In the prescription of hearing aids, providing insufficient high-frequency gain may have a negative impact on detection of phonemes such as word final /s/ and /z/. Modern techniques for frequency lowering offer an opportunity for improving detection of these phonemes. In recent years these techniques for frequency lowering have been introduced to commercially available hearing aids. The first of these, introduced by the Widex Hearing Aid Company, uses linear frequency transposition (LFT) to lower high-frequency information above a specified start frequency to a lower frequency. Specifically, the algorithm identifies prominent spectral peaks in a frequency region up to two octaves above a specified start frequency. A frequency region of one octave around the identified spectral peak is filtered and transposed to a lower frequency region and mixed with the conventionally amplified lower frequencies.

A third strategy for frequency lowering, spectral envelope warping (SEW), introduced by Starkey Hearing Technologies, uses linear frequency transposition (LFT) to lower high-frequency information above a specified start frequency to a lower frequency. Specifically, the algorithm identifies prominent spectral peaks in a frequency region up to two octaves above a specified start frequency. A frequency region of one octave around the identified spectral peak is filtered and transposed to a lower frequency region and mixed with the conventionally amplified lower frequencies.

In recent years, Phonak introduced a commercial hearing aid that features non-linear frequency compression (NFC). This technique for frequency lowering moves high-frequency input to a lower frequency; this translation does not extend beyond a low-frequency cutoff that is defined within the programming software. Inputs above this cutoff are frequency compressed into a region specified by the frequency compression ratio; lower frequencies are compressed to a lesser extent than the highest frequencies.

A third strategy for frequency lowering, spectral envelope warping (SEW), introduced by Starkey Hearing Technologies, uses linear frequency transposition (LFT) to lower high-frequency information above a specified start frequency to a lower frequency. Specifically, the algorithm identifies prominent spectral peaks in a frequency region up to two octaves above a specified start frequency. A frequency region of one octave around the identified spectral peak is filtered and transposed to a lower frequency region and mixed with the conventionally amplified lower frequencies.

Objective

The objective of the current study was to examine behavioral outcomes with three commercially available frequency lowering algorithms in a group of adults with sloping severe high-frequency hearing loss. The ability of this participant group to detect word final /s/ and /z/ sounds with broadband and bandlimited conventional processing was assessed and compared with the participants’ ability to identify word final /s/ and /z/ with each of three frequency lowering algorithms activated. For reporting, each strategy was randomly assigned to a consistent identifier: A, B, or C.

Participants

Twelve adults with sloping high-frequency hearing loss were recruited for participation in this study. All but one participant routinely wore hearing aids.

Hearing aid products

Commercially available behind-the-ear (BTE) hearing aids and programming software were used in this study; the Widex Max64 FM-10 BTE, the Phonak Audeo SP-BTE, and Starkey’s Series Power BTE. All participants were fit with full shell custom earmolds; each earmold used a standard size 13 tube and clinically appropriate venting ranging from 1.5 to 3 mm.

Veriﬁcation

Each hearing aid ﬁtting was matched to DSL v5.0 adult targets within ±5 and ±10 dB through 4 kHz. Attempts to meet the 6 kHz DSL v5.0 target were made; however, in most cases, it was not possible to increase gain sufﬁciently to match target.

Test Conditions (4)

1. Broadband Conventional Processing

Conventionally processed hearing aid with gain set to create a 35-dB signal-to-noise ratio condition.

2. Bandlimited Conventional Processing

Conventionally processed hearing aid with gain set to create a 35-dB flat condition.

3. Default Frequency Lowered

Each frequency lowering algorithm is active. Adjustable parameters are left at the patient’s manufacturer’s default.

4. Validated Frequency Lowered

The validation process was done with singular and plural stimuli randomly selected from the ‘S-text’ (Robinson et al., 2007). Participants identified each presented word as singular or plural. The variable parameters of each algorithm were made more aggressive until correct identification reached 60%.

Methods

Testing was done with the S-test as described by Robinson et al. (2007). In this test, 24 distinct pairs of words spoken by a female talker are randomly presented. Each word was presented twice in the singular form and once in the plural. The listener is tasked with detecting which form of the word was presented. Test presentation, randomization, scoring, and a graphical user interface were managed by a custom Matlab script. Participants were presented with one word from 0 degrees azimuth in soundfield at a calibrated level of 65 dB SL. A steady-state background noise, shaped to the spectrum of the speech stimuli, was also presented from 0 degrees azimuth at a signal-to-noise ratio of +20 dB.

Results

A two-factor repeated measures ANOVA showed a significant main effect of strategy (F_{12;48} = 12.44, p<0.001) and condition (F_{3;48} = 17.62, p<0.001). A significant interaction between strategy and condition (F_{36;144} = 3.22, p<0.01) was observed.

Post hoc analyses using pairwise multiple comparisons (Tukey Test) within the factor of strategy showed that strategy A offered significantly greater performance than both B (p<0.004) and C (p<0.001); strategies B and C were not significantly different.

Analysis within the factor of test condition showed that bandlimiting a conventionally processed hearing aid resulted in significantly worse performance compared to the default condition (p<0.001), but was not significantly different than broadband performance (p=0.28).

Correlation between benefit of frequency lowering and high-frequency hearing loss slope

Correlations between individual benefit from each frequency lowering strategy and hearing loss slope were found to be non-significant. Analyses included slope calculated between 0 and 4 kHz, 4-6 kHz, 6 and 8 kHz, and 8 and 10 kHz. The results of the analyses between 1 and 8 kHz are shown in the table and figure 7.


discussion

Even with advances in modern hearing aids there remain electroacoustic limitations that prevent restoration of availability for high-frequency speech for individuals with severe to profound high-frequency hearing loss. As illustrated by the inability to meet prescribed DSL v5.0 adult targets for any of twelve participants beyond 4 kHz, three strategies for frequency lowering were evaluated and compared to conventionally processed test conditions. None of the evaluated frequency lowering strategies provided significant benefit for the detection of word final /s/ and /z/ when compared to a broadband hearing aid fitting that approximated each participant's DSL v5.0 prescription. Combinations of performance in the frequency lowered test conditions to bandlimited conditions, representative of some clinical hearing aid fittings, revealed significant benefits for each of the strategies discussed.

No significant correlations were present between group or strategy and the magnitude of benefit received from frequency lowering. This suggests that benefit from frequency lowering, on the experimental task, does not hold a significant relationship to the slope or severity of hearing loss.

These observations should be considered in tandem with the acoustic fact that each strategy introduces distortion to the amplified signal. For some patients this additional distortion will not be acceptable. The prescription of frequency lowering should begin with a behavioral validation process that ensures improved detection of high-frequency sounds. Once a set of validated parameters have been determined the patient should be queried regarding acceptance of the resulting sound quality.

References


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