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Recognition of Speech in Noise
with Hearing Aids Using Dual-Microphones

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Introduction

Directional microphones have been available in hearing aids for over twenty years. During this time considerable research has been reported examining the benefits of directional microphones. Several early studies showed an improvement in speech recognition using a directional microphone when speech was presented at 0° azimuth and noise at 180° azimuth (Lentz, 1972; Frank and Gooden, 1973; Sung etal., *1975).* Nielsen (1973) performed one of the first clinical and field trials comparing hearing aids with omnidirectional and directional microphones. In this study, performance was significantly better with the directional microphone when measured in the sound suite, but the advantage disappeared when the hearing aids were worn in the field.

A number of studies have reported on the limited benefits of directional microphones. Studebaker, Cox and Formby (1980) reported that the advantages of a directional microphone were greatest under anechoic conditions and the advantage decreased as reverberation time increased. Madison and Hawkins (1983), using subjects with normal hearing, reported a directional advantage of 10.7 dB in improved signal to noise ratio (SNR) in an anechoic room and the advantage decreased to 3.4 dB under more reverberant conditions (0.6 seconds). Hawkins and Yacullo (1984) reported a directional advantage of improved SNRs ratios of 3-4 dB for conditions when speech originated from the front and noise originate from the back in rooms with relatively short reverberation times (0.3 and 0.6 seconds). This advantage decreased as reverberation increased (1.2 seconds) and as speech and noise originated from diffuse fields.

In the past, the directional microphone was a single microphone with a front and rear port which typically created a 58 microsecond delay in the sound reaching the microphone diaphragm from the rear port (Skinner, 1988). Despite the improved SNR provided by hearing aids with directional microphones, Leeuw and Dreschler (1991) concluded that in order for hearing impaired subjects to realize an improvement in their listening situations, a better directional microphone needed to be developed. In the past several years a number of microphone designs have been explored to improve directionality. One improvement has been based on array techniques (Bilsen et al., 1993; Stadler and Rabinowitz, 1993; Kates, 1993). One study reported an average improvement in SNR of *7.5* dB using a fixed array directional microphone measured on KEMAR in a diffuse sound field (Soede et al., 1993a). In a follow-up study Soede et al., (1993b) reported an average improvement in speech reception thresholds of approximately 7.0 dB. While these studies report an improvement in directionality in comparison to traditional directional microphones, these microphone arrays require a large spatial separation and have been built only as research prototypes.

Recently, Phonak introduced a programmable behind-the-ear hearing aid that uses dual-microphone technology (PiCS Audio Zoom). This hearing aid is digitally programmable and allows selective use of the dual-microphone array for directional microphone operation, or an omnidirectional microphone via a hand-held remote control. In addition, the user may select from three different electroacoustic settings for distinct listening situations. The “basic” frequency response may be programmed to match the NAL-R prescriptive formula (Byrne and Dillon, 1986) or other fitting formulae. The two remaining memories may be programmed with “comfort programs” algorithms and the directional or omnidirectional microphone mode for optimal listening in various acoustic environments.

The primary objectives of the present study were to determine if:

1. significant differences were present in signal-to-noise ratio when the dual-microphones of the Audio Zoom was active in comparison to when only the omnidirectional microphone was active,
2. significant differences were present in the mean benefit scores for the subscales of the Profile of Hearing Aid Benefit (PHAB) or Abbreviated Profile of Hearing Aid Benefit (APHAB) for the Audio Zoom hearing aid in comparison to the mean benefit scores reported for experienced hearing aid users as reported by Cox, Gilmore and Alexander (1991), Cox (1994) and Cox and Alexander *(1995),* and
3. if subjects reported differences in performance between the Audio Zoom hearing aids and their current hearing aids after using the Audio Zoom hearing aids for thirty days.

Methods

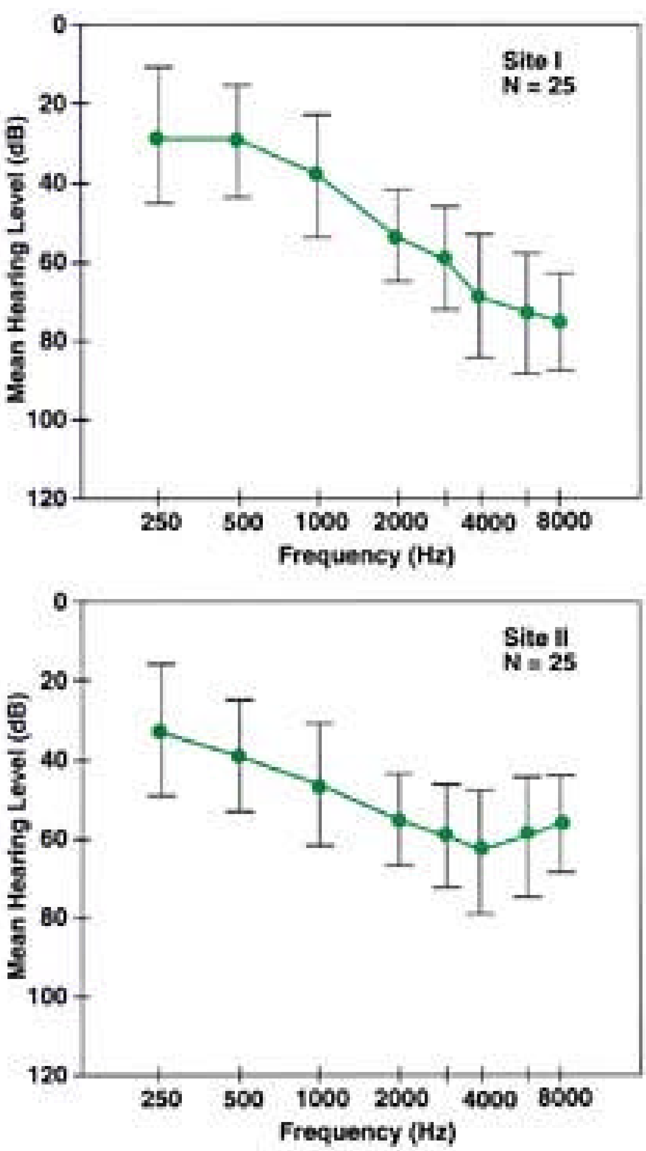
Subjects:
Twenty-five adult hearing aid users were included as participants at each of two sites. Site I was the Hearing Laboratory at Washington University School of Medicine in St. Louis, Missouri and Site II was the Hearing Laboratory at the Mayo Clinic in Rochester, Minnesota. At Site I there were 13 males and 12 females with a mean age of 68.2 years and a range from 30 to 82 years. At Site II, there were 14 males and 11 females with a mean age of 53.2 years and a range from 20 to 83 years. All subjects at Site I had prior experience with binaural amplification (mean years of experience = *5.1* years). At Site II, all subjects had prior experience with amplification

(mean years of experience = *5.7* years). Eighteen subjects wore monaural amplification while the remaining seven subjects wore binaural amplification.

Air and bone conduction pure-tone thresholds (ANSI-1989) were measured at 250-8000 Hz in the conventional manner (ASHA- 1978) and the results indicated the presence of sensorineural hearing loss. See Figure 1 for the mean air conduction thresholds at Site I (upper panel) and Site II (lower panel). In addition, immittance audiometry indicated normal middle ear function.

Procedure

Fig. 1: Mean air conduction thresholds (dBHL) for the 25 subjects at Site I (upper panel) and Site II (lower panel). Also included is +/- 1 standard deviation.



A. Objective Measures

Hearing aid fitting

Each subject was evaluated under four different combinations of electroacoustic settings on the hearing aids. These conditions were: 1) basic NAL-R frequency response with omnidirectional microphone; 2) basic NAL-R frequency response with dual-microphone directional microphone; 3) "party" frequency response with omnidirectional microphone; and 4) "party" frequency response with dual-microphone directional microphone. These four conditions were counterbalanced to minimize order effects.

The "party" frequency response is one of many "comfort" programs available on the hearing aid to enhance listening in backgrounds of various noise sources (Baechler and Vonlanthen, 1994). Each "comfort" program is designed to maximize the Articulation Index (Al) and/or listening comfort in a target noise source through adjustments of the compression variables (kneepoint, time constants, etc.), changes to the low, mid and high filters, and overall SSPL9O and gain levels of the hearing aid. In this case, the design of the "party" frequency response assumed a high intensity, broadband, multi-babble noise as the noise source.

For each subject, real-ear measurements were made using a Frye 6500 system, to match the real-ear insertion response (REIR) to NAL-R (Byrne and Dillon, 1986) prescribed gain for condition 1 (basic frequency response with omnidirectional microphone). With the probe and reference microphones located in the standard positions and the loudspeaker placed at 00 azimuth, the REIR was matched as closely as possible to the prescribed NAL-R target using a speech-weighted composite noise as the signal. In greater than 80% of the 100 ears, the measured REIR came to within *5* dB of the prescribed REIR up to 3000-4000 Hz. Subsequently, binaural balance between the two hearing aids was pursued by utilizing the loudness balancing procedure of the PiCS software. For each subject, this completed the fundamental settings for condition 1, upon which the settings for conditions 2-4 were based.

Measuring speech in noise using the HINT

To measure the benefit obtained from the four experimental conditions, the Hearing in Noise Test (HINT) (Nilsson et al., 1991; Nilsson et al., 1992; Nilsson et al.,1993) was selected for this study.

The HINT consists of 250 sentences (25 lists of 10 sentences per list) read by a male speaker. The sentences are of approximately equal length (six to eight syllables) and difficulty (first grade reading level). The HINT estimates the signal-to-noise ratio (SNR) at which the sentences, embedded in noise, can be repeated correctly 50% of the time. This type of measure is useful because it enables accurate, reliable estimation of speech recognition in noise for context-rich speech materials. Furthermore, the HINT materials have been digitally recorded for standardized presentation.

In this study, the sentences were presented at 00 azimuth and the noise, which is temporally and spectrally matched to the sentences, was presented at 1800 azimuth. The subject was seated approximately 1.1 meters equidistant from two loudspeakers in a 8’4” by 9’ (Site I) or 10’ x 8’ (Site II) double-walled sound suite. Neither sound suite was anechoic and reverberation time was not measured. However, Nielsen and Ludvigsen (1978), Studebaker, Cox and Formby (1980) and Madison and Hawkins (1983) report reverberation times of between 0.1 to 0.6 seconds in audiometric sound suites of similar sizes. The sentences and competing noise were presented through a GrasonStadler 16 (Site I) or Grason-Stadler 10 (Site II) clinical audiometer via a Sony DTC-690 Digital Audio Tape (DAT) deck.

The administration of the HINT requires two lists to be presented (20 sentences) for each experimental condition. The first sentence was presented 10 dB below the attenuator setting necessary for the noise to be presented at 65 dB(A). The first sentence was presented repeatedly, increasing the level of the presentation by 4 dB, until repeated correctly by the subject. Subsequently, the intensity level was decreased by 4 dB and the second sentence presented. Stimulus level was raised (incorrect response) or lowered (correct response) by 4 dB after the subject’s response to the second, third and fourth sentences. The step size was reduced to 2 dB after the fourth sentence, and a simple up-down stepping rule was continued for the remaining sixteen sentences. The calculation of the signal-to-noise ratio (SNR) necessary for 50% sentence recognition was based on averaging the presentation levels of sentences five through twenty, plus the intensity of a twenty-first presentation (based on the accuracy of the subject’s response to sentence #20).

Upon completing the measurement of the SNR of the HINT test for the four experimental conditions, the basic/omnidirectional program was loaded into Memory #1. The basic/directional program was loaded into Memory #2 and the party/directional program was programmed into Memory #3. Patients were counseled on the use and care of the hearing aids, earmolds and remote control and wore the hearing aids for four weeks. To obtain a subjective measure of the perceived benefits of the Audio Zoom hearing aids the subjects were asked to complete Form B of the Profile of Hearing Aid Benefit (PHAB) at Site land Form A of the Abbreviated Profile of Hearing Aid Benefit (APHAB) at Site II.

B. Subjective Evaluation

Profile of Hearing Aid Benefit (Site I)

The Profile of Hearing Aid Benefit (PHAB) is a subjective assessment scale which reportedly measures perceived benefit from amplification (Cox and Gilmore, 1990; Cox et al., 1991; Cox and Rivera, 1992). The PHAB is a 66-item inventory. Each item is a statement and the subject indicates the proportion of time the statement is true, using a seven-point scale. The subject responds to each question on the basis of unaided and aided responses. Responses to the unaided segment were obtained prior to the fitting of the hearing aids, while responses to the aided segment were obtained at the end of the trial period. Hearing aid ‘benefit’ (in percent) is defined as the difference between the unaided and aided scores. The PHAB is scored for seven subscales which include: 1) Familiar Talkers (FT); 2) Ease of Communication (EC); 3) Reverberation (RV); 4) Reduced Cues (RC): *5)* Background Noise (BN); 6) Aversiveness of Sounds (AV); and 7) Distortion of Sounds (DS).

Abbreviated Profile of Hearing Aid Benefit (Site II)

The Abbreviated Profile of Hearing Aid Benefit (APHAB) is a 24-item inventory modified from the original PHAB (Cox and Alexander, 1995). The APHAB is scored for four subscales which include: 1) Ease of Communication (EC); 2) Reverberation (RV); 3) Background Noise (BN); and 4) Aversiveness of Sounds (AV).

Comparison with Present Hearing Aids

In addition, the subjects at Site I were asked to report if they felt that the perceived benefit provided by the Audio Zoom was 1) significantly better; 2) better; 3) equal to; 4) poorer or *5)* significantly poorer than the perceived benefit of their current hearing aids after they had the opportunity to wear the hearing aids for thirty days.

Results

HINT Scores

Tables 1 and 2 (see appendix) report the individual SNR necessary to achieve 50% intelligibility on the HINT test for the four experimental conditions (Columns A-D) for Site I and Site II, respectively. Also reported are the improved SNRs for the effects of the directional microphone with the basic frequency response (Column B minus Column A- Figure 2), the effects of the “party” comfort program (Column C minus Column A- Figure 3), and combined benefit of the “party” response and the directional microphone over the basic response/omnidirectional microphone (Column D minus Column A - Figure 4). The bottom of Tables 1 and 2report the mean, standard deviation, minimum score and maximum score for each of the conditions. Figure 5 reports the mean and standard deviation in the improved SNR re: the basic response/ omnidirectional microphone for Site I (upper panel) and Site II (lower panel).

Fig. 2: *Signal-to-Noise Ratio (SNR) for the directional microphone condition relative to the SNR obtainedfor the basic omnidirectional condition. The upperpanel reports the results from Site I and the lower panel reports the results from Site IL*

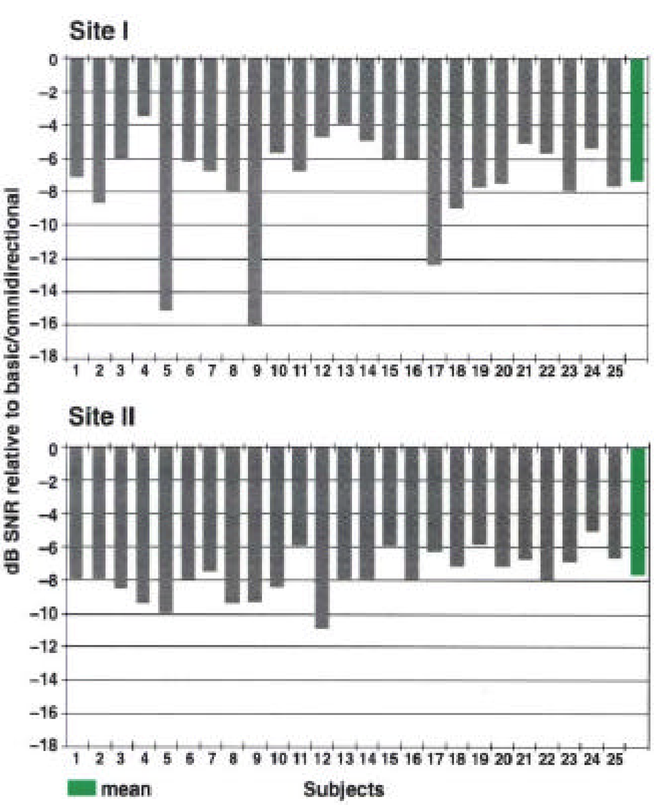


Fig. 3: *Signal-to-Noise Ratio (SNR) for the party condition relative to the SNR obtained for the basic condition. The upper panel reports the results from Site I and the lower panel reports the results from Site IL*

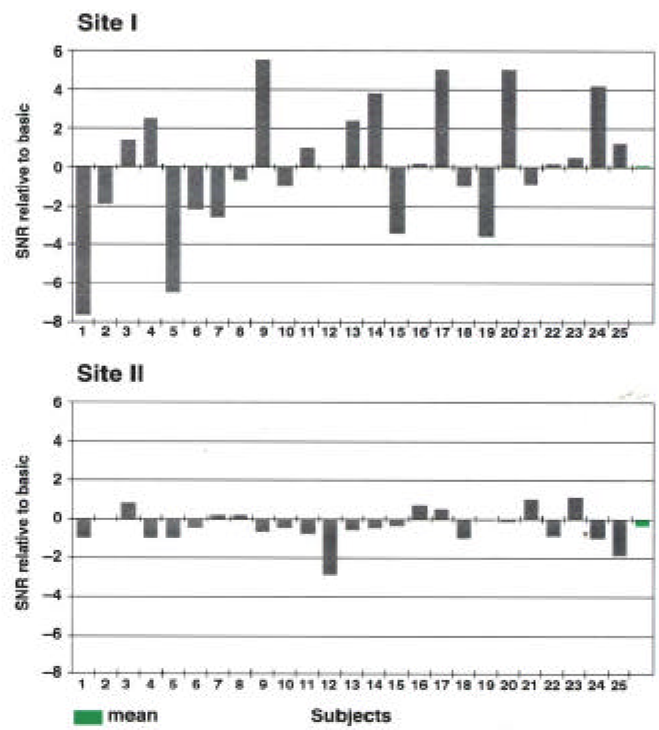
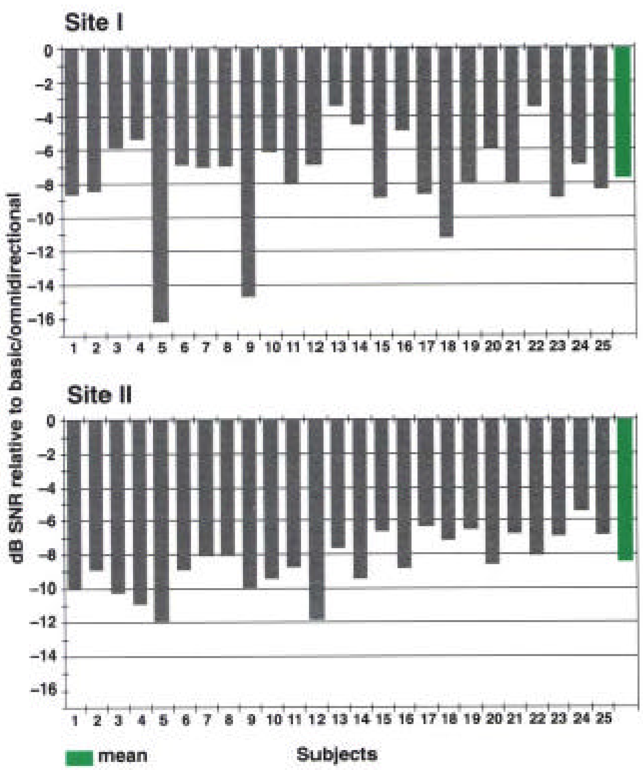


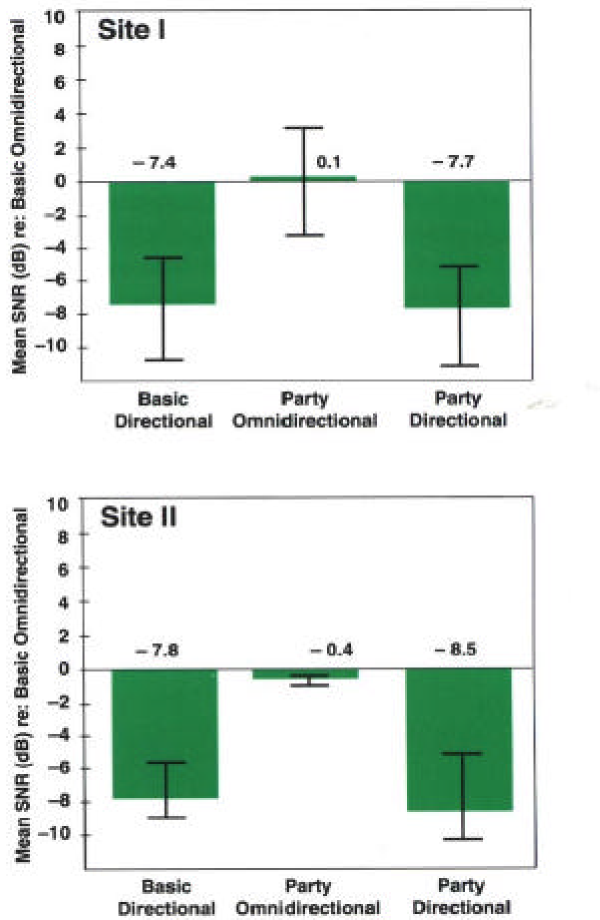
Fig. 4: *Signal-to-Noise Ratio (SNR) for the combined party and directional condition relative to the SNR obtainedfor the basic-omnidirectional condition. The upper panel reports the results from Site land the lower panel reports the results from Site IL*



A one-way repeated measures ANOVA for the results at Site I revealed that significant differences (F=86. 13; df=3,72; p< 0.000 1) were present across the mean performance for the four experimental conditions. A post-hoc Analysis of Variance of Contrast Variables revealed significant differences existed between means for 1) basic/ omni (mean = 0.0 dB) and basic/directional (mean= -7.4 dB) (F=68.65; df=1,24; p<.Ol), 2) basic/omni (mean= 0.0 dB) and party/directional (mean= -7.7 dB) (F=66.3; df=1,24; p<.Ol), 3) party/omni (mean= 0.1 dB) and party/ directional (mean= -7.7 dB) (F= 103.26; df=1,24; p<.O 1), and 4) party/omni (mean= 0.1 dB) and basic/directional (mean= -7.4 dB) (F=68.65; df=1,24; p<.Ol). The mean differences between the basic/omni and party/omni conditions and the basic/directional and party/directional conditions were not significantly different.

A one-way repeated measures ANOVA for the results at Site II revealed that significant differences (F=66.38; df=3,72; p< 0.000 1) were present across the mean performance for the four experimental conditions. Post-hoc comparisons, using the Tukey HSD method (HSD= 2.11) revealed significant differences existed between means for 1) basic/omni (mean= -0.2 dB) and basic/directional (mean= -8.0 dB), 2) basic/omni (mean= -0.2 dB) and party/directional (mean= -8.8 dB), 3) party/omni (mean= -0.7 dB) and party/directional (mean= -8.8 dB), and 4) party/omni (mean= -0.7 dB) and basic/directional (mean= -8.0 dB).

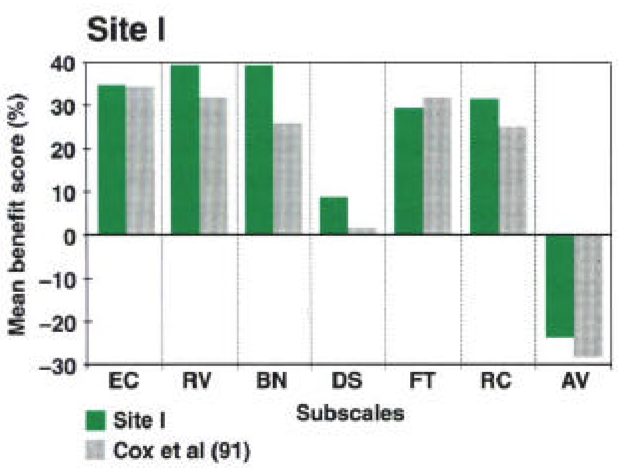
Fig. 5: *Mean and standard deviation of the improved Signal-to-Noise Ratio for the three experimental conditions re: the basic frequency response /omnidirectional microphone. The upper panel reports the results from Site land the lower panel reports the results from Site IL*



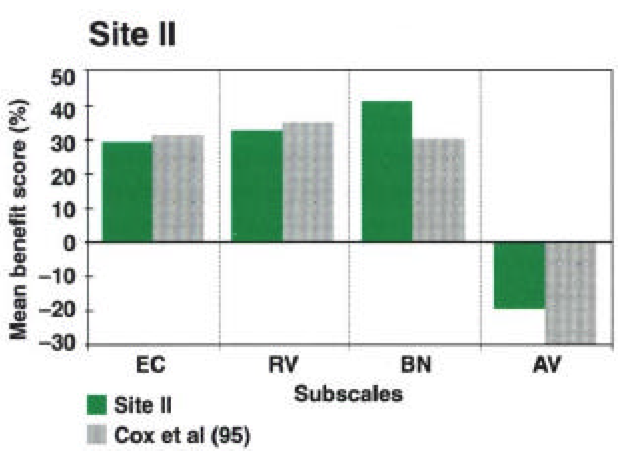
Profile of Hearing Aid Benefit (Site I)

The upper graph in Figure 6 reports the average PHAB benefit scores for the seven subscales. Positive scores suggest benefit from amplification, while a negative score reflects the subject's perception that aided performance was poorer than unaided performance. Paired t-tests on the mean benefit scores reported in Figure 6 revealed that the mean benefit scores for the BN-Background Noise (tscore= 3.97; p < .01) and RC- Reduced Cues (t-score= 2.31; p < .05) subscales for the present study were significantly better than the mean benefit scores reported by Cox et al., (1991). The paired t-tests for the remaining subscales revealed that the mean differences between the current study and those reported by Cox et al., (1991) were not significantly different from each other. These data suggest that the directional microphone used by the Audio Zoom provided greater benefit in noisy listening environments and in situations with reduced visual cues in comparison to the benefits reported by experienced users of linear amplification (Cox et al., 1991; Cox, 1994).

Fig. *6: Mean benefit scores for the PHAB (upper graph) andAPHAB (lower graph)forSites land IL Also included are the mean benefit scores reported for the PHAB (Cox et al., 1991) and APHAB (Cox and Alexander, 1995).*



	EC	RV	BN	DS	FT	RC	AV
Present Study	34.6	39.5	39.1	8.4	29.5	31.9	−23.8
Cox et al. (1991)	34.3	32.1	25.9	1.5	31.7	24.9	−28.5



	EC	RV	BN	AV
Present Study	29.2	32.5	41	−19.6
Cox et al. (1995)	31	35	30	−30

Abbreviated Profile of Hearing Aid Benefit (Site II)

The lower graph in Figure 6 reports the average APHAB benefit scores for the four subscales of the APHAB for Site II. Paired t-tests on the mean benefit scores reported in Figure 6 revealed that the mean benefit scores for the BN- Background Noise (t-score= 2.65; p < .01) and AVAversiveness of Sound (t-score= 2.22; p < .05) subscales were significantly better than the mean benefit scores reported by Cox (1994) and Cox and Alexander (1995) reported for experienced users of linear amplification. These data suggest that the directional microphone used by the Audio Zoom provided substantial benefit in noisy listening situations, and also fared better (on average) than linear (peak clipping) amplification for preventing aversive sounds from becoming uncomfortable.

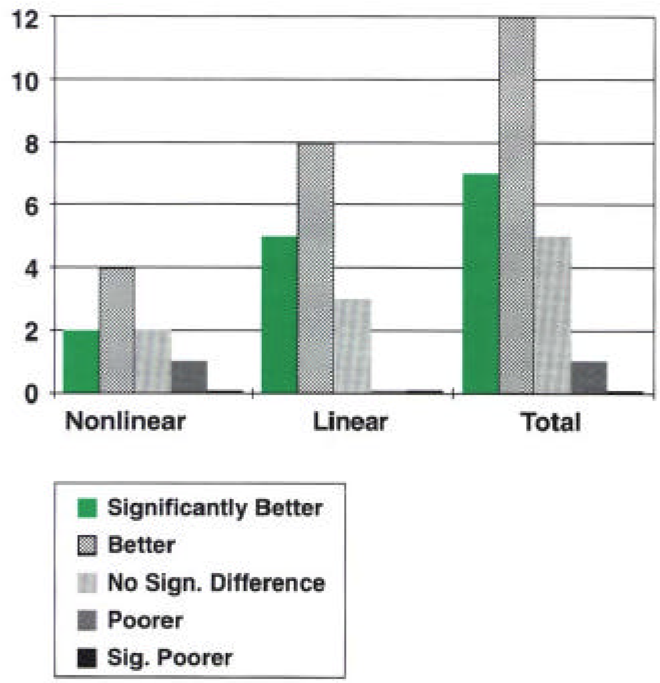
Comparison with current hearing aids (Site I)

Following are the responses to the question which asked the 25 subjects at Site Ito report on their perceived benefit of the Audio Zoom with dual-microphone technology (Memory 2 or 3) in comparison to their current hearing aids at the conclusion of the 30 day trial period. It is important to note that 22 of the 25 users current hearing aids were fit by two of the authors (MV or LP) and are known to be fitted appropriately. The REIR measures for the re-maining three subjects revealed that the measured REIR was reasonably close to the prescribed NAL-R.

Seven subjects (2, 7, 9, 11, 14, 19, and 20) reported that the performance of the Audio Zoom hearing aid was significantly better than their own hearing aids. Twelve subjects (3, 6, 10, 12, 13, 16, 18, 21, 22, 23, 24, and 25) reported that the performance of the Audio Zoom was better than the performance of their hearing aids. Five subjects (4, *5*, 8, 15 and 17) commented that the performance of the Audio Zoom was similar to their own hearing aids. Two of these subjects (8 and 15), however, added that the performance of the Audio Zoom was similar to their own hearing aids "in quiet", but better than their own hearing aids in noise . One subject (1) reported that the Audio Zoom was poorer than his own hearing aids. Figure 7 summarizes the frequency at which each rating category was assigned as a function of the class of hearing aids (linear versus non-linear) that the subjects wore. Both programmable and conventional hearing aids were included in the comparison. Six of 9 subjects who used nonlinear hearing aids, and 13 of 16 subjects who used linear hearing aids rated the performance of the Audio Zoom to be "better" or "significantly better" than their own hearing aids. In all 19 out of 25 subjects (or 76%) preferred the Audio Zoom hearing aids over their own hearing aids. If one includes the two subjects (8, 15) who rated the Audio

Zoom as better in noise but not in quiet, 21 subjects, or 84% of subjects preferred the Audio Zoom over their own hearing aids. This was statistically significant at the p= 0.01 level (Binomial test, SPSS, 1988).

Fig. 7: *Users preference for the performance of Audio Zoom in noise compared to the performance of their current hearing aids (Site I).*



Discussion

The average improvement reported in this study (7.4 to 7.7 dB for Site I and 7.8 to 8.5 dB for Site II) is nearly double the 3-4 dB improvement in SNR reported by Madison and Hawkins (1983) and Hawkins and Yacullo (1984) when using a single directional microphone with front and rear ports. There are several reasons which may account for the significant improvement in SNR reported in this study when compared to the results reported in the past.

First, the effectiveness of a directional microphone is determined, in part, by the difference in amplification between the front (00) and the back (1800). This is referred to as the front-to-back ratio (FBR) and increased attenuation of the noise source from the back results in improved noise suppression. The FBR for the directional microphone used in the Madison and Hawkins (1983) study revealed FBRs of approximately 8, 13, 12, 10 and 2 dB at 500, 1000, 2000, 3000 and 4000 Hz, respectively. The FBR for the dual microphones used in the present study is reported by the manufacturer to be approximately 27, 20, 20, 20 and 12 dB for the same frequencies. Clearly, the FBRs for the dual-microphone provides significantly greater attenuation of signals arriving from the rear. In addition, the effectiveness of the dual-microphone extends to a broader frequency range than the directional microphone used in the Madison and Hawkins (1983) study. Mueller and Johnson (1979) reported improved speech recognition in noise for the Synthetic Sentence Identification (SSI) test as the FBR reported at 1000 Hz, was increased from 6-20 dB. Along the same line, the hearing aid used in this study is reported to possess higher directivity (Baechler & Vonlanthen, 1995).

The Directivity Index (DI), measured across frequency and expressed in dB, is a way to measure the directional properties of an acoustic system (e.g., ear canal., microphone, etc.) in a diffuse field. When applied to hearing aid microphone systems, the DI can be taken as the amount of attenuation that the hearing aid microphone system achieves in the diffuse sound field over that achieved with an omnidirectional microphone in a BTE case worn over the ear of a mannequin. A DI of 0 dB would suggest that the hearing aid microphone system achieves the same extent of attenuation as an omnidirectional microphone worn over the ear. The higher the DI, the more directional the hearing aid microphone system. Well designed directional microphones yield aDI of approximately 2-3 dB up to 2000 Hz and 0 dB at 4000 Hz. The PiCS Audio Zoom hearing aid yielded a DI of 4 dB up to 2000 Hz and 2.5 dB at 4000 Hz (Baechler & Vonlanthen, 1995). These differences may account for the higher SNR reported in this study.

The difference is in the type of material used between this study and that of Madison and Hawkins (1983) and Hawkins and Yacullo (1984). This study used sentence material as the stimulus, whereas the other two studies used the NU-6 monosyllabic word lists. Meaningful sentence material used in the HINT, because of its rich-contextual cues, may allow easier identification and yield a steeper slope on the performance-intensity (P-I) function than monosyllabic words. This suggests that for a given value of SNR enhancement, the percentage change in intelligibility may be higher for sentence materials than for monosyllabic words. It does not suggest, however, that the magnitude of SNR improvement seen in this study would decrease if monosyllabic words were used instead. Considering that daily speech communication occurs in a context-rich environment, the choice of sentence materials in this study may reflect more closely the real-world potential benefit of this directional microphone system in optimal noisy situations.

The results reported in Tables 1 and 2 and Figures 2,4

&5 reveal that the addition of the dual-microphone provided significant improvements for both the basic and party frequency responses, in terms of SNRs by an average of 7.4 to 8.5 dB at Sites I and II, respectively (Columns B-A and D-A). The improvement was as little as 3.5 dB and as great as 16.1 dB across the 50 subjects. Soli and Nilsson (1994) reported that an improvement by 1 dB could lead to an improvement in speech recognition scores of 8.5% on the HINT. Although it is tempting to speculate that the observed SNR improvement could lead to 62% to 72% improvement in sentence intelligibility, it needs to be pointed out that the normative conditions used in the Soli and Nilsson (1994) study are different from the present study. Soli and Nilsson (1994) presented a binaural noise source at 45^o on each side of the subject, while in the present study a single noise source was presented at 1800. Assuming that the single noise source is a less difficult listening situation than the binaural noise source, the slope of the P-I function obtained with the single noise source will be steeper than reported for the binaural noise source. If this is a correct assumption, one would expect that the percent improvement in sentence intelligibility may exceed the 62% to 72% calculated with the 8.5%/dB slope factor. Obviously the calculation assumes that the differences are measured along the monotonic portion of the P-I function of the sentences of the HINT, and that the same P-I function can be used for normal and hearing impaired listeners. In addition, it must be pointed out hearing impaired listeners may show less change in sentence intelligibility than normal hearing listeners.

Finally, post-hoc analysis at Sites I and II indicated that the addition of the party frequency response versus the basic frequency response did not result in significant enhancement of the SNR. A separate evaluation of these algorithms is warranted before a conclusion on their effectiveness can be made. Interestingly, this finding mirrors the results reported for single-microphone adaptive frequency response hearing aids reported in the literature (Van Tasell et al., 1988; Klein, 1989; Tyler and Kuk, 1989; Fabry, 1991).

Conclusions

Fifty subjects were evaluated with the Phonak Audio Zoom under four experimental conditions at two sites. The major findings of this project showed that:

1. use of the dual-microphone of the Audio Zoom improved the SNR necessary to achieve 50% intelligibility of sentences in noise by an average of 7.4 to 7.7 dB (Site I) and 7.8 to 8.5 dB (Site II) relative to the condition where the omnidirectional microphone was active and the frequency/gain response “matched” the prescribed NAL-R. These results, however, represent optimal environment for directional microphones: a sound suite with low levels of reverberation and with speech and noise originating from separate loudspeakers positioned at ideal locations. The effects of reverberation and diffuse speech and noise will undoubtedly degrade the magnitude of the effect.

2. the “party” frequency response, under the present experimental design, did not significantly improve the mean SNR.

3. the magnitude of the PHAB benefit scores for two sub-scales (BN- Background Noise, RC - Reduced Cues) were statistically greater than the mean benefit reported by Cox et al., (1991) for users of linear amplification. The magnitude of the APHAB benefit scores for two sub-scales (BNBackground Noise, AV - Aversiveness of Sound) were statistically greater than the mean benefit reported by Cox and Alexander (1995) for users of linear amplification. For the other sub-scales of either the PHAB or APHAB, there were no significant difference between the present data and the data reported by Cox et al., (1991) for the PHAB or Cox and Alexander (1995) for the APHAB.

4. the subjects at Site I reported a general preference for the Audio Zoom when asked to compare the performance of the Audio Zoom to the performance of their current hearing aids. This finding was present for users of both linear and nonlinear hearing aids.

Appendix

Table 1: *Signal-to-noise ratio (SNR) necessary to obtain 50% intelligibility on the HINT test for the four experimental conditions (Columns A—D). Also provided are the SNR for the experimental conditions (B—D) relative to the SNR obtained for the Basic Omnidirectional condition (A) for Site I.*

Site I

Subject	Basic Omni A	Basic Directional B	Party Omni C	Party Directional D	Directional Effect B–A	Party Effect C–A	Combined Effect D–A
1	–0.4	–7.6	–8.1	–9.1	–7.2	–7.7	–8.7
2	0.6	–8.1	–1.3	–7.9	–8.7	–1.9	–8.5
3	–4.1	–10.2	–2.7	–10	–6.1	1.4	–5.9
4	–0.6	–4.1	1.9	–6	–3.5	2.5	–5.4
5	11.1	–4.1	4.6	–5.1	–15.2	–6.5	–16.2
6	1.8	–4.5	–0.4	–5.1	–6.3	–2.2	–6.9
7	–0.8	–7.6	–3.4	–7.9	–6.8	–2.6	–7.1
8	0.1	–7.9	–0.6	–6.9	–8	–0.7	–7
9	8	–8.1	13.5	–6.8	–16.1	5.5	–14.8
10	–3.6	–9.3	–4.6	–9.8	–5.7	–1	–6.2
11	–2.5	–9.3	–1.5	–10.5	–6.8	1	–8
12	–3.6	–8.4	–3.6	–10.5	–4.8	0	–6.9
13	–5.3	–9.3	–2.9	–8.8	–4	2.4	–3.5
14	0.6	–4.4	4.4	–4	–5	3.8	–4.6
15	–2.7	–8.8	–6.1	–11.6	–6.1	–3.4	–8.9
16	–4.6	–10.7	–4.4	–9.5	–6.1	0.2	–4.9
17	9.5	–2.9	14.5	0.8	–12.4	5	–8.7
18	1.1	–7.9	0.1	–10.2	–9	–1	–11.3
19	–2.2	–10	–5.8	–10.2	–7.8	–3.6	–8
20	8.8	1.3	13.8	2.7	–7.5	5	–6.1
21	–2	–7.2	–2.9	–10	–5.2	–0.9	–8
22	–2.9	–8.6	–2.7	–6.5	–5.7	0.2	–3.6
23	0.1	–7.9	0.6	–8.8	–8	0.5	–8.9
24	–5.5	–10.9	–1.3	–12.4	–5.4	4.2	–6.9
25	–0.4	–8.1	0.8	–8.8	–7.7	1.2	–8.4
Average	**0**	**–7.4**	**0.1**	**–7.7**	**–7.4**	**0.1**	**–7.7**
St. dev.	**4.5**	**2.8**	**5.9**	**3.5**	**3**	**3.3**	**2.9**
Minimum	**–5.5**	**–10.9**	**–8.1**	**–12.4**	**–3.5**	**5.5**	**–3.5**
Maximum	**11.1**	**1.3**	**14.5**	**2.7**	**–16.1**	**–7.7**	**–16.2**

Table 2: *Signal-to-noise ratio (SNR) necessary to obtain 50% intelligibility on the HINT test for the four experimental conditions (Columns A—D). Also provided are the SNR for the experimental conditions (B—D) relative to the SNR obtained for the Basic Omnidirectional condition (A)for Site IL*

Site II

Subject	Basic Omni A	Basic Directional B	Party Omni C	Party Directional D	Directional Effect B–A	Party Effect C–A	Combined Effect D–A
1	–2	–10	–3	–12	–8	–1	–10
2	0	–8	0	–9	–8	0	–9
3	–1.7	–10.3	–0.9	–12	–8.6	0.8	–10.3
4	–1	–10.5	–2	–12	–9.5	–1	–11
5	1	–9	0	–11	–10	–1	–12
6	–0.4	–8.5	–0.9	–9.4	–8.1	–0.5	–9
7	–0.5	–8	–0.3	–8.6	–7.5	0.2	–8.1
8	–1.7	–11.2	–1.5	–9.8	–9.5	0.2	–8.1
9	0.8	–8.6	0.1	–9.2	–9.4	–0.7	–10
10	0.5	–8	0	–9	–8.5	–0.5	–9.5
11	2	–4	1.2	–6.8	–6	–0.8	–8.8
12	6	–5	3.1	–5.9	–11	–2.9	–11.9
13	4	–4	3.4	–3.7	–8	–0.6	–7.7
14	4.5	–3.5	4	–5	–8	–0.5	–9.5
15	2.2	–3.8	1.8	–4.5	–6	–0.4	–6.7
16	0.5	–7.6	1.2	–8.4	–8.1	0.7	–8.9
17	–3.6	–9.9	–3.1	–10	–6.3	0.5	–6.4
18	–2.1	–9.3	–3.1	–9.3	–7.2	–1	–7.2
19	–4.5	–10.4	–4.6	–11.1	–5.9	–0.1	–6.6
20	0.1	–7.1	–0.1	–8.6	–7.2	–0.2	–8.7
21	–2.1	–8.9	–1.1	–8.9	–6.8	1	–6.8
22	1	–7.1	0.1	–7.1	–8.1	–0.9	–8.1
23	–1.1	–8.1	0	–8.1	–7	1.1	–7
24	–5.6	–10.7	–6.6	–11.1	–5.1	–1	–5.5
25	–2.2	–8.9	–4.1	–9.1	–6.7	–1.9	–6.9
Average	**–0.2**	**–8**	**–0.7**	**–8.8**	**–7.8**	**–0.4**	**–8.5**
St. Dev.	**2.7**	**2.3**	**2.5**	**2.2**	**1.4**	**0.9**	**1.7**
Minimum	**–5.6**	**–11.2**	**–6.6**	**–12**	**–5.1**	**1.1**	**–5.5**
Maximum	**6**	**–3.5**	**4**	**–3.7**	**–11**	**–2.9**	**–12**

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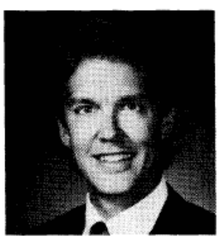

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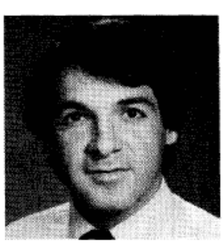

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