

IMPROVING THE PATIENT EXPERIENCE IN NOISE: FAST-ACTING SINGLE-MICROPHONE NOISE REDUCTION

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Background

Hearing-impaired listeners experience their greatest auditory challenges when listening in noise (Plomp, 1994; Kochkin, 2002). For this reason, developers of hearing instruments have made improving patient satisfaction when listening in noise an important goal. This paper introduces SpeechTrax, a new Digital Noise Reduction (DNR) algorithm available in the MicroTech Axio™ ST family of hearing instruments. Originally developed at our Hearing Research Center, SpeechTrax has undergone numerous research and clinical trial evaluations. These studies quantified two outcomes: first, ensuring that the aggressive noise suppressing nature of SpeechTrax does not degrade speech quality or understanding, and second, demonstrating improved ease of listening in noise.

A review of the research literature shows that DNR algorithms may improve comfort and sound quality when listening in noise (Bentler & Chiou, 2006; Mueller, Weber, & Hornsby, 2006; Ricketts & Hornsby, 2005). Listeners may also experience a decrease in listening effort as a result of DNR when listening in noise (Sarampalis, Kalluri, Edwards, Hafter, 2009). Sarampalis and colleagues suggest that reducing listening effort through the use of a DNR algorithm may improve a patient's ability to focus on a secondary task. This hypothesis originates from the theory that attention is drawn from a single, finite, cognitive resource (Baddeley, 1998). In other words, if a DNR algorithm can reduce the effort required to understand speech in noise, the hearing-impaired listener will be able to allocate more cognitive resources to a secondary task. Additionally, an idealized goal of any DNR algorithm would be the improvement of speech recognition in noise; however, research in this area suggests that patients may experience improved, decreased, or unchanged speech understanding, depending upon the test conditions (Galster & Ricketts, 2004; Mueller et al., 2006). The apparent lack of consistency throughout the literature reinforces the fact that improved speech understanding remains an elusive goal for DNR. However, because modern DNR algorithms reduce output in order to manage undesirable noise, it follows that a poorly designed algorithm risks degrading speech cues and compromising the audibility of speech.

Digital Noise Reduction Behavior

Traditional DNR algorithms have worked in a binary manner when processing speech and noise. If noise is the dominant signal in a hearing aid channel, a traditional DNR algorithm reduces gain in that channel by a specified amount; when speech is the dominant signal, the prescribed gain is unaffected. If the DNR algorithm responds slowly, the result is DNR that is inactive in the presence of speech and only active in high levels of noise. SpeechTrax benefits from voice-finding technology that allows for near-instantaneous classification of desired speech or unwanted noise. The fast and accurate identification of speech allows SpeechTrax to analyze and adapt at speeds fast enough to reduce segments of noise within sentences and speech.

Figure 1 is an illustration of overlapping noise (red) and speech (black). SpeechTrax uses a number of cues, such as signal-to-noise ratio, overall level and signal modulation to classify acoustic environments. Speech is highly modulated whereas noise is typically more steady state in nature. The modulations of speech allow SpeechTrax to identify noise as it becomes the dominant signal during the gaps in speech. When noise is identified in any channel, the gain in that channel is quickly reduced and reapplied as soon as the speech signal returns — this behavior is illustrated in Figure 2. In the case of fast-acting DNR algorithms such as SpeechTrax, special consideration must be made to avoid the reduction of speech cues.

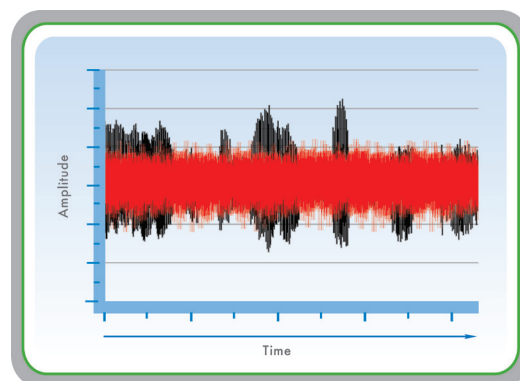


Figure 1. Illustration of a noise waveform in red, overlapping a speech waveform in black.

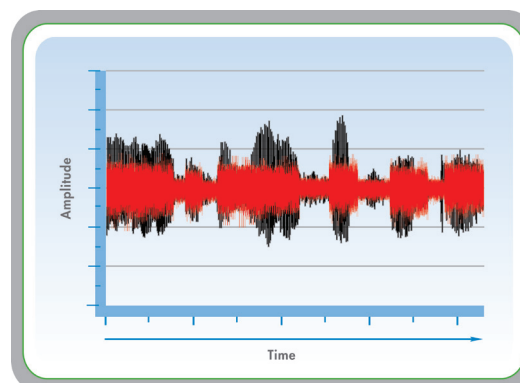


Figure 2. Illustration of noise in red, overlapping a speech waveform in black. This illustration demonstrates the behavior of SpeechTrax to suppress noise between gaps in running speech.

Evaluation of Digital Noise Reduction Algorithms

Developed at our Hearing Research Center, SpeechTrax underwent a battery of sound quality studies throughout research and development. Individual parameters of the algorithm were adjusted to accommodate the listening preferences of patients and to ensure that the algorithm was appropriately targeting noise in the gaps of speech. These early studies were completed prior to the implementation of the SpeechTrax in a hearing aid. By focusing early development outside of the hearing aid platform, appropriate adjustments were easily made. After establishing algorithm parameters that ensured patient success in a laboratory setting, the next step was clinical validation of SpeechTrax in the Axio ST hearing aid.

The successful transfer of SpeechTrax to the MicroTech Axio ST hearing aids was validated through systematic clinical research. Forty-four hearing-impaired adults participated in a comprehensive clinical trial. Detailed results of this clinical trial are presented and discussed by Pisa, Burk, and Galster (In Press). In their study, the authors found that the Axio ST hearing aids significantly improved patients' ability to tolerate noisy environments. Participants also reported reduced listening effort, as measured by the Device-Oriented Subjective Outcome Scale (DOSO) (Cox, Alexander & Xu, 2009), with the test devices when compared to their own hearing aids.

Preservation of Speech in Noise

A system that is designed to reduce noise between gaps in speech must also retain the integrity of the valuable speech signal. Because speech modulations occur over a period of milliseconds, this can be a challenging task. If hearing aid output is reduced during gaps in speech, appropriately prescribed gain must be reapplied to the speech signal when it returns. A poorly designed noise reduction algorithm may not accurately track speech modulations, thereby compromising the integrity of the speech signal. A major design focus of SpeechTrax was to ensure the preservation of these speech cues while aggressively reducing noise.

An electroacoustic benchmarking evaluation developed by Hagerman and Olofsson (2004) was used to illustrate the speech-preserving capability of SpeechTrax. This evaluation method allows for the extraction of speech from a background of noise after processing through a digital noise reduction algorithm. For the purpose of this paper, the extracted waveforms are used to provide a qualitative visual example of how digital noise reduction algorithms implemented in today's hearing aids may distort or reduce speech when presented in background noise.

The test method developed by Hagerman and Olofsson (2004) is described in an excerpt from their publication: Our approach is to present speech and noise simultaneously and make two measurements, one of them with the noise phase reversed. Taking the sum of the corresponding two output signals, or the difference, the output speech or the output noise can be extracted. Thus, the gain can be calculated for each of them, although they are present at the same time and influence the signal processing of the hearing aid in a normal way. (p. 356)

Figures 3 and 4 show speech waveforms extracted from a background of noise using the Hagerman and Olofsson benchmarking evaluation. In Figure 3, a fast-acting noise reduction algorithm, currently available from a leading hearing instrument manufacturer, was used to process the speech and noise signals. In figure 3, it is readily apparent that the speech peaks have been compromised by the noise-reduction algorithm. Figure 4 shows the effect of SpeechTrax on the same speech and noise samples. The lack of difference between the green and gray waveforms highlights the success of SpeechTrax in maintaining the integrity of the speech signal, even while effectively reducing noise levels.

It was important to reinforce the electroacoustic evaluation of SpeechTrax with perceptual measures of speech understanding. Forty-four hearing-impaired adults completed the Nonsense Syllable Test (NST) (Resnick, Dubno, Hoffnung & Levitt, 1975) after being fit with Axio ST hearing aids, the results of which are shown in Figure 5. The mean group performance without SpeechTrax was 54.1 percent correct, with SpeechTrax activated the mean performance of the same group was 55.4 percent correct, a difference of 1.3 percentile points. A one-way repeated-measures analysis of variance with a Bonferroni correction for multiple comparisons showed this difference to be insignificant ($p > .05$); the absence of a significant difference indicates that even when evaluating easily degraded high-frequency speech components, SpeechTrax retains the integrity of that speech signal.

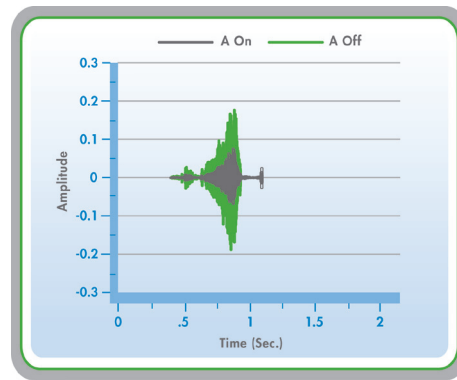


Figure 3. Two speech waveforms are shown, the green is speech processed through a hearing aid with no noise reduction, the gray waveform is speech processed through a commercially available digital noise reduction algorithm. Both examples are extracted from a background of noise using the Hagerman and Olofson (2004) evaluation technique. The green waveform shows the effect of a competitive digital noise reduction algorithm on the speech waveform.

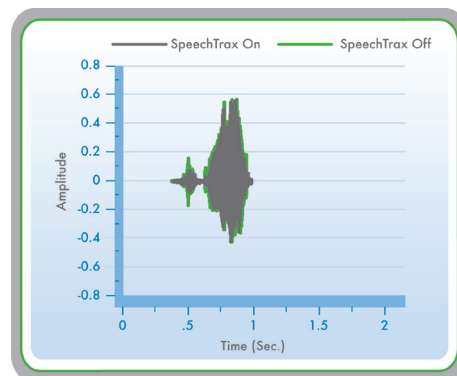


Figure 4. Two speech waveforms are shown, the green is speech processed through the Axio ST with no noise reduction, the gray waveform is speech processed through the same Axio ST with SpeechTrax active. Both examples are extracted from a background of noise using the Hagerman and Olofson (2004) evaluation technique. The gray waveform shows the minimal effect of SpeechTrax on the speech waveform.



Figure 5. Percent correct on the nonsense syllable test (NST) with and without SpeechTrax digital noise reduction processing.

Summary

Data collected from over 40 hearing-impaired research participants have demonstrated the benefits of SpeechTrax and the Axio ST hearing aids. Based on these findings, professionals fitting an Axio ST instrument can expect patients to experience improved comfort and ease of listening in noise without sacrificing valuable speech cues.

Documenting and understanding the benefits of digital noise reduction has challenged the hearing aid industry for years. This new body of data surrounding SpeechTrax and the Axio ST family of hearing aids helps to establish clinical expectations for modern digital noise reduction. By ensuring the integrity of speech, while documenting patient preferences and benefits, SpeechTrax represents the paradigm of an evidence-based design.

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