Performance of an Automatic Adaptive Dual-Microphone ITC Digital Hearing Aid

A clinical study of an automatic adaptive directional microphone system finds exceptional benefits are available relative to hearing in noise.

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In recent years, there has been a resurgence of interest in the use of hearing aids with a directional microphone. This type of transducer has been reported to improve the speech recognition ability of hearing-impaired patients in moderately noisy listening environments when evaluated in a sound-treated booth.1-6

Recently, the hearing aid industry incorporated the use of digital signal processing (DSP) techniques into the design of directional hearing aids and introduced hearing aids with adaptive directional microphones (ADM).7 In adaptive microphone systems, the polar pattern of the directional microphone reportedly changes in response to signals arriving at different azimuths to the listener. This switching of polar patterns is designed to ensure the best signal-to-noise ratio (SNR) for the wearer regardless of the azimuth of the noise. The wearer, however, may still need to switch from the ADM mode to the omnidirectional (omni) mode in quiet.

Recently, Widex introduced an automatic adaptive microphone system, called Locator™, in its Senso Diva digital hearing instrument. This ADM features an automatic Adaptive SNR Optimizer system that changes the polar pattern from omnidirectional to any directional pattern while compensating for the changes in low frequency response associated with each pattern. The hearing aid can be dispenser-programmed into a fixed directional mode with a hypercardioid pattern, an omnidirectional mode, or an adaptive Locator mode (default setting). The system also contains an OptiMic system that reportedly ensures identical sensitivity and phase characteristics of the dual microphones.

In contrast to other ADMs, the Locator is reportedly capable of automatically changing from an omnidirectional microphone to any of the polar patterns, depending on the listening situations. In quiet, where the overall input level is below a conversational level (the precise level is proprietary), when the noise source is wind, or when the signal source is directly from the front (ie, 0°), an omnidirectional microphone is automatically assumed. In all other listening situations, the adaptive microphone assumes a polar pattern that is designed to optimize the SNR of the listening situation. Consequently, the default mode may eliminate the wearers’ need to manually switch between omni and directional microphone modes and may ensure the best SNR in most listening situations without wearer participation. This ADM feature is available in the Senso Diva BTE, ITE, and ITC models.

Although the close microphone separation in the ITC model (about 5 mm) provides for a cosmetically pleasing hearing aid, some may question if it is large enough to result in a significant SNR improvement. Because the performance of this adaptive microphone has
neither been compared to its omnidirectional counterpart nor has its effectiveness been demonstrated when noise sources are generated from the sides and/or the back, we conducted the current study to establish the effectiveness of this automatic ADM system.

Study Method
Subjects. Twenty adults with a mild-to-moderately severe bilateral symmetrical (+/−15 dB from 250-4000 Hz) sensorineural hearing loss were included in the study. All the subjects had word recognition scores greater than 40% at their most comfortable listening level (MCL). All the subjects were experienced binaural hearing aid wearers. The average experience with the current analog omnidirectional hearing aids was slightly more than 5 years (64.5 months, s.d. = 28.7 months). At the time of the evaluation, all the subjects’ hearing aids were found to be functioning properly and providing satisfactory use to their wearers.

Subjects were not informed about the signal processing or identity of the hearing aids during the study. It is important, however, to note that in spite of all efforts to “mask” the subjects to the identity of the experimental hearing aids, the subjects obviously were not “blinded” as to which was the control condition (ie, own aids) or the test aid condition (ie, Senso Diva). Therefore, due to the Hawthorne (or “Halo”) effect, any difference in subjective performance between the subjects’ own aids and the experimental hearing aids must be viewed with caution. Subjects were offered the option to purchase the experimental aids at a reduced cost at the conclusion of the study or be provided financial compensation.

Fitting the Digital ITC Aids. Binaural Senso Diva ITC/ITE hearing aids were fit using the manufacturer’s recommended protocol. Briefly, four criteria were met. First, the faceplate of the aid could not be inserted greater than 3 mm beyond the tragus. Second, the alignment of the two microphones could not exceed 20° from the horizontal plane. Third, the sagittal deviation of the two microphones could not be greater than 20°. Finally, the two microphone openings had to be clearly visible.

Sixteen subjects were fit with ITC and four were fit with ITE models because of ear sizes. The in-situ directivity index of the ITE is identical to the ITC because of the same port separation and internal time delay. All the hearing aids were vented based on the degree of hearing loss at 500 Hz. Vent diameter was 2 mm for 30 dB HL or less, with a 0.5 mm decrease in vent diameter for every 10 dB increase in hearing loss.

The Widex fitting software (Compass version 3.1) was used to program the hearing aids following the recommended procedure. An in-situ threshold (or sensogram) was determined at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz followed by a feedback test. The initial fit was verified by using the Input-Output curve in the fitting software to assure that the predicted aided thresholds were around 20 dB HL to 2000 Hz, and at least 30-40 dB HL at 4000 Hz. The Frequency-Output graph within the software was used to ensure that the predicted in-situ output for input levels at 40 dB, 65 dB, and 90 dB SPL was within the dynamic range of the listener. These two steps ensured optimal audibility and comfort with the initial fit. Subjects wore the hearing aids for 1 week before the aids were
fine-tuned. Afterwards, subjects wore the aids for 4 weeks before returning for laboratory testing.

Testing for Unaided and Aided Thresholds. Monaural unaided and aided (own aid and Senso Diva with Locator) thresholds were obtained using warble tones at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz.

Hearing in Noise Test (HINT). The HINT was used to estimate the required speech level for 50% recognition of the test sentences in a fixed noise background. To avoid possible loudness difference between subjects’ own hearing aids and the study hearing aids, attempts were made to adjust gain on the subjects’ current aids to match the root-mean-square (RMS) output of the test aids to a 65 dB SPL speech composite signal in a HA-1 2cc coupler. The match was within ±1 dB in 33% of the cases (13/40 aids) and within ±5 dB in 85% of the cases. Attempts to match the frequency-gain response of the subjects’ own aids to the test aids were largely unsuccessful because the subjects’ own analog aids were either single- or two-band processors. This limited our ability to shape the frequency-gain response to match the test aids. The reader needs to keep this in mind when viewing any comparisons between the subjects’ own aids and the test aids.

HINT Reception Threshold for Sentences (RTS, in dB) was obtained for three loudspeaker conditions (180° [rear]; 90°+270° [right+left sides]; and 90°+180°+270° [right+left+rear]) with each loudspeaker placed at 1 meter from the subject. Four listening conditions (unaided; aided with own aids; Senso Diva [test aid] programmed in omnidirectional mode; and test aid in automatic adaptive microphone mode) were evaluated. Unaided and aided RTS for the subjects’ current aids were measured when the subject first entered the study. All 12 experimental conditions were randomly assigned to avoid order effects. In addition, no sentence list was repeated to reduce potential learning effects. An uncorrelated continuous party noise, presented at an overall level of 68 dBA recorded in a room with approximately 4-5 s reverberation time, was used as the competing noise.

Abbreviated Profile of Hearing Aid Benefit (APHAB) The APHAB\textsuperscript{10,11} is scored as four subscales: Ease of Communication (EC), Background Noise (BN), Reverberation (RV), and Aversiveness to Sounds (AV). Subjects respond to each question for unaided and aided problem scores. Responses to the unaided and aided segments for subjects’ own hearing aids were obtained prior to the fitting of the test hearing aids. Responses to the aided segment for the test aids were obtained at the end of the 4-week trial after the subjects had worn them in the automatic ADM mode. Hearing aid “benefit” (in percent) is defined as the difference between the unaided and aided problem scores.
Figure 1. Mean and soundfield thresholds (dB HL) at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz for unaided, aided-own, and aided Senso Diva Locator (test aid w/ADM). Each bar represents the mean of the right and left ears.

Results
Unaided and Aided soundfield Thresholds: Figure 1 reports the mean unaided and aided (own and test aids) soundfield thresholds at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. Because of similar findings between ears, the thresholds for the right and left ears were averaged. A repeated randomized block ANOVA revealed a significant main effect of hearing aid (F = 171.30; df = 2,239; p < 0.0001), frequency (F = 73.82; df = 3,239; p < 0.0001) and a hearing aid by frequency interaction (F = 7.85; df = 6,239; p < 0.001). Post-hoc analysis using the Tukey Honestly Significant Difference (HSD) (p < 0.05) revealed that, at each test frequency, the mean difference in the soundfield threshold between the test aid and unaided, test aid and aided-own, and aided-own and unaided was significant. The post-hoc HSD test on the hearing aid effect revealed that the mean difference between unaided and omni-own (10.2 dB) and test aid (22.2 dB) was significant. The HSD also revealed that the mean difference (11.9 dB) between the subjects’ own aids and the test aid was significant.

Figure 2. Mean Reception Threshold for Sentences (RTS in dB) on the HINT for unaided, aided-own, test aid in omnidirectional mode and test aid in ADM mode at the three loudspeaker conditions.
HINT: Figure 2 reports the mean RTS (in dB) for the unaided and three aided conditions under the three loudspeaker conditions (ie, rear, right+left, and right+left+rear). A high RTS reflects poor performance and a lower RTS reflects better performance. Figure 2 shows stable RTS performance across the three loudspeaker conditions for unaided (4.3 dB, 4.3 dB, and 4.6 dB, respectively), aided-own (2.3 dB, 2.1 dB, and 2.0 dB, respectively) and aided-Senso Diva omni (0.9 dB, 1.0 dB, and 0.6 dB, respectively) conditions. In addition, the performance of the adaptive microphone remained stable between the right+left (-4.1 dB) and right+left+rear (-3.9 dB) loudspeaker conditions.

When the loudspeaker condition changed from a single-noise source at the rear (-6.3 dB) to multiple noise sources (ie, right+left and right+left+rear) there was a mean difference of 2.2 and 2.4 dB, respectively. Thus, for 11 of the 12 experimental conditions, performance within the unaided and aided conditions did not significantly change across the three loudspeaker conditions.

Relative to the unaided condition, the aided-own condition improved the mean RTS between 2.0 dB and 2.6 dB; the test aid in omni mode improved the mean RTS between 3.3 dB and 3.9 dB; and the test aid with ADM improved the mean RTS between 8.4 dB and 10.6 dB depending on the loudspeaker condition. Relative to the aided-own condition, the test aid in omni mode improved the mean RTS between 1.1 dB and 1.3 dB, and in ADM mode improved the mean RTS between 5.8 and 8.6 dB, depending upon loudspeaker condition. Relative to the test aid in omni condition, the test aid in ADM mode improved the mean RTS between 4.5 dB and 7.2 dB depending upon loudspeaker condition.

A repeated randomized block ANOVA revealed a significant hearing aid main effect (F = 69.23; df = 3,239; p < 0.0001). The mean differences in RTS for the loudspeaker conditions effect were not significant (F = 0.60; df = 2,239; p < 0.55) and there was a lack of significant hearing aid by loudspeaker interaction (F = 0.81; df = 6,239; p < 0.56). Post-hoc analysis using the Tukey HSD test (alpha set at 0.05) showed that the mean differences in RTS between the three aided conditions and the unaided condition, collapsed across loudspeaker conditions (2.3 dB, 3.5 dB, and 9.1 dB for aided-own, test aid in omni mode, and test aid in ADM mode, respectively) were significant. In addition, the HSD revealed that the mean difference in RTS between the test aid in the ADM condition and the subjects’ own aid (6.9 dB) and the test aid in the omni condition (5.6 dB) was significant. Finally, the mean difference of 1.3 dB in RTS between the subjects’ own analog hearing aids and the test aid in omni mode was not significant.

The lack of a significant difference in hearing aid performance relative to loudspeaker condition was initially surprising because the mean performance for the test aid with ADM decreased (-6.3 dB at the rear condition to -3.9 dB at the right+left+rear condition) as the loudspeaker condition became more diffuse. As was reported earlier, it is probable that the lack of a significant “hearing aid/loudspeaker interaction” was a result of the stable performance of the unaided, aided-own, and aided Senso Diva-omni over the three loudspeaker conditions, as well as the stable performance of the adaptive microphone at the right+left and right+left+rear loudspeaker conditions. Thus, the results of the repeated ANOVA suggest that the three loudspeaker configurations did not play a significant role.
in the differences for the unaided and three aided conditions, and the automatic ADM in the test aid appears to maintain a relatively constant SNR as the noise source originates from the sides and rear of the subject.

Although statistically inappropriate for the current study, it is interesting to note that, if the experiment’s design would have been limited to measuring only differences in performance of the adaptive microphone system across the three loudspeaker conditions, a repeated ANOVA would have revealed no significant differences in adaptive microphone performance between the right+left sides compared to the right+left+rear loudspeaker conditions; however, there would be a significant difference (F = 6.35; df = 2,59; p<0.0032) between the mean RTS for the rear compared to the right+left sides (difference of 2.2 dB) and compared to the right+left+rear (difference of 2.4 dB) loudspeaker conditions.

![APHAB Scores](image)

**Figure 3.** Mean APHAB benefit scores for the EC, RV, BN and AV subscales for the subjects’ own hearing aids and the test aid in ADM mode.

APHAB: Figure 3 reports the mean APHAB benefit scores for own and Senso Diva-Locator aided conditions. Separate ANOVAs were performed for each of the four APHAB subscales. The results of the ANOVA revealed that the mean difference in the benefit scores for the EC (F = 5.22; df = 1,37; p < 0.03), BN (F = 6.72; df = 1,37; p < 0.01) and RV (F = 6.86; df = 1,37; p < 0.01) subscales obtained between the subjects’ own aids and the test aids employing the adaptive microphone system were significant. No significant difference was found for the AV subscale.

**Discussion**

Comparison to studies using similar loudspeaker configurations: There are at least two recent studies3,5 that investigated directional performance using loudspeaker conditions similar to those used in the current study. With a loudspeaker at 180° (rear condition), Ricketts5 reported a mean RTS of -5.3 dB for the Senso C9 (BTE DSP aid with a fixed hypercardioid response), while the current study reported a mean absolute RTS of -6.3 dB for the ITC/ITE Senso Diva-Locator. It is important to note that, in the Ricketts study,5 the mean RTS (-5.3 dB) represented the average of two reverberation conditions (631 ms and 1097 ms). This procedural difference, along with other possible differences—such as signal processing between the Senso C9 and Senso Diva, BTE...
versus custom ITE/ITC, type of noise (cafeteria noise vs party noise), magnitude and configuration of the hearing loss, and overall level of the noise (65 dBA versus 68 dBA)—may partly explain the 1 dB poorer performance reported in the Ricketts study compared to the results reported here.

With loudspeakers at the five side and rear ordinates (90° + 135° + 180° + 225° + 270°) and a reverberation time of 642 ms, Ricketts & Dhar reported a mean RTS of -4.1 dB for the Senso C9, while Ricketts reported a mean RTS of -3.9 dB averaged across reverberation times of 631 ms and 1,097 ms for the same BTE aid. In the current study, using a similar loudspeaker arrangement, but with minimal reverberation, the mean RTS for the Diva-Locator ITE/ITC was -3.9 dB. Thus, the results from the current study are in close agreement to those reported in the other two studies.

Comparison to studies using custom hearing aids: Many studies have reported the benefit of directional BTEs in improving the recognition of speech in noise (see Amlani for an excellent review of directional advantages). Few studies have looked at the benefits provided by directional microphones in custom products. The current study is one of a few that revealed a directional benefit (directional minus omnidirectional performance) between 4.5 dB and 5.1 dB for the two more diffuse listening conditions (ie, sides and sides+rear).

Preves et al. reported a mean directional benefit of 1.4 dB to 2.8 dB for a dual-microphone ITE. In that study, the noise (uncorrelated HINT noise fixed at 65 dB SPL) was presented from loudspeakers placed at 115° and 245°, and the frequency response for the directional mode was either unequalized or equalized to the frequency response of the omnidirectional mode. Pumford et al. reported a mean directional benefit of 3.3 dB for a dual-microphone ITE. In that study, the noise (uncorrelated HINT noise fixed at 65 dBA) was presented from loudspeakers placed at 72°+144°+216°+288°. Valente et al. in a two-site study, reported a mean directional benefit of 2.7 dB to 3.7 dB for dual-microphone ITE hearing aids when correlated HINT noise was presented from four loudspeakers at 45°+ 135°+225°+315° at an overall level of 65 dB-A. For the current study, the mean directional benefit for the 90°+180°+270° condition was 4.5 dB, despite the close (5 mm) microphone port separation used in the current ITC style hearing aid.

Aided soundfield thresholds: Aided soundfield threshold represents the softest audible sound that the wearer perceives at a fixed gain/VC setting. Thus, a hearing aid with a low compression threshold should provide greater gain for soft inputs levels (with all other electroacoustic characteristics being equal) than a hearing aid with a higher compression threshold. One of the characteristics of the Senso Diva is a compression threshold as low as 0 dB HL (approximately 8 dB, 6 dB, 7 dB, and 1 dB SPL at 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz, respectively) if the results from the feedback test are “perfect” and the pure-tone average does not exceed approximately 60 dB HL. Of the subject’s own hearing aids, the lowest compression threshold was approximately 45 dB SPL (GN ReSound ED3 and IC4). Thus, the smallest difference in compression threshold between the test aid and the subject’s own aid was approximately 37 dB SPL.
In this study, the average difference in aided soundfield thresholds between the test aids with ADM and the subjects’ own aids was 10 dB to 15 dB depending on the individual test frequencies between 500 Hz and 4000 Hz. In addition, the average difference in aided soundfield thresholds between the test aid in ADM mode and unaided performance was 24 dB to 30 dB depending on the test frequencies. The average difference between the subjects’ own aids and unaided performance was 9 dB to 20 dB at the same test frequencies.

The advantage of having a low compression threshold is that it allows the softest input signals to be more audible. Thus, if the overall output of two hearing aids were adjusted to be equal for an input of 65 dB SPL, then the hearing aid with the lower compression threshold would result in the lower aided soundfield threshold. Pascoe\textsuperscript{13}, Mueller & Killion,\textsuperscript{14} and Skinner et al.\textsuperscript{15} suggested that achieving an aided soundfield threshold of 20 dB HL may ensure that all speech cues are audible from 300 Hz to 4000 Hz for patients having a moderate to gently sloping hearing loss. As stated by Skinner et al.: “….the greater the portion of speech sounds that are audible, the greater the potential is that soft sounds will be recognized and conversation will be more fluent”\textsuperscript{15} (p. 316).

APHAB: In this study, the mean difference in benefit scores between the Locator and the subjects’ own aids were 12.4\%, 15.5\%, and 15.8\%, for the EC, BN, and RV subscales respectively. Cox\textsuperscript{11} suggested that a difference of 10\% in benefit scores between hearing aids would reflect a 96\% probability that the difference was statistically significant. This suggests that the study hearing aids provided greater benefit than the subjects’ own hearing aids in daily communication situations (as seen in the EC subscale) and in situations where reverberation and background noise (as seen in the RV and BN subscales) are prevalent.

This is opposite to Cord et al.\textsuperscript{16} who reported no benefits on the APHAB questionnaire with directional hearing aid use. If one recalls that the default Locator microphone automatically switches between omnidirectional and directional microphones, it is not difficult to realize that the study hearing aids have the potential to optimize the SNR in most listening situations and not just in noisy listening situations. Indeed, if one examines the absolute scores (not reported here), the average rating for these subscales would place the subjects in the “generally (75\%)” rating category for the study hearing aids. The finding that the subjects reported more benefit with hearing aids having an adaptive directional microphone, in comparison to hearing aids with an omnidirectional microphone, is in agreement with the findings of Kochkin\textsuperscript{17,18} who reported greater consumer satisfaction with directional hearing aids regardless of signal processing (ie, analog\textsuperscript{17} or digital\textsuperscript{18}).

As stated earlier, it was not feasible to incorporate “blinding” procedures into the experimental design of the current study. Therefore, due to the Hawthorne, or “Halo” effect\textsuperscript{8}, the improved benefit reported for the test aid over their current analog omnidirectional hearing aids should be interpreted with caution.
Conclusion
Despite the closeness (5 mm) of the microphone ports in the ITC/ITE Senso Diva, the adaptive directional microphone (Locator) in the Senso Diva is effective in improving the SNR of the listening environments over an unaided condition, aided with own hearing aids, and aided with the Senso Diva in the omnidirectional mode. This improvement is also reported in various daily listening environments. The automatic adaptive directionality, as well as the improved audibility for soft sounds (as seen by the aided thresholds), may have contributed to the positive findings.

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