Use of Nonlinear Frequency Compression for Children with Severe to Profound Hearing Loss

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Introduction

Children with a severe to profound hearing loss experience great difficulties in identifying important information such as high-frequency speech cues, in part because hearing loss tends to increase with frequency whereas speech levels tend to decrease with frequency (see a recent review by Stelmachowicz, Pittman, Hoover, Lewis and Moeller 2004). The more severe the hearing loss, the more gain needs to be applied at these frequencies in order to achieve audibility. However, in many cases hearing sensitivity in high frequencies is so poor that it is not technically possible to increase gain sufficiently in order to achieve audibility. Further, in very high frequencies conventional hearing aids normally have less gain. Thus, the spectral energy needed especially for most fricatives cannot be reached and therefore they cannot be made audible. On the other hand, if high-frequency output of conventional hearing aids is sufficient, it sometimes will not be useable due to feedback problems. Extension of the signal bandwidth is particularly problematic because providing adequate gain in the 6 to 10 kHz range often generates acoustic feedback in infants and young children who have smaller ear canals compared to adults. Thus, although high-frequency gain could be provided it might not be beneficial because the perceived sound quality might be too shrill or too loud. Furthermore some hearing losses are associated with cochlear dead regions (Moore 2001; Baer, Moore and Kluk 2002). That is to say that even when high-frequency information can be made audible, it may not be discriminated due to irreversible damage to the hair-cell receptors in the inner ear.

Stelmachowicz, Pittman, Hoover, Lewis and Moeller (2004) and their colleagues showed that children with a severe to profound hearing loss needed good access to high-frequency speech cues in order to recognize speech sounds as well as their normal hearing peers. Therefore, various sound-processing schemes have been developed with the aim of presenting high-frequency information and components of speech at lower frequencies (Simpson, Hersbach and McDermott 2005, 2006) where audibility is usually more achievable.

Recent studies have provided early evidence that nonlinear frequency compression (NFC) may provide benefit for children. Specifically, Wolfe and colleagues (2010) described benefits of NFC in children with mild to moderate hearing loss, while Glista and colleagues (2009) provide evidence of NFC benefit, particularly for children with greater degrees of high-frequency hearing loss. In this chapter, we report a study that supports significant improvements of speech intelligibility as well as increased satisfaction with NFC for a group of children with severe to profound hearing loss. Within this group, a variety of hearing loss configurations, ranging from flat to steeply sloping, is included.

Study Design

Thirteen children (ages 6–15 years) with a severe to profound hearing loss participated in the study. The average age was 10 years and 5 months. They were all experienced wearers of high quality digital hearing instruments that had been fitted closely to DSL targets (Scollie et al. 2005). The same fitting protocol was followed for the NFC instruments in this study (i.e.,

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Phonak Naida V UP®) to ensure that audibility between instruments was similar. Children performed speech recognition tests in quiet and in noise at the time of fitting (baseline) and at three consecutive assessments. In order to evaluate improvements in speech intelligibility in quiet and in noise, the G II (Gabriel, Chilla, Kiese, Kabas and Bansch 1976) or the Freiburger word test (Hahlbrock 1953) was used depending on the developmental age of the test subject. Additionally, the Adaptive Auditive Speech Test (AAST; Mackie and Dermody 1986; Coninx 2005) was used. The AAST consists of the spondee and the spine test. The spondee is delivered in quiet as well as in noise. Scores with the children's own hearing instruments were compared to scores with the NFC devices, with repeated evaluations over six months. The second appointment was one week after fitting, in order to ensure that listening in school was acceptable with the new hearing instrument. The following appointments had longer intervals of three weeks, eight weeks and twelve weeks. The results for this group of children are currently under analysis. In this chapter, we present two case studies from the larger group, for children who have audiograms spanning the audiometric range tested in this study.

The first case is a 10 year-old child with a steeply sloping hearing loss (Figure 1), and the second, an 8 year-old child with a flat hearing loss (Figure 3). They are described here to illustrate fitting these different hearing loss configurations. Both children's own hearing instruments were verified using running speech on the Audioscan Verifit® (see left panels of Figures 2 and 4). For both children, their own hearing aids provided good matches to targets in the low-frequency range, but failed to provide audibility for very high frequencies (note that peak levels of their own hearing aid responses fall below threshold above 6 kHz for both cases). Audiblity in this

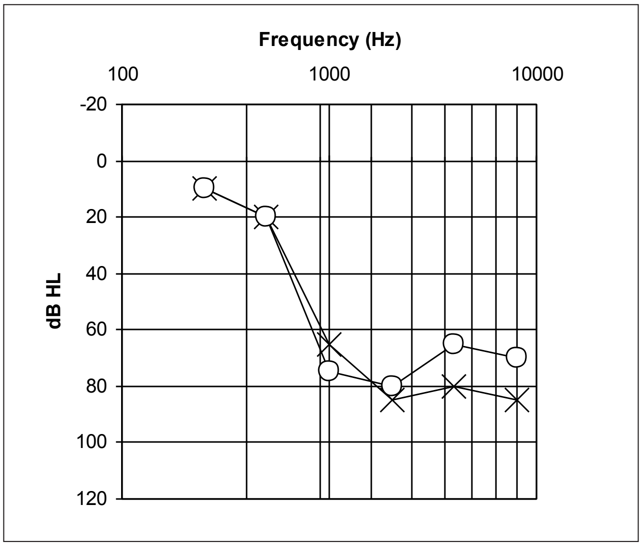
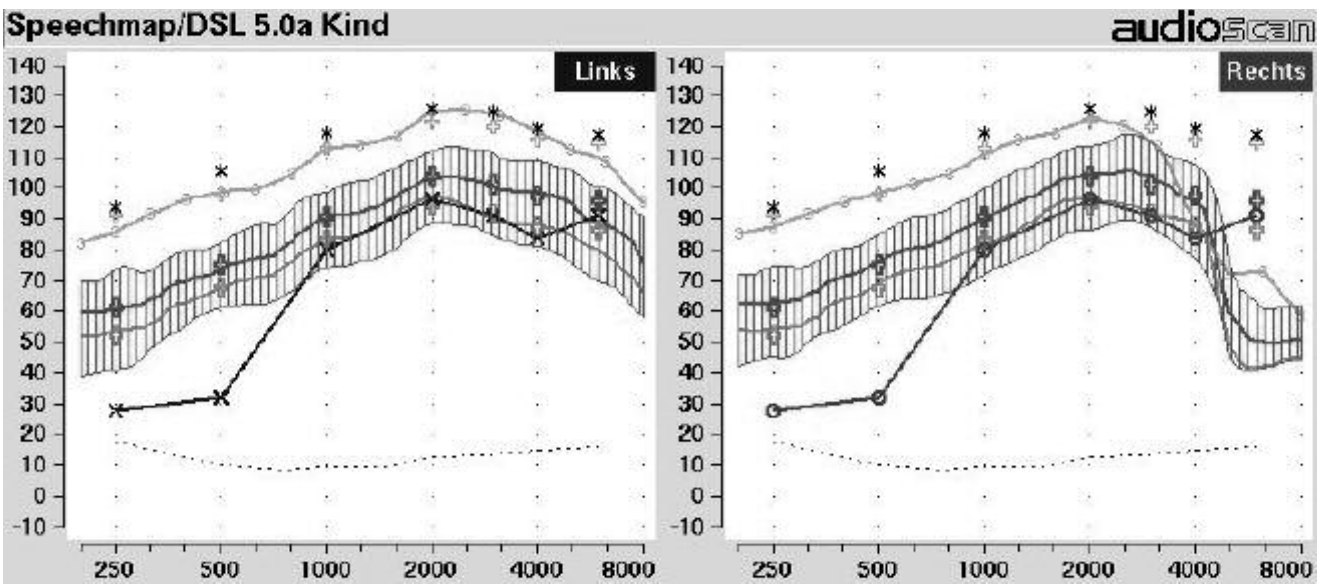


Figure 1. Audiogram for Case 1

Figure 2. Verification of hearing aid fittings for Case 1. The left panel shows the performance of the child's own hearing instrument, verified for speech at input levels of 55 and 65 dB SPL as well as maximum output. The right panel shows the fitting using the NFC hearing instrument.



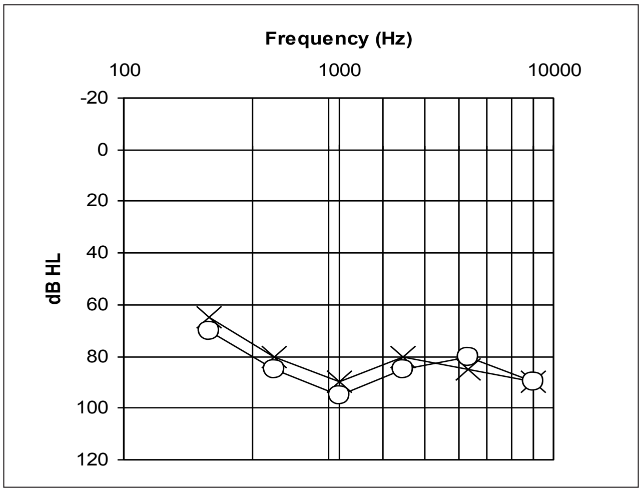


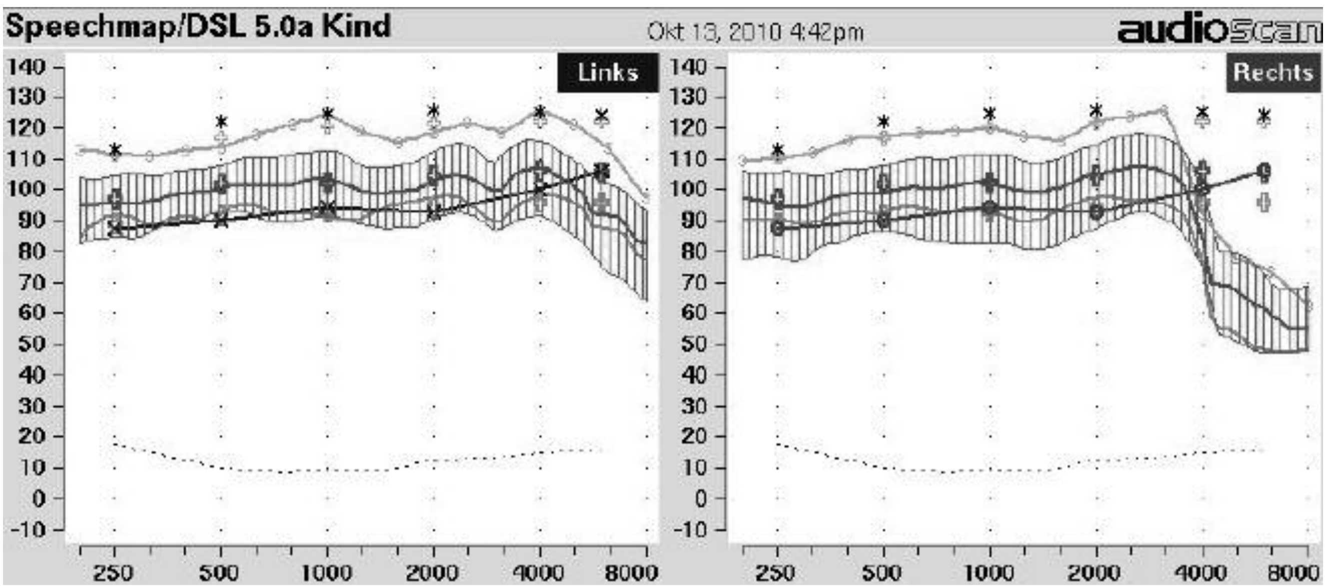
Figure 3. Audiogram for Case 2.

frequency range is important for speech development (Stelmachowicz, Pittman, Hoover and Lewis 2001; Stelmachowicz et al. 2004). The NFC instrument fittings are shown in the right panels of figures 2 and 4. This instrument processes sounds up to and including 6300 Hz, before NFC processing is activated. With NFC enabled, the upper cut-off frequency of the hearing aid response is placed at a lower and audible frequency. This means that speech energy in the 6300 Hz range is presented at about 5000 Hz for Case 1 (Figure 2, right panel), and at about 4000 Hz for Case 2 (Figure 4, right panel). Thus, while amplification with a conventional hearing aid is not able to deliver sufficient gain to exceed threshold levels at high frequencies, with NFC incoming speech sounds are compressed and shifted to lower frequencies, thereby allowing high-frequency speech energy to become audible. The outcomes for each of these cases will be discussed further below.

Case 1

Case 1 is a 10 year-old boy with a good speech and language development. He has a hereditary steeply sloping hearing loss (Figure 1) which was identified at the age of 2 years and 2 months. He attends a mainstream school and does well in class, but his mother reported that he often is very tired after school. He likes seeing his friends, but is only able to do so on weekends because of fatigue or because of the work needed to catch up on what he has missed in class. He was fitted with NFC devices, and his speech recognition scores were evaluated with his own hearing instruments (prior to the NFC fitting) and with the NFC devices over time. The results of this testing are shown in Table 1. After one week of wearing the NFC hearing instruments, his open-set word recognition scores improved by 10 to

Figure 4. Verification of hearing aid fittings for Case 2. The left panel shows the performance of the child's own hearing instrument verified for speech at input levels of 55 and 65 dB SPL as well as maximum output. The right panel shows the fitting using the NFC hearing instrument.



	Own Hearing Instrument	Frequency Compression Instrument	
		One week	6 months
Open Set Words (% correct)			
55 dB SPL	30%	50%	60%
65 dB SPL	60%	70%	90%
Closed Set Words (dB HL)			
SRT in quiet	36	32	27
SRT in noise	2	-5	-3.5

Table 1. Results of speech recognition testing for Case 1.

20%, and his closed set word recognition improved by 4 to 7 dB. Further improvements were measurable after six months of using the NFC instruments (Table 1). Subjectively, the child reported hearing new sounds, being more relaxed in general, and earlier recognition of trivial sounds in the environment. His parents noted that he speaks with clearer pronunciation and is more self confident. Further, the mother reported that his facial expression is now more relaxed after school and that he sees his friends after school once or twice a week.

Case 2

Case 2 is an 8 year-old child with good speech and language development. She has a hereditary flat progressive hearing loss (figure 3) which was identified at the age of 3 years and 1 month. The frequency response of the child's own conventional hearing aid, as well as the frequency response of the NFC devices are shown in figure 4. Her own hearing instrument provided a good match to targets and good audibility of speech to 4 kHz. However, she perceived the high frequencies as being too shrill and sharp. Therefore, she only wore her hearing instruments at the recommended volume control position in quiet situations where she wanted to understand speech very well. In noisy situations, she would reduce the volume control setting because hearing these shrill and sharp high frequencies was too exhausting for her.

For this child, open set word recognition scores were low with her own hearing instrument, ranging from 0-10%. These scores improved significantly over six months of using NFC hearing instruments. For the closed set testing in quiet, improvement was noted after only one week of use, and showed no further improvement after an acclimatization period of six months. In noise, the improvement was only slight one week after fitting NFC, but was significantly improved after six months (Table 2).

Subjective results indicated that she no longer experiences the shrill and/or sharp aspects associated with audibility of the high frequencies. She describes hearing as being softer and more pleasant as well as clearer. Therefore, she is able to wear the NFC hearing instruments at recommended volume control settings in almost every situation and has less listening effort. She reported being able to follow the teacher at school with less effort and therefore was more relaxed after school. She also reported hearing audio books at normal volume, and her parents reported that she is more open-minded and willing to debate rather than accepting everything. Her mother also reported decrease in shyness, as exemplified by her unexpected wish to attend a holiday camp with 50 other children.

Summary

These two cases are consistent with the published literature on NFC: improved speech recognition is associated with NFC use for these children with severe to profound high-frequency hearing loss. Our clinical experience has been that all children have shown spontaneous acceptance of the new hearing instruments. More specifically, all children preferred the use of the new NFC instruments after only one day of wearing them. In

	Own Hearing Instrument	Frequency Compression Instrument	
		Time 2	Time 5
Open Set Words (% correct)			
55 dB SPL	0%	0%	40%
65 dB SPL	10%	40%	70%
Closed Set Words (dB HL)			
SRT in quiet	56	42	42
SRT in noise	9	8	3

Table 2. Results of speech recognition testing for Case 2.

our previous study of NFC fittings for adults (Bohnert, Nyffeler and Keilmann 2010), test subjects noticed an improvement after four or five weeks of wearing the NFC devices, while family members or friends noticed an improvement after approximately two or three weeks. In contrast, the children in the present study noticed substantial changes immediately. They reported hearing many new sounds like birds, frogs, door bells or bells from the mobile phone and could differentiate door bells from telephone rings. The children have taken part in group conversations more often and have talked more. They participated in more activities after school, and their families perceive their children's speech as clearer and more precise. We don't yet know the exact causes of these differences between adults and children, but we speculate that brain plasticity may play a role.

Although the children obviously noticed an immediate change and/or improvement it was not always correlated with objective changes in speech recognition scores. Furthermore, after an acclimatization period, the test results of some children showed additional improvements. From the results of this project, we do not yet know how long it takes for full acclimatization. We also do not know if the measures used were optimal for measuring speech recognition benefits. Are our current test methods sensitive enough to show the effects of NFC? Should we include subjective assessments of real-world listening in our test batteries? The children's comments reflect benefits of improved environmental sound awareness, reduced listening fatigue, and improved social participation. It is possible that our traditional test batteries are not optimized for the evaluation of this type of technology, and that robust and sensitive measures may yet require further development.

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