Understanding Speech in Noise: A new beginning for an age-old problem

AUDIBEL

Sarah R. Iverson, Au.D., CCC-A, Maddie M. Olson, Au.D., and Ben Waite, M.Eng.

Being able to help patients with hearing loss understand speech in noise is one of the main goals of a hearing aid, but not all hearing aid manufacturers apply the same philosophy to the problem. Audibel Intrigue AI hearing aids combine our new digital noise reduction algorithm with the benefits of directional microphones to provide patients with better speech understanding in noise, while achieving significant improvements in ratings of sound quality, speech clarity, and listening effort.

Introduction

As hearing aid technology evolves, one of the top goals remains the same: improving speech understanding in noise. A common complaint of patients with hearing loss is that even with hearing aids, they have difficulty hearing in background noise. From the MarkeTrak 2022 survey, respondents indicated lower overall satisfaction with the sound of their hearing aids than with physical aspects of their hearing aids. This was particularly seen in satisfaction with the hearing aids' ability to minimize background noise *(Picou, 2022)*. To combat the problem of background noise, most hearing aids fit today have both directional microphones and digital noise reduction. Directional microphones are known to provide benefit for speech understanding in background noise *(Ricketts & Hornsby, 2006; Walden et al., 2005)*. And while digital noise reduction features alone rarely show a benefit for speech understanding, when partnered with directional microphones, the combined features may provide other benefits, such as decreased objective listening effort *(Desjardins, 2015)*.

The Intrigue AI noise reduction system was designed with the goal of providing patients with the optimal mix of audibility, speech clarity, and listening comfort. Since the appropriate balance of these attributes varies with the listening environment, the Intrigue AI noise reduction system constantly analyzes the auditory scene to make decisions about when and how much noise reduction processing to provide. When the patient is in a loud and noisy environment, the noise reduction system prioritizes listening comfort and applies the greatest noise reduction. However, when the patient is in an environment with more speech content, the noise reduction system prioritizes audibility and clarity. In between these two extremes, the system will adjust automatically to a middle ground, providing an appropriate balance of audibility, clarity, and comfort.

As one example, imagine a trip to the grocery store. On the way to the store, car noise dominates the auditory scene; the loud, unmodulated noise is detected as undesired content and the noise reduction system prioritizes listening comfort and acts to suppress the noise.

When speech is introduced into the scene in the form of a car passenger, the system adjusts to a middle ground where the car noise is reduced, but the impact to speech is minimized so that speech is still audible. At the checkout counter, conversation with the store clerk is prioritized and the amount of noise reduction is significantly reduced to ensure audibility.

One of the aims in evaluating Intrigue AI was to assess the performance of the new Intrigue AI hearing aids and signal processing features, including the new additive compression architecture, the new e-STAT 2.0 fitting formula, and updated noise reduction algorithms and directionality. Specifically, two experiments were designed to demonstrate performance for speech understanding while listening in background noise (in this case, multi-talker speech babble). The first experiment was conducted to detail the combined effects of noise reduction and directional microphones on speech understanding in noise, quantified as the percent of sentences repeated correctly when presented in background noise at a fixed signal-to-noise ratio (SNR). This experiment also measured subjective impressions of speech in noise under the same listening conditions. The second experiment, completed using the QuickSIN test, was conducted to quantify performance as an estimated SNR loss, or the ratio of speech to noise needed for an individual with hearing loss to understand speech in noise in comparison to someone with normal-hearing sensitivity *(Killion, 1997)*. Although two different methodologies were used, the results from both experiments align: Intrigue AI provides significant benefit for hearing in noise.

Experiment 1

Participants

Forty-three participants, 27 males and 16 females, ages 45 to 87 years old, with an average age of 72 years old, completed testing in all conditions. The average hearing loss for the group was mild sloping to moderately-severe sensorineural hearing loss. Figure 1 shows the average audiogram of participants tested in Experiment 1.

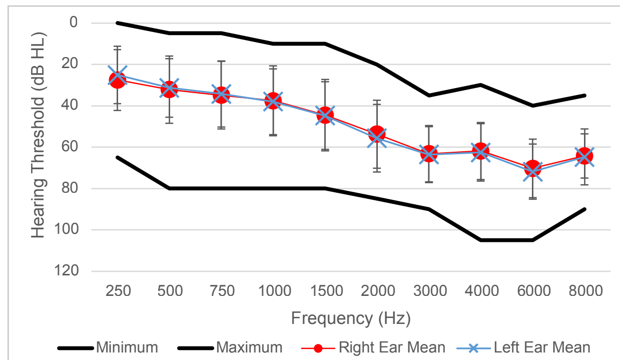

Figure 1: Average audiogram for participants in Experiment 1 (n=43). Red and blue lines and symbols show the average hearing thresholds for the right and left ears, respectively. The black lines show the minimum and maximum hearing thresholds for the group.

Methods

The first experiment was conducted to assess the combined effects of the Intrigue AI noise reduction algorithms and directional microphones on speech understanding in noise. Participants were fitted with Intrigue AI 24 rechargeable hearing aids in one of the following styles: Receiver-in-Canal (RIC RT) (n=14), Micro Receiver-in-Canal (mRIC R) (n=13), In-The-Ear (ITE R) (n=6), or In-The-Canal (ITC R) (n=10). All device styles had the same default noise reduction settings and adaptive-directional microphones. Hearing aids were programmed to e-STAT 2.0 using Pro Fit, Audibel's new fitting software.

This testing was conducted after participants had worn the Intrigue AI hearing aids in the field for six-to-eight weeks to acclimate to the devices. Laboratory testing was conducted in a randomized order for the following conditions:

- Unaided: No hearing aids
- NR Off + Omni: Hearing aids with noise reduction features turned off and microphones in an omnidirectional mode
- NR On + Omni: Hearing aids with noise reduction features at the default settings and microphones in an omnidirectional mode
- NR On + Dir: Hearing aids with noise reduction features at the default settings and microphones in the default adaptive-directional mode

Test Setup

Participants were tested in a sound booth set up to simulate a noisy restaurant, using an 8-speaker array with the participant seated in the center. Speech was presented from the front (0 degrees azimuth) and uncorrelated multi-talker babble noise was presented from the remaining seven speakers, summated to 67 dBA. Participants were asked to repeat two lists of IEEE sentences in each condition, for a total of 20 sentences per condition. To begin, sentences were presented in the NR Off + Omni condition, to calculate an SNR50, or the presentation level at which 50% of the sentences were repeated back correctly. During this initial testing, with each correct and incorrect repetition of a sentence, the presentation level of the speech was decreased 2 dB or increased 2 dB, respectively. The mean presentation level across all sentences in this initial NR Off + Omni condition was then used to test each of the four experimental conditions in randomized order. Thus, the SNR50 was individualized for each participant. Except for the unaided condition, participants were blinded to which condition was being tested.

Outcome Measures

There were four outcome measures assessed. The primary outcome measure was an objective measure of speech understanding in multi-talker babble, calculated by totaling the number of sentences for which all five target words were repeated back correctly by the participant. The other three outcome measures were subjective measures assessed using 7-point Likert scales, rated by the participant after each test condition. Those three subjective measures were ratings of sound quality, listening effort, and speech clarity.

Objective Results

Results are plotted in Figure 2, showing percentage of sentences correct in each condition: Unaided, NR Off + Omni, NR On + Omni, and NR On + Dir. The box plot displays the distribution of the data for each condition, such that the lines represent the range of the scores from minimum to maximum, and the boxes represent the first and third quartiles of the data, with the lines through the boxes representing the median result.

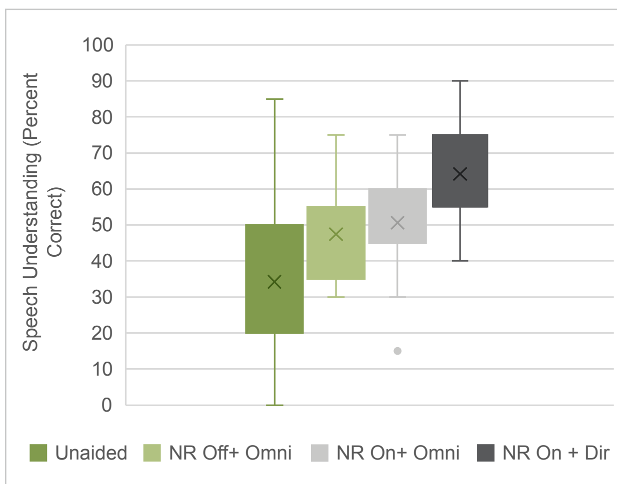

Figure 2: Box plot of speech understanding (plotted as percent of sentences correct) for IEEE sentences presented in multi-talker babble at the participant-specific SNR50 for the speech stimulus and 67 dBA for the noise stimulus. The "X" symbols represent the mean performance. The dot shows an outlier in the data.

A Friedman test revealed a statistically significant difference in speech understanding scores ($\chi^2(3)=49.99$, $p<0.001$) across conditions. Post-hoc analyses conducted using Wilcoxon Signed-Rank Tests are presented in Table 1. Blue highlighting shows the statistically significant findings ($p<0.05$). Asterisks indicate which condition had the statistically higher mean. Comparisons revealed improvement in speech understanding in noise for all aided conditions (NR Off + Omni, NR On + Omni, and NR On + Dir) over unaided. Additionally, comparisons revealed improvement in speech understanding in noise for NR On + Dir over the other aided conditions (NR Off + Omni and NR On + Omni). Importantly, the best speech understanding in noise performance was observed with the combination of default noise reduction and directionality settings that are used in the default Best Fit Personal Program from the Pro Fit fitting software.

Table 2 highlights the mean percent correct in each condition. Recall that this task was completed at an SNR50 established for each participant in the NR Off + Omni condition. Of note, the mean speech understanding score in noise improved 13% from unaided to amplification alone (NR Off + Omni) and an additional 17% with the noise reduction and directionality features active (NR On + Dir). Thus, average speech understanding in noise scores increased 30% from unaided to aided with the default noise management settings used in Intrigue AI.

Subjective Results

After each test condition, participants were asked to use 7-point Likert scales to rate their perception of the following: sound quality, speech clarity, and listening effort, with a 7 indicating the best perceptual rating. Perceptual findings are consistent with the objective data documented above, meaning that all aided conditions were found to be rated higher than unaided, and that the default NR On + Dir condition was rated higher than the other aided conditions. These findings are plotted in Figures 3, 4, and 5.

COMPARISON	*z*-VALUE	*p*-VALUE
Unaided: NR Off + Omni*	-3.814	<0.001
Unaided: NR On + Omni*	-4.069	<0.001
Unaided: NR On + Dir*	-5.352	<0.001
NR Off + Omni: NR On + Omni	-1.554	0.121
NR Off + Omni: NR On + Dir*	-4.880	<0.001
NR On + Omni: NR On + Dir*	-4.249	<0.001

Table 1: Wilcoxon Signed-Rank Tests for the objective speech understanding testing. Blue highlighting shows significant findings (p<0.05). The asterisk in each row indicates the condition which performed significantly better in each comparison.

TEST CONDITION	MEAN SPEECH
Unaided	34.14%
NR Off + Omni	47.44%
NR On + Omni	50.58%
NR On + Dir	64.14%

Table 2: Summary of mean speech understanding scores in multi-talker babble for each test condition.

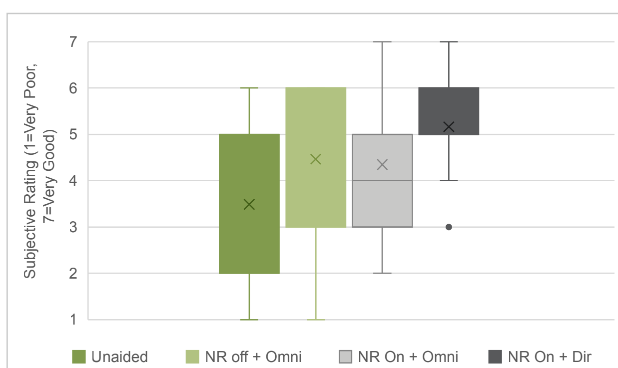

Figure 3: Box plot of sound quality ratings for speech presented in multi-talker babble (n=43). The "X" symbols represent the mean sound quality rating. The dot shows an outlier in the data.

These results indicate that the default hearing aid programming with Intrigue AI, using e-STAT 2.0 with directional microphones and noise reduction, not only provided significantly better speech understanding, but was also preferred over all other conditions for sound quality, speech clarity, and listening effort for speech presented in multi-talker babble.

Friedman tests conducted to examine ratings across each of the conditions revealed that there was a statistically significant difference in the ratings for each perceptual domain: sound quality ($\chi^2(3)=29.71$, $p<0.001$), speech clarity ($\chi^2(3)=17.31$, $p<0.001$), and listening effort ($\chi^2(3)=38.39$, $p<0.001$). Post-hoc analyses conducted using Wilcoxon Signed-Rank Tests revealed improvements in perceived sound quality, speech clarity, and listening effort for all aided conditions over unaided. Additionally, comparisons revealed that the default NR On + Dir condition was rated significantly higher than all of the other aided conditions for each of the three subjective domains. Results of the analyses are presented in Table 3. Blue highlighting shows the statistically significant findings ($p<0.05$). Asterisks indicate which condition had the statistically higher mean.

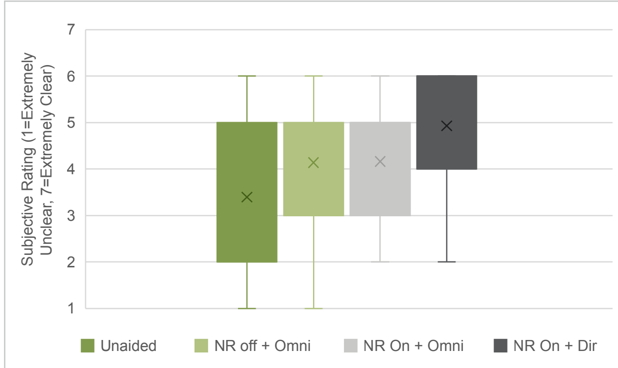

Figure 4: Box plot of speech clarity ratings for speech presented in multi-talker babble (n=43). The "X" symbols represent the mean speech clarity rating.

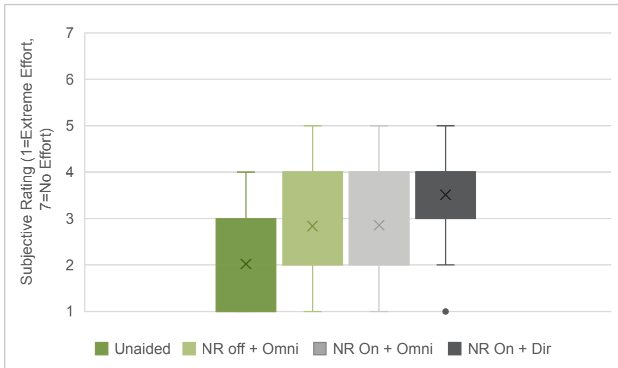

Figure 5: Box plot of listening effort ratings for speech in multi-talker babble (n=43). The "X" symbols represent the mean listening effort rating. The dot shows an outlier in the data.

	SOUND QUALITY		**SPEECH CLARITY**		**LISTENING EFFORT**	
COMPARISON	***z*-VALUE**	***p*-VALUE**	***z*-VALUE**	***p*-VALUE**	***z*-VALUE**	***p*-VALUE**
Unaided: NR Off + Omni*	-2.910	0.003	-2.540	0.011	-3.484	<0.001
Unaided: NR On + Omni*	-2.800	0.005	-2.551	0.012	-3.929	<0.001
Unaided: NR On + Dir*	-4.701	<0.001	-4.469	<0.001	-5.018	<0.001
NR Off + Omni: NR On + Omni	-0.357	0.719	-0.205	0.834	-0.076	0.936
NR Off + Omni: NR On + Dir*	-2.618	0.009	-2.966	0.003	-3.146	0.002
NR On + Omni: NR On + Dir*	-3.171	0.002	-3.211	0.001	-2.854	0.004

Table 3: Wilcoxon Signed-Rank Tests for sound quality, speech clarity, and listening effort ratings for speech in multi-talker babble. Blue highlighting shows significant findings (p<0.05). An asterisk indicates the condition which performed significantly better in the comparison.

Experiment 2

Participants

Thirty-three participants, 23 men and 10 women, ages 57 to 84 years old, with an average age of 72 years old, completed unaided and aided QuickSIN testing. The average hearing loss for the group was mild sloping to moderately-severe sensorineural hearing loss. Figure 6 shows the average audiogram of participants tested in this study.

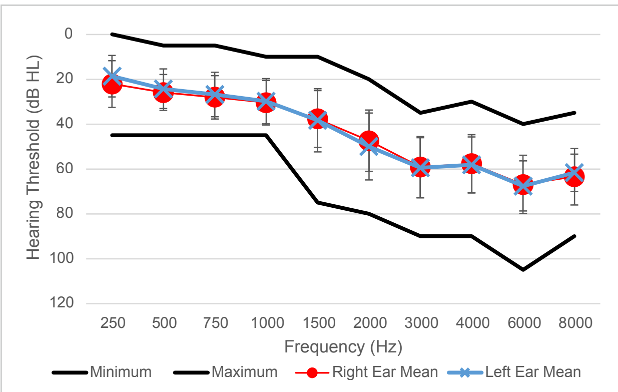

Figure 6: Average audiogram for participants in Experiment 2 (n=33). Red and blue lines and symbols show the average hearing thresholds for the right and left ears, respectively. The black lines show the minimum and maximum hearing thresholds for the group.

Methods

Participants were tested with the QuickSIN to compare estimated SNR loss for unaided and aided conditions. Participants were fitted with Intrigue AI 24 rechargeable hearing aids in one of the following styles: RIC RT (n=11), mRIC R (n=9), ITE R (n=6), or ITC R (n=7). All device styles had the same default noise reduction settings and adaptive-directional microphones. Hearing aids were programmed to e-STAT 2.0 using the Pro Fit fitting software. This testing was conducted after participants had worn the Intrigue AI hearing aids in the field for four to six weeks to acclimate to the devices. Participants were randomized as to whether they completed the unaided or aided testing first.

Test Setup

The QuickSIN test estimates the SNR loss compared to normal-hearing individuals by presenting a list of six IEEE sentences, each with five target words, in multi-talker babble noise. The SNRs decrease for each sentence in 5 dB steps from 25 to 0, as the noise level increases *(Killion et al., 2004)*. Two lists of six sentences were presented in each condition for this study. The speech and noise sources were spatially separated by 180 degrees; speech was presented from a speaker at 0 degrees azimuth and the babble noise was presented from a speaker at 180 degrees azimuth, with the participant seated centered between the speakers. The setup was calibrated to 65 dBC.

The QuickSIN assigns ranges of estimated SNR loss to degrees of SNR loss, calculated using the formula 25.5 – (total words correct) *(Killion, 2004)*. The categories assigning SNR loss to degree of SNR loss are as follows:

- 0-3 dB is normal/near normal SNR loss
- 3-7 dB is a mild SNR loss
- 7-15 dB is a moderate SNR loss
- >15 dB is a severe SNR loss

Outcome Measure

The primary outcome measures were the unaided and aided estimated SNR loss as measured by the QuickSIN.

Results

A Wilcoxon Signed-Rank Test revealed that aided QuickSIN performance was significantly better than unaided performance ($z=-2.961$, $p=0.002$), indicating that participants could perform the task in a more challenging SNR with Intrigue AI than they could without hearing aids. More interesting, however, are the results when individuals are grouped into the four performance categories above based on their unaided estimated SNR loss. Average unaided and aided QuickSIN results for each group are plotted in Figure 7.

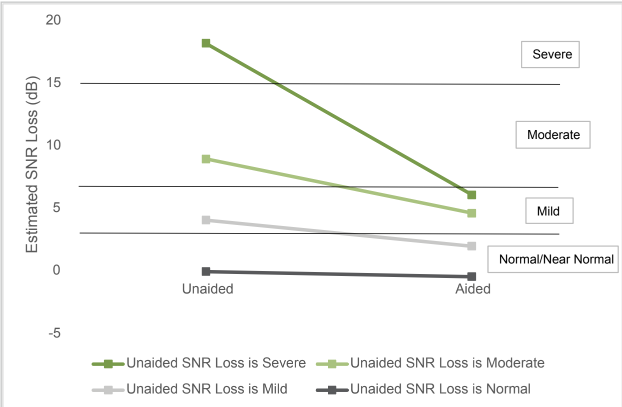

Figure 7: Line plot showing the average change in estimated SNR Loss categorized by estimated unaided SNR loss (n = 33).

Looking at the means plotted in Figure 7, for participants in the unaided severe or moderate SNR loss range, Intrigue AI improved their performance, bringing their aided SNR loss into the mild range. For participants in the unaided mild SNR loss range, their performance with Intrigue AI brought their aided SNR loss into the normal/near-normal range.

Individuals whose unaided SNR loss fell into the normal/near-normal range showed essentially no improvement as they were already at or near their best performance in the unaided condition. These results suggest that those participants that may need assistance the most in noise (ie., have the poorest unaided SNR loss), tend to benefit the most from Intrigue AI hearing aids.

Conclusions

Intrigue AI hearing aids use a new additive compression architecture, with new digital noise reduction algorithms and directionality to provide patients with aided benefit in the presence of background noise. These algorithms apply a more finely tuned approach to manage noise in the presence of speech. To help prevent loss of speech content from an overly aggressive noise reduction system, input levels and signal-to-noise ratios dictate the processing applied to the signal. Low-level noise is treated differently than loud noises in order to retain as much speech as possible while reducing the overall noise level.

With these updates to Intrigue AI, the goal is not only to ensure that speech is audible, but also to provide an overall positive listening experience with optimal speech clarity and listening comfort.

As hearing in noise continues to be one of the primary drivers of patient satisfaction with hearing aids *(Picou, 2022)*, improvements to technology in this area are essential. With the Intrigue AI default noise reduction and directionality features, average speech understanding scores in multi-talker babble increased 30% over unaided performance, and 13% over amplification without these features. Subjective ratings of sound quality, speech clarity, and listening effort were also significantly better than unaided and amplification without these features. Additionally, QuickSIN testing revealed that those with greater SNR loss when unaided tended to benefit the most with Intrigue AI than those with less SNR loss. Taken together, the results of these two experiments provide evidence that Intrigue AI provides hearing aid users with significant speech intelligibility benefit in noise.

References

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Author Biographies

Sarah Iverson, Au.D., CCC-A, joined Starkey in 2021 as a Research Audiologist. She earned her B.A. at the University of Minnesota and her Au.D. at Northwestern University in Illinois. Her work at Starkey covers clinical validation of hearing aids prior to market release. Dr. Iverson works to include clinically relevant outcome measures in her research. Other areas of interest include competitive benchmarking and product usability, with the goal of ensuring hearing aids are meeting patient needs.

Maddie Olson, Au.D. joined Starkey as a Research Audiologist in 2021, and earned her Au.D. at the University of Wisconsin - Madison. She organizes product validation efforts to evaluate hearing technologies prior to market release, ensuring patients' needs are being met. Additionally, Dr. Olson evaluates device efficacy over the lifetime of hearing aids, allowing for longitudinal assessment of patient benefit, through post-market studies. She is particularly interested in areas of research that help to investigate long-term, positive patient outcomes for hearing aid users.

Ben Waite, M.Eng, is a Senior Firmware Engineer at Starkey who specializes in compression and noise reduction algorithms. Ben joined Starkey in 2014 and has held several roles within the Research and Development department, spanning Feature Management, Systems Engineering and Firmware Development teams. Since joining the team, Ben has made significant contributions to the design and implementation of various hearing aid features, as well as the development of simulation tools that are used to better understand and evaluate hearing aid algorithms.