In the hearing instrument world, evidence-based design (EBD) is an essential component of the product-development process. It is aimed at: (1) ensuring that the product is reliable and functions as intended, and (2) ensuring that the product provides a measurable, real-world benefit to users. From this point of view, a successful noise-management algorithm must improve subjective comfort in noise without degrading objective speech intelligibility for the hearing aid user.\(^1,2\) Although these objectives seem straightforward, earlier iterations of noise-management algorithms had difficulty meeting both goals.

First-generation algorithms attempted to apply an overall gain reduction in response to broadband, unmodulated “noise” at relatively high input levels.\(^3\) While these early algorithms were able to improve subjective comfort in response to higher levels of environmental noise, they had two main drawbacks: slower time constants and a lack of specificity. The result was an inability to decrease gain for noise without also decreasing gain for speech.\(^4\)

Second-generation algorithms attempted to correct this problem by using faster time constants and varying the input levels at which gain reduction for noise was applied.\(^5\) These algorithms had limited success, as researchers had difficulty demonstrating improved speech understanding in noise or user preference for these types of noise-reduction schemes in the field.\(^6-8\)

As third-generation noise-management algorithms begin to emerge, manufacturers are trying various methods to improve their performance. Yet, proving efficacy for this type of technology remains elusive.\(^9,10\) Although some studies have shown improved comfort and sound quality\(^1,11\) and others have objectively demonstrated enhanced or unchanged speech understanding in noise, the debate over their benefits to users is far from over.\(^11,12\) However, as the potential for improved patient benefit from a third-generation algorithm grows, Starkey Laboratories has developed a fast-acting noise adaptation system called Voice iQ.

Voice iQ was initially developed at the Starkey Hearing Research Center (SHRC) in Berkeley, CA, with the intent to create a noise-reduction algorithm fast enough to reduce gain during the pauses in speech over a broad range of input levels, while achieving the combined goals of maintaining comfort without reducing speech intelligibility in noise. The system detects and continually monitors the spectral and temporal characteristics of both speech and noise levels to estimate signal-to-noise ratio (SNR). Fast-acting gain adaptation is applied to unmodulated noise sources during the gaps in speech, even at lower input levels. Voice iQ initiates gain adaptation at a +5-dB SNR and reaches its maximum potential for gain reduction at 0-dB SNR, attempting to optimize performance as the listening environment becomes more challenging.

**STUDY OBJECTIVES**

Preliminary research conducted at the SHRC confirmed the efficacy of fast-acting noise management by demonstrating that the algorithm worked as designed in a laboratory environment and was preferred by the majority of hearing-impaired participants involved in multiple field trials. Once the project was transferred to Starkey’s headquarters in Eden Prairie, MN, additional clinical trials with hearing-impaired patients were conducted to further refine the algorithm parameters and
evaluate if it provided patient benefit in the real world for various device styles and degrees of hearing loss.

In the latest clinical trial, the authors assessed the effect of Voice iQ on speech understanding in noise, subjective tolerance for noise while attending to speech, and hearing aid performance in real-world listening environments.

CLINICAL TRIAL METHODS

Participants

We conducted a clinical trial over a period of 8-10 weeks that included 44 adults with varying degrees of hearing loss (Figure 1). Study participants (15 female, 29 male) ranged in age from 22 to 78 years with a mean of 59.7 years. Both new and experienced users of hearing instruments were included. The five styles used for this investigation were in-the-canal (ITC), receiver-in-the-canal (RIC) in both an “open-ear” configuration (115/50) and a high-power (131/71) custom-occluded configuration, behind-the-ear (BTE) with a 13 battery and standard tubing, and a BTE with a 312 battery and thin tubing. All study participants were fitted bilaterally and participated in a minimum of four laboratory sessions.

Hearing aid fitting

Starkey’s proprietary fitting formula, eSTAT, was used for the initial fitting of each test device. We conducted real-ear probe-microphone measurements using the Audioscan Verifit hearing aid analyzer on all fittings to evaluate the frequency response of the initial prescriptive fit (i.e., first fit) to eSTAT. To evaluate audibility for soft sounds and comfort for loud sounds, we obtained real-ear measurements using the International Speech Test Signal (ISTS)\(^\text{13}\) at 50, 65, and 75 dBA and a pure-tone sweep at 85 dBA SPL. The test devices were fine-tuned during each laboratory session, as needed, based on patient reports of performance and comfort with the devices in real-world listening situations.

On average, the mean real-ear aided response (REAR) of the test devices generated outputs equal to or greater than the subjects’ own hearing instruments. During each field trial, the devices were programmed with the full complement of digital signal processing, including: Voice iQ, wind and machine noise management, InVision directionality, and PureWave Feedback Eliminator.

RESULTS

Objective testing

After the participants had worn the test hearing aids for approximately 3 weeks, we used the Hearing in Noise Test (HINT)\(^\text{14}\) to objectively evaluate their ability to understand speech in noise. Administration of the HINT incorporated 20-sentence lists presented at 0º azimuth with uncorrelated speech-shaped noise generated at 65 dBA from seven additional speakers surrounding the subjects. Testing was conducted in four hearing instrument conditions: (1) omnidirectional mode with Voice iQ disabled, (2) omnidirectional mode with Voice iQ enabled, (3) directional mode with Voice iQ disabled, and (4) directional mode with Voice iQ enabled. A lower HINT score signifies better performance.

We analyzed the data using a one-way repeated-measures analysis of variance (RMANOVA) with a Bonferroni correction for multiple comparisons. Figure 2 shows the average HINT results (dB SNR) for the four test conditions. There were no significant differences in mean SNR scores between the two omnidirectional conditions, nor was there a significant difference between the directional conditions (p>0.05). The average SNR scores of -3.26 dB and -3.24 dB SNR, for the directional and the directional-plus-Voice iQ conditions, respectively, represented a significant improvement (p<0.001) over the omnidirectional conditions of approximately 2.6 dB. The lack of any significant difference between the Voice iQ-on versus Voice iQ-off conditions, in either the omnidirectional or directional condition, suggests that directionality, not Voice iQ, was responsible for the improvement in speech understanding on the HINT.

As stated in the introduction, the goal of a noise-management algorithm is to improve listening comfort in noise without degrading speech understanding. These findings demonstrated that Voice iQ met the design goal of not adversely affecting speech intelligibility in either omnidirectional or directional-microphone configurations.

Subjective testing

In addition to evaluating speech understanding via the HINT, we assessed perceived comfort in noise. For this evaluation, we conducted the Acceptable Noise Level (ANL) test\(^\text{15,16}\) using the same four hearing aid conditions described for the HINT. Since the potential additive benefit of directionality was of interest in this test, administration of the ANL was modified by presenting...
running speech from 0º azimuth and uncorrelated speech-shaped noise from 180º azimuth.

Participants were instructed to obtain their most comfortable loudness level (MCL) for speech and their tolerable background noise level (BNL) for noise in relation to the running speech. The results were averaged across two runs for each test condition. The BNL was then subtracted from the MCL to derive a participant’s average ANL. A lower ANL score signifies tolerance for higher noise levels while attending to the speech signal.

We analyzed the data using a one-way RMANOVA with a Bonferroni correction for multiple comparisons. Figure 3 shows the average ANL results (dB) for the four test conditions. Mean ANL scores ranged from +2.0 dB in the omnidirectional condition to -1.33 dB in the directional-plus-Voice iQ condition. Despite a high degree of individual variability, the improvement of 3.33 dB in the directional-plus-Voice iQ condition versus the omnidirectional condition was significant (p<0.001). The trend shown in Figure 3 suggests an increase in subjective comfort in noise using the Voice iQ algorithm over both the omnidirectional-only and directional-only conditions.

**Real-world performance**

To gauge the real-world performance of Voice iQ and assess user benefit in the field, we had the participants complete Form C of a questionnaire called the Device Oriented Subjective Outcome Scale (DOSO). Form C is a 24-item outcome assessment focused on speech cues and listening effort in an attempt to measure benefit received from wearing the test devices in a variety of listening environments.

Participants were asked to rate the performance of the hearing instruments on a seven-point scale where a value of 1 indicated very poor performance and 7 was considered excellent performance in various social situations. Participants assessed the performance of their own hearing aids at the start of the clinical trial and rated the test hearing aids at the conclusion of the study.

Figure 4 summarizes the average performance ratings for participants’ own devices and for the test instruments. These average results indicated that the test devices outperformed the participants’ own devices in a various real-world scenarios as indicated by significantly higher scores for the test devices on the Listening Effort and Speech Cues subscales (P<0.001), using a Wilcoxon signed rank test.

**DISCUSSION**

Since Voice iQ was designed with the needs of persons with hearing loss in mind, the goals of this study were to validate the performance of the noise-reduction algorithm and to measure patient benefit in the field. The major findings of this clinical trial revealed:

- The addition of a fast-acting noise-reduction algorithm, such as Voice iQ, did not adversely affect speech intelligibility as measured using the Hearing in Noise Test (HINT).
- Voice iQ significantly improved subjective comfort in noise as measured via the Acceptable Noise Level (ANL) test.
Participants consistently rated real-world performance of the test hearing instruments with Voice iQ higher than that of their own hearing aids. The results of this clinical trial indicate that Voice iQ met the design goals of providing a fast-acting, noise-reduction algorithm capable of both identifying and reducing gain for unwanted noise during the pauses in conversational speech. As a result, new and experienced hearing aid users demonstrated increased tolerance for noise without any decrease in their ability to understand speech. Additionally, participants reported increased benefit in real-world environments compared to their own hearing aids.

In future clinical trials, researchers at Starkey Laboratories will continue to evaluate the performance of the Voice iQ noise-adaptation algorithm to confirm the current findings and address unanswered research questions. For instance, research will attempt to derive user preference for various gain adaptation presets offered in the Inspire fitting software. Thus, Starkey will continue to pursue an evidence-based approach to making design decisions on emergent technology.

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