

# Acceptable Noise Level as a Measure of Directional Hearing Aid Benefit

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## Abstract

An acceptable noise level (ANL) procedure for measuring hearing aid directional benefit was compared with masked speech reception threshold (SRT) and front-to-back ratio (FBR) procedures. ANL is the difference between the most comfortable listening level and the maximum accepted background noise level while listening to speech. Forty adult subjects wearing their own binaural hearing aids were evaluated in omnidirectional and directional modes. The subjects were fitted with a variety of hearing aids by clinical audiologists, independent of the study. For each procedure, speech and noise were presented through loudspeakers located at 0° and 180° azimuth, respectively. Mean ANL (3.5 dB), SRT (3.7 dB), and FBR (2.9 dB) directional benefits were not significantly different. The ANL and masked SRT benefits were significantly correlated. The ANL appears to be a quick, clinician/user friendly procedure for measuring hearing aid directional benefit.

**Key Words:** Acceptable noise level, background noise level, directional benefit, directional microphone, front-to back ratio, speech reception threshold

**Abbreviations:** ANL = acceptable noise level; BNL = maximum acceptable background noise level; FBR = front-to-back ratio; MCL = most comfortable listening level; SNR = signal-to-noise ratio; SPL = sound pressure level; SRT = speech reception threshold

## Sumario

Se comparó un procedimiento de nivel aceptable de ruido (ANL) para medir el beneficio direccional de un auxiliar auditivo, con un procedimiento de umbral de recepción del lenguaje (SRT) y uno de tasa de adelante-a-atrás (FBR). El ANL es la diferencia entre el nivel de audición más confortable y el nivel máximo aceptado de ruido de fondo para escuchar lenguaje. Se evaluó a cuarenta sujetos adultos utilizando sus propios auxiliares auditivos binaurales en modo direccional y omni-direccional. Audiólogos clínicos independientes del estudio adaptaron a estos sujetos una variedad de auxiliares auditivos. Para cada procedimiento, el lenguaje y el ruido se presentaron a través de altoparlantes colocados a 0° y a 180° azimut, respectivamente. El beneficio direccional de la media del ANL (3.5 dB), del SRT (3.7 dB) y de la FBR (2.9 dB) no fue significativamente diferente. Los beneficios del ANL y del SRT

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enmascarado correlacionaron significativamente. El ANL parece ser un procedimiento rápido y amigable para el clínico y el usuario, en la medición del beneficio direccional del auxiliar auditivo.

**Palabras Clave:** Nivel aceptable de ruido, nivel de ruido de fondo, beneficio direccional, micrófono direccional, tasa adelante-a-atrás, umbral de recepción del lenguaje

**Abreviaturas:** ANL = nivel aceptable de ruido; BNL = nivel máximo aceptable de ruido de fondo; FBR = tasa de adelante-a-atrás; MCL: nivel auditivo más confortable; SNR = relación señal-ruido; SPL = nivel de presión sonora; SRT = umbral de recepción del lenguaje

One of the most frequent complaints of hearing aid users is difficulty understanding speech in the presence of background noise. As a result of these complaints, a primary rehabilitation goal is to improve the signal-to-noise ratio (SNR) at the listener's eardrum (Kochkin, 1993; Killion et al, 1998). Directional microphones, which maintain sensitivity to signals arriving from the front and suppress signals arriving from the sides and back (Dillon, 2001), have shown promise in achieving this rehabilitation goal and are becoming typical hearing aid features (Ricketts and Mueller, 2000). While literature reports have shown beneficial effects for directional processing, there is no standard method for evaluating the performance of directional hearing aids.

The benefit of directional microphones has been shown through improvements in speech perception (Agnew and Block, 1997; Gravel et al, 1999; Kuk et al, 1999; Wouters et al, 1999; Ricketts and Mueller, 2000; Kuhnel et al, 2001), subjective quality ratings (Valente et al, 1995; Preves et al, 1999; Schuchman et al, 1999), and sound pressure levels (SPLs) measured through electroacoustic analysis at the ear canal (Ricketts, 2000a; Dhar et al, 2004). None of these procedures, however, have gained widespread use for the evaluation of directional benefit in clinical settings.

In 1991, Nabelek et al developed a procedure for measuring the amount of background noise individuals are willing to accept while listening to speech. This measure was termed "acceptable noise level" (ANL)

and is defined as the difference between a listener's most comfortable listening level (MCL) while listening to speech in quiet and the maximum amount of background noise they are willing to accept while listening to the speech. The listener's maximum acceptable background noise level is termed BNL (i.e.,  $ANL = MCL - BNL$ ). ANL does not appear to depend on age, gender, hearing sensitivity, or type of background noise (Nabelek et al, 1991; Freyaldenhoven and Fisher-Smiley, 2001; Rogers et al, 2003; Nabelek, Tampas, et al, 2004). ANL can, however, predict success with hearing aids (Nabelek, Freyaldenhoven, et al, 2004). Listeners who accept large amounts of background noise are successful hearing aid users, while those who accept small amounts of background noise are unsuccessful hearing aid users. This success can be predicted with 82.5% accuracy. The ANL procedure is reliable, quick, and easy to administer (Nabelek, Tampas, et al, 2004).

The present investigation was designed to determine if the ANL procedure is suitable for assessing directional benefit in hearing aids in a clinical population. The relative merits of the ANL procedure were compared with the relative merits of the masked speech reception threshold (SRT) procedure and ear canal SNR determined by electroacoustic analysis (i.e., SPLs in the ear canal). The electroacoustic procedure used in this study was based on front-to-back ratio (FBR) measures (Ricketts and Mueller, 1999). FBR is typically used to measure the directional benefit of one microphone by comparing

responses to the same stimulus arriving from 0° and 180° azimuth (Ricketts and Dittberner, 2002). In this study, FBRs for two microphone modes (i.e., omnidirectional and directional) were compared using two different stimuli (i.e., speech originating from 0° and background noise originating from 180°). The benefit measured from these responses was termed FBR benefit.

## METHODS

### Subjects

Forty adult patients from the University of Tennessee Hearing and Speech Clinic were selected for participation on the basis of (1) being fitted binaurally with hearing aids containing omnidirectional and directional modes and (2) having worn hearing aids for at least three months. Twenty-seven males and 13 females between the ages of 30 and 89 years (mean age = 69 years, SD = 12.3) with a pure-tone average of 47.3 dB HL (SD = 14.6) served as experimental subjects. The subjects were tested using their personal hearing aids, which were fitted by staff audiologists at the University of Tennessee Speech and Hearing Clinic independent of the study. The subjects utilized 15 analog and 25 digital hearing aids. Twenty-eight of these were in-the-ear (ITE), and 12 were BTE hearing aids. The hearing aids were fitted to best meet the subject's amplification needs and were not adjusted for the purposes of this study. At the University of Tennessee Speech and Hearing Clinic, adults are fitted with hearing aids based on the National Acoustics Laboratory-Revised rationale; real ear measures are performed to verify target match at 50 and 70 dB, and maximum output is evaluated at 90 dB to ensure comfort.

### Apparatus and Test Materials

For all procedures, the speech stimuli and background noise were delivered by a Dell (OptiPlex GX 400) personal computer compact disc player routed through an audiometer (GSI-16) calibrated to American National Standards Institute (ANSI, S3. 6-1996) standards. The stimuli were routed into two loudspeakers located at ear level 1.5 m from the subject at 0° and 180° azimuth

on the diagonal of an audiometric booth (IAC, model #404A; 2.7 x 2.5 m). The audiometric booth met ANSI standards (S3. 1-1991) for acceptable ambient noise levels. The FBRs were measured using the Audioscan RM500 computerized probe microphone system and downloaded to a PC using the Audioscan RM500 XDATA32 extraction program. The program converted all data stored in the Audioscan RM500 into ASCII test files. The ASCII text files were then saved and stored as individual subject files in Microsoft Excel.

For the ANL and FBR, a recording of male running speech (Arizona Travelogue, Cosmos Inc.) was used as the speech stimulus. The speech stimulus for masked SRT was a male recording of a list of spondee words (Basic Auditory Tests: CD #101 R2, Auditec of Saint Louis). All speech stimuli were delivered by the loudspeaker located at 0° azimuth. Revised Speech Perception in Noise multitalker speech babble (Bilger et al, 1984) was used as the competing background noise for all procedures and delivered by a loudspeaker located at 180° azimuth. The output levels of the loudspeaker were regularly calibrated for the point occupied by the subject with a precision Type II sound level meter. The calibration signal was speech-shaped noise having a root mean square level equivalent to the root mean square level of the stimuli (speech and speech babble).

The 0°/180° loudspeaker arrangement is one of many possible arrangements. This arrangement allows for optimal directional benefit for microphones with cardioid polar responses, which have polar nulls at 180° azimuth (Walden et al, 2003). Directional benefit for other polar responses (e.g., hypercardioid, supercardioid, and bi-directional), with polar nulls at other azimuths, may be optimized using different loudspeaker arrangements. Because the goal of this study was to assess the ANL procedure's ability to measure directional benefit and not to determine maximal benefit, one loudspeaker arrangement (0°/180°) was utilized.

### Procedures

#### *Acceptable Noise Level*

Prior to testing, subjects were given verbal and written instructions describing the experiment. Following the instructions,

subjects were then given two handheld buttons, which were used to adjust the intensity of the speech to their MCL. The buttons were connected to an indicator box that signaled the examiner to manipulate the intensity level of the speech up or down in 2 dB steps until the MCL was established. The starting level for determining the MCL was 30 dB HL. The verbal and written instructions for determining the MCL were as follows:

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 up and down 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.

With speech held constant at MCL, the background noise (multitalker speech babble) was added from 180° azimuth. The subjects adjusted the background noise in 2 dB steps to their maximum acceptable background noise level (BNL). The starting level of the background noise was 30 dB HL. The subjects were given the following written and verbal instructions:

You will now listen to the same story with background noise. After you have listened to this for a few moments, select the level of the background noise that you would be willing to accept or “put-up-with” without becoming tense or 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 level that you would “put-up-with” for a long time while following the story.

To simplify the procedure, the MCL obtained for the omnidirectional microphone mode was used to obtain the ANL for the directional mode. Because the MCL might change from the omnidirectional to the directional microphone mode, pilot MCL data was obtained for five subjects fitted with various hearing aids and revealed a mean difference of only 2.2 dB. This data also showed no trend for either microphone mode; therefore, it was assumed that the two microphone modes produced similar loudness, which did not affect the ANL or directional benefit. It should be noted that since the MCL obtained in the omnidirectional mode was used to obtain the ANL in the directional mode, data collection for the two modes was not counterbalanced.

For the ANL procedure, the following binaural measurements were obtained: MCL for the omnidirectional microphone mode and BNLs for the omnidirectional and directional microphone modes. The ANLs were then calculated as differences between MCL and the respective BNL, in dB ( $ANL = MCL - BNL$ ). ANL was calculated for (1) the omnidirectional mode and (2) the directional mode. The directional benefit was determined by subtracting directional ANL from the omnidirectional ANL. Estimated time of ANL testing and calculation was approximately five to seven minutes for each subject.

### ***Masked Speech Reception Threshold***

The masked SRT was obtained by using a modified version of the Tillman and Olsen (1973) procedure. This procedure was used because the signal could be presented at the subjects' MCL, and both the signal and background noise could be adjusted independently. The spondaic words were presented at the MCL established in the ANL procedure, and the background noise was adjusted until 50% intelligibility was achieved. The background noise was initially presented 30 dB below the subject's MCL, and one spondee word was presented. If the subject correctly identified the word, the noise was increased by 10 dB until the subject missed two consecutive spondee words at the same level. At that time, the noise was reduced by 10 dB (called the starting level), and pairs of spondee words were presented as the background noise was raised in 2 dB increments. If the subject missed five out of the first six words presented, the level of the background noise was reduced to 6 dB below the starting level. If the subject, however, identified five out of the first six words correctly, the original starting level was used. Pairs of spondee words were then presented as the noise was raised in 2 dB increments until the subject missed five out of six consecutive words.

By presenting pairs of words for each 2 dB increase in intensity, the subject had the opportunity to correctly identify one word for each one dB increase in intensity. The masked SRT (point in which the background noise meet 50% criterion) was established by adding one dB for every correctly repeated word to the starting background noise level and then subtracting one (half the number in which the noise was increased).

Two binaural masked SRTs were measured, one for the omnidirectional microphone mode and one for the directional microphone mode. Masked SRTs for the omnidirectional and directional modes were counterbalanced. Directional SRT benefit was calculated by subtracting directional SRT from omnidirectional SRT. Estimated time of masked SRT testing and calculations was approximately 11–15 minutes for each subject.

### ***Front-to-Back Ratio at the Ear Canal***

SPLs in the ear canal were determined using probe microphone measurements for the omnidirectional and directional microphone modes. Speech and background noise were presented separately in the sound field through the loudspeakers at 0° and 180° azimuth, respectively. The input intensity levels of the speech stimuli and background noise used to make these measurements were obtained from the ANL procedure in the omnidirectional microphone mode. Separate microphone responses were recorded for the speech and noise stimuli for the omnidirectional microphone mode and for the directional microphone mode. This resulted in ear canal SPLs for the omnidirectional mode for speech at MCL and speech babble noise at the listener's acceptable BNL. The MCL and speech babble noise were, then, held constant, and the hearing aid mode was changed from omnidirectional to directional. Ear canal SPLs were again recorded. All electroacoustic measurements were obtained for the right and left ears separately.

Because speech and speech babble were used as the stimuli and because both stimuli fluctuated over time, four sweeps were recorded for each SPL measurement. For each sweep, 61 data points measured in 1/12th octave steps over the frequency range of 200 Hz to 5000 Hz were obtained. The four sweeps obtained for each SPL measurement were averaged at each of the 61 frequencies. The resultant values were again averaged across the 61 frequencies, which resulted in one number for the following four conditions for each ear: (1) omnidirectional MCL, (2) omnidirectional BNL, (3) directional MCL, and (4) directional BNL. The BNL for each microphone mode was then subtracted from its respective MCL,

resulting in one number for the omnidirectional mode and one number for the directional mode for the right and left ears. The numbers for the right and left ears were then averaged, resulting in one number for the omnidirectional and one number for the directional modes. The FBR benefit was obtained by subtracting the omnidirectional number from the directional number. It should be noted that the order of subtraction between omnidirectional and directional scores for the FBR benefit was reversed relative to the ANL and SRT benefits. This was done to avoid negative numbers. Estimated testing and data analysis was approximately 30 minutes for each subject.

## **RESULTS**

Means, standard deviations, and ranges for ANL, masked SRT, and FBR directional benefit scores are shown in Table 1. A one-factor repeated measures ANOVA was computed to compare the directional benefits assessed with ANL, masked SRT, and FBR. Results of this ANOVA showed no significant main effect ( $F_{2,37} = 1.011$ ,  $p = 0.374$ ), suggesting that ANL may be an alternative method of measuring directional benefit.

To further compare the directional benefit of the three procedures, Pearson's correlation coefficients were calculated (Table 2). These calculations showed that ANL and masked SRT benefits were significantly correlated. They also showed that FBR benefit was significantly, although weakly, correlated with masked SRT benefit. Figures 1 and 2 show the comparison of the significantly correlated benefits.

## **DISCUSSION**

Results of this experiment showed that the mean directional benefits assessed with the ANL, masked SRT, and FBR procedures are not significantly different (Table 1). This suggests that ANL is comparable to the other procedures used to assess directional benefit. Masked SRT data were further compared with data reported by other studies for adults with hearing impairment (Table 3). The SRTs were collected with various speech and noise stimuli and various loudspeaker

**Table 1. Benefit Scores (in dB)**

<b>Benefit</b>	<b>ANL</b>	<b>Masked SRT</b>	<b>FBR</b>
Mean	3.50	3.65	2.91
Standard Deviation	2.89	2.61	3.16
Range	-4 to 12	-2 to 9	-2 to 11

*Note:* N = 40.

arrangements. In spite of the procedural differences, the mean SRT benefits are similar to the benefit of 3.7 dB obtained in this study. All of these studies, however, show a large range of benefits. Cord et al (2004) suggested large individual differences are sometimes related to poor microphone directivity when measuring directional benefit in a clinical population. Ricketts (2000a, 2000b) described additional factors that could contribute to the variability

associated with directional benefit. These include vent size, alignment of microphone ports, and types of hearing aid model used (Ricketts, 2000a). Ricketts (2000b) also reported that various hearing aid features (i.e., compression, noise reduction, etc.) can affect directivity. For the present study, it should be noted that hearing aid properties did not change between the omnidirectional and directional modes. In other words, if a hearing aid feature was activated for one

**Table 2. Pearson's Correlation Coefficients for Directional Benefit, as Measured by the ANL, Masked SRT, and FBR Procedures**

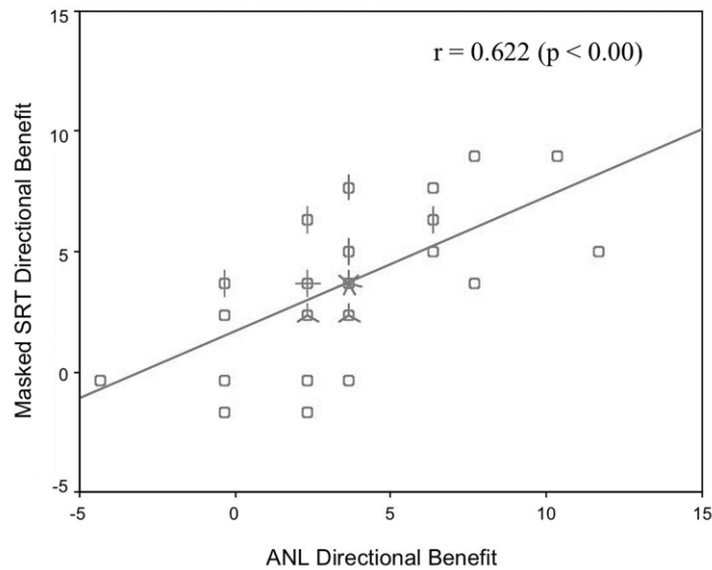
<b>Procedure</b>	<b>ANL</b>	<b>Masked SRT</b>	<b>FBR</b>
ANL	–	.622*	.256
Masked SRT	–	–	.333*
FBR	–	–	–

*Note:* N = 40.

\*Significant correlation ( $p < 0.05$ )

**Table 3: Directional Benefit Shown by Improvements in SRT for Adults with Hearing Impairment**

<b>Investigators</b>	<b>Speech Stimuli (from 0° azimuth)</b>	<b>Competing Stimuli</b>	<b>Noise Azimuth</b>	<b>Mean Benefit (dB)</b>	<b>Benefit Range (dB)</b>
Valente et al (1995) N = 50	HINT Sentences	Spectrally Matched Noise	180°	3.5	2.7 to 12.4
Preves et al (1999) N = 10	HINT Sentences	Speech Spectrum Noise	115° and 245°	2.8	-4.0 to 4.7
Wouters et al (1999) N = 10	Bi-syllabic Words	Multitalker Noise	90°	3.3	-9.8 to 3.6
Jespersen and Olsen (2003) N = 32	Dantale II Hagerman Test	Unspecified Masking Noise	90°, 180° and 270°	3.0	-1.0 to 6
Cord et al (2004) N = 20	HINT Sentences	Spectrally Matched Noise	90°, 180° and 270°	2.7	-2.5 to 10.5
Walden et al (2004) N = 17	HINT Sentences	Spectrally Matched Noise	90°, 180° and 270°	3.3	-1.9 to 9.0
Present Investigation N = 40	Spondee Words	Multitalker babble	180°	3.7	-2.0 to 9.0

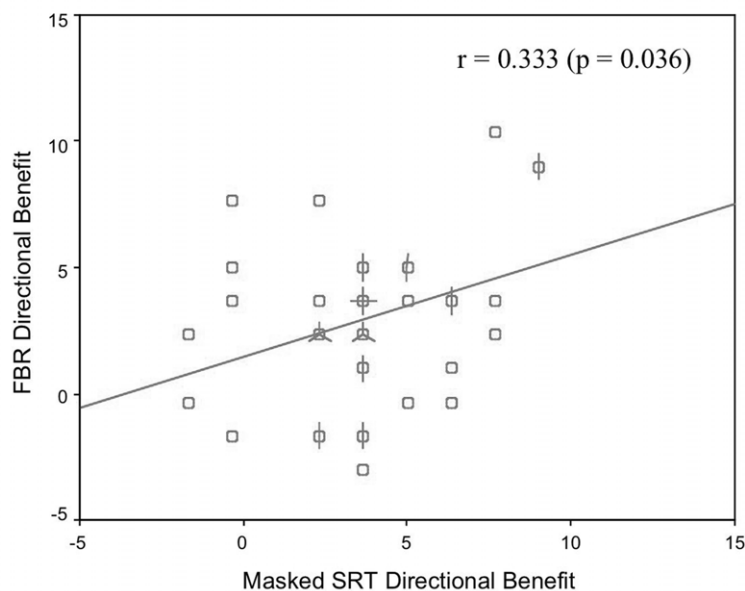


**Figure 1.** Scatterplots with a line of best fit for directional benefits between ANL and masked SRT for 40 listeners. Sunflowers represent overlapping data points. Each petal extending off a point represents one subject.

microphone mode, it should have been activated for the other microphone mode. Independent of hearing aid features, directional benefit measured with the ANL, masked SRT, and FBR procedures showed the same trend.

The mean FBR benefit of 2.9 dB obtained in this study is comparable to the mean FBR benefit reported by Dhar et al (2004) for the 0°/180° loudspeaker arrangement, yielding scores of 2.5 and 5.0 dB for Oticon and Phonak hearing aids, respectively. Dhar et al (2004)

FBR procedures were, however, simpler than the procedures used in the current study. These investigators recorded monaural real ear responses and compared them to monaural SRT measurements. Conversely, in the current study, binaural masked SRTs were compared to average FBRs obtained for two ears separately. Dhar et al (2004) also used a swept pure tone when measuring both the front and back ear canal responses for FBR. Using the same swept tone signal helped to avoid complicated averaging and



**Figure 2.** Scatterplots with a line of best fit for directional benefits between masked SRT and FBR for 40 listeners. Sunflowers represent overlapping data points. Each petal extending off a point represents one subject.

comparison across two stimuli. In the current study, speech and multitalker speech babble noise were selected for two reasons: (1) to utilize the same signals as used with the ANL procedure and (2) to approximate signals that may be encountered in daily listening situations. This procedure is problematic because in daily listening situations, signals enter the hearing aid simultaneously instead of separately. The separation of these signals when conducting soundfield measurements introduces measurement error because two signals delivered separately are processed differently by hearing aids than two signals entering simultaneously. Because of the stimuli used, this procedure became cumbersome and time-consuming.

Dhar et al (2004) reported correlations between masked SRT and FBR benefit that were relatively weak. Using the 0°/180° arrangement, a significant correlation was reported for Phonak hearing aids ( $r = 0.47$ ,  $p < 0.05$ ). The correlation for Oticon hearing aids was not significant. In the present investigation, the correlation coefficient between masked SRT and FBR benefits was weak but significant ( $r = 0.33$ ,  $p < 0.05$ ). One possible explanation for the differences in correlation values between Dhar et al (2004) and the present study may be due to the differences in stimuli, measurement technique (i.e., monaural versus binaural), and the use of a variety of hearing aids. Results of these FBR studies appear to suggest that even when using a simplified form of the FBR procedure, inconsistencies between individual responses to procedures measuring directional benefit continue to exist. They also suggest that the FBR procedure may be too cumbersome to be considered for clinical use.

In this study, mean directional benefits of 3.5 dB for ANL and 3.7 dB for masked SRT obtained were not significantly different. Likewise, a benefit of approximately 3 dB would equate to about 30% improvement in speech recognition (Killion and Villchur, 1993). Furthermore, the individual ANL and masked SRT benefit for 40 subjects were significantly correlated, suggesting benefits measured from the two procedures were somewhat consistent (Table 2). Large ranges of directional benefit were, however, seen in both procedures. The large range of benefits may have been due to the fact that the subjects were fitted with a variety of hearing

aids using various polar plots, circuitry, and features (i.e., compression, noise reduction, etc.). The primary goal of this study, however, was not to measure maximal directional benefit but to assess the viability of the ANL procedure, which can be easily replicated in a clinical setting. The ANL procedure, in comparison to the masked SRT and FBR, was the quickest and easiest for the subject and did not require any specific equipment beyond that which is used routinely in clinical settings. Therefore, it appears that the ANL procedure is a quick, clinician/user friendly procedure for measuring hearing aid directional benefit.

## CONCLUSIONS

In clinical settings, patients with hearing impairment often have difficulty understanding speech in background noise. One technological advance that has shown promise in improving understanding in background noise is directional microphones in hearing aids. There is, however, no standard clinical procedure to evaluate directional microphone benefit. In the present study, the acceptable noise level (ANL) procedure for measuring hearing aid directional benefit was compared with two other procedures currently recognized in audiology, masked speech reception threshold (SRT) and front-to-back ratio (FBR). Results of this investigation ( $N = 40$ ) revealed that mean ANL benefit was comparable to masked SRT and FBR mean benefits. The results also revealed that the correlation between individual ANL and masked SRT benefits was significant while the correlation between ANL and FBR benefits was not significant. The ANL procedure was found to be quick, easy to administer, and only required standard clinical equipment. Therefore, it appears that the ANL procedure may be a viable alternative to the other procedures for measuring directional benefit in hearing aids.

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