Fitting hearing aids on non-wearers can be a challenge. By a non-wearer, we mean a patient with a hearing loss who has never previously tried hearing aids or has tried and rejected them.

Many of these patients do not have enough communication difficulty to require them to seek professional help. Also, because of their milder degree of hearing loss, they are less likely than other patients to agree to wear hearing aids in a style (e.g., behind-the-ear [BTE], in-the-ear [ITE]) that they object to on cosmetic grounds. On the other hand, when they are fitted, previous non-wearers often expect their chosen hearing aids to enable them to understand speech in noise perfectly without any negative hearing aid effects such as occlusion and acoustic feedback.

Like everyone with a hearing loss, non-wearers also have difficulty understanding speech in noise. Although hearing aids with directional microphones have proven effective in enhancing the signal-to-noise ratio (SNR) of listening environments, most come in BTE and ITE styles that may be unacceptable to these patients. Furthermore, most, if not all, published research in this area has used experienced hearing aid wearers as test subjects. Published reports supporting the benefit of such a feature for new wearers are almost non-existent. One may assume that the same benefits seen in experienced hearing aid wearers can be generalized to all people with a hearing impairment. This is a reasonable assumption considering that the improvement in SNR is correlated to the directivity index (DI) of the directional microphone.1

Current hearing aid fitting practice may obscure the benefit of directional hearing aids for previous non-wearers...
not informed of the features on the study hearing aids.

Hearing aids

 Widex Senso Diva ITC instruments were used as the study hearing aids for 13 of the 14 subjects (one experienced subject used binaural ITEs because of small ear canals). This DSP hearing aid uses 15 compression channels with a compression threshold of 0 dB HL in each channel. The device has three dispenser-selected microphone options: an adaptive directional mode, a fixed directional mode, and an omnidirectional microphone mode.

 The dual-microphone, adaptive directional system in the hearing aid tracks single noise sources and reacts to the noise pattern to place the noise source at its null. An OptiMic matches the sensitivity and phase of the dual microphones to ensure consistent directivity at all times. In addition, a Noise Classification Unit identifies the nature of the input and automatically switches to an omnidirectional microphone mode in quiet or when the input is primarily wind noise or circuit noise.

 This hearing aid also compensates for the low-frequency response, regardless of the resulting polar pattern. The DI of this hearing aid ranges from 5 dB to 6 dB across frequencies when measured on KEMAR. Kuk and Ludvigsen have provided a more detailed description of the features on this hearing aid.4

Stimulus and test conditions

 The subjects’ ability to recognize speech in the presence of noise was evaluated using the Speech Perception In Noise (SPIN) test and the Hearing In Noise Test (HINT). For the SPIN test, the speech level was fixed at 68 dB SPL, while noise levels of 61 dB SPL, 68 dB SPL, and 75 dB SPL were selected. This yielded fixed SNRs of +7, 0, and -7 dB, respectively. The percentage of words correctly identified was reported for each SNR condition. A fixed noise level of 68 dB SPL was used for the HINT. The level of the speech signal was adaptively varied until 50% correct identification was reached. The SNR for 50% correct identification was reported for the HINT.

 For both the SPIN and HINT, the speech signal was presented at the front of the subjects while three noise locations—two from the sides (90° and 270°) and one from the back (180°)—were used. The noise source was an uncorrelated party noise recorded with babble and music in a reverberant background. It was played continuously during the test.

Procedure

 Binaural custom ITC hearing aids (ITEs for one subject) with Select-A-Vent (SAV) were ordered for all subjects during the initial visit. Five of the non-wearers used a vent diameter of 2 mm and two used a diameter of 1 mm. The vent diameters were smaller for the experienced wearers: Four had occluding vents, one had a 1-mm vent, and two had 2-mm vents. These vent diameters are 1 mm to 2 mm narrower than the typical diameters used by the authors when fitting conventional single- or dual-channel hearing aids.

 The study hearing aids were fitted during the second visit. This procedure included checking the fit of the hearing aids, obtaining in situ threshold measurements, and performing a feedback test to initialize the active feedback-cancellation mechanism. The fitting software calculated the target gain for each input level at each frequency. No adjustment or fine-tuning of the gain parameters was made on the hearing aids unless the subject complained of loudness intolerance. In addition, the speech-recognition scores for the SPIN and HINT sentences were measured for both the omnidirectional microphone mode and the adaptive microphone mode. This served to familiarize the subjects with the tests.

 Subjects were given 1 month to acclimate to the hearing aids in their daily environments. At the end of the month, they returned for speech testing and fine-tuning of the hearing aids. The fine-tuning process included adjustment of frequency gain settings on the hearing aids, activation of the Occlusion Manager to resolve amplication complaints, and adjustment to minimize any unresolved feedback issues. Generally, all subjects were satisfied with the overall sound quality of the hearing aids. In addition, all reported that their own voice was acceptable.

 After their hearing aids were adjusted, the subjects wore them for another month before returning for the final evaluation. During the final follow-up session, the speech-recognition scores in noise on the SPIN and HINT sentences were again measured for both the omnidirectional and the adaptive microphone modes. Testing was counterbalanced across subjects and test conditions. Only the speech test results obtained during the final session are reported in this article.

RESULTS

Hearing In Noise Test (HINT)

 Figure 2 shows a scatter plot of the required signal-to-noise ratios for 50% correct identification of the HINT sentences between the omnidirectional microphone (X-axis) and the directional microphone (Y-axis) for both subject groups. A diagonal line is drawn to show equal performance in both modes. Data points below the diagonal line indicate better performance (lower SNR) for the directional mode than the omnidirectional mode.

 It is clear that all subjects (both wearers and non-wearers) required a lower SNR in the directional mode than in the omnidirectional mode for 50% correct on the HINT. For the non-wearer group, the required SNR in the omnidirectional mode varied from -0.24 dB to 6.6 dB, whereas the required SNR in the direc-
Directional benefits in smaller hearing aids

The hearing aid’s omnidirectional mode ranged from -4.5 dB to 1.6 dB. For the wearer group, the required SNR in the omnidirectional mode varied from -0.24 dB to 16 dB and the required SNR in the directional mode ranged from -8.0 dB to 6.8 dB.

On average, the experienced wearers required an SNR of +5.6 dB in the omnidirectional mode and -0.4 dB in the directional mode for 50% correct on the HINT. This represents an SNR improvement of 6.0 dB. On the other hand, the non-wearers required an SNR of 2.76 dB in the omnidirectional mode and -1.14 dB in the directional mode. This yields an SNR advantage of 3.9 dB over the omnidirectional mode.

**SPIN test**

Figure 3 shows a composite scatter plot of the individual total scores on the SPIN test for the two subject groups at all three SNR test conditions with the study hearing aids in the omnidirectional (X-axis) and directional (Y-axis) microphone modes. Again, the diagonal line indicates equal performance for both microphone modes. Data points above the diagonal line indicate better performance (higher speech scores) in the directional mode.

Several observations are apparent. First, significant variability in the amount of benefit (defined as the difference in speech scores between omnidirectional and directional microphone modes) was seen across subjects and across listening conditions. For example, many subjects in both groups obtained a score of 0% in the omnidirectional microphone mode at the SNR=-7 listening condition. However, in the directional mode, two of these subjects improved by as much as 60% over the omnidirectional mode while two improved by only 10%.

Secondly, subjects obtained a higher score in the directional mode than in the omnidirectional microphone mode in all but the SNR=+7 condition where a few subjects had equal performance in both microphone modes.

Thirdly, the advantage of the directional microphone over the omnidirectional microphone decreases as the SNR condition improves. This can be seen in the average data. For example, the experienced wearers showed an improvement (from omnidirectional to directional microphone) of 5.5% at SNR=+7 dB, 31% at SNR=0 dB, and 29% at SNR=-7 dB. For the non-wearer group, the average improvement was 8.5% at SNR=+7 dB, 23% at SNR=0 dB, and 36% at SNR=-7 dB. This observation suggests that the optimal SNR condition for examining the maximum directional advantage by means of the SPIN test was 0 dB for the experienced wearers but -7 dB for the non-wearers. This indicates that the performance-intensity (P-I) functions of these two subject groups may be different.

**DISCUSSION**

The present study showed that the Locator (adaptive directional) microphone was effective in improving the speech-recognition ability of both new (non-wearer) and experienced hearing aid wearers over the omnidirectional microphone mode. All subjects showed objective directional benefits in at least some test conditions. This is reflected in the 3.9 dB to 6.0 dB average SNR improvement on the HINT sentences and over 30% improvement in total speech scores on the SPIN sentences across different test conditions.

The magnitude of improvement seen in the experienced subjects (i.e., 6 dB) is just as high, if not higher, than the improvement of 3 dB to 4 dB typically reported with directional ITE hearing aids. When the ITC hearing aids in the study were in the adaptive directional mode, the experienced subjects required an SNR (-0.4 dB) similar to that required by normally hearing individuals (0 dB) to achieve 50% performance on the HINT. The non-wearers required an even lower SNR (-1.14 dB) than the normally hearing listeners.

Although both groups of subjects showed objective benefit from the use of directional microphones, the magnitude of that benefit differed between subject groups on the HINT (6.0 dB for the wearer group, 3.9 dB for the non-wearer group).

**Reasons for differing benefits**

There are many possible reasons for this difference. One may be related to the P-I characteristics of the two subject groups. Support for this possibility is the different SNR test conditions on the SPIN test where both groups showed maximum directional benefit.

Another reason may be the larger vent diameter used by the non-wearers. Rick-etts showed that a 2-mm vent could reduce the DI below 500 Hz by more than
2 dB and cause an overall reduction in AI-DI of more than 0.8 dB in comparison with an occluded vent.6 This may account for the smaller directional advantage seen in the non-wearer group than in the wearer group.

If vent size explains the difference found in SNR improvement between the groups, then one could expect a smaller improvement in SNR for both subject groups if they were fitted with larger vents. If we were to fit the average subjects with conventional single-channel hearing aids, the non-wearers would require at least 3-mm or IROS vents and the experienced wearers would require vents with diameters of at least 1.5 mm to 2.0 mm to minimize any potential ampclusion complaints. This would lower the AI-DI by 1 dB to 2 dB from the theoretical maximum of 6 dB that can be achieved in the unvented or occluded state. In other words, the directional benefit may be only 4 dB to 5 dB for the experienced group and 3 dB to 4 dB for the non-wearers if a larger vent is used.

The fact that many of the subjects (both non-wearers and experienced wearers) were able to achieve greater directional advantage while still being satisfied with their own voice in an unvented ITC (wearers) or a 2-mm vent ITC (non-wearers) indirectly supports the efficacy of the different features used to manage ampclusion on this hearing aid. Features such as multiple independent filter channels, short group delay, and the occlusion manager allowed the use of a smaller vent while circumventing potential ampclusion complaints.

While active feedback cancellation may allow for more venting before feedback, such a feature may not always be necessary if ampclusion can be managed without an increase in the vent size. Indeed, if one increases the vent size to manage occlusion, one may compromise the theoretical benefits offered by the directional microphones.

**CONCLUSION**

One important objective in hearing aid design is to improve the patient’s ability to understand speech in noise. Directional microphones have proven effective in achieving that objective. However, when other features on a hearing aid compromise their effectiveness, one needs additional design goals to ensure that the maximum benefit of directional microphones can be delivered to the wearer. Thus, providing algorithms that minimize ampclusion without the use of a large vent may also be an important objective.

With an adaptive directional microphone containing a compression system that uses 15 steep and narrow compression channels, each with precise gain specification, the Senso Diva has demonstrated how such an objective can be realized. While its algorithms may not, by themselves, improve speech understanding in noise, they may help minimize the negative experience (e.g., ampclusion) that wearers sometimes encounter with hearing aid use. By minimizing the need for a large vent, these algorithms may make it possible to more fully realize the potential of other features on the hearing aids (e.g., directional microphone, noise-reduction algorithm) that are designed to enhance speech understanding in noise.

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**REFERENCES**