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Uses of Expansion to Promote Listening Comfort with Hearing Aids

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Abstract

Wide-dynamic range compression (WDRC) has been largely successful at managing recruitment and reducing the discomfort of loud stimuli while making speech audible. However, WDRC can contribute to the complaint that soft environmental sounds are abnormally loud, resulting in user annoyance, stress, and fatigue. This paper explores the application of programmable, multi-channel audio expansion algorithms in a multi-channel WDRC digital hearing aid to control the amplification of low-level noise in various listening environments.

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INTRODUCTION

Multi-channel WDRC provides frequency-specific compensation for abnormal loudness growth in impaired ears. One downside of the compression required to make soft speech audible while keeping loud stimuli comfortable is the over-amplification of soft environmental background sounds. Research has demonstrated repeatedly that hearing-impaired individuals require a better signal-to-noise ratio (SNR) than normal listeners for equivalent speech understanding performance[1,2]. Villchur observed that over-amplification of soft sounds was an undesirable by-product of compression[3] and was probably the first to suggest that expansion could be employed below the compression kneepoint to alleviate this problem in hearing aids.

Audio expansion is the functional reciprocal of compression. The change in the output of an expander is greater than the change in its input, unlike a compressor where the change in the output is smaller than the change in the input. When used below the compression kneepoint, expansion applies increasingly less gain to sounds as they become softer and can begin to restore the broadband SNR that is otherwise compromised by WDRC. Technical discussions of audio expansion in hearing aids can be found elsewhere[4] and will not be addressed in this poster.

This paper examines the spectral characteristics of speech and common environmental noise along with the parameters of programmable expansion in a multi-channel DSP hearing aid. Optimization of a multi-channel expansion/compression function will be shown to enhance speech while contributing to greater listener comfort in different environments and across different hearing loss configurations.

EXPANSION PARAMETERS

When expansion is used to reduce the gain applied to soft sounds, care must be taken to affect only the sounds which could become unnaturally loud or compete with speech information; the soft speech sounds themselves should receive appropriate gain. The parameters of interest in this regard are the kneepoints and the slopes of the expansion functions. Speech and noise spectra, degree and shape of hearing loss, and loudness growth function determine how these are set. **SONIC innovations**' NATURA™ and CONFORMA™ hearing aids have the necessary flexibility to allow consideration of these factors in nine half-octave bands.

THE KNEEPOINT: Figure 1 shows how each of the nine kneepoints are set to underscore the long-term-average speech spectrum (LTASS). This is done in order to apply the greatest gain to soft speech sounds. Above the kneepoints, compression amplification normalizes the loudness growth function. Below the kneepoints,

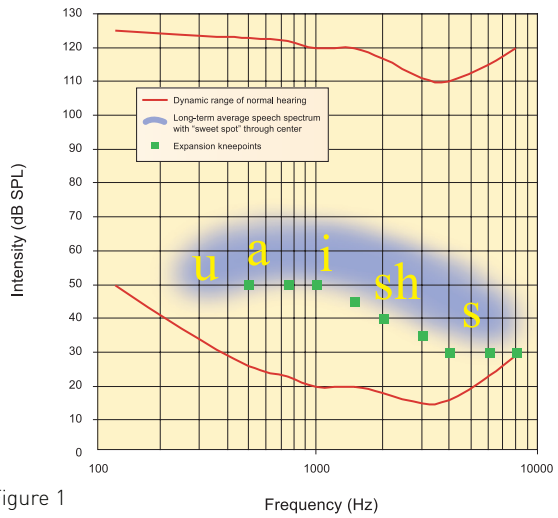

Figure 1

expansion applies reduced gain for sounds softer than the speech energy in each channel. This gives rise to the term "speech-weighted expansion."

While the LTASS does not change, people with different hearing loss configurations may lack adequate hearing sensitivity at certain frequencies. Therefore, it is necessary to be able to "tilt" the speech-weighted expansion kneepoints to increase spectral sensitivity. Conversely, it may also be necessary, in the case of those with high-frequency hearing losses, to decrease sensitivity in regions like the lower frequencies where better hearing, higher concentrations of noise energy, and upward-spread-of-masking, can become troublesome. In the case of severe hearing losses, where over-amplification of soft sounds is not a problem, expansion can be removed and linear amplification applied below the kneepoint. Figure 2 shows how the speech-weighting of the kneepoints can be tilted for different types of losses. For example, mild hearing losses cannot tolerate over-amplification of low-level noise, so the kneepoints are higher than those for a moderate hearing loss. For a high-frequency loss, the kneepoints are set such that sensitivity for critical high frequencies is maximized (where kneepoints are lowest) and low-frequency sensitivity is reduced in favor of comfort and to avoid additional masking of high frequencies by low-

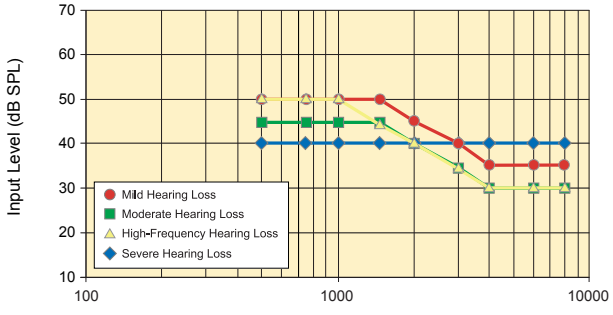

Figure 2

frequency energy.

From the foregoing, it can be generally said that the LTASS and an individual's hearing loss dictate the setting of the kneepoints in this multi-channel system.

THE EXPANSION RATIO OR SLOPE: The slope of an expansion function determines the rate at which the gain is reduced as the input signal continues to drop below the kneepoint. A steeper slope causes applied gain to be reduced more rapidly. Therefore, sounds falling in an expansion region having a steep slope will fall off more rapidly than if the slope were milder.

If the transition from the expansion function to the compression function is too acute, artifacts due to gain jumping may occur around the level of the kneepoint as the intensity of the input signal changes back and forth across it (Figure 3). This is more likely to occur at hearing loss frequencies because recruitment compensation usually results in higher compression ratios. Such artifacts can be distracting to the hearing aid wearer because loudness recruitment, which contributes to a smaller difference limen, may accentuate the artifacts.

With the foregoing in mind, expansion slopes must be selected with consideration also given to the ratio of noise energy to useful speech energy in a given band and the dynamic range of the speech energy in a given band. Most low-level sounds which become aversive with over-amplification are low-frequency weighted. Since vowel energy is significant but doesn't contribute as much to speech understanding as consonants, steeper expansion slopes can generally be used in the low frequencies. This must be balanced with any gain demanded by the hearing loss.

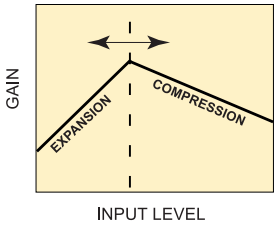

Figure 3

Noise spectrum, loudness growth function, and the shape of the hearing loss are factors that determine expansion slope. The expansion slopes in each of the nine channels have been optimized for the different kneepoint weightings shown in Figure 2 to avoid artifacts and still be effective at reducing gain for soft environmental sounds.

REAL-WORLD EXAMPLE

Following is an example of NATURA's and CONFORMA's speech-weighted expansion programmed according to the guidelines in the previous section. Figure 4a displays the range and rms spectrum of the HINT sentences spoken by a male talker[5], along with the spectra of environmental sounds commonly encountered by hearing aid wearers. All measurements were made at ear level and at typical distances from the sources. Figure 4b is the audiogram entered into the EXPRESS*fit* fitting software. The gain and compression for fitting the hearing loss in Figure 4b are determined by the proprietary EXPRESS*fit* algorithm.

Figure 5a depicts the spectra, post-amplification, with WDRC and linear functions below 40 dB kneepoints in all nine channels. Figure 5b shows the I/O function in the 2,000 Hz channel. This behavior is typical of most WDRC hearing aids. Notice how the spectra are compressed together in the frequency range where the greatest hearing loss is located. Depending on the frequency, the SNR for soft speech vs. low-level environmental noise can be compromised by more than 6 dB, as shown in Figure 5b.

When expansion is programmed below the kneepoints in the nine channels, the soft environmental sounds receive less gain and increase their distance from the rms average of the speech sounds, as shown in Figure 6a. At 2,000 Hz, the SNR is restored to nearly normal (Figure 6b) and gain for the soft parts of speech remains intact.

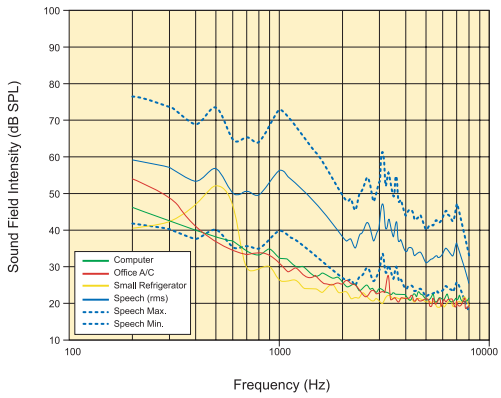

Figure 4a. Speech & Environmental Noise Spectra

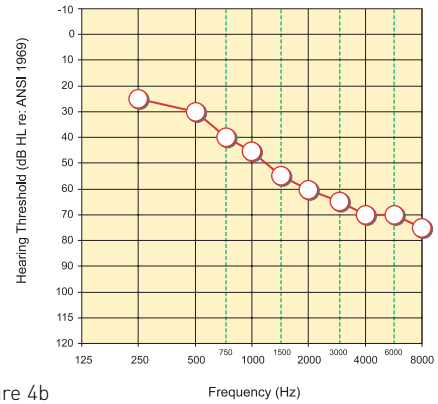

Figure 4b

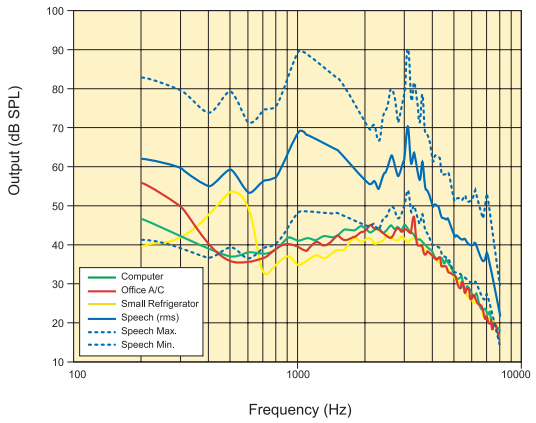

Figure 5a. Speech & Noise Spectra—WDRC, No expansion

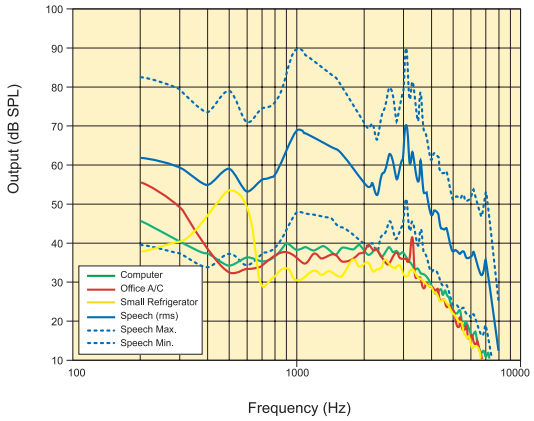

Figure 6a. Speech & Noise Spectra—WDRC with Expansion below the Kneepoints

CONCLUSIONS

Development of the Profile of Aided Loudness (PAL) yielded strong justification for audio expansion in hearing aids, as implemented in NATURA's unique gain structure. The PAL was designed as a means to validate normalization of loudness growth perception on patients fit with WDRC amplification. A four-quadrant matrix was used to evaluate attainment of clinical goals and patient expectations. One quadrant of the matrix collected cases where clinical goals were met, but patients still were not pleased with the results. A review of patient responses indicated that the dissatisfaction stemmed from over-amplification of low-level environmental sounds[6].

Subjective responses in studies using NATURA hearing aids with speech-weighted expansion have included significantly less aversiveness to amplified sound and better tolerance of background noise than with typical linear and WDRC amplification[7]. Subjects also reported more comfort and less listener fatigue, resulting in longer wear time.

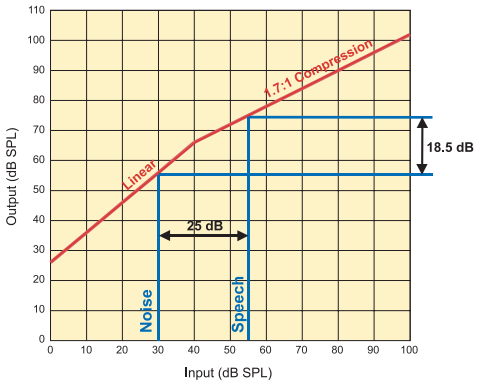

Figure 5b

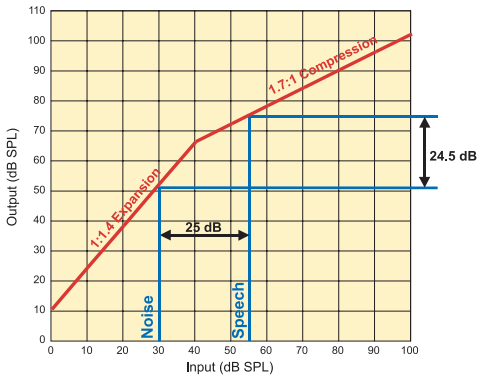

Figure 6b

REFERENCES

1. Killion, M. (1997). Hearing aids, past present, future: Moving toward normal conversations in noise. *Br. J. Aud., 31*, 141–148.
2. Soede, W. (1990). Improvement of speech intelligibility in noise. Ph.D. thesis, Delft University of Technology, Delft, The Netherlands.
3. Villchur, E. (1973). Signal processing to improve speech intelligibility in perceptive deafness. *J. Acoust. Soc. Am., 53*(6), 1646–1657.
4. Ghent, R., Nilsson, M., Bray, V., & Johnson, J. (1999). Expansion as a sound processing tool in hearing aids. Poster, AAA 11th Annual Convention, Miami Beach, Florida.
5. Nilsson, M., Soli, S., & Sullivan, J. (1994). Development of the hearing in noise test for the measurement of speech reception thresholds in quiet and in noise. *J. Acoust. Soc. Am., 95*(2), 1085–1099.
6. Mueller, G. and Palmer, C. (1999). Verification and validation of normal loudness perception. Instructional Course, AAA 11th Annual Convention, Miami Beach, Florida.
7. Bray, V., Nilsson, M., Ghent, R., & Johnson, J. (1999). Results from a clinical evaluation of a new DSP hearing aid using an optimized platform. Poster, AAA 11th Annual Convention, Miami Beach, Florida.

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