

# Case Study Outcomes of Hearing Impaired Listeners Using Nonlinear Frequency Compression Technology

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## Background

Providing audibility of a wide range of input levels from a broad frequency spectrum is a goal of any hearing aid fitting. For listeners with high-frequency sensorineural hearing loss, this goal can be challenging to meet with amplitude compression technology for several reasons. Firstly, this technology is limited in its ability to provide the appropriate amount of gain for soft, high-frequency sounds. If suitable gain is achieved in the high-frequency region, acoustic feedback may result when the aid is worn by the listener. Thus, application of a feedback management strategy and/or gain reduction is a common solution. Additionally, the output bandwidth of conventional hearing aids is not broad enough to make high-frequency sounds consistently audible for listeners with hearing loss (Stelmachowicz, et al., 2004). These factors limit the audibility of important high-frequency sounds, especially for individuals with sloping and/or severe to profound hearing losses.

It is important to point out that providing audibility of high-frequency information to listeners with severe to profound hearing impairment remains a controversial topic. Large variability in aided listening performance is thought to be due to both the level of high-frequency audibility the listener is receiving as well as the listener's ability to extract useful information from the audible signals. Some studies suggest that listeners who are provided with audibility at frequencies where hearing levels are severe and/or sloping will not show speech recognition benefit (Ching, Dillon, & Byrne, 1998; Ching, Dillon, Katsch, & Byrne, 2001; Hogan & Turner, 1998). This is thought to be due to a limited ability to use the amplified signal in that frequency region. On the other hand, other studies have reported that significant improvements in speech understanding, especially in noisy environments, occur when listeners with sloping sensorineural hearing loss are provided with high-frequency information (Plyler & Fleck, 2006; Turner & Henry, 2002). Additionally, listeners with suspected dead regions in the high-frequencies perform better on speech recognition tasks when broadband amplification is used (Mackersie, Crocker. & Davis, 2004), while listeners without dead regions are better able to make use of high-frequency cues (Moore, 2004). Thus, the different

outcomes may be due to factors such as the inner hair cell (IHC) function (i.e. dead regions), congenital versus acquired hearing loss, and frequency lowering technology.

## Nonlinear Frequency Compression

Various signal processing strategies have emerged to allow high-frequency information to be moved to a lower-frequency region so it can be more easily accessed by the listener. Frequency transposition and frequency compression technology are the two main types of frequency-lowering technology available today. Frequency transposition shifts the signal down the frequency axis by a fixed amount. Nonlinear frequency compression technology compresses the output bandwidth of the signal by a specified ratio.

The case studies described in this paper utilized a prototype hearing aid employing multichannel nonlinear frequency compression (NFC) technology. This multichannel strategy compresses only the high-frequency region while the low band is not compressed in frequency. This strategy is intended to preserve the natural formant ratios in the low band while giving the listener access to important high-frequency information.

## Case Study Evaluation of Nonlinear Frequency Compression

This article provides case study outcomes of one adult and one child with high-frequency hearing loss using a prototype NFC hearing aid. The evaluation was conducted both objectively and subjectively using real-world and laboratory measures. Each listener's performance and preference were evaluated first with Conventional technology (amplitude compression), then with NFC technology, and then again with Conventional technology. This strategy attempts to show behavioural changes when the intervention, in this case NFC, is applied. During the course of the evaluation, neither the experimenter nor the participant knew when the intervention was applied. This removes any bias from either the experimenter or the listener influencing the results.

## Hearing Aid Fitting and Data Collection

The prototype hearing aids were fitted to the subject according to the Desired Sensation Level (DSL) Method v5 for the selection and fitting of hearing aids (Scollie, et al., 2005; Bagatto, et al., 2005). The aids were either Phonak SaviaArt 311 or 411 digital BTEs. The performance of the aids was verified using the Audioscan Verifit, and adjustments to preference were conducted as needed. This was considered to be the baseline fitting with Conventional technology. During the treatment phase of the study, NFC was enabled and overlaid on the baseline fitting. There were two adjustable parameters of frequency compression that were programmable: 1) the cut-off frequency, which determined the start of the upper band; and 2) the compression ratio, which determined the amount of frequency compression applied to the upper band. The cut-off frequency and compression ratio were determined on an individual basis.

## Outcome Measures

To evaluate each hearing aid setting, subjective and objective measures were completed by the subject. They are listed and described in Tables 1 and 2 below.

Objective Measures	Purpose
Detection of speech sounds	Assesses auditory detection thresholds of /m, a, u, i, sh, s/
Consonant recognition	Ability to recognize high-frequency consonants in a nonsense word format (i.e. aSHil, aSil).
Plural identification	Assesses subject's ability to use the sounds /s/ and /z/ within a word.

Table 1. Objective measures for hearing aid settings.

Subjective Measures	Purpose
Abbreviated Profile of Hearing Aid Performance (APHAP): Ease of Communication Subscale	Administered to subjects aged 13 years and older. Pertains to hearing aid performance and administered after the first month of use (no NFC) and the second month of use (NFC)
Child's Home Inventory for Listening Difficulty (CHILD)	Administered to children under age 13. Filled out by child and parent.
Diary	Completed during final phase of study to facilitate comparison of different conditions. Completed away from the laboratory in everyday listening situations.

Table 2. Subjective measures for hearing aid settings.

## Case Study Outcomes

### Subject 1105 - Case History

Subject 1105 is a 70-year-old male with a moderate sloping to profound sensorineural hearing loss in both ears (see Figure 1). He reported that his hearing loss was noise induced. Cochlear dead region testing using the Threshold Equalizing Noise (TEN) test (Moore, et al., 2004) was inconclusive as the presentation of the TEN could not be made sufficiently intense to produce masking due to audiometer

limitations. Upon entering the study, Subject 1105 had been wearing binaural hearing aids for approximately 15 years. His own hearing aids were behind-the-ear (BTE) with analogue compression circuitry, which he had been wearing for six years. His main concerns were his ability to hear voices more clearly in quiet and noisy situations.

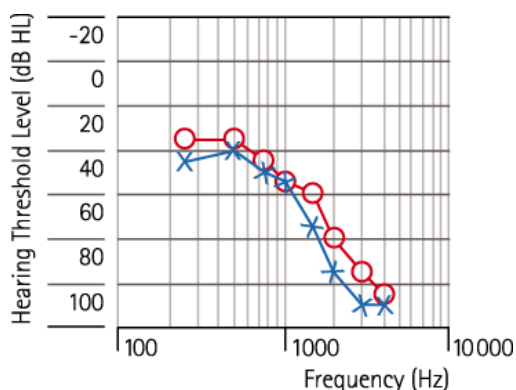


Figure 1. Audiogram for Subject 1105

## Device Fitting

The feedback manager was applied to both aids during the initial Conventional hearing aid fitting to eliminate the occurrence of acoustic feedback. Subject 1105 had some difficulty adjusting to gain provided in the high-frequency region. When the aids were providing the recommended gain across frequency, he often reported "scratchiness" especially for loud sounds. In addition, he reported an "echo sound" while wearing the hearing aids. Baseline settings were finalized during a four-week period of which the subject returned to the laboratory four times for adjustments. The period of acclimatization with the final settings was approximately five weeks. When NFC processing was applied during the treatment phase of the study, the cut-off was set to 2600 Hz with a NFC ratio of 5:1. These parameters were chosen based on output measurements of high-frequency audibility of /s/ and /sh/, as well as sound quality as judged by the experimenters (Scollie, et al., in review). When NFC was applied to the aids, the subject did not report any significant changes in sound quality when compared to the same hearing aids without NFC.

## Objective Outcomes

This participant showed a significant improvement in his ability to detect /sh/ with NFC compared to Conventional Technology, but no significant change in his ability to detect /s/ ( $p < 0.05$ ). His overall ability to detect speech sounds was not normalized with either processing strategy. Overall, Subject 1105's speech recognition performance improved significantly when using NFC compared with Conventional Technology. Specifically, his ability to identify plurals in a word format changed from 45% correct with Conventional technology to 85% correct when NFC was enabled. His ability to recognize high-frequency consonants in a nonsense word format did not improve significantly when NFC was applied.

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## Subjective Performance/Preference

The results from the APHAP-EC for this subject did not indicate benefit from the use of NFC technology compared to Conventional. In addition, his diary comments did not reveal a preference for one type of signal processing over the other in real-world listening situations.

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## Subject 2063 – Case History

Subject 2068 is a 14-year-old male with a mild sloping to profound sensorineural hearing loss in both ears (see Figure 2). His mother reported that his hearing loss was due to a ventilator used as a result of respiratory complications following birth. Cochlear dead region testing using the Threshold Equalizing Noise (TEN) test (Moore, 2004) revealed no dead regions in the right ear and a dead region at 3000 Hz in the left. Upon entering the study, Subject 2063 had been wearing binaural hearing aids for approximately 11 years and his current aids were behind-the-ear (BTE) with digital compression circuitry. He reported no major concerns with his current hearing aids.

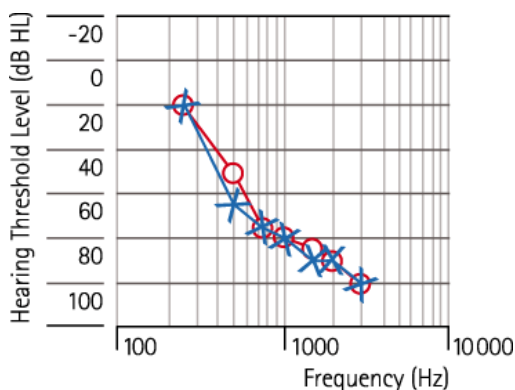


Figure 2. Audiogram for Subject 2063

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## Device Fitting

Within a few days of the baseline fitting, the subject indicated that average and soft sounds were not loud enough. The aids were adjusted to better reflect his previous hearing aid fitting. The adjustments were acceptable to the subject, therefore the modified settings were used as the baseline fitting for the study. For the NFC fitting, the cut-off was set to 2300 Hz with a NFC ratio of 6:1. The subject did not perceive a significant change in sound quality or loudness when NFC was applied.

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## Objective Outcomes

This young participant showed a significant improvement in his ability to detect /s/ with NFC compared to Conventional Technology, but no significant change in his ability to detect /sh/ ( $p < 0.10$ ). His overall ability to detect speech sounds was not normalized with either processing strategy. His ability to recognize high-frequency consonants in a nonsense word format changed from 70% correct with Conventional technology to 87% correct with NFC technology. He achieved

55% identification of plurals in a word format with Conventional technology and 80% correct with NFC technology.

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## Subjective Performance/Preference

The results from the APHAP-EC for this subject did not indicate benefit from the use of NFC technology compared to the same hearing aids without NFC. However, his diary comments revealed a preference for NFC processing, rather than without NFC, in real-world listening situations. Specifically, the ability to understand speech, the quality of people's voices and the loudness of the NFC technology was preferred over the fitting without NFC.

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## Discussion

These case studies illustrate the effects of a prototype NFC hearing aid relative to the same hearing aid fitting without NFC. The NFC technology was evaluated using both objective and subjective measures. The subjects presented here had severe to profound high-frequency hearing loss and the NFC parameters were set similarly. Both showed significant improvement on at least one speech recognition task when NFC was enabled. What is of interest when comparing the two subjects reported here is that the adult subject did not report a preference for NFC technology even though his performance improved. This was not the case for the child. NFC was preferred by the child when compared to Conventional technology. There is literature to suggest that children need more high-frequency audibility compared to adults for speech and language development to be consistent, and this could be the focus of future research (Stelmachowicz, Pittman, Hoover, Lewis, & Moeller, 2001).

In conclusion, NFC technology provided significant benefit for both the adult and child listener when compared to Conventional technology. However, the adult subject did not report a preference for NFC technology while the child subject did.

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