Frequency Compression through Beltone Sound Shifter

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Hearing loss that slopes to greater degrees in the high frequencies is very common; however, it often presents problems with individuals’ ability to discriminate speech. In some cases, today’s hearing instruments may not be able to provide adequate audibility for these high frequencies. Frequency lowering strategies have been used in the hearing instrument industry as an alternative for clients who do not benefit from traditional amplification in the high frequencies. However, many of these strategies also introduce significant distortion by means of this feature. Beltone Sound Shifter is a new frequency lowering approach that improves high frequency audibility, with minimal degradation of sound quality.

INTRODUCTION

Hearing loss that slopes to greater degrees of severity for the high frequencies is commonly encountered in hearing clinics. This common hearing loss configuration, however, presents its own challenges, both for the client and for the hearing care professional. For the client, many consonant sounds important for accurate speech discrimination lie in the high frequency region. For example, the /s/, /th/, and /t/ phonemes may be rendered inaudible with only a mild degree of high frequency hearing loss. Figure 1 shows a bilateral steeply sloping high frequency hearing loss. A speech banana is superimposed on the audiogram, which indicates the common distribution of speech sounds in the frequency-intensity realm over time (aka, the long term average speech spectrum, or LTASS). Individual phonemes indicate on the audiogram their specific frequency and intensity ranges in everyday speech. Sounds below the hearing thresholds on the figure are audible to the client, and sounds above the thresholds are inaudible. Without amplification, the /s/, /th/, /t/ and /k/ phonemes are inaudible for this individual client.

The loss of certain phonemes produced at typical speech levels may present significant problems for the client. For example, the /s/ phoneme is necessary in the English language to distinguish plurality (e.g., “bag” versus “bags”). The sentence “Please bring the bags” will have a different meaning to the client if she only hears “Please bring the bag.”

A hearing loss such as the one shown in Figure 1 affects the audibility for environmental sounds as well as speech. For this client, environmental sounds such as birdsong will be inaudible without some form of high frequency amplification (Figure 2).

Traditional amplification using wide dynamic range compression (WDRC) provides greater audibility for low-level sounds in the necessary frequency regions, in an attempt to raise the level of speech and other environmental sounds to an audible level per the individual’s hearing loss.

The success of this approach often depends on the severity of the hearing loss in the high frequencies; for greater degrees of high-frequency hearing loss, traditional amplification may have limited success in providing audibility for these high frequency sounds.

There are a number of reasons why a traditionally-fitted hearing instrument may not be able to effectively amplify more severe degrees of high frequency hearing loss. The most common culprits include feedback from high gain requirements in this frequency region, and limitations of the receiver. The physical properties of larger receivers, which are used in high power hearing instruments, result in a lower-frequency roll-off than what is observed for lower-power hearing instruments.

Aside from the technical issues in providing this large amount of high-frequency amplification, there may be a physiological issue to consider as well. In some cases, providing high frequency amplification for severe hearing losses may not be beneficial. It has been suggested that the corresponding high frequency areas on the cochlear basilar membrane may represent a “dead region,” characterized by non-functioning inner hair cells. Applying amplification to these “dead regions” may result in poorer speech understanding.
Results obtained with Beltone Sound Shifter. Panel B shows the results and frequency compression activated (right). Panel A shows the reconventional amplitude compression (left) and with both amplitude quality with frequency lowering as compared to traditional hearing thresholds may distinguish a difference in sound quality is not generalizable. Individuals with milder or normal hearing impaired listeners without frequency lowering, or with up to moderate frequency lowering settings. Results and considerations from the literature were instrumental in developing Sound Shifter and its settings, in order to provide the desired audibility for high frequency sounds with the least amount of impact on the sound quality.

To provide maximal listening benefits with minimal signal distortion, Sound Shifter is a proportional frequency compression strategy. This approach was chosen over a non-proportional frequency compression technique, currently offered by another hearing aid manufacturer. To illustrate the differences in the processing of a signal, a 90 dB SPL pure tone sweep was processed through Beltone’s proportional frequency compression and the competitive non-proportional frequency compression to create spectrograms (Figure 4). Each spectrogram is an input/output function, showing the input frequency on the x-axis and the output frequency on the y-axis. Colors indicate the intensity of the signal, with red indicating the most intense and blue indicating the least intense. Both hearing instruments were programmed with amplitude compression for a mild-to-moderate hearing loss, with similar frequency compression knee points and ratios.

Panel A shows the signal processed through Beltone WARP 17 amplitude compression alone, and then with Sound Shifter activated. In Panel B, the same signal is processed first through the competitor’s wide-dynamic range amplitude compression, and then also through the competitor’s non-proportional frequency compression. The frequency compression knee points are shown as the point where the slope of the response changes. (Note there no change in slope for the response when no frequency compression is activated).

The results for Beltone Sound Shifter show a clean response; minimal differences in energy were present in the output above the frequency compression knee point as compared to the output below the knee point, where frequency compression was not active. In contrast, the results for the competitive frequency compression feature were not as clean, as indicated by the jagged response above the frequency compression knee point. This is due to the non-proportional relationship of the competitor’s frequency compression. More distortion products are generated by this approach. These distortion products manifest themselves on the spectrogram with a blurred quality of the response curve above the frequency compression knee point.

Figure 4. Spectrograms for a swept pure tone were measured with conventional amplitude compression (left) and with both amplitude and frequency compression activated (right). Panel A shows the results obtained with Beltone Sound Shifter. Panel B shows the results for a competitor’s hearing instrument. These spectrograms show the difference in distortion generated by Beltone’s proportional frequency compression strategy, compared to that generated by the competitor’s non-proportional frequency compression (FC) approach.

Sound quality for music was also evaluated for proportional and non-proportional frequency compression. In this comparison, each hearing instrument was programmed for 3 hearing losses: mild flat, mild sloping to moderately-severe, and mild sloping to profound. Gains were set according to the default prescriptive targets in the respective manufacturer’s fitting software. Frequency compression was set to “off,” “moderate” and “strong.” The “moderate” setting had a frequency compression knee point as close to 3 kHz as possible, and a compression ratio as close to 2:1 as possible. The “strong” setting had a frequency compression knee point as close to 2 kHz as possible, with the same 2:1 compression ratio as used by the “moderate” setting.

Figure 5. Sound quality for music, as predicted by the HASQI, revealed better sound quality preservation for Sound Shifter than for a non-proportional frequency compression strategy.


**DEVELOPMENT OF SOUND SHIFTER SETTINGS**

All frequency lowering techniques introduce a compromise between audibility and sound quality. Some users will benefit greatly from the increased audibility of high-frequency sounds, while others may be bothered by the feature’s inherent distortion and perceptual sound quality. As previously stated, there are no defined guidelines about which individual clients will be the best candidates for frequency lowering. Further, there is no “cookbook approach” to fitting the technology. For instance, two individuals with similar hearing losses may derive the greatest benefit from different frequency compression knee points and ratios, or from no frequency lowering at all. For these reasons, the best approach to applying and fitting frequency compression is often a conservative one.

As such, Sound Shifter in Solus Pro fitting software was designed with a limited number of settings, which were found through internal testing to provide the greatest audibility benefit while also minimizing deleterious effects on the sound quality. Results of initial testing indicated that the compression frequency knee point had a greater effect on the feature than the compression ratio.

To determine the most effective and differentiated compression knee points and ratios, a second internal test was conducted. The goal of this trial was to evaluate 8 frequency compression settings in addition to the “off” setting (Table 1). Seventeen test subjects with steeply sloping hearing loss and 20 with severe-to-profound hearing loss participated in the trial.

<table>
<thead>
<tr>
<th>Test Setting</th>
<th>Frequency Compression Knee Point</th>
<th>Frequency Compression Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Off</strong></td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>1 (weakest)</td>
<td>5000</td>
<td>1.33</td>
</tr>
<tr>
<td>2</td>
<td>4000</td>
<td>1.33</td>
</tr>
<tr>
<td>3</td>
<td>4000</td>
<td>2</td>
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<tr>
<td>4</td>
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<td>6</td>
<td>2500</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>2250</td>
<td>2</td>
</tr>
<tr>
<td>8 (strongest)</td>
<td>2000</td>
<td>2</td>
</tr>
</tbody>
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Table 1. Eight frequency compression settings evaluated during the internal trial.

Objective measures during the fitting appointment included real ear insertion gain (REIG) measurements for Ling sounds /s/ and /sh/. Forty ears were evaluated for each of the 8 frequency compression settings plus the “off” condition. Results revealed 3 distinct grouping of REIG measurements among the conditions (Figure 6).

Results of other studies using frequency compression, group data did not indicate optimal frequency compression settings nor average benefit. Also as expected, certain individuals did obtain improved outcome measure results and expressed preference for frequency compression processing, although variability was observed. Figure 7 shows the distribution of individual scores with and without Sound Shifter for the UWO Plurals Test. Subjects who obtained positive benefit performed better with Sound Shifter on this test than with conventional amplification. Two of the 16 subjects achieved better scores with conventional amplification than frequency compression, which is indicated by the negative benefit. Test subjects who preferred Sound Shifter processing over conventional amplification indicated that the sound quality was crisper and clearer.

The overall conclusion from these tests was that the fitting process could be simplified to a smaller number of settings. Since REIG measurements revealed three grouped responses across the eight settings evaluated, and more than one setting was found to provide comparable benefit for individuals, three Sound Shifter settings were derived: “Mild,” “Moderate” and “Strong.” Table 2 shows the corresponding frequency compression knee points and ratios for each of these settings.

<table>
<thead>
<tr>
<th>Sound Shifter Setting</th>
<th>Frequency Compression Knee Point</th>
<th>Frequency Compression Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild</td>
<td>1000 Hz</td>
<td>1.33</td>
</tr>
<tr>
<td>Moderate</td>
<td>2500 Hz</td>
<td>2</td>
</tr>
<tr>
<td>Strong</td>
<td>2500 Hz</td>
<td>2</td>
</tr>
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</table>

Table 2. Frequency compression knee points and ratios for each setting of Sound Shifter.

To activate Sound Shifter, choose a setting in the drop-down menu. The recommended setting based on the client’s audiogram will be indicated in “bold” font style. When frequency compression is not expected to provide optimal results for the client (e.g., flat hearing losses, noise notches, reverse slope hearing losses), the recommended setting will be “Off.” The criteria for recommending “Mild,” “Moderate” and “Strong” settings are as follows:

- A “Mild” setting is recommended if the audiogram has a slope of 10 dB or greater per octave frequency, and the slope begins at 4000 Hz or higher (Figure 9).
- A “Moderate” setting is recommended if the audiogram has a slope of 10 dB or greater per octave frequency, and the slope begins at 2000 Hz (Figure 10).
- A “Strong” setting is recommended if the audiogram has a slope of 10 dB or greater per octave frequency, and the slope ends at 2000 Hz (Figure 11).
Upon choosing a Sound Shifter setting, a solid dark vertical line and a gray area will appear in the graph. The vertical line indicates the frequency compression knee point, and the gray area denotes the frequency range that is compressed (Figure 12).

Recommendations for Sound Shifter are specific to the ear’s audiometric thresholds. It is possible that different Sound Shifter settings for each ear may be recommended in the case of asymmetric hearing losses. Further, Sound Shifter may be activated in one or more programs, binaurally or monaurally, per the individual’s needs.

SUMMARY

Sound Shifter provides yet another tool for hearing care professionals to improve high frequency audibility, especially for individuals who do not receive optimal audibility through traditional amplification. For certain individuals, Sound Shifter can improve audibility for high frequency speech sounds, such as /s/ and /θ/, while maintaining sound quality to a greater degree than can be offered by a non-proportional frequency compression strategy. Research revealed that a limited number of settings were appropriate to fit Sound Shifter for a wide range of individuals who may benefit from this feature. Thus, Beltone Sound Shifter is an option that enables the hearing care professional to better accommodate the needs of individual clients.

REFERENCES


