



Clinical Research Findings Confirm Benefits of Advanced Signal Processing

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ABSTRACT

This is an interim report from a three-site, multi-phase hearing aid field trial. Results from the first phase of the study have already been published from Site 1 (Bray & Nilsson, 2000) and Site 2 (Bray & Valente, 2001). This report contains results from the Phase 1 at Site 3. Site 3 found improved speech intelligibility in noise for an omni-directional, digital signal processing hearing aid in comparison to unaided and analog conditions. Site 3 determined that the digital noise reduction algorithm of the digital signal processing hearing aid was a significant contributor to overall aided benefit.

INTRODUCTION

Our profession operates, as most fields do, on research, wisdom, and insight from researchers, clinicians, and educators. For many hearing healthcare professionals the accepted conclusions within our profession include: (a) without directional microphones, hearing aids cannot improve speech intelligibility in noise, (b) there is no significant difference for speech intelligibility in noise when comparing analog and digital signal processing (DSP) hearing aids, and (c) there is no significant objective benefit associated with digital noise reduction (DNR) algorithms. Evidence for these assertions is found in the following quotes:

1. "Results revealed a significant speech recognition in noise advantage for all directional hearing aids in comparison to their omni-directional counterparts" and "On average, most of the omni-directional fittings (A, P, and S) resulted in poorer SNR performance (as measured on the HINT) than the unaided condition" from Ricketts & Dhar (1999), pages 180 and 188.
2. "Studies indicate that digital signal processing alone may not be sufficient to significantly improve speech understanding in noise" from Kuehnel & Checkley (2000), page 58.
3. "These findings are consistent with other reports that suggest that digital signal processing, in and of itself, does not provide greater benefit than comparable analog signal processing" from Walden et al (2000), page 555.
4. "Bottom Line: Based on evidence from the laboratory measures, DSP technology does not yield significantly better performance over comparable HAs when listening to speech in background noise" from Newman & Sandridge (2002), page 364.
5. "I don't believe it has been clinically proven that any DSP algorithm alone can improve the signal-to-noise ratio, thus improving speech intelligibility in noise without the aid of some kind of directional system," says Ruzicka. "But I still believe there is opportunity for that to occur in the future." from Strom (2002), pages 14 & 18.

Importantly, data to challenge these conclusions are emerging. For example, Larson et al (2000) investigated analog, omni-directional, custom hearing aids and found a significant improvement for

speech intelligibility in noise over the unaided condition. In addition, Bray & Nilsson (2001) investigated DSP, omni-directional, BTE hearing aids and also found a significant improvement in speech intelligibility in noise. The current study continues to investigate previous research conclusions using custom, DSP hearing aids, while benchmarking against custom, analog hearing aid performance.

METHODS

Research Site: Site 3 was the Audiology Research Laboratory at the Cleveland Clinic Foundation in Cleveland, Ohio co-directed by Dr. Craig Newman and Dr. Sharon Sandridge. Dr. Suzanne Kornhass, Research Associate in the Audiology Research Lab, conducted data collection.

Subjects: All subjects were adults with bilateral, symmetrical, sensorineural hearing loss. The mean age of the subjects was 65 years old, with a range from 36 to 85 years. Nine subjects were female and fourteen were male. All subjects had prior experience with amplification for greater than six months before being enrolled in this study.

Hearing Aids: Subjects entered the study wearing well-fit, binaural, non-linear analog hearing aids from a variety of manufacturers. Sixteen subjects had ITC hearing aids with 2-channel WDRC circuitry, two subjects had CIC hearing aids with 2-channel WDRC circuitry, and five subjects had CIC hearing aids with K-AMP circuitry.

The test hearing aid under evaluation was manufactured by Sonic Innovations, Inc. This DSP hearing aid utilizes nine narrowband compression channels, with very fast and symmetric attack and release times, and an optional, adaptive DNR algorithm. When DNR is inactive, the test hearing aid mimics the ALTAIR® device; when DNR is active, the hearing aid is the NATURA® 2 SE device.

Testing: The subjects were evaluated across four listening conditions: Unaided, Analog, DSP (ALTAIR), and DSP+NR (NATURA 2 SE). Speech intelligibility in noise was measured using the Hearing in Noise Test [HINT; Nilsson, Soli, and Sullivan (1994)]. The HINT uses an adaptive procedure to determine the 50% intelligibility threshold for sentences in noise. The results are reported as dB sig-

nal-to-noise ratio (SNR) with lower scores indicating better performance. The HINT masker is steady-state noise filtered to match the long-term average spectrum (LTAS) of the sentences.

For all aided conditions the noise was presented at 65 dB A. For the unaided conditions, the masker was presented at 65 dB A when the unaided threshold in quiet was less than 55 dB A. In cases where the unaided threshold in quiet was greater than 55 dB A, the unaided threshold in noise was established with the masker level set at 10 dB sensation level (SL) with respect to the quiet threshold. This adjustment of the masker SL insured that the noise was audible for the unaided measurement.

In order to allow the DNR algorithm to engage, the HINT masker was modified to increase the onset time from 0.5 seconds to 5.0 seconds. The HINT sentences and masker were delivered from a single loudspeaker placed one meter away from the subject at 0° azimuth. This test configuration was very challenging, as the matched LTAS of the speech and masker limit spectral cues, and the single loudspeaker configuration eliminates spatial cues.

Procedure: Subjects were fit with the DSP hearing aids in a style and with options that matched their own analog hearing aids. DSP device fittings were conducted using the manufacturer's recommended protocol, and appropriate modifications were made based on an *in situ* dynamic range mapping procedure, probe microphone measurements, and subjective comments. After the fittings were determined to be satisfactory by both the subject and the investigator (Sandridge) during follow-up visits, the subject wore the DSP hearing aids for approximately one month prior to testing. Conclusion of Phase 1 of this study occurred with HINT measurements made in an audiometric test room during a single, two-hour test session. The testing order of the unaided and aided conditions was counterbalanced across subjects.

RESULTS

Audiogram: The audiometric profile for Site 3 is shown in Figure 1. The data are plotted as the mean values, with standard deviation and range of thresholds. The degree and slope of hearing loss is similar to the subject groups from Site 1 (Bray & Nilsson, 2000) and Site 2 (Bray & Valente, 2001).

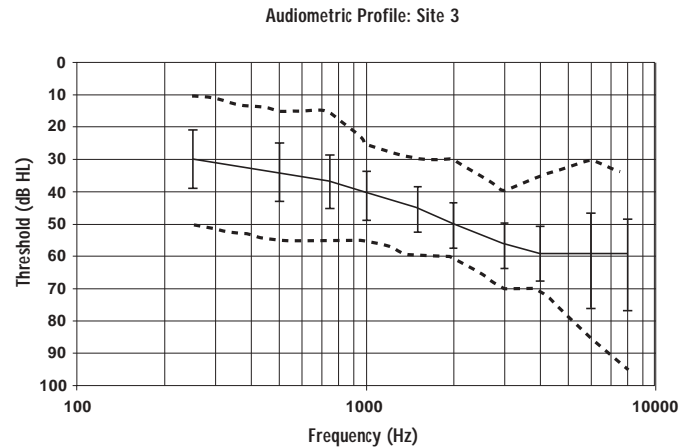


Figure 1: Audiometric profile for Site 3 showing the mean audiogram, standard deviation, and range for 23 subjects.

Speech Intelligibility in Noise: The mean HINT reception thresholds for sentences (RTS) in each listening condition at Site 3 are shown in Figure 2. The data show a significant effect for listening conditions [$F(3,66) = 9.67, p < 0.001$]. Post hoc analysis for repeated measures revealed (a) no significant difference between Unaided and Analog ($p = 0.23$), (b) a significant difference between Unaided and DSP ($p = 0.02$), (c) a significant difference between Unaided and DSP+NR ($p < 0.001$), (d) no significant difference between Analog and DSP ($p = 0.10$), (e) a significant difference between Analog and DSP+NR ($p < 0.001$), and (f) a significant difference between DSP and DSP+NR ($p = 0.03$).

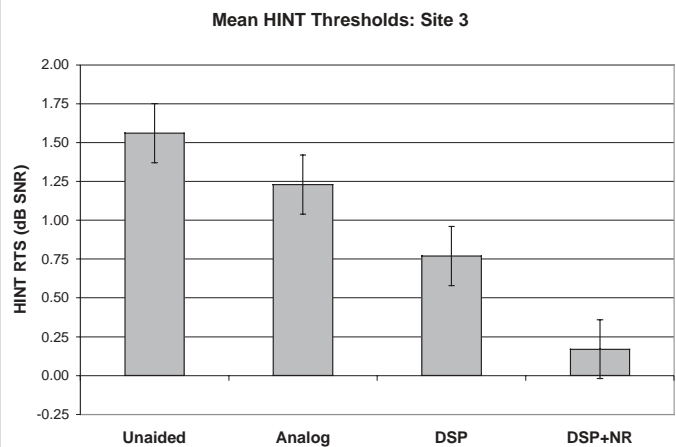


Figure 2: Mean HINT RTS values with error bars from Site 3 with 23 subjects. Listening conditions are Unaided, aided Analog, aided DSP, and aided DSP+NR.

The individual HINT RTS values for Site 3 are shown in Figure 3. The individual thresholds in the scatterplot are shown with unaided values on the x-axis and aided values on the y-axis.

If there were no difference for speech intelligibility in noise between the unaided and aided conditions, the data would fall on the diagonal line. Data points above the diagonal line indicate better performance unaided; data points below the diagonal line indicate better performance aided.

Compared to Unaided performance for the 23 subjects in this study, 15 subjects (65%) had as good or better performance in noise for the Analog condition, 16 subjects (70%) had as good or better performance in noise for the DSP condition, and 21 subjects (91%) had as good or better performance in noise for the DSP+NR condition.

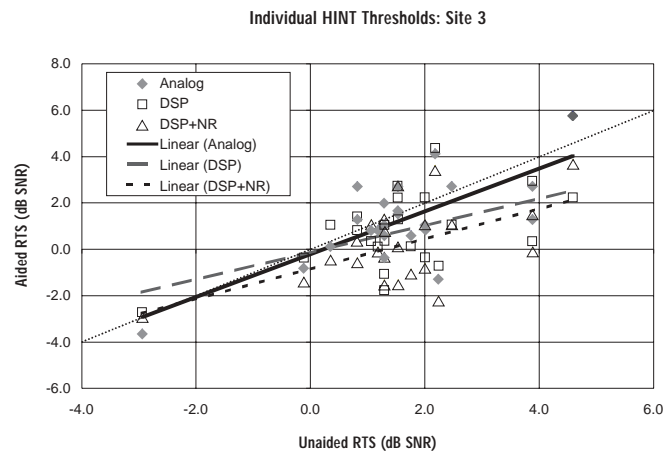


Figure 3: Individual HINT RTS values from Site 3. The dotted, diagonal line represents equal RTS scores unaided and aided. Regression lines are linear best-fit lines for the three aided conditions, with respect to the unaided condition.

DISCUSSION

Three test sites have evaluated the Unaided, DSP, and DSP+NR conditions employing identical test protocols and instrumentation. Two of these sites (Sites 2 and 3) also evaluated an Analog condition. In all cases, the rank order of performance for speech intelligibility in noise, from worst to best, was Unaided, Analog, DSP, and DSP+NR.

At Site 3 there was an overall significant improvement to speech intelligibility in noise from amplification. While the results provided by the Analog aids were not significantly different from the unaided condition, the result with DSP and DSP+NR were significantly better than unaided. In addition, the results with the DSP+NR hearing aid were significantly better than either the Analog or the DSP hearing aids.

Mechanism for Benefit: Sites 2 and 3 evaluated analog performance, and found the digital benefit in speech understanding in noise resulted from about 1/2 dB SNR improvement in the DSP condition combined with about 1/2 dB SNR improvement in the DSP+NR condition. It is interesting to note that while there was a significant difference between Analog and DSP only for Site 2 and a significant difference between DSP and DSP+NR only for Site 3, the combined difference between Analog and DSP+NR was significant for both Sites 2 and 3.

One hypothesized benefit from the 9-channel compression system over the 1- and 2- channel analog compression systems is improved frequency-shaping flexibility, allowing the DSP hearing aid to be better matched to the individual's hearing loss. Another hypothesized benefit from the 9-channel system is enhanced audibility for speech cues in noise resulting from narrowband, very-fast-acting compressors rather than wideband, slow compressors. The hypothesized benefit from the DNR algorithm is a signal processing improvement in the long-term, wideband SNR for steady-state noise in the presence of modulated speech (Bray & Nilsson, 2002). Additional experiments to test these hypotheses are in process.

Future Data Collection: It is of great interest to determine to what degree the 2-3 dB SNR improvement of DSP+NR over Unaided condition and the 1 dB improvement for DSP+NR over Analog condition represent clinical benefit perceptible to the subjects in the real world. Phase 2 of this study at Sites 2 and 3 has subjects alternating between their analog and DSP hearing aids at 30-day intervals in an A-B-A-B design. The order of analog first or DSP first is counterbalanced across subjects.

At the conclusion of each 30-day period, objective and subjective measures for the respective analog or DSP condition are obtained. Objective measures use the HINT in a quasi-free soundfield con-

dition, with the modified steady-state noise and new 4-, 8-, 12-, and 16-talker maskers (Nilsson et al, in submission). Subjective measures include the Profile of Hearing Aid Performance (Cox & Gilmore, 1990), Client Oriented Scale of Improvement (Dillon, James & Ginis, 1997), and International Outcomes Inventory (Cox, Hyde & Gatehouse, 2000). The results of Phase 2 testing at Sites 2 and 3 will be released in a follow-up publication and the results of the objective and subjective measures will be combined to address the issue of clinical significance.

CONCLUSION

The results from Site 3 are consistent with Sites 1 and 2 demonstrating that Sonic Innovations DSP hearing aids can improve speech intelligibility in noise without using directional microphones. The Site 3 results are also consistent with Site 2 demonstrating that use of the NATURA 2 SE hearing aids with DSP+NR significantly improved speech intelligibility in noise over the Analog condition. In addition, the Site 3 results are consistent with Site 1 indicating that the Sonic Innovations Personalized Noise Reduction™ algorithm provides significant additional benefit for speech intelligibility in noise over the no NR condition.

Contrary to previously published results, we find that (a) hearing aids with omni-directional microphones can improve speech intelligibility in noise, (b) a DSP hearing aid can outperform analog hearing aids, and (c) there is objective evidence for the benefit of a DNR algorithm.

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REFERENCES

Bray & Nilsson (2000). Objective test results support benefits of a DSP noise reduction system. *The Hearing Review*, 7(11): 60-65.

Bray & Nilsson (2001). Additive SNR benefits of signal processing features in a directional hearing aid. *The Hearing Review*, 8(12): 48-51, 62.

Bray & Nilsson (2002). What digital hearing aids can do: Another perspective. *The Hearing Journal*, 55(4): 60-64.

Bray & Valente (2001). Can omni-directional hearing aids improve speech understanding in noise? *Audiology Online*, September 24, 2001.

Cox & Gilmore (1990). Development of the profile of hearing aid performance (PHAP). *JSHR*, 33:343-357.

Cox, Hyde & Gatehouse, (2000). Optimal outcome measures, research priorities, and international cooperation. *Ear and Hearing*, 21:106S-15S.

Dillon, James & Ginis (1997). Client oriented scale of improvement (COSI) and its relationship to several other measures of benefit and satisfaction provided by hearing aids. *JAAA*, 8: 27-43.

Kuehnel & Checkley (2000). Advantages of an adaptive multi-microphone system. *The Hearing Review*, 7(5): 58-60, 74.

Larson, Williams & Henderson (2000). Efficacy of 3 commonly used hearing aid circuits. *JAMA*, 284(14): 1806-1813.

Newman & Sandridge (2002). Review of research on digital signal processing. In *Hearing Aids: Standards, Options, and Limitations*, M. Valente (ed). Thieme: New York.

Nilsson, Soli, & Sullivan (1994). Development of the Hearing In Noise Test for the measurement of speech reception thresholds in quiet and in noise. *JASA*, 95(2): 1085-1099.

Nilsson, Ghent, Bray, Enrietto, & Kornhass (manuscript submitted for publication). Development of test materials to evaluate noise reduction and directional hearing aids.

Ricketts & Dhar (1999). Comparison of performance across three directional hearing aids. *JAAA*, 10: 180-189.

Strom (2002). DSP: Past, Present, and Future. *The Hearing Review*, 9(1): 12-19, 52.

Walden, Surr, Cord, Edwards & Olson (2000). Comparison of benefits provided by different hearing aid technologies. *JAAA*, 11: 540-560.

