# Evaluation of a Second-Order Directional Microphone Hearing Aid: I. Speech Perception Outcomes

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**Abstract**

This clinical trial was undertaken to evaluate the benefit obtained from hearing aids employing second-order adaptive directional microphone technology, used in conjunction with digital noise reduction. Data were collected for 49 subjects across two sites. New and experienced hearing aid users were fit bilaterally with behind-the-ear hearing aids using the National Acoustics Laboratory—Nonlinear version 1 (NAL-NL1) prescriptive method with manufacturer default settings for various parameters of signal processing (e.g., noise reduction, compression, etc.). Laboratory results indicated that (1) for the stationary noise environment, directional microphones provided better speech perception than omnidirectional microphones, regardless of the number of microphones; and (2) for the moving noise environment, the three-microphone option (whether in adaptive or fixed mode) and the two-microphone option in its adaptive mode resulted in better performance than the two-microphone fixed mode, or the omnidirectional modes.

**Key Words:** Adaptive-directional microphone, directional, fixed-directional microphone speech perception, hearing aid, second-order microphone

**Abbreviations:** DI = directivity index; DNR = digital noise reduction; HINT = Hearing in Noise Test; NAL-NL1 = National Acoustics Laboratory—Nonlinear version 1; SNR = signal-to-noise ratio; SPIN = Speech Perception in Noise (test)

**Sumario**

Este estudio clínico fue llevado a cabo para evaluar el beneficio generado por los auxiliares auditivos que utilizan tecnología adaptable de segundo de orden para micrófonos direccionales, usados en conjunto con reducción digital del ruido. Se recolectaron datos de 49 sujetos en dos contextos. Se les adaptaron curvetas retroauriculares a usuarios nuevos y con experiencia en el uso de auxiliares auditivos usando el método de prescripción del Laboratorio Nacional de Acústica – Versión no lineal 1 (NAL-NL1), con la programación original del fabricante en varios parámetros de procesamiento de la señal (p.e., reducción del ruido, compresión, etc.). Los resultados de laboratorio indican que (1) para el ruido ambiental estacionario, los micrófonos direccionales aportaban mejor percepción del lenguaje que los micrófonos omnidireccionales, independientemente del número de micrófonos; y (2) para el ruido de fondo en movimiento, la opción de tres micrófonos (tanto en modo fijo como

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adaptable) y la opción de dos micrófonos en modo adaptable, rindieron un mejor desempeño que el modo fijo de dos micrófonos, o los modos omnidireccionales.

**Palabras Clave:** Micrófono direccional adaptable, direccional, percepción del lenguaje con micrófono direccional fijo, auxiliar auditivo, micrófono de segundo orden

**Abreviaturas:** DI = Indice de direccionalidad; DNR = reducción digital del ruido; HINT = Prueba de Audición en Ruido; NAL-NL1 = Laboratorio Nacional de Acústica – Versión no lineal 1; SNR = tasa señal/ruido; SPIN = Prueba de Percepción del Lenguaje en Ruido

With the advent of digital platforms for signal processing in hearing aids, a number of features, including directional microphones and noise reduction, can be implemented in a variety of manners. In this study, both of these features were evaluated in multiple laboratory environments and with self-report measures following field testing. The laboratory results of speech perception outcomes are presented here; self-report outcomes obtained following the field trials are reported in a companion paper (Palmer et al, in this issue).

Directional microphone options are available on most of today's hearing aids. Those options include use with different hearing aid styles (e.g., BTE, ITE, ITC), choice of different fixed polar patterns, a first-order or second-order design, manual or automatic switching between omnidirectional and directional modes, and adaptive "morphing" of the polar pattern null to the primary noise source. For laboratory measures of directional microphone effectiveness, it has been well documented that the magnitude of measured improvement depends on the source(s) and distance of the noise and the primary signal, as well as the amount of reverberation in the test environment (e.g., Hawkins and Yacullo, 1984; Ricketts and Dhar, 1999; Novick et al, 2001; Ricketts and Hornsby, 2003). Efforts to measure real-world effectiveness must rely upon self-report documentation, although the same factors of distance, noise source(s), and reverberation have been identified as primary determinants of successful use in everyday activities as well (Walden et al, 2003).

Many of today's digital directional microphone hearing aids utilize a two-microphone approach, using two omnidirectional microphones in endfire geometry. A first-order delay-and-subtract processing creates a spatial dependent sensitivity (maximum located directly in front). A BTE directional product has been introduced that uses the same delay-and-subtract approach with a second-order three-microphone endfire system (see Benesty and Gay, 2000, and Powers and Hammaker, 2002, for review). The second-order array should improve the theoretical directivity index (DI) by 3 dB (Ricketts and Dittberner, 2002). There has been little behavioral research, however, directly comparing the three-microphone array to the more common two-microphone product.[1]

When examining directional technology, another aspect to consider is the polar pattern. Most of the studies to date have evaluated the *fixed* one- or two-microphone designs; that is, the polar pattern achieved by the microphone characteristics (particularly, the spacing and delay element, whether acoustic or electrical) is held constant. More recently, the *adaptive* directional design has become available from a number of manufacturers. In this design, the characteristics of the polar pattern are controlled by a manufacturer-specific algorithm and continually adjust to provide the optimum signal-to-noise ratio (SNR) that can be achieved for a given environment. The evolving polar pattern depends on the summed outputs of the separate microphone signals, and the noise source is suppressed by the resultant low sensitivity of the microphone in one or more directions (Soede et al, 1993). Several studies have investigated the advantages of a first-order (two microphones) adaptive microphone design (Cord et al, 2002; Ricketts and Henry, 2002; Surr et al, 2002; Bentler et al, 2004; Ricketts and Hornsby, 2005). Although the results were promising for single or slow moving noise sources, these investigators questioned whether the results can be generalized to real-world listening situations. With the introduction of second-order (three-microphone design) directional hearing aids, with higher directivity capability, one might expect even better performance for the adaptive feature by the hearing impaired/hearing aid user.

Digital noise reduction (DNR) schemes also are available on many hearing aids. Most of these schemes utilize a modulation-based approach (with manufacturer-specific implementation) to reduce the gain differentially in each channel. Published evidence, to date, has not shown improved speech perception ability with this feature (Ricketts and Dhar, 1999; Walden et al, 2000; Alcantara et al, 2003). This is due, primarily, to the temporal and spectral overlap of speech and the interference, making it difficult to improve the overall signal-to-noise ratio.

Some studies have shown, however, that even though speech understanding is not enhanced with DNR, this signal processing may result in improved listening comfort. For example, Walden et al (2000) reported that the combination of DNR with directional microphone technology improved listening comfort when compared to an omnidirectional condition with no DNR. The effects of DNR were minimal, however; when the hearing aid was fixed in the directional mode, adding DNR *did not* significantly improve listening comfort. In agreement with the Walden et al (2000) findings, Boymans and Dreschler (2000) and Alcantara et al (2003) were not able to demonstrate that the activation of the noise reduction scheme resulted in any additional benefit in sound quality or listening comfort. In contrast, Ricketts and Hornsby (2005) found a strong preference for DNR-on versus DNR-off for listening to speech in noise for both omnidirectional and directional settings. Drawing conclusions from these studies of DNR is difficult, due to differences in methodologies and DNR algorithms.

The purpose of the present clinical trial research was to answer the following questions:

1. Does a three-microphone directional hearing aid provide better speech reception in multisource noise than a two-microphone system?
2. Does an adaptive directional microphone improve speech reception in moving noise compared to a fixed directional microphone? Is this result dependent on the number of microphones (two versus three)?
3. Does digital noise reduction (or an interaction between noise reduction and directivity) improve understanding in noise for the three-microphone design?

## METHODS

### Subjects

Participants in this clinical trial study met the following criteria: (1) downward-sloping bilateral sensorineural (A/B [air/bone] gap <10 dB) hearing loss; (2) hearing levels no better than 20 dB HL (American National Standards Institute, 1996) at 500 Hz and no worse than 75 dB HL at 3000 Hz; (3) hearing symmetry within 15–20 dB for all test frequencies; and (4) no cognitive, medical, or language-based disorder that would preclude reading and understanding directions, consent form agreement, or other experimental tasks. The participant was considered a new user of amplification if he or she reported less than 60 days of hearing aid use within the past 12 months, and an experienced user if he or she had at least six months of regular use in the past 12 months. Forty-nine individuals participated in this clinical trial (25 from the University of Iowa site and 24 from the University of Pittsburgh site). Based on a .05 level of significance and a desired power of .8 with a medium effect size (.6), a power analysis indicated that 45 subjects were needed for the analysis. The subject pool consisted of 22 females and 27 males; 18 new hearing aid users; and 31 experienced hearing aid users. The mean age of the participant was 62.1 (SD = 13.73). The age range was 27 to 85 years.

### Procedures

Audiometric evaluations were conducted for all subjects. Pure-tone thresholds were obtained using ER-3A insert earphones for the frequencies of 250, 500, 1000, 2000, 4000, and 8000 Hz, using a Grason-Stadler GSI-61 audiometer (re: ANSI S3.6, 1996 [American National Standards Institute, 1996]). The mean thresholds are shown in Figure 1.

### Hearing Aids

Two different models of the Siemens Triano™ behind-the-ear hearing aid were evaluated: The Triano-3, a second-order, three-microphone directional design, and the Triano-S, a first-order, two-microphone directional design. The polar patterns that can be achieved with the second-order design are considerably more complex and the resultant directivity index (DI) theoretically higher. The Triano-S could be switched between omnidirectional and directional, and the directional function for both models could be programmed to either a fixed or adaptive mode. In the fixed mode, the polar pattern is hypercardioid in shape; in the adaptive mode, if a dominant signal is present from a specific azimuth, the polar pattern adjusts the null(s) to minimize total output. The Triano-3 could be programmed to be omnidirectional, or to automatically switch between omnidirectional and directional. In the automatic switching setting, either a fixed polar pattern (hypercardioid) or adaptive polar pattern could be selected. When set to automatic switching, the algorithm for determining switching from omnidirectional to directional was based on the spectral content of the signal (e.g., speech versus noise), the duration of the signal, and the overall level of the signal (>54–57 dB SPL). The default pattern in a diffuse-like environment for the test instruments is hypercardioid. The manufacturer-stated DI for the Triano-3 ranges from 6.5 to 7.0; the manufacturer-stated DI for the Triano-S is 4.3 dB. To verify those values, a random sample of the experimental hearing aids was assessed pre- and post-testing. The free-field DI values for the Triano-3 model ranged from 6.5 up to 7.8 dB DI-a (flat average across .5–5 kHz). The KEMAR DI values for the Triano-3 model ranged from 4.5 up to 6.0 dB DI-a (flat average across .5–5 kHz). The DI measured for the Triano-S model also was comparable to the manufacturer-stated DI (4.3 dB). The methodology used to measure and compute the DIs is discussed in Dittberner and Bentler (2002). No significant change was observed for any of the hearing aids on post-test measurement; for some products this testing was conducted 12 months after the initial testing.

The test hearing aids utilize both input and output compressors. The AGC-O serves as an output limiter, with a ratio of 10:1, an attack time (TA) of <.5 msec, and a release time (TR) of 100 msec. Channel specific kneepoints vary as a function of the patients' frequency-specific thresholds of discomfort (TDs), which were entered in the fitting software. In general, AGC-0 kneepoints were in the 102–110 dB range. The individual 16

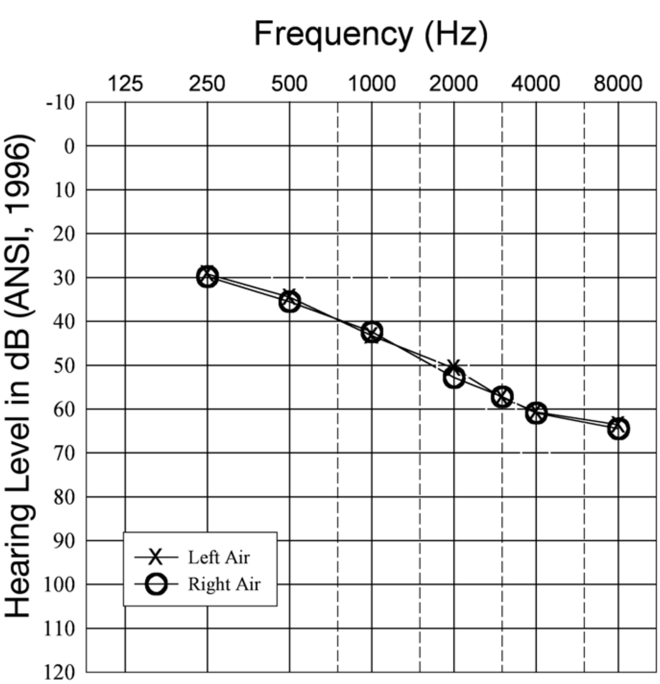


**Figure 1.** Average pure-tone threshold results for the right and left ear of the 49 hearing-impaired subjects.

channels employ AGC-I compression (TA of 5 msec and TR of 90 msec for short duration signals, and TA of 900 msec and TR of 1.5 sec for longer duration signals). The AGC-I compression kneepoints varied as a function of hearing loss and dynamic range, but generally fell in the range of 40–50 dB SPL.

The circuit uses two overlapping noise reduction algorithms. The first is a modulation-based scheme, similar to the algorithm explained in detail by Powers et al (1999). Maximum gain reduction for a steady-state signal usually is reached in six to eight seconds after onset. When speech is the primary signal, gain returns to programmed levels in approximately 500 msec. The second noise reduction algorithm uses Wiener filter theory (see Vaseghi, 2000, for review). In the fitting software, the modulation-based scheme is adjustable using the "DNR" control (off, medium, high). The early version of software used in this investigation did not allow for shutting off the Wiener filter (in the directional modes), so only the combination of these two schemes was investigated for all directional testing. For the omnidirectional microphone modes of testing, however, both schemes were turned off.

The subjects were fit with the hearing aids using the manufacturer-implemented NAL-NL1 (National Acoustics Laboratory—Nonlinear version 1) fitting strategy (Dillon, 1999), with frequency specific thresholds of discomfort (TDs) entered for output limitation. Binaural summation was set to 0 dB, and a pressure (1 mm) vent setting was used for the earmold. The low frequencies were "equalized" for the directional mode using the manufacturer's default algorithm. Automatic feedback suppression was maximized. Automatic digital noise reduction (DNR) was adjusted during the investigation to assess the impact on speech perception and sound quality; for some testing it was turned off. Following initial programming, probe-microphone measures were conducted at inputs of 50, 70, and 85 dB SPL to ensure audibility and observe general function of the hearing aid. Figure 2 shows the average output across subjects for both models of the hearing aid. No attempt was made to alter the response to obtain closer proximity to the NAL-NL1 target values.

## Speech Testing

Speech perception ability was assessed using the Hearing in Noise Test (HINT) (Nilsson et al, 1994) and the Speech Perception in Noise (SPIN) test (Kalikow et al, 1977; Bilger et al, 1984). The HINT is an adaptive, psychometric procedure that requires the participation of a subject to repeat back recorded sentences of a male talker in the presence of speech-shaped noise. The intensity of the sentence is adaptively adjusted whereas the noise level remains fixed. All the key words of a sentence must be accurately repeated in order for the sentence to be considered correct. The HINT noise was presented at 70 dB SPL. The SPIN test is comprised of 50 sentences, half of

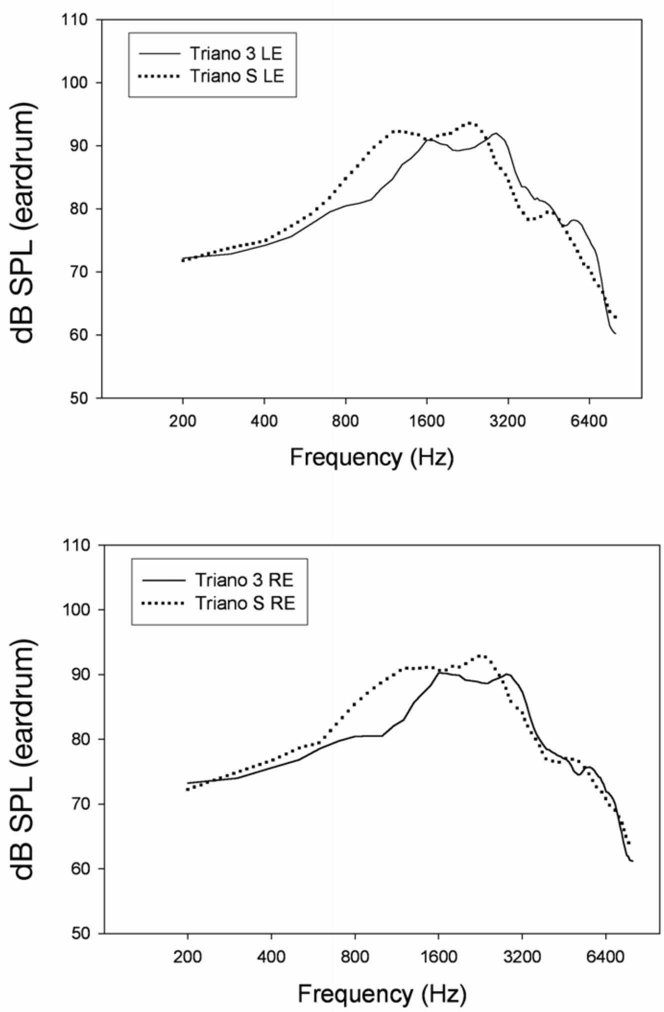


**Figure 2.** Average output (for 70 dB input) across subjects for Triano-3 and Triano S. Left ear (*top*); right ear *(bottom)*.

which are high context/predictability and half of which are low context/predictability. Using a fixed signal-to-babble ratio, the subject's task is to repeat back the last word in each sentence. The SPIN sentences were presented at 70 dB SPL with a +8 signal-to-babble ratio.

Tannoy® i5 AW point source speakers were used for speech test presentation as well as for the noise presentation. Separate Samson® Servo 120 power amplifiers with separate channel attenuators were used to drive the primary and background noise speakers. A Marantz® PMD 331 compact disc player was used for presentation of the sentences; three two-channel Teac P1250 compact disc players were used to present the background noise. The frequency response of the speaker presenting the test signal was matched to the speakers presenting the background noise using ART® 355 31-band graphic equalizers. For the fixed noise condition, the six separate speakers were used to present the same uncorrelated noise. For the moving noise condition, only one speaker at a time presented two seconds of noise, and the speaker presentation was randomized with no silent intervals. The two-second duration was chosen following measurements of time and level of background interference measured in two different restaurants.

An identical soundfield arrangement was used at each site. The subject was placed in the center of the 84 x 88 inch field (IAC™ booth) at 0° azimuth to the single primary signal speaker located at eye level in one corner of the booth, and the six speakers with background noise were placed at the top and bottoms of the other three corners of the booth, angled to the center position. The same calibration equipment, operated by the same researcher, was used at both test sites to verify that each speaker, power amplifier channel, and graphic equalizer was contributing equally.

Each subject was first advised as to his or her rights as a test subject and the investigator's obligations to the subject and current study.

## RESULTS

The first question posed in this investigation was whether directional microphones provide for better speech perception than omnidirectional microphones. The average HINT SNR scores for the unaided condition and with the various microphone schemes (two-microphone, three-microphone, omnidirectional, and/or fixed directional) are presented in Figure 3. A one-way repeated measures ANOVA was used to compare the listening conditions ($p = .05$), and Bonferroni adjustment was made for post hoc testing. Results show that subjects did better in the six-speaker noise environment in the unaided condition than when using the hearing aids in the omnidirectional condition. The omnidirectional conditions for the two hearing aids were not significantly different from each other. The directional conditions were not significantly different from each other. Both directional conditions, however, were significantly better than the unaided or omni conditions.

The second question posed in this investigation was whether an adaptive microphone could improve sentence reception in noise compared to a fixed directional microphone, and whether this result was dependent on the number of microphones (two versus three). To answer this question,

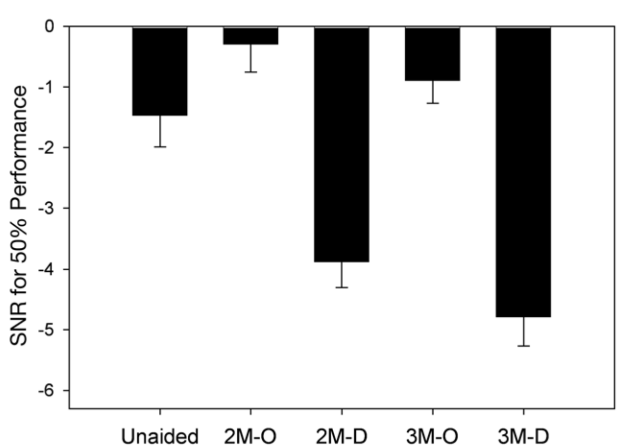


**Figure 3.** Means and +/-1 standard deviation bars of HINT results for five listening conditions (Unaided; 2M-O = two-microphone hearing aid set in the omnidirectional mode; 2M-D = two-microphone hearing aid set in the fixed directional mode; 3M-O = three-microphone hearing aid set in the omnidirectional mode; 3M-D = three-microphone hearing aid set in the fixed directional mode).

individuals completed the HINT with the primary signal at 0° azimuth and the noise (70 dB) moving around them from the sides and back. The average HINT SNR scores for the various microphone schemes (two-microphone, three-microphone, omnidirectional, fixed directional, and adaptive directional) are presented in Figure 4. A one-way repeated measures ANOVA was used to compare the listening conditions ($p = .05$). Post hoc testing was conducted using a Bonferroni adjustment for multiple comparisons. Results indicate that the omnidirectional conditions (2M-O and 3M-O) were significantly poorer than all directional conditions. Both fixed and adaptive three-microphone directional modes (3M-D and 3M-AD) and the two-microphone adaptive mode (2M-AD) resulted in similar performance/benefit as measured by the HINT. The two-microphone fixed directional mode resulted in significantly better performance than the omnidirectional modes but was not equal to the other directional modes.

The third question posed in this investigation was whether digital noise reduction (or an interaction between directionality and noise reduction) could improve speech understanding in noise. The SPIN test was used for this evaluation. Examination of the High Predictability items revealed that this portion of the SPIN test was subject to ceiling effects, with all average scores for the different hearing aid conditions above 96%. No further analysis was carried out for those scores. Analysis of the Low Predictability SPIN items indicated that these data had a normal distribution and could be treated parametrically. The average SPIN Low Predictability scores for the various conditions (unaided, omnidirectional, and fixed directional, with DNR off and on) are shown in Figure 5. The data were analyzed two ways to determine the significance of these small differences in scores.

Using a one-way repeated-measures ANOVA and post hoc testing with Bonferroni adjustment, it was found that the directional microphone with DNR on (D-C on) was better than unaided, and better than the omnidirectional microphone with DNR off (O-C off), but not different from directional microphone with DNR off (D-C off) or omnidirectional microphone with DNR on (O-C on). Restated, there was not a significant effect for the DNR or an additive impact of

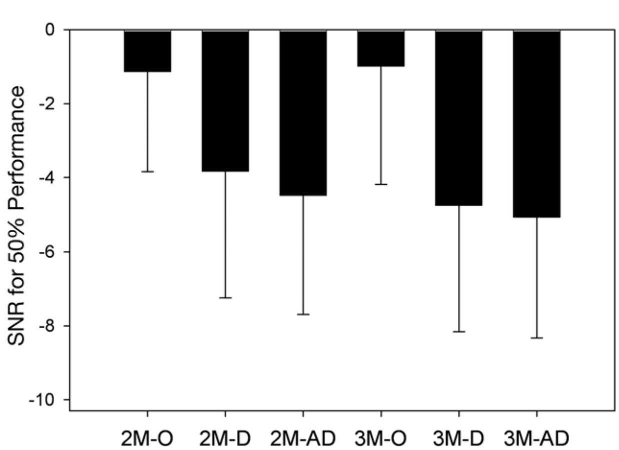


**Figure 4.** Means and +/-1 standard deviation bars of HINT results with moving noise for listening conditions (2M-O = two-microphone hearing aid set in the omnidirectional mode; 2M-D = two-microphone hearing aid set in the fixed directional mode; 2M-AD = two-microphone hearing aid set in the adaptive directional mode; 3M-O = three-microphone hearing aid set in the omnidirectional mode; 3M-D = three-microphone hearing aid set in the fixed directional mode; 3M-AD = three-microphone hearing aid set in the adaptive directional mode).

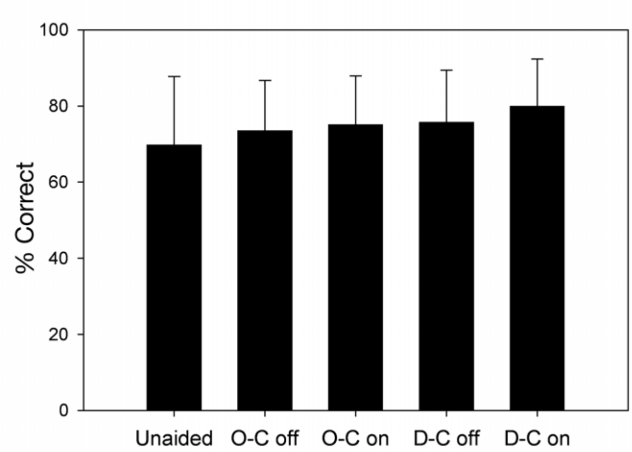


**Figure 5.** Means and +/-1 standard deviation bars of SPIN Low-Predictability items for five listening conditions (unaided; O-C off = three-microphone hearing aid set in omnidirectional mode with DNR off; O-C on = three-microphone hearing aid set in omnidirectional mode with DNR on; D-C off = three-microphone hearing aid set in fixed directional mode with DNR off; D-C on = three-microphone hearing aid set in fixed directional mode with DNR on).

combining the directional microphone with the DNR system in this environment/task, since the combined condition was not better than directional with DNR off or better than omnidirectional with DNR on.

Using a two-way ANOVA, thus combining conditions for additional power, assumed that microphone type and noise reduction were separate features. We did that with the findings in Table 1. Using a .05 alpha level, the directional microphone mode/condition was better whether noise reduction was off or on; the noise reduction "on" condition provided significant advantage whether directional microphone was off or on. (There was no interaction, as noted by p = .453.) Consequently, combining conditions increased the power enough to make the combined means significant from each other. Since there is no interaction and the main effects are significant, there must be an additive effect of including either directionality or noise reduction. This was seen only when the power was doubled from the original design where the power analysis was based on a medium size effect.

## DISCUSSION

The primary focus of this clinical trial study was to ascertain the advantage of first- and second-order directional microphones, both in fixed and adaptive modes, as well as the noise reduction scheme implemented in the Siemens Triano™ hearing aid. While this paper focuses on the speech perception measures, self-report judgments also were obtained for these features (see Palmer et al companion paper in this issue).

The outcome of the first experimental question involving comparison of performance with a two-microphone system to a three-microphone system was somewhat unexpected. While both directional microphone conditions showed improved results over the omnidirectional conditions, the added directivity provided by a second-order directional microphone might have been expected to result in significantly better performance. A close examination of the data, however, indicates that although there was not a *significant* difference, the mean HINT scores for the two instruments fall relatively close to theoretical predictions. Although the directivity index (DI) has not been found to correlate directly to speech perception task performance (Killion, 1997; Ricketts, 2000; Ricketts and Dittberner, 2002; Dittberner and Bentler, 2002), a monotonic relationship generally is expected. As we discussed earlier, the average measured difference in DI between the two hearing aid designs was approximately 2 dB. Ricketts and Dittberner (2002) noted that a 2 dB increase in DI should increase directional benefit on the HINT by approximately 1 dB. In fact, this was the mean improvement in benefit for the three-microphone versus the two-microphone design (see Figure 3). It should be recognized that the expected relationship between directivity and performance assumes a diffuse-like background noise (Ricketts and Dittberner, 2002). The six-speaker arrangement used in this investigation provided a closer approximation to that environment than some of the earlier reports of directional benefit (e.g., Valente et al, 1995).

A second research question concerned the benefit of an adaptive polar pattern when subjects are listening to speech signals with a moving background noise. The addition of the adaptive feature resulted in a significant additional benefit for the two-microphone

**Table 1. Statistical Analysis of SPIN-LP Data Using a Two-Way ANOVA**

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Mic (dir/omni) | .060 | 1 | .060 | 6.946 | .011 |
| Error (dir) | .417 | 48 | .009 | | |
| NR (off/on) | .042 | 1 | .042 | 5.543 | .023 |
| Error (comf) | .366 | 48 | .008 | | |
| dir * comf | .008 | 1 | .008 | .572 | .453 |
| Error (dir*comf) | .701 | 48 | .015 | | |

design but not the three-microphone design. Both fixed and adaptive three-microphone directional modes (3M-D and 3M-AD) and the two-microphone adaptive mode (2M-AD) resulted in similar performance/benefit as measured by the HINT. One could interpret these findings as indicating that having three microphones or having adaptive directionality is important to achieve the best performance in this listening condition (moving noise) but that combining these two features (three microphones and adaptive directionality) does not produce a significant additive effect. The additive benefit favoring the two-microphone design was only 0.31 dB (0.63 versus 0.32; see Figure 4).

A number of authors have noted that in the presence of multiple noise sources, an adaptive directional two-microphone system may not be advantageous (e.g., Peterson et al, 1990; Greenberg and Zurek, 1992; Kompis and Dillier, 2001; Bentler et al, 2004). In this study, only one noise source was present at a time, and that noise was randomly moved between the speakers. The benefit for adaptive directionality observed in this research, however, is not as great as has been demonstrated in other studies using the same hearing aids with a moving noise source (see Ricketts and Hornsby, 2005, for review). This probably is due to the azimuths used to present the competing noise signals. Recall that the moving noise signal was presented from 90°, 180°, and 270° azimuth. While in the free field it is possible to observe a polar null at 90° and 270° azimuth, it is not as likely to observe a null at these points with BTE hearing aids worn on the side of the head. Hence, it is possible that for these two presentation azimuths (which were the noise locations during 2/3 of sentence presentations), the adaptive pattern resulted in an output that was no lower than the fixed directional pattern. The only advantage expected for the adaptive pattern, therefore, would be when the noise was at the 180°azimuth (cardioid versus hypercardioid).

The variance in the scores in the moving noise conditions also is greater than has been previously reported (refer to Figure 4), and is greater than was measured with the same subjects on the other speech perception tasks. It is possible that the moving noise source served as a distraction for some of the listeners, resulting in greater variability in the scores. If the moving noise allowed for a better SNR at one ear (e.g., the right ear when noise was presented at 270 degrees), and we assume that the better ear SNR contributes significantly to performance (Zurek, 1993), then the improvement in mean HINT scores appears lower than expected. Bentler et al (2004), for example, report that when normal-hearing individuals perform this same task, their HINT scores improve by nearly 2 dB when the noise is switched from stationary to moving.

The final area of research interest was the effectiveness of the modulation-based noise reduction. The two approaches to analysis resulted in different conclusions. Using a one-way ANOVA, recall that no significant improvement in mean SPIN test scores was observed when the DNR was turned "on" for either the omnidirectional or the directional listening conditions. To some extent, interpretation of these data is clouded by the fact that the Wiener filter noise reduction feature was always active during the directional mode testing. That is, when DNR was "off," only the modulation-based component of the DNR processing was "off." We do not know, therefore, if the Wiener filter DNR had a significant impact or not.

Another factor that makes the DNR data difficult to interpret is that for the SPIN test results there also was no significant effect for the directional microphone mode. Yet, these were the same subjects, using the same hearing aids, in the same listening environment as used for the HINT. A highly significant 3.9 dB advantage for directional was observed for the HINT test condition. While the performance functions for the HINT and the LP-SPIN are not the same, it is important to point out that the mean HINT score for these subjects for the unaided condition was -1.5 dB. We chose a +5 SNR ratio for the SPIN, as this is a relatively common listening situation. It appears, however, that this SNR was not difficult enough, and that many, if not most of the subjects were at or near their LP-SPIN-in-quiet performance level. Hence, ceiling effects could have contributed to the nonsignificant finding for the DNR. While not significant, it is worth noting that activation of the DNR in the directional mode actually showed the same general improvement in mean SPIN scores (4.2%) as the directional versus omnidirectional advantage (4.8%).

Using a two-way ANOVA, a different

conclusion could be made. By combining conditions, we were able to increase the power enough to make the combined means significant from each other. Since there is no interaction and the main effects are significant, there must be an additive effect (opposite conclusion). The real-world difference most likely will be going from an OMNI with no noise reduction (73%) to directional with noise reduction (79.9%).

We now recognize that our use of the SPIN test in this study was perhaps not as effective as it could have been for the purposes of evaluating the DNR of these hearing aids. These results do remind us of some important things to remember concerning the interpretation of laboratory speech-in-noise tests. First, if the SPIN had been the only speech test used in this study, we would have concluded that directional hearing aids with (theoretical or free field) DIs of 6 dB are no better than omnidirectional for understanding speech in noise. Secondly, from a clinical perspective, it sometimes is tempting to observe an SNR improvement with directional technology (in this case, 3.9 dB) and multiply this by 9–15% to "predict" the percentage of speech understanding improvement (Dirks et al, 1982; Soli and Nilsson, 1994; Killion et al, 1998). For these subjects, using this approach, one would have predicted a 35–60% improvement, and for some listening conditions, this indeed might have occurred. But for the relatively common listening situation that we used (surrounded by noise), and a relatively common signal-to-noise ratio (S/N = +5), the improvement for speech understanding in the directional mode was no more than 2–4%. This, of course, could explain why in field studies, some subjects rate omnidirectional and directional technology the same; their listening situations might, in fact, be less adverse than tested in the laboratory setting.

## Conclusions

In this investigation the performance of 49 subjects with mild-to-moderate degrees of hearing loss was evaluated within a clinical trial context for a second-order directional microphone hearing aid. The following conclusions can be drawn from the data:

- For the stationary noise environment, the directional microphone modes provided better speech perception than the omnidirectional modes, regardless of the number of microphones.
- For the moving noise environment, the three-microphone option (whether in adaptive or fixed mode) and the two-microphone option (in its adaptive mode) resulted in improved performance over the two-microphone fixed option and both omnidirectional modes.
- Assuming microphone type and noise reduction are separate features (and using a two-way ANOVA for increased statistical power), both resulted in improved performance in this investigation; that is, the directional microphone mode/condition was better whether noise reduction was off or on; the noise reduction "on" condition provided significant advantage whether the directional microphone was off or on.

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## NOTE

1. The device under investigation only functions as a second-order system for frequencies above 1000 Hz (Powers and Hammaker, 2004)

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