Evaluation of Objective and Subjective Benefit of a Novel Frequency-Lowering Algorithm

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Starkey Hearing Technologies

Introduction

A common goal for most hearing aid fittings is to restore access to speech information that has been lost as a result of hearing loss. At the most elementary level, this has traditionally been achieved by applying appropriate levels of gain across the channels of a hearing aid to restore audibility for speech level inputs while maintaining comfort for louder level inputs. Despite advances in compressor and prescriptive fitting approaches, in some cases, the hearing loss is so severe in certain frequency regions that it is not possible to achieve audibility within that particular frequency region of the cochlea. Therefore, frequency-lowering technologies were developed to restore access to high-frequency speech information such as consonant sounds. In addition, a useful byproduct of this technology is a reduction in the potential for feedback due to decreased high-frequency gain requirements. Currently, three distinct types of frequency-lowering technology are available in hearing aids: 1) nonlinear frequency compression, 2) linear frequency transposition and 3) spectral envelope warping.

In this study, subjects with varying degrees of hearing loss were fit with custom or receiver-in-canal (RIC) hearing aids and a new frequency-lowering algorithm (Spectral iQ; Starkey Hearing Technologies). Spectral iQ uses real-time spectral envelope warping to reproduce high-frequency spectral information in a lower frequency region where audibility can be achieved with less high-frequency gain. Over a six-week clinical evaluation, objective performance and subjective outcomes were measured with a variety of laboratory and field tests, including a final consonant identification speech test and subjective outcome measures evaluating perceived sound quality and speech understanding. Specifically, objective tests and subjective measures focused on:

- Plural identification
- Speech recognition in noise
- Patient perceived sound quality
- Patient perceived speech understanding

Background

The primary goal of spectral envelope warping technology is to provide access to high-frequency speech cues in participants with steeply-sloping, moderately-severe to profound high-frequency hearing loss. This access creates the potential to improve speech intelligibility performance. The algorithm, illustrated in Figure 1, identifies high-frequency spectral peaks and replicates the envelope of this high-frequency information around a lower target frequency. The newly introduced spectral envelope is mixed with the amplified pathway. The replicated stimulus cue is only presented while the corresponding high-frequency energy is present; otherwise, the amplified pathway is maintained[1,2].

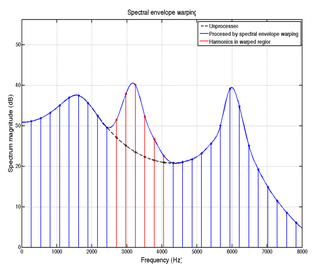

Figure 1: Spectral peak is identified at 6 khz and replicated at 3.1 kHz as indicated by the red area, which is within the patient's audable hearing range (figure obtained with author permission from Acoustics Today, July 2011) [2].

Adjustments to the spectral envelope warping algorithm (Spectral iQ) can be made through Starkey Hearing Technologies' Inspire programming software (see Figure 2). Two major parameter adjustments can be performed: 1) Translated bandwidth: the range of frequencies over which the algorithm will look for spectral peaks to translate and the bandwidth of frequencies it will translate the peaks into and 2) Translated gain: which adjusts the amplitude of the translated signal.

Figure 2: Screenshot of Spectral iQ controls in Inspire software (Starkey Hearing Technologies).

Research Questions

- Do participants perform significantly better on an objective test of speech perception when fit using spectral envelope warping versus using conventional processing?
- Do participants who are candidates for spectral envelope warping (as determined by the audiogram) perceive significant benefit to subjective speech understanding?
- Do participants fit with spectral envelope warping report acceptable sound quality?

Methods

Participants

- 20 adults with varying degrees of sensorineural hearing loss. The average audiogram is shown in Figure 3.
- Participants (3 female, 17 male) were 57 to 80 years with a mean age of 68.8.
- All participants were experienced users of hearing instruments, although none had experience with frequency-lowering technology.
- Participants were fit bilaterally with Completely-in-the-Canal (CIC), In-the-Canal (ITC), In-the-Ear (ITE), and Receiver-in-the-Canal (RIC) devices.

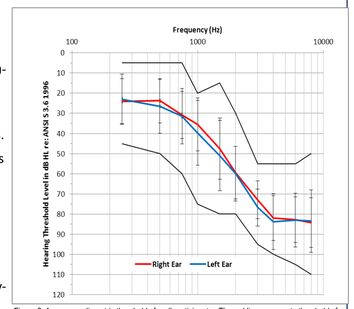

Figure 3: Average audiometric thresholds for all participants. The red line represents thresholds for the right ear. The blue line represents thresholds for the left ear. Black lines above and below the average thresholds represent the minimum and maximum audiometric thresholds. Error bars represent ±1 standard deviation (SD).

Hearing Aid Fitting

- Starkey's proprietary e-STAT fitting formula was used for the initial fitting of each test device.
- Real-ear probe-microphone measurements (REM) were performed using the Audioscan Verifit hearing aid analyzer to evaluate the frequency response of the initial prescriptive fit. Real-ear measurements were obtained at 50 dBSPL, 65 dBSPL, and 75 dBSPL using the International Speech Test Signal (ISTS)[5]. A pure-tone sweep was recorded at 85 dBSPL to set appropriate maximum output.
- The test devices were fine-tuned, as needed, based on patient reports of performance and comfort.
- Patient preferred (field use) spectral envelope warping settings were determined by patient performance on a live-speech plural identification task and fine-tuned based on subjective sound quality reports.

Test Methods

Each participant was seen for a minimum of 4 laboratory sessions over a period of 6-8 weeks.

The S-Test[3] was completed at week 4 and the Computer-Assisted Speech Assessment (CASPA)[4] was completed at week 6 of the study. Subjective outcome measure data was collected at week 4.

Objective Testing

All laboratory testing was conducted in three specific hearing instrument conditions:

1. Spectral envelope warping off.
2. Spectral envelope warping on at patient preferred settings of bandwidth and gain (shown in Table 1).
3. Spectral envelope warping on at maximum bandwidth settings (setting 7) and gain at 8 dB.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	S16	S17	S18	S19	S20
Bandwidth	6	6	6	4	5	5	4	4	4	5	5	3	3	5	3	4	6	4	6	7
Gain	5	3	3	6	3	3	3	3	4	3	4	0	2	3	3	3	5	3	5	5

Table 1: Participant preferred (field use) settings for Spectral iQ bandwidth and gain. Default settings for spectral envelope warping for this study were bandwidth at setting 5 and gain at 3 dB.

· The S-Test was administered using two 48-word lists per condition. Participants were required to identify the spoken word as having a final /s/ or /z/ consonant either present or absent in a two-alternative forced-choice procedure. The speech and a speech-shaped background noise were presented at 0° azimuth at a +20 dB signal-to-noise ratio (SNR). Speech was presented at 60, 65, or 70 dBSPL, depending on d' (d prime) values calculated during a practice word list (d' values with spectral envelope warping off were expected to be between 0.6 and 1.1 to avoid ceiling effects). Scoring was done through a statistical measure of d' and converted to percent correct [6].

· The CASPA test was administered at 65 dBSPL from 0° azimuth using a recorded female talker and a spectrally-matched steady-state noise at +10 dB SNR. Participants were required to repeat target words which were scored in percent correct at the vowel, consonant, phoneme and word level. Two 10-item word lists were administered per test condition.

Subjective Testing

Perceived subjective benefit for speech understanding and sound quality were assessed during field trials with subjective outcome measures developed by the authors.

Results

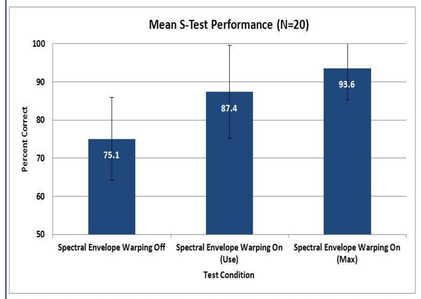

Figure 4: Percent correct identification of word final consonants (/s/ or /z/) as a function of spectral envelope warping (Spectral iQ) settings on the S-test.

Participant performance on the S-Test was significantly improved with spectral envelope warping on at their preferred settings (use) than with spectral envelope warping off ($F_{(2,19)}$ *=26.85, p<0.001*), as shown in Figure 4. Furthermore, moving from the preferred settings to the maximum settings showed significant improvements in word final consonant identification as well (*t=3.025 =3.025, p<0.05*). Error bars represent ±1 SD.

Figure 5 shows individual performance on the S-Test for participant preferred settings (use) and maximum settings. The majority of participants scored between 90% and 100% correct with either spectral envelope warping settings at preferred and/or maximum spectral envelope warping settings. Symbols located above the line demonstrate improved performance with spectral envelope warping on (in either preferred or maximum settings.

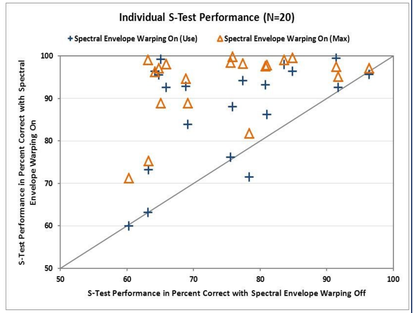

Figure 5: Individual performance with spectral envelope warping on (both use and max settings) as a function of performance with spectral envelope warping off.

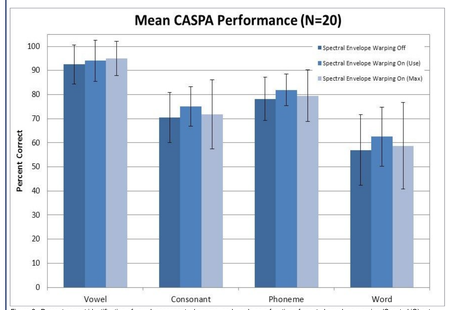

Figure 6: Percent correct identification of vowel, consonant, phoneme, and words as a function of spectral envelope warping (Spectral iQ) settings on the CASPA test.

CASPA test results are displayed in Figure 6 for each test condition based on percent correct identification of vowel, consonant, phoneme and words. Analysis of the data demonstrated there was no statistically significant difference between test conditions for the identification of vowels, consonants, phonemes, or words. Error bars represent ±1 SD.

Participant responses to questions on subjective outcome measures regarding sound quality and speech understanding are shown in Figure 7. Responses were collected during week 4 of the field trial. 75% (15/20) of participants reported good to very good speech understanding and 55% (11/20) of participants reported good to very good sound quality with spectral envelope warping on.

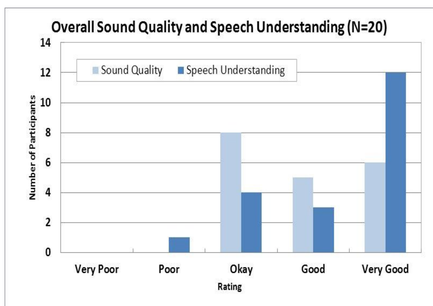

Figure 7: Participant ratings for overall sound quality and speech understanding in quiet environments.

Discussion/Conclusions

The use of the spectral envelope warping algorithm, Spectral iQ, significantly improved speech identification for plural sounds in a laboratory environment. Participants also reported acceptable speech understanding and sound quality in the field as measured on subjective measures of outcome. No significant differences were observed between CASPA test conditions. This was not unexpected as the words used in the CASPA test are not high-frequency weighted nor do they focus on high-frequency speech components, although high-frequency speech cues are present.

- Frequency-lowering technology utilizing spectral envelope warping, in combination with appropriately amplified hearing instruments, significantly improved objective speech understanding as measured by the S-Test.
- Participants reported enhanced subjective speech understanding on subjective outcome measures when utilizing spectral envelope warping relative to conventional processing.
- Participants did not report deleterious effects on their perceived speech understanding or sound quality when spectral envelope warping was on, as reported on subjective outcome measures.

Summary

Frequency-lowering technologies have been developed to provide hearing-impaired listeners access to high-frequency speech cues critical for speech understanding. One of the newest types of frequency-lowering technologies is spectral envelope warping (Spectral iQ) from Starkey Hearing Technologies. Spectral envelope warping identifies spectral peaks in the high-frequency region of the signal and replicates this part of the speech signal at a target lower frequency. Significant objective benefit was measured during laboratory tests of final consonant identification (S-Test) when this algorithm was turned on versus when the algorithm was off. In addition, participants reported improved speech understanding and no deleterious effects on sound quality as shown in subjective outcome measures.

References

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