Nabelek et al (2004). Listeners were tested individually in an audiometric booth (IAC 400C) that met ANSI standards for ambient noise levels (ANSI S3.1 – 1991). Test stimuli were delivered from a two-track compact disc (CD) routed through an audiometer, calibrated to ANSI (ANSI, S3.6 – 1996) standards. The stimuli were presented through a loudspeaker located at 0° azimuth 1.5 m from the listener. The output levels of the speech stimuli and background noise were calibrated at the position to be occupied by the listener and were checked periodically throughout the experiment.

Prior to data collection, the listeners were given oral and written instructions for each procedure (Appendix 2). For the ANL procedure, the listener was given two handheld buttons to signal the examiner to adjust the volume up or down. The intensity of the stimuli was adjusted in 5 dB steps while the listeners were exploring their listening range (i.e., “turn the loudness up until it is too loud and then down until it is too soft”) and 2 dB steps when the listeners were selecting the final level (i.e., “finally, select the loudness level that is most comfortable for you”). First, listeners adjusted the level of the story to their MCL in quiet. Multitalker babble was then added at 30 dB HL, and listeners adjusted the babble to their acceptable background noise level (BNL). The BNL was defined as the maximum level of the background noise the listener would be willing to accept or “put up with” without becoming tense or tired while listening to and following the words of the story. The listeners' comprehension of the story was not tested. The ANL (in dB) was calculated as the difference between the MCL (dB HL) and BNL (dB HL). The ANL procedure was conducted two times in the unaided and aided conditions, and an average of the two calculated ANLs served as the mean ANL for each listener in the given condition.

The SPIN test was administered at the listeners' MCLs, which ranged from 41 to 83 dB HL in the unaided condition and from 32 to 63 dB HL in the aided condition. Speech babble was used at the recommended +8 dB S/N. Again, for the 27 nonusers who did not retain their hearing aids, only unaided SPIN scores were recorded. The SPIN test was conducted two times in the unaided and aided conditions, and an average of the two scores served as the mean SPIN score for each listener in the given condition. The presentation order of ANL and SPIN tests was counterbalanced across listeners.

During each session, listeners completed the questionnaire categorizing themselves as full-time users, part-time users, or nonusers. For the listeners tested over three months, the responses obtained from Session 3 were used for data analysis.

RESULTS

Relationship between ANLs and Predictive/Outcome Data

In order to determine the relationship between unaided or aided ANLs and the other measures collected in this study, a correlation matrix was calculated, and the results are shown in Table 2. A Bonferroni adjustment for multiple correlations was applied. A significant correlation was seen between aided ANLs and age. A significant correlation also was seen between both the aided and unaided ANLs and hours of daily hearing aid use. No other significant correlations were observed.

Questionnaire Responses

To determine the questionnaire response reliability, 58 listeners (50 full-time and eight part-time users) completed the questionnaire at Sessions 2 and 3. Of the 58 listeners, only three reported a decline in pattern of use from full-time to part-time (N = 2) or no use (N = 1). Furthermore, the reliability of the questionnaire was assessed using the average intraclass correlation coefficients based on the consistency definition. The correlation coefficient was r = 0.74 (p < 0.001), suggesting the responses were reliable over a three-month time period.

Group Data

Based on the questionnaire (Appendix 1) responses, the listener data (N = 191) were separated into three groups. Listeners were assigned to the groups based on pattern of hearing aid use: full-time users (N = 69), part-time users (N = 69), or nonusers (N = 53). Mean unaided and aided MCLs, BNLs, ANLs, SPIN scores, and hours of daily hearing aid use for each group are shown in Table 3. In the nonuser group, unaided data are presented for all 53 listeners while aided data are presented for the 26 listeners who retained but no longer used their hearing aids.

To determine which measurements can differentiate the three groups of hearing aid users, a MANOVA was performed on the data from Tables 1 and 3. The dependent variables were gender, age, binaural PTA, unaided and aided ANLs, unaided and aided SPIN scores, and hours of daily hearing aid use. The factor was group (full-time user, part-time user, and nonuser).

Group Data and Predictive Measures

The MANOVA revealed main effects for unaided ANL: $F(2,161) = 58.15$; $p < 0.001$ and binaural PTA: $F(2,161) = 7.63$; $p = 0.001$. All other effects and interactions were not significant. Bonferroni post hoc tests were used to evaluate group differences for the unaided ANL and binaural PTA. The analysis showed that the mean unaided ANLs and binaural PTAs for the full-time users were significantly different from the respective means for either the part-time users or nonusers. The means for the part-time users and nonusers were not significantly different.

Group Data and Outcome Measures

The MANOVA revealed main effects for aided ANL ($F[2,161] = 60.67$; $p < 0.001$) and hours of daily hearing aid use ($F[2,161] = 95.99$; $p < 0.001$). Bonferroni post hoc tests were used to evaluate significant group differences. Post hoc analyses of hours of daily hearing aid use and aided ANLs revealed that all three groups were significantly different. The difference in the hours between the part-time users and nonusers was not, however, pertinent because by definition nonusers wore hearing aids zero hours per day. The difference in aided ANLs between the part-time users and nonusers was statistically significant but was deemed to be clinically insignificant.

Effect of Hearing Aids on ANLs and SPIN Scores

As discussed in the introduction, background noise is a frequent complaint of hearing aid users. Two of the measures collected in the present study are perceptual responses to moderate levels of background noise, SPIN scores and the ANLs. For that reason, a

Table 2. Correlations between Unaided (N = 191) and Aided (N = 164) ANLs and Other Predictive and Outcome Measures

Predictive Measures		Unaided ANL	Aided ANL
Gender	r	-0.043	0.027
	p	0.552	0.736
Age	r	-0.187	-0.210
	p	0.050	0.035*
PTA	r	-0.148	-0.155
	p	0.164	0.188
Unaided SPIN Score	r	-0.123	-0.058
	p	0.270	0.918
Aided SPIN Score	r	-0.123	-0.114
	p	0.234	0.435
Hours/Day	r	-0.461	-0.507
	p	<0.001**	<0.001**

*p < 0.05 **p < 0.01

Table 3. Means of MCLs and BNLs (in dB HL), ANLs (in dB), SPIN Scores (in % correct) and Hours of Daily Hearing Aid Use with Respective Standard Deviations and Ranges

		Unaided			Aided		
Group	Test	M	SD	Range	M	SD	Range
Full-time users N = 69	MCL	59.0	8.1	43–83	49.4	6.0	36–63
	BNL	51.2	8.4	31–74	42.3	5.8	26–56
	ANL	7.7	3.0	2–16	7.3	3.2	1–18
	SPIN	63.6	23.7	6.4–94.3	76.8	18.9	30.1–97.7
	Hours/Day				10.1	3.8	2–18
Part-time users N = 69	MCL	55.7	5.6	42–73	50.2	4.8	37–60
	BNL	42.1	5.9	30–61	36.4	4.9	23–47
	ANL	13.5	3.9	9–26	12.6	3.4	7–26
	SPIN	62.1	23.0	8.5–97.0	76.7	19.3	26.4–97.7
	Hours/Day				4.5	3.5	1–12
Nonusers N = 26 (53)	MCL	54.5 (52.7)	4.7 (5.7)	47–66 (41–69)	47.4	5.0	32–58
	BNL	40.3 (38.3)	6.1 (7.0)	26–53 (17–56)	33.0	6.1	21–42
	ANL	14.4 (14.4)	4.0 (4.0)	11–27 (9–27)	14.5	4.1	10–26
	SPIN	63.4 (63.4)	18.2 (22.4)	30.1–92.9 (7.1–92.9)	76.8	19.0	15.9–97.0
	Hours/Day				0.0	0.0	

Note: *In the nonuser group, N = 26 for the numbers outside the parentheses, which represents individuals who were nonusers but retained their hearing aids. N = 53 for the numbers inside parentheses, which represented all nonusers.

comparison of the ANLs and SPIN scores deserves special attention. Such comparisons have already been performed in the Nabelek et al (2004) study, but the listeners in that study were mostly full-time hearing aid users. The data in the present study were collected with three large groups of listeners who differ by their pattern of hearing aid use.

The effect of hearing aids on the ANLs and SPIN scores was determined by several analyses. Correlations (Table 2) between these two measures were not significant for both unaided (N = 191) and aided (N = 164) data. The unaided and aided mean ANLs and SPIN scores in the three groups were compared by a doubly multivariate repeated measures analysis of variance. The dependent variables were ANLs and SPIN scores. The within-subject factor was listening condition (unaided and aided), and the between-subject factor was group (full-time user, part-time user, or nonuser). The analysis revealed significant main effects for listening condition ($F[2,160] = 44.78$; $p < 0.001$) and group ($F[4,322] = 24.01$; $p < 0.001$) but no significant group by listening condition interaction. Further examination of listening condition revealed that the listening condition (unaided and aided) was not significant for ANLs but was significant for SPIN scores: $F(1,161) = 90.02$; $p < 0.001$. The main effect for group has already been examined by the MANOVA in the Group Data and Predictive and Outcome Measures sections. These results indicated that ANLs were not affected by the use of hearing aids for any group. SPIN scores, however, increased equally when hearing aids were used in all three groups.

Logistic Regression Analysis

The mean unaided ANL for the full-time users was significantly different from the means for either the part-time users or nonusers; however, because means for the latter two groups' unaided ANLs were not significantly different from each other, the groups were redefined for further statistical analyses. Full-time users were considered successful users, and part-time users and nonusers were collapsed into one group termed "unsuccessful users." Although mean aided ANLs separated all three groups (Table 3), the 1.9 dB difference between the mean for part-time user and nonuser groups was not clinically significant.

Using unaided ANL as the predictor variable, logistic regression analysis was then employed to predict the probability an individual would be a successful hearing aid user. The logistic regression equation showed probability of success = $1/(1+e^{-z})$, where $z = 7.59 - 0.803$ (unaided ANL), ($\chi^2 = 124.399$, $p < 0.001$), indicating that unaided ANLs can predict probability of success with amplification. To determine the predicted probability of success with hearing aids, the listener's unaided ANL should be located on the x-axis of Figure 2. Then, the predicted probability of success corresponding to the unaided ANL can be located on the curve (Figure 2). In order to express the listener's probability of success in percent, the number on the y-axis of the curve should be multiplied by 100. For example, if the listener's unaided ANL is 5 dB, the probability of success with hearing aids is almost 100% (denoted by the arrows on Figure 2).

Examination of individual data (N = 191) indicated that the frequency distribution for unaided ANLs was normal, ranging from 2 to 28 dB (Figure 3). The most prevalent ANLs occurred between 10 and 11 dB. The remaining question is what percentage of all tested listeners can be expected to become successful hearing aid users or full-time users as defined in this study. This percentage can be calculated by dividing the number of observed successful users (N = 69) by the total number of tested listeners (N = 191) and multiplying by 100. This calculation indicated that 36% of the hearing aid candidates will be successful hearing aid users.

Accuracy of the Prediction

The numbers of observed and predicted successful and unsuccessful hearing aid users were compared in order to calculate the accuracy of predictions. The observed numbers were established by responses to the questionnaire, and the predicted numbers were obtained from the regression analysis. The observed and predicted numbers and calculated percent correct responses are shown in Table 4. The accuracy of prediction, expressed as percent correct responses, was 87.0% for the successful users and 83.6% for the unsuccessful users. The overall accuracy of the prediction for all users was 84.8%. The overall accuracy was obtained by dividing the number of predicted correct responses (60 + 102 = 162) by the number of all responses (191) and multiplying by 100%. It has to be noted, however, that since statistical models tend to fit the data upon which they were developed better than a new set of data, one can expect a lower percent correct than shown in Table 4 when using the logistic regression equation in clinical practice.

The MANOVA results revealed that both unaided ANLs and binaural PTAs differentiated full-time listeners from part-time users and nonusers. Therefore, logistic regression was also performed with both binaural PTAs and unaided ANLs. Results of these analyses showed that the accuracy of the prediction was poor with PTA as a single variable and did not significantly improve with inclusion of both variables.

DISCUSSION

Relationship between ANLs, Gender, Age, and PTA

Correlational analysis indicated that both unaided and aided ANLs were not related to

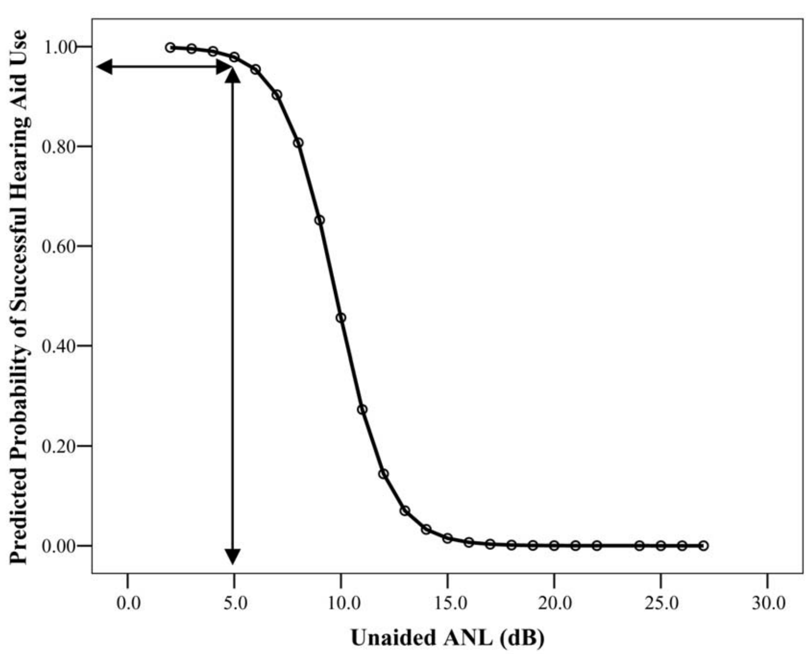

Figure 2. Logistic regression curve displaying the predicted probability of hearing aid success as a function of unaided ANL. To obtain probability in %, the values on the vertical axis should be multiplied by 100. As an example, the arrows denote the probability of success for a listener with an ANL of 5 dB.

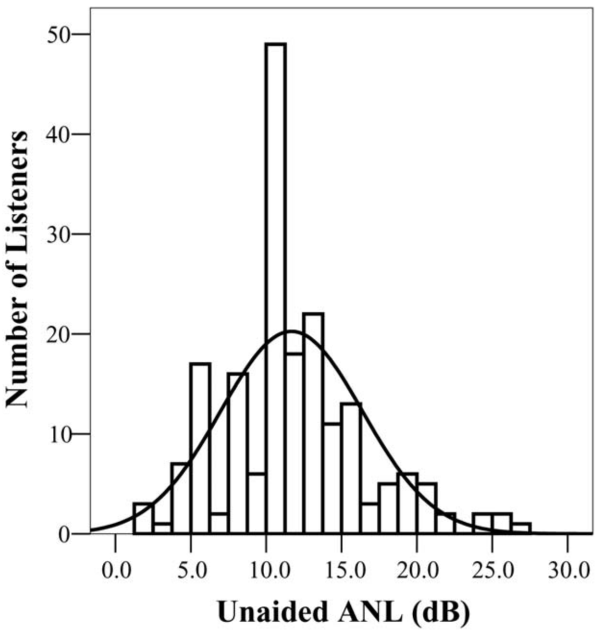

Figure 3. Histogram displaying the frequency distribution of unaided ANLs (in dB) for the 191 listeners with impaired hearing.

gender, which agrees with results obtained by Crowley (1994) for 46 hearing aid users and Rogers et al (2003) for 50 listeners with normal hearing. The same correlational analysis conducted in the present study indicated that unaided ANLs were not related to PTA or age; however, aided ANLs were weakly correlated with age. No correlation between aided ANLs and age was observed by Crowley (1994). In the present study, the correlation of 0.035 shows that age accounted for less than 1% of the variance of aided ANLs; therefore, the correlation between aided ANL and age was deemed to be clinically insignificant and probably occurred because of the large sample size (N = 191). Based on this information, the authors concluded that unaided and aided ANLs were not dependent on gender, age, or PTA, indicating that ANL may be an inherent characteristic of the individual that does not change with age or acquired hearing loss.

Relationship between ANLs and Hours of Daily Hearing Aid Use

Both unaided and aided ANLs were significantly correlated with hours of daily hearing aid use. Pattern of hearing aid use, however, was deemed to be a more meaningful outcome measure than hours of hearing aid use because in some professional lifestyles (e.g., computer programming), hearing aids may be worn a minimal number of hours. The results shown in Table 3 illustrate this point. One full-time hearing aid user wore hearing aids for only two hours a day while a part-time user wore hearing aids for 12 hours a day. Also, hours of daily hearing use are not typically reliable in assessing hearing aid outcome. Humes et al (1996) reported that subjects tend to overestimate hearing aid use time. Furthermore, Taubman et al (1999) found discrepancies between actual and self-reported time of use and concluded that documenting satisfaction or hearing aid benefit based on hours of hearing aid use may be misleading.

Questionnaire Responses

In the present study, pattern of hearing aid use was assessed using the questionnaire (Appendix 1). Only 3 of the 58 listeners who completed the questionnaire two times reported less hearing aid use after three months compared to one month. This decline is consistent with data reported by Humes et al (2002), who observed a slight decline in hearing aid use between one and six months postfitting. It is also consistent with reports from Walden and Walden (2004), which state that success with hearing aids tends to decrease over time. Furthermore, Surr et al (1998) recommended that after a six-week period of adjustment, listeners can reliably evaluate hearing aid performance. Therefore, the three-month adjustment period selected for the present study appears to be sufficiently long for the reliable determination of pattern of hearing aid use.

Table 4. Number of Successful and Unsuccessful Hearing Aid Users

	Predicted		Observed	Percent Correct
N of Listeners	Successful	Unsuccessful		
Successful	60	9	69	87.0
Unsuccessful	20	102	122	83.6
All			191	84.8

Note: Number of successful and unsuccessful hearing aid users predicted by logistic regression analysis and observed through identification by questionnaire.

Effect of Hearing Aids on ANLs and SPIN Scores

Results of the present study confirmed the conclusions of Nabelek et al (2004) with 50 listeners, most of whom were full-time hearing aid users. The ANLs and SPIN scores were not correlated in the aided condition (N = 164) in agreement with Crowley (1994), or in the unaided condition (N = 191). The mean unaided and aided ANLs were not different in any of the three groups. In contrast, the mean unaided and aided SPIN scores were different in all three groups. SPIN scores improved with amplification. Speech perception scores, however, are generally only weakly correlated with hearing aid benefit, satisfaction, or use (Humes et al, 1996).

The unaided ANLs were different among listeners with different patterns of hearing aid use and can predict who will likely be a successful user of hearing aids. The SPIN scores, however, were not different among listeners with different patterns of hearing aid use and cannot predict who will be a successful user of hearing aids. The comparison of the ANLs and SPIN scores showed clearly the differences between these two measures. While SPIN scores determined benefit of amplification for speech perception, the ANLs determined the differences between successful and unsuccessful hearing aid use. In conclusion, the acceptance of background noise and speech perception of background noise are two different measures of reaction to moderate levels of noise and provide different contributions to assessment of hearing aid outcome use and improvement of speech understanding in noise.

Clinical Applications

ANLs can be completed in approximately two to three minutes (e.g., establishment of MCL and BNL for one listening condition) and can be measured using test materials and equipment found in standard audiology clinics. To obtain ANLs, MCLs should be measured using a recording of running speech, and BNLs should be measured using multitalker speech babble. The speech and noise stimuli should be delivered by a loudspeaker located in front of the listener in an audiometric booth. Several variations from the procedures described in the present study can be considered: the use of different running speech recordings, including recordings of non-English speech, use of different recordings of babble or different noise than babble, presentation of stimuli through two loudspeakers located at 0° and 180° azimuth from the listeners for assessment of benefit of hearing aid directivity, or presentation of the stimuli through an earphone.

Commercially available recordings of stimuli needed for ANL procedures provide calibration signals. We used recordings and calibrations provided by Cosmos, Inc. However, because there are no standardized methods to calibrate such stimuli as running speech and babble noise, calibrations can cause small differences in measured ANLs. For example, recordings other than those used in the current study, as with Freyaldenhoven, Plyler, et al (this issue), report a 2 dB difference between mean ANLs for speech spectrum and babble noises, while no such differences were reported by Lytle (1994) and Crowley and Nabelek (1996). Therefore, if ANL data are collected differently than in the present study, new baseline data should be developed.

If the same ANL procedures used in the present study are replicated, it can be assumed that the results will be similar to our data. Using a patient's unaided ANL, the predictive probability of success with hearing aids can be determined based on the logistic regression curve (Figure 2). For example, if a patient's ANL is 5 dB, the probability of success with hearing aids is almost 1, or 100% if expressed as a percentage (denoted by the arrows on Figure 2). The information obtained from probability of success with hearing aids may help the audiologist make a decision about the type of amplification suitable for a patient.

Patients with low ANLs (no greater than 7 dB) are likely to become successful, full-time hearing aid users. Patients will midrange ANLs (between 7 and 13 dB) may be either successful or unsuccessful users. Special care should be taken to provide these patients with hearing aids that reduce background noise. Patients with high ANLs (greater than 13 dB) are likely to become unsuccessful users who wear hearing aids occasionally or not at all. Because they accept very little background noise, they should be counseled regarding the limitations of hearing aids even in quiet listening situations. They should also be advised to consider devices that incorporate directional microphones and frequency modulation systems, which have been shown to improve performance in background noise.

Future Studies

The present study introduces several issues that need to be addressed: (1) how to enhance the prediction of hearing aid success for individuals with midrange ANLs, (2) how to better differentiate between part-time users and nonusers, and (3) how to increase the number of successful hearing aid users.

The predictive probability of hearing aid success for individuals with low and high ANLs (i.e., <7 and >13 dB, respectively) is informative. Unfortunately, the prediction for individuals with midrange ANLs between 7 and 13 dB is not helpful. For example, with an ANL of 10 dB, the most prevalent value among 191 listeners, the probability of success is 50%, a result not very useful for audiologists or patients in making decisions regarding amplification. Some additional measures should be found to resolve this ambiguity. One measure to consider is growth of ANL with an increase of speech presentation level. Franklin et al (2006) and Tampas and Harkrider (2006) found for listeners with normal hearing that an increase in speech presentation level above individual MCL causes an increase in ANL. The rate of ANL growth, however, was different among listeners. It can be expected that this growth also will differ among listeners with impaired hearing and might be related to success with hearing aids. In everyday life, some listening occurs at levels different than MCL. It is possible, therefore, that the individuals who experience rapid growth of ANL with increase of speech presentation level will be less successful hearing aid users than the individuals experiencing slow growth.

The part-time users were considered unsuccessful hearing aid users because they did not use their hearing aids whenever they needed them and reported hearing aid use in easy listening situations only. Regarding nonusers, the reason for complete rejection of hearing aids remains unclear and should be investigated in future studies. The growth of ANL with increase of speech presentation level also should be investigated as a measure differentiating part-time users from nonusers of hearing aids. It can be hypothesized that for some individuals the ANL growth is so rapid that even hearing aids with compression do not prevent the ANL from reaching values associated with rejection and nonuse of hearing aids. For other individuals, the ANL growth is slow and the ANL remains in the range associated with part-time use.

The third issue is the expected percentage of successful hearing aid users. For the tested population, this percentage was 36%. The 36% corresponds to survey data published by Kochkin (2002 a, 2000b), who found that only 31% of hearing aid users reported satisfactory communication in noisy conditions. It appears that in order to increase the percentage of successful hearing aid users, some strategies to increase individuals' acceptance of background noise should be developed. Three strategies could be investigated: (1) hearing aids and listening devices reducing the amount of background noise delivered to the eardrums, (2) pharmacological interventions, and (3) auditory training.

Freyaldenhoven, Nabelek, et al (2005) demonstrated that when speech was delivered from a loudspeaker at 0° azimuth and the babble noise was delivered from another loudspeaker at 180° azimuth, hearing aids with directional microphones allowed listeners to accept more background noise than when listening through hearing aids with omnidirectional microphones. Mean benefit of the directionality measured with ANL was 3.6 dB. It has been well documented that the amount of noise reaching listeners can be substantially reduced by using FM and infrared listening devices (Nabelek et al, 1986; Kuhnel et al, 2001). Future studies should investigate the amount of ANL reduction that could be obtained using these technologies.

Whereas the mean unaided and aided ANLs were not very different in any of the three groups, inspection of the individual ANL data indicated that in the total group of 164 listeners who were tested both aided and unaided, the aided ANLs improved by at least 3 dB for 23 listeners (14%), and the aided ANLs declined by at least 3 dB for 12 listeners (7%). We do not have an explanation for these changes. Lytle (1994), who used linear hearing aids, found no difference between ANLs with and without amplification. In the present study, improvement for some listeners possibly was achieved by advanced hearing aid features that were not controlled. The influence of these features on ANL should be determined in the future.

The effect of pharmacological intervention on ANL was evaluated by Freyaldenhoven, Thelin, et al (2005), who found that stimulant medication improved ANLs in individuals with attention deficit/ hyperactivity disorder (ADHD). There may be other pharmacological options that could be used to improve ANLs. It should be determined if any pharmacological interventions are useful for improvement of ANL in individuals with hearing impairment.

Another possibility to modify ANL is through some auditory training. Formby and Gold (2002) and Jastreboff and Jastreboff (2002) reported success in the improvement of sound tolerance and satisfaction with hearing aids for some tinnitus patients by managing them in a habituation-based tinnitus retraining therapy (TRT) protocol. Hence, can TRT help listeners with high ANLs? If the ANL decreases with TRT, then this may be another means of improving hearing-aid use.

CONCLUSIONS

The primary purpose of this study was to determine if acceptable noise level (ANL) when listening to speech can be used to predict hearing aid use. The prediction method was developed based on unaided ANLs and a questionnaire, which assigned listeners to one of three groups, full-time users, part-time users, or nonusers, according to their pattern of hearing aid use (Appendix 1). It was found that ANLs for full-time users were lower than ANLs for either part-time users or nonusers, but in the latter two groups, unaided ANLs were not significantly different. Therefore, the three groups were dichotomized as successful (i.e., full-time users) and unsuccessful (i.e., part-time users and nonusers), and a method for determining successful hearing aid use was developed. The method was based on the logistic regression analysis and revealed that listeners with low ANLs were more likely to become successful hearing aid users, and listeners with high ANLs were more likely to become unsuccessful users. The ANL measure predicted hearing aid success with 85% accuracy.

Two measures of perceptual responses to moderate levels of background noise, ANLs and speech perception in noise (SPIN) scores, also were compared. SPIN scores improved with the introduction of hearing aids; therefore, SPIN scores can be used as a measure of benefit from amplification. SPIN scores, however, were not different for successful and unsuccessful hearing aid users and, therefore, cannot be used as a means to predict successful hearing aid use. Whereas the ANLs did not significantly change with the use of amplification, the unaided ANLs were different for successful and unsuccessful hearing aid users and, therefore, could be used to predict who is likely to succeed with hearing aids. These data indicate that willingness to listen to speech in the presence of noise, measured with the ANL procedure, and speech perception in noise, measured with the SPIN test, provide different information about hearing aid outcome.

Data of 191 listeners also revealed that 36% of these listeners would be successful hearing aid users. It follows that, in order to increase the percentage of successful hearing aid users, various means to increase listeners' acceptance of background noise should be explored. This may be accomplished through advanced hearing aid technology, auditory training, or pharmacological intervention.

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Appendix 1. Questionnaire

How do you use your hearing aids? (Check 1, 2, or 3)

1. I wear my hearing aids whenever I need them ________________

   Approximately how many hours? ________________

2. I only wear my hearing aids occasionally________________

   Approximately how many hours?________________

   Why? Briefly describe the situations ______________________________

3. I do not wear my hearing aids ________________

   Why do you not wear them?______________________________

Appendix 2. ANL Instructions

Instructions for establishing MCL:
You will listen to a story through a loudspeaker. After a few moments, *select the loudness of the story that is most comfortable for you, as if listening to a radio*. Handheld buttons will allow you to make adjustments. First, turn the loudness up until it is too loud and then down until it is too soft. Finally, select the loudness level that is most comfortable for you.

Instructions for establishing BNL:
You will listen to the same story with background noise of several people talking at the same time. After you have listened to this for a few moments, *select the level of background noise that is the MOST you would be willing to accept or "put up with"* without becoming tense and tired while following the story. First, turn the noise up until it is too loud and then down until the story becomes very clear. Finally, adjust the noise (up and down) to the *MAXIMUM* noise level that you would be willing to "put up with" for a long time while following the story.