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Predicting Directional Hearing Aid Benefit for Individual Listeners

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Abstract

The fitting of directional microphone hearing aids is becoming increasingly more routine, and this fitting option has proven to be a successful method to improve speech intelligibility in many noisy listening environments. Data suggest, however, that some hearing-impaired listeners receive significantly more directional benefit than others. It is of interest, therefore, to determine if directional benefit is predictable from identifiable audiologic factors. In this report, we examined whether the slope of audiometric configuration, amount of high-frequency hearing loss, and/or the aided omnidirectional performance for a speech-in-noise intelligibility task could be used to predict the magnitude of directional hearing aid benefit. Overall results obtained from three separate investigations revealed no significant correlation between the slope of audiometric configuration or amount of high-frequency hearing loss and the benefit obtained from directional microphone hearing instruments. Although there was a significant, negative relationship between aided omnidirectional performance and the directional benefit obtained in one study, there was considerable variability among individual participants, and nearly all of the listeners with the best omnidirectional hearing aid performance still received significant additional benefit from directional amplification. These results suggest that audiologists should consider the use of directional amplification for patients regardless of audiogram slope, high-frequency hearing loss, or omnidirectional speech intelligibility score.

Key Words: Benefit prediction, directional microphones, Directivity Index, hearing aids

Abbreviations: BTE = behind the ear, DI = Directivity Index, DSP = digital signal processing, HINT = Hearing in Noise Test, ITE = in the ear, NAL-NL1 = National Acoustic Laboratories-Nonlinear 1, SNR = signal-to-noise ratio

Directional hearing aids have regained popularity in recent years. Advances in microphone design have resulted in substantial improvements in performance of these instruments. When the signal(s) of interest and the "noise" are spatially separated, these devices offer an excellent means for improvement of the signal-to-noise ratio (SNR) at the ear of the listener (for review, see Preves, 1997; Ricketts and Mueller, 1999; Mueller and Ricketts, 2000). Directional hearing aids reduce the intensity level of sounds arriving from behind and/or from the sides of the listener relative to that arriving from in front of the listener. This has the effect of improving the effective SNR when listening to a talker in the presence of a diffuse noise source (Ricketts and Mueller, 1999). The magnitude of SNR improvement in an anechoic chamber for a signal of interest directly in front of the listener relative to a spatially diffuse noise can be quantified by the Directivity Index (DI).

If clinicians simply use the published DI of directional hearing aids as a predictor, it would seem that nearly all patients could benefit from these instruments in listening conditions where the listener is surrounded by noise. Data generally suggest that DIs measured in situ (on the head) can be used to predict the average directional hearing aid benefit a user will obtain in a noisy, near-field listening environment (Killion et al, 1998; Ricketts, 2000b). However,

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these same studies suggest that individual hearing aid wearers exhibit great variability in the additional benefit they receive from directional hearing aids in comparison with their omnidirectional counterparts.

The positive impact of directional hearing aids on word recognition has been reported in terms of absolute scores and difference scores between directional and omnidirectional hearing aid conditions (see Ricketts and Mueller, 1999, for a review). These two constructs have been referred to as directional performance and directional benefit, respectively. It is important to distinguish directional benefit from directional performance in any discussion of prediction of directional hearing aid benefit. Directional performance (absolute score) is influenced by the hearing aid as a whole, including not just the directional microphone but also all other signal-processing and frequency-shaping properties. Consequently, performance is not predictable based solely on the contribution of the directional microphone. In contrast, it is assumed that directional benefit (difference score) reflects the impact of the directional microphone on the hearing aid processing system. That is, the measured directional benefit is mainly the result of differences in the DI of the directional and omnidirectional conditions. Both directional benefit and performance are important quantifiers for directional hearing aids. Specifically, directional performance is useful for comparing across hearing aids and fittings in an attempt to determine which instrument is likely to perform the best for a given listener. In contrast, directional benefit is a useful measure for exhibiting the positive impact of directional microphones and quantifying the impact of various fitting parameters (e.g., venting, microphone inlet orientation, etc.).

From a clinical standpoint, it is important to know if there are audiometric findings that can be used to identify people who might and who might not achieve benefit from directional hearing aids. For example, one study has suggested that benefit from these instruments can be influenced by the slope of the unaided audiogram and the degree of high-frequency thresholds (Killion et al, 1998). Using Articulation Index theory and participant data, these authors reported that listeners with flat audiometric configurations should have less directional benefit than those with sloping hearing loss. It was argued that the reduced benefit for listeners with flat audiometric configurations was related to the directivity pattern of the specific instrument under investigation in combination with the inability of some users with more severe high-frequency hearing losses to make use of high-frequency speech information. Specifically, research suggests that some listeners' pattern and degree of cochlear hair cell damage precludes them from using high-frequency speech information, even when presented at suprathreshold levels. That is, for listeners with more severe high-frequency hearing loss, increasing the audibility of high-frequency speech cues may not result in the expected improvements in speech understanding (see Turner and Cummings, 1999, for review). Killion et al (1998) reported that the improvement in DI for the directional hearing aid setting over the omnidirectional counterpart was greater in the low frequencies than the high frequencies, a common finding for many in-the-ear (ITE) and behind-the-ear (BTE) directional hearing aids (Ricketts, 2000a; Ricketts et al, 2000). Based on these data, it was argued that the directional benefit for listeners with flat hearing loss was predictable from an Articulation Index-weighted DI, whereas the directional benefit of listeners with sloping or more severe high-frequency hearing losses was dependent mainly on the low-frequency DI values. Since the improvement in directivity between directional and omnidirectional conditions is greatest in the low frequencies, those listeners who rely primarily on low-frequency speech information (those with sloping hearing losses) will achieve greater directional benefit than those who are able to use speech information across the entire frequency range (those with less severe high-frequency loss).

A number of researchers have differentiated hearing loss into losses of sensitivity (a change in hearing thresholds) and losses of SNR (e.g., Schum, 1996; Killion, 1997). Since omnidirectional hearing aids have been shown to provide limited SNR benefit, it is of interest to examine directional benefit as a function of omnidirectional hearing aid performance. Speech intelligibility tests with variable SNR that provide a measure of SNR loss (e.g., Hearing in Noise Test [HINT], Speech in Noise Test) are commonly used in the evaluation of directional hearing aids. Some research has shown that hearing aid wearers with greater SNR loss appear to receive greater directional benefit (Killion et al, 1998). Although the differences in directional benefit measured in the Killion et al work were later attributed to differences in threshold slope (Killion and Christensen, 1998), it is unclear whether the difference in directional benefit was truly the result of threshold slope alone or the result of other, unknown factors related to SNR loss.

Previous research suggests that there seem to be at least three factors that may influence patient benefit with directional microphone hearing aids. These include the slope of the audiometric configuration, the magnitude of the high-frequency hearing loss, and the SNR loss. Since we are specifically concerned with directional benefit, it is of interest to examine directional benefit as a function of SNR loss in the presence of omnidirectional amplification rather than examining unaided SNR.

Modern directional hearing aids have been shown to provide the average hearing-impaired listener with significantly more hearing aid benefit in noisy, near-field listening situations than their omnidirectional counterparts. However, reverberation, distance from talker, increased venting, and other subject and measurement variables have been shown to reduce the benefit that hearing aid wearers receive when using directional amplification (e.g., Hawkins and Yacullo, 1984; Mueller and Wesselkamp, 1999; Ricketts, 2000a, b). In addition, data reveal that the magnitude of directional benefit can vary across directional hearing aid models and that the pattern of directional benefit across specific models can vary interactively with the test environment (Ricketts, 2000b). The fact that several subject and measurement factors affect directional benefit complicates our ability to predict who will and who will not benefit from this technology. However, if average directional benefit that individual listeners receive is calculated across several test conditions and environments and prediction of benefit is compared across several studies, the impact of specific subject and measurement factors on directional benefit and the resulting bias in prediction data are reduced.

In this report, using the results obtained in three separate investigations, we review directional hearing aid benefit (as measured using the results of speech intelligibility testing in background noise) and compare these results to three different patient-specific factors: slope of audiometric configuration, amount of high-frequency hearing loss, and aided omnidirectional performance for a speech-in-noise test.

METHOD

The data of three different experiments were evaluated. In experiment 1 (Ricketts et al, 2000), the average directional benefit of two groups of participants (25 at one test site and 19 at a second test site) was calculated across five different models of directional hearing aids programmed for nine different hearing aid conditions. In experiment 2 (Ricketts, 2000b), the average directional benefit of 26 participants was calculated across three different models of directional hearing aids as evaluated in eight different listening environments. In experiment 3 (Bentler, 1999), the average directional benefit of 10 participants was calculated using a single hearing aid condition and two different listening environments. In all three studies, directional benefit was defined as the difference between the participant's omnidirectional HINT threshold and the HINT threshold obtained using directional hearing aid amplification. All three experiments were conducted under laboratory conditions, and the participants did not have a real-world trial period with directional hearing aids prior to the speech testing. Although there is no evidence to suggest that there is acclimatization for directional microphone technology, these results should be viewed as indicative of initial directional benefit.

Participants

The 80 participants in the three studies ranged in age from 36 to 94 years old (median age = 66). All participants had symmetric, mild to moderately severe, sensorineural hearing impairment (Fig. 1). Symmetry between ears was defined as exhibiting no more than a 15-dB difference in pure-tone thresholds at any octave frequency from 250 through 8000 Hz. The participants' unaided loudness discomfort levels were measured at octave frequencies from 500 through 4000 Hz, and these values were entered into the fitting software. All participants had normal immittance findings and exhibited no significant air–bone gap at any frequency (≤ 10 dB). Across the three experiments, 31 participants were experienced hearing aid users, with at least 6 months of hearing aid use. The remaining 49 participants had no previous experience with amplification.

Hearing Aids

Experiment 1

The HINT was administered to participants fitted binaurally with five different models of hearing aids. The hearing aids evaluated in this study consisted of one BTE and four ITE models.

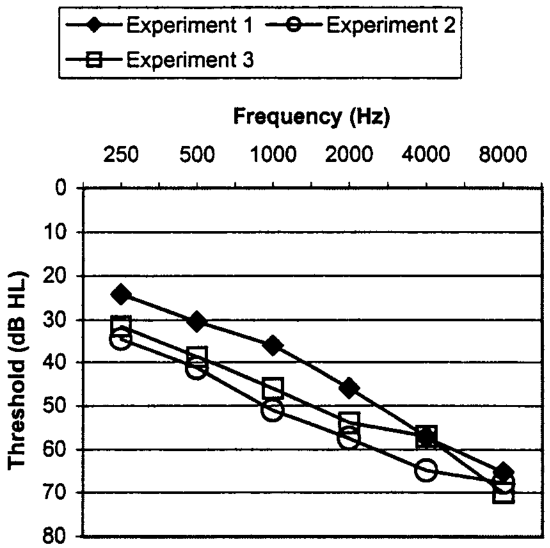

Figure 1 Mean thresholds and range of hearing loss measured for each of the three groups of experimental participants. Mean thresholds represent the combined average threshold of both the left and right ears.

The BTE hearing aids were coupled to the ear using a custom silicon, full-shell earmold with a 3-mm Libby horn. One-millimeter pressure relief venting was used across all five hearing aid models. The five hearing aid models were selected to provide a range of linear and compression parameters. Of these five models, four were capable of both linear and low-threshold compression processing, whereas the fifth model was linear only. The four models capable of compression were programmed using both linear and compression prescriptions. Participants were then fit with these nine prescriptions (five linear, four compression) in both directional and omnidirectional modes for a total of 18 fitting conditions.

Hearing aid 1 was a single-channel, digitally programmable BTE instrument with a compression threshold of 52 dB SPL. Hearing aid 2 was a single-channel, digitally programmable ITE model with a compression threshold of 52 dB SPL. Hearing aid 3 was a four-channel, digital signal-processing (DSP) ITE model with the compression threshold fixed at 34 dB SPL in all four channels. Hearing aid 4 was a two-channel digitally programmable ITE model with a compression threshold of 45 dB SPL in both channels. Hearing aid 5 was a nonprogrammable, linear ITE instrument that implemented hard peak clipping for output limitation. Hearing aids 1, 2, and 3 used two microphones for directional processing, whereas a single microphone and acoustic delay network was used to achieve directivity in hearing aids 4 and 5.

All eight compression conditions (four hearing aid models × two microphone types) were programmed using the National Acoustic Laboratories-Nonlinear 1 (NAL-NL1) prescription. Prescription gain for all 10 linear conditions (five hearing aid models × two microphone types) was matched to the NAL-NL1 prescription target for an average speech input level (65 dB SPL). Verification of target gain was accomplished in a 2-cc coupler. Consequently, 2-cc coupler gain was matched across all 18 conditions given a 65 dB SPL composite noise input signal.

Experiment 2

Directional benefit using the HINT was obtained for all participants fitted binaurally with four different BTE hearing aid models. These four models included (1) Phonak Piconet P2 AZ™, a single-channel, digitally programmable BTE instrument with a compression threshold of 52 dB SPL; (2) Siemens Prisma™, a four-channel DSP instrument with a programmable compression threshold in all four channels; (3) Widex Senso™ C8 (omnidirectional only); and (4) Widex Senso™ C9 (directional only), a three-channel DSP instrument with compression thresholds fixed at 25 dB SPL and an expansion threshold fixed at 40 dB SPL. Hearing aids 1 and 2 used two microphones for directional processing, whereas a single microphone and acoustic delay network was used to achieve directivity for hearing aid 4. For each participant, all hearing aids were coupled to custom silicon, full-shell earmolds (3-mm Libby horn and 1-mm vent). All omnidirectional hearing aid conditions were programmed according to each manufacturer's recommended method for fitting low-threshold (wide dynamic range) compression (compression threshold < 57 dB SPL). These same fitting parameters were used for the directional fittings. However, a natural low-frequency reduction occurs with directional microphone activation, and, as a result, the directional fittings provided less low-frequency gain in comparison with their omnidirectional counterparts. Other than this difference in low-frequency gain and the presence or absence of directional microphones, all fitting parameters were identical across directional and omnidirectional instruments of the same brand. For further fitting details, please refer to Ricketts (2000b).

Experiment 3

In this experiment, all participants were fitted binaurally with a single DSP instrument, the Oticon DigiFocus ITE with the D-Mic™ option, and a single microphone and acoustic delay network to achieve directivity. This hearing instrument employs a two-channel compression circuit with wide dynamic range compression processing and programmable compression thresholds in both channels.

Pure-tone thresholds and most comfortable range values were obtained and used in the programming of the hearing aids. Each participant was then fit with the hearing aids according to the manufacturer's prescribed fitting procedure (referred to as the adaptive speech alignment scheme). Testing using the HINT was conducted for both the omnidirectional and directional settings of the instruments.

Speech Material

The HINT (Nilsson et al, 1994) served as the speech test material for all three experiments. The participant's task for the HINT was to repeat sentences spoken by a male talker in the presence of a fixed-level (65 dBA SPL) speech-shaped noise. The intensity of the sentences was adaptively adjusted, and correct identification of each sentence was based on proper repetition of all words of the sentence, with minor exceptions. Small substitutions in verb tense and the articles "a" and "the" were allowed without scoring a sentence as incorrect (Nilsson et al, 1994). A threshold SNR was calculated as the SNR necessary to achieve 50 percent correct performance. The sentences are typically presented in blocks of 10; however, in these investigations, all participants received two blocks of 10 sentences for each test condition.

The competing noise was modified from the original HINT recording for each of the three experiments. In experiments 1 and 2, the standard competing signal of the HINT was replaced with five uncorrelated samples of amplitude normalized cafeteria noise. Peak-to-valley ratios observed with a 10-msec time window did not exceed 7 dB after amplitude normalization. The noise sources were then filtered to provide a long-term average spectral shape identical to that of the test stimuli (see Ricketts, 2000b, for further description). In experiment 3, the single competing noise of the HINT was replaced with eight uncorrelated samples of the original competing noise for routing to eight separate loudspeakers.

Test Environment and Procedure

Evaluation of directional benefit in a single test environment can result in misleading information concerning the performance of directional microphone hearing aids in other environments (Ricketts, 2000b). Therefore, the data reported here have been gathered from a variety of test environments encompassing a broad range of listening conditions. One consistent variable, however, was the primary speech signal, which was presented from a single loudspeaker positioned at 0° azimuth for all three experiments.

Experiment 1

All testing was performed in moderately reverberant rooms selected to be representative of the reverberation present in an average room (Moncur and Dirks, 1967; Nabelek and Mason, 1981). At site 1 (25 participants), testing was conducted in a 10.5 ft square (6′, 7″ high) sound-treated booth that was modified with reflective panels. At site 2 (25 participants), a 10′ × 10′ × 8′ carpeted office was selected as the test environment. Average reverberation times were 408 and 456 msec at sites 1 and 2, respectively.

The noise source configuration was chosen to be representative of restaurant-type listening environments (Ricketts, 2000b). The five-speaker competing noise arrangement included placement at 30°, 105°, 180°, 255°, and 330°. The intensity level of the competing noise sources presented from the speakers placed at 30° and 330° was reduced 5 dB relative to the other competing noise sources. The reason for this reduction was because in many listening situations, noise sources in front of the listener are farther away (consequently lower intensity) than noise sources behind the listener. All sound sources were placed at ear level at a distance of 1.25 meters from the listener.

The order of hearing aid conditions and HINT list presentations was randomized within and across participants. Overall, in two different sessions (separated by at least 2 days), each participant was tested with 18 different hearing aid fittings (9 directional and 9 omnidirectional in combination with five linear and four compression fittings). Therefore, the directional benefit data for each participant of this experiment were calculated as the difference score based on 36 HINT lists (2 lists per condition).

Experiment 2

Two rooms were selected for this study that were representative of the reverberation present in average living rooms and classrooms (Moncur and Dirks, 1967; Nabelek and Mason, 1981). The "living room" environment measured 7 meters (long) × 5.4 meters (wide) × 3 meters (high). The "classroom" environment measured 8 meters (long) × 6 meters (wide) × 3.5 meters (high). Average reverberation times were 631 and 1097 msec for the living room and classroom environments, respectively (Ricketts, 2000b).

Four different competing noise source arrangements were used: a single source placed at 180° azimuth (0/180) and three different arrangements of five uncorrelated noise sources. The five-source arrangements were chosen in an attempt to represent near-field, real-world listening conditions for which noise sources either surrounded the listener (e.g., restaurants, party) or were concentrated behind the listener (e.g., the front of a theater, classroom, or meeting). The five speaker arrangements included the three following placements: (1) 90°, 135°, 180°, 225°, and 270° azimuth; (2) 30°, 105°, 180°, 255°, and 330°; and (3) 30°, 105°, 180°, 255°, and 330°, with a 5-dB reduction in average intensity and a decrease in spectral slope applied to the noise originating from the 30° and 330° locations (Ricketts, 2000b). The loudspeakers used to present the speech and competing noise signals were placed at a distance of 1.25 meters from the listener.

The choice of the first listening environment and hearing aid fitting was counterbalanced. The remaining listening conditions were randomized within and across participants. Overall, in two different sessions (separated by at least 1 week), each participant was tested with six different hearing aid fittings, in two different listening environments, using four different competing speaker configurations. Therefore, the directional benefit data for each participant of this experiment were calculated as the difference score based on 48 HINT lists (1 list per condition).

Experiment 3

Two different listening environments were chosen for testing in this investigation: an anechoic chamber (minimal reverberation) and a classroom (average reverberation time = 0.670 msec). Within the two environments, a diffuse soundfield system was used with four loudspeaker pairs (eight loudspeaker cubes total) arranged around a center point (Veit and Sander, 1985). The center point was measured at 42 inches (1.07 m) from the front main loudspeaker. The primary loudspeaker was set between the two front loudspeaker pairs.

The eight loudspeakers were angled facing toward the participant. The noise signal was routed through the eight loudspeakers, whereas the main test signal was passed through the loudspeaker at 0° azimuth and elevation. The order of hearing aid conditions and HINT list presentation was randomized within and across participants. Overall, in two different sessions, each participant was tested with two different hearing aid fittings (directional and omnidirectional) in two different environments. Therefore, the directional benefit data for each participant of this experiment were calculated as the difference score based on eight HINT lists (two lists per condition).

RESULTS AND DISCUSSION

For the purposes of the present analysis, we collapsed the directional hearing aid results across different models and speaker configurations to obtain a single, average, directional benefit value for each participant in each of the three experiments. We believed that these averaged data for each individual, collected using groups of 44, 26, and 10 participants, provided a relatively stable measure of directional benefit and sufficient data to elicit a predictive relationship, if one existed. This pooling of the data for each participant was performed to examine the relationship between the three audiologic factors (threshold slope, high-frequency average threshold, omnidirectional speech intelligibility performance) and directional benefit. Due to the possibility of an interaction between the experimental parameters used, a separate analysis for each of the three investigations was performed and plotted on the same graph. Given the varied experimental factors across these three investigations, a similar predictive trend across all three studies is assumed to provide strong evidence for the generalization of these data to prediction of directional hearing aid benefit in near-field listening environments. The possible relationship between each of the predictive factors and directional benefit was examined using Pearson's r correlation analysis.

Pooling data across hearing aids and test paradigms resulted in each participant having an overall directional benefit "score." This directional benefit score was computed by subtracting the average HINT threshold across all directional conditions from the average HINT threshold across all omnidirectional conditions specific to each investigation. Average directional benefit ranged from 0.3 to 5.5 dB in experiment 1, from 2.9 to 7.6 dB in experiment 2, and from 0.5 to 5.5 dB in experiment 3. The corresponding directional benefit ranges for these three experiments exceed the 95 percent confidence interval of 1.86 dB for 20 modified HINT sentences (two lists) reported previously (Ricketts and Dhar, 1999). Since these benefit scores were based on 8 to 48 HINT lists (depending on the experiment), rather than 2, these ranges appear not only to represent statistically significant differences but also reflect clinically significant differences in directional benefit.

Slope of Hearing Loss

The audiometric slope of each participant in this investigation was calculated as the difference between the threshold measured at 500 Hz and the average of the thresholds measured at 2000, 3000, and 4000 Hz divided by 2.5 octaves (separation between 500 and 3000 Hz). Using this method, the resulting audiometric slope of the participants varied considerably, from 18 dB/octave to −2.7 dB/octave across the three experiments. These audiometric slope values were then plotted against average directional benefit for each of the three experiments, as shown in Figure 2. Correlation analysis revealed no significant relationship between audiometric slope and directional benefit: experiment 1 ($r = -.18$, $p < .24$), experiment 2 ($r = -.03$, $p < .86$), and experiment 3 ($r = .31$, $p < .38$). That is, individuals with relatively flat audiograms showed the same directional benefit as those with steeply sloping audiograms across all three experiments. A trend of slightly decreasing benefit with increasing threshold slope is evident, on average, across all three experiments. However, the predictive relationship for any individual listener is weak. For example, the seven individual listeners in experiment 1 with threshold slopes of between 0 and 5 dB/octave (the lower limit) exhibited directional benefit ranging from 1 to 3.5 dB, whereas the seven listeners in this same experiment with threshold slopes ranging from 14 to 18 dB/octave (the upper limit) exhibited a similar range of directional benefit from 1.3 to 3.1 dB. In contrast, two listeners in this same experiment with threshold slopes near 10 dB/octave (9 and 11 dB/octave) obtained average directional benefit values greater than 5 dB.

High-Frequency Hearing Loss

Using the pure-tone thresholds for 2000, 3000, and 4000 Hz for both ears, we calculated a high-frequency average for each participant. These average values ranged from 36 to 77.5 dB HL across the three experiments. Figure 3 shows the relationship between high-frequency hearing loss and directional benefit for each of the three experiments. No significant correlation was observed: experiment 1, $r = -.03$, $p < .82$;

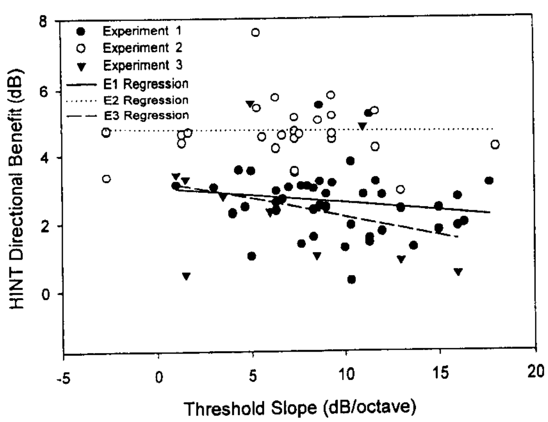

Figure 2 Mean directional benefit (difference between omnidirectional and directional conditions) as measured by the HINT plotted against the slope of the audiometric configuration (dB/octave) for each of the three experiments. Linear regressions of these data are also plotted.

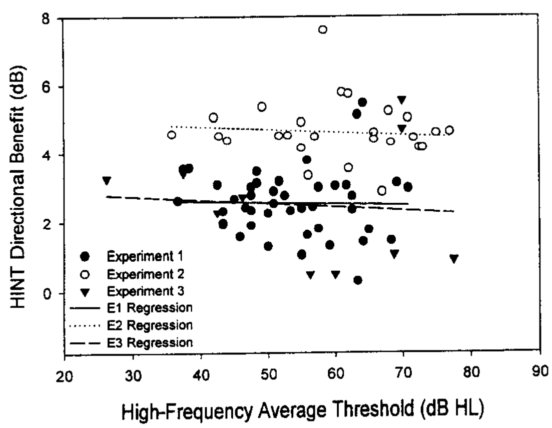

Figure 3 Mean directional benefit (difference between omnidirectional and directional conditions) as measured by the HINT plotted against average high-frequency threshold (2000, 3000, and 4000 Hz) for each of the three experiments. Linear regressions of these data are also plotted.

experiment 2, $r = -.11$, $p < .59$; and experiment 3, $r = -.09$, $p < .79$. That is, there was no significant reduction in directional benefit when greater high-frequency hearing loss was present; observe that 19 participants had high-frequency averages greater than 65 dB HL.

The lack of a significant relationship was somewhat surprising given data such as that of Turner and Cummings (1999). For example, the seven individual listeners in experiment 1 with high-frequency thresholds between 35 and 45 dB HL (the lower limit) obtained average directional benefit of 2.7 dB, and the eight listeners in this same experiment with high-frequency thresholds between 63 and 71 dB HL (the upper limit) obtained essentially the same average benefit (2.6 dB). Moreover, the individuals in all three experiments exhibiting the most directional benefit all had high-frequency average thresholds of greater than 58 dB HL.

Omnidirectional Speech Test Results

The third patient-specific factor that we considered was the participant's average HINT threshold for omnidirectional hearing aid conditions. We questioned if a listener who did very poorly for a speech-in-noise test with omnidirectional amplification would be able to take advantage of the benefits of directional microphone technology. The average omnidirectional HINT thresholds ranged from a high of –2.5 to a low of 12.3 dB across the three experiments. The relationship between omnidirectional scores and directional benefit is displayed in Figure 4.

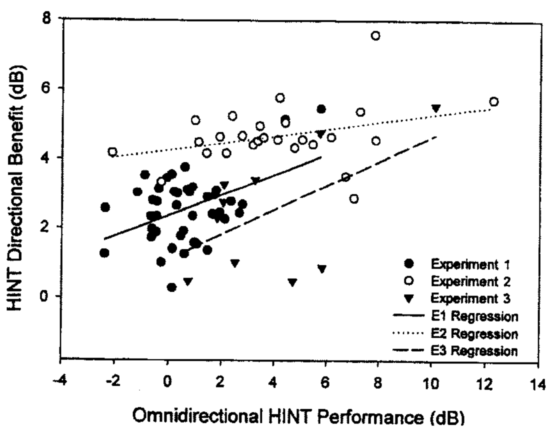

Figure 4 Mean directional benefit (difference between omnidirectional and directional fittings) as measured by the HINT plotted against omnidirectional HINT thresholds for each of the three experiments. Linear regressions of these data are also plotted.

As shown, there was either a significant relationship between the participants' omnidirectional HINT performance and the benefit they derived from the directional microphone mode (experiment 1: $r = .47$, $p < .002$) or a nonsignificant trend toward this relationship (experiment 2: $r = .33$, $p < .09$ and experiment 3: $r = .55$, $p < .09$), depending on the study. These combined results suggest that, on average, listeners with the poorest omnidirectional performance may have the greatest potential for taking advantage of directional hearing aid technology.

As with the other parameters, however, the predictive relationship for any individual listener still appears somewhat weak. For example, the eight individual listeners in experiment 1 with omnidirectional HINT thresholds of between –2.4 and –0.5 (the upper limit) exhibited directional benefit ranging from 1.2 and 3.5 dB, whereas the eight listeners in this same experiment with omnidirectional HINT thresholds of between 1.8 and 5.8 (the lower limit) exhibited the higher, but broad, range of directional benefit of 2.4 to 5.4 dB. It is noteworthy that, although the trend of increasing directional benefit with decreasing omnidirectional HINT thresholds is evident in this analysis of the extreme groups, the range of directional benefit obtained by these listeners overlapped. However, it is also of note that the single individual in each experiment who obtained the greatest average directional benefit also exhibited the poorest omnidirectional performance.

SUMMARY AND CONCLUSIONS

We compared three different patient-specific variables that could possibly influence the benefit that a listener would obtain with directional microphone hearing aids. The 80 participants across three experiments provided a heterogeneous sampling for each of the variables, and the averaging across multiple experimental parameters within each experiment provided a stable measure of directional benefit across a number of test conditions. In summary, the results of each of these three studies revealed no significant predictive relationship between the slope of the audiometric configuration or high-frequency hearing loss and the measured SNR benefit obtained with directional microphone amplification. The similarity in the relationships between these two factors and average directional benefit measured across all three studies further strengthens the argument that the slope of the audiometric configuration and high-frequency hearing loss cannot be used to predict directional benefit on an individual basis, at least under the participant constraints set forth by these three experiments. Specifically, no individual in any of these experiments exhibited a hearing threshold at 3000 Hz greater than 80 dB HL. Therefore, these conclusions cannot be applied to listeners with more severe-to-profound hearing losses.

Somewhat surprisingly, omnidirectional hearing aid performance did appear to be a reasonable predictor of directional benefit. Although there was a fair amount of variability across individuals, on average, those hearing aid wearers with the poorest omnidirectional performance received the greatest directional benefit. It is noteworthy, however, that even among those listeners with the best omnidirectional performance (better than 0-dB HINT thresholds), a significant average directional benefit of 2.6 dB was measured across listeners and experiments. These data are in good agreement with other findings (Killion et al, 1998). However, these data do not support audiometric configuration as the main factor responsible for the relationship between SNR loss and directional benefit, as suggested previously (Killion and Christensen, 1998).

Despite some trends present in the group data, the variability of individual subject data leads us to conclude that until contrary evidence emerges, clinicians should consider the use of directional amplification for patients regardless of audiogram slope, degree of high-frequency hearing loss, or omnidirectional HINT threshold. Further, it appears that those listeners who have the poorest performance in noisy environments may receive the greatest benefit from directional technology.

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