Nonlinear Frequency Compression Hearing Aids: Do Children Need an Acclimatization Time?

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Introduction

Hearing aid users often require a period of time to adjust to new hearing aid signal processing. For example, the auditory system of a novice hearing aid user must accommodate new, amplified sounds; this is often accompanied by improved performance. The same can be said for experienced hearing aid users receiving a new, improved hearing aid fitting (e.g., new audibility of speech cues). This adjustment period is often termed *auditory acclimatization*. The definition of this term, as provided in an article summarizing the Eriksholm Workshop on Auditory Deprivation and Acclimatization (Arlinger et al. 1996), is as follows:

…a systematic change in auditory performance with time, linked to a change in the acoustic information available to the listener. It involves an improvement in performance that cannot be attributed purely to task, procedural or training effects (p. 87).

There are many dimensions of hearing aid performance to consider when evaluating a new fitting. For the purpose of the case study presented here, the dimension of interest is speech perception.

Why Study Auditory Acclimatization with Nonlinear Frequency Compression (NLFC) Fittings?

A growing body of literature on nonlinear frequency compression (NLFC) hearing aids suggests speech perception benefit for adult and child listeners with high-frequency hearing loss (Simpson, Hersbach and McDermott 2005, 2006; Glista, Scollie, Bagatto et al. 2009; Glista, Scollie, Polonenko and Sulkers 2009; Simpson 2009; Bohnert, Nyffeler and Keilmann 2010; Wolfe et al. 2010). Findings from these studies relate specifically to NLFC signal processing and include varying degrees and configurations of high-frequency hearing loss and fitting approaches. In general, they suggest NLFC as a way of improving high-frequency hearing for hearing-impaired (HI) listeners. They also demonstrate a considerable amount of variability at the level of the individual. One possible explanation for varying degrees of benefit with NLFC hearing aids may relate to auditory acclimatization. As with all hearing aid fittings involving new, complex signal processing, listener adaptation time may be an important factor. It is likely that HI listeners require a period of time to acclimatize to alterations in the frequency domain of the hearing aid response caused by NLFC processing. Several studies of short- versus long-term benefit of NLFC suggest that speech perception benefit related to newly audible high-frequency cues may increase over time for school-aged listeners (Glista, Scollie, Polonenko and Sulkers 2009; Bohnert et al. 2010; Wolfe et al. 2010). However, none of these studies were designed to formally evaluate the exact time course of auditory acclimatization.

Previous studies on auditory acclimatization post hearing aid fitting report mean improvement in benefit over time in the range of 0 to 10 %, with some individuals demonstrating larger improvement in speech perception measured over time (Gatehouse 1992, 1993; Silman, Silverman, Emmer and Gelfand 1993; Arlinger et al. 1996; Cox, Alexander, Taylor and Gray 1996; Horwitz and Turner 1997; Kuk, Potts, Valente, Lee and Picirrillo 2003; Yund, Roup, Simon and Bowman 2006). This knowledge is important on many accounts: it informs

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hearing aid counseling efforts and implies the importance of measuring aided performance on more than one occasion. This chapter presents a pediatric case study evaluating the time course and magnitude of auditory acclimatization to newly audible high-frequency sounds, as delivered via NLFC hearing aids.

A Case Study on the Acclimatization Effect Post NLFC Fitting

This case study describes an 11 year old listener with congenital, symmetrical bilateral sensorineural hearing impairment (hearing threshold data are included in the Results section). Hearing levels were stable over the course of the study. This listener was an experienced hearing aid user who maintained full-time hearing aid usage over the course of the study. Dead region testing was completed using the Threshold Equalizing Noise (TEN) test (Moore, Glasberg and Stone 2004); results suggest the presence of cochlear dead regions at 2000 Hz and above on the right side (test ear). Prior to beginning outcome measurement testing, the opportunity to fine-tune the hearing aid fitting was presented. The participant requested a reduction to the amount of gain provided in the frequency range consistent with the cochlear dead regions. This fitting modification agrees with reports in the literature pertaining to sound quality at frequencies where dead regions are suspected (Moore 2004).

This case study is part of a series of cases in a study on auditory acclimatization post NLFC hearing aid fitting in pediatric listeners. Outcomes were measured across three phases: baseline (NLFC not enabled in study worn aids); treatment (NLFC enabled); and withdrawal (NLFC disabled for lab testing only; see Table 1). Acclimatization effects were evaluated over the course of the treatment phase, across a battery of speech-based outcomes measures including: a) detection of /s/ and /ʃ/ (Glista, Scollie, Bagatto et al. 2009); b) plural recognition (Glista, Scollie, Bagatto et al. 2009); c) consonant recognition (Cheesman and Jamieson 1996); and d) speech sound discrimination. The measure of speech sound discrimination (developed at The University of Western Ontario) included 6 consonant-vowel (CV) pairs: /si-ʃi/, /sa-ʃa/ and /su-ʃu/. Stimuli were spoken by 3 female speakers and presented in a three alternative-forced-choice paradigm. The listener was instructed to identity the "oddball" stimulus on a computer monitor. Test stimuli were presented monaurally to the ear with better hearing thresholds via modified direct-audio-input connection to the listener's hearing aid.

Study Phase	Structure/Objective
Baseline Phase (No NLFC)	Real-world usage of study hearing aids Hearing aid fitting: DSL v5.0 with adjustments to preference 2 - 3 testing sessions Stopping criterion: Asymptotic performance Goal: Minimize practice effects and/or acclimatization effects from previous fitting
Treatment Phase (with NLFC)	4 testing sessions, spaced 2 weeks apart + 2 monthly testing sessions Goal: Track time course/magnitude of an acclimatization effect
Withdrawal Phase (No NLFC)	1 testing session NLFC disabled in lab only Goal: Establish NLFC effect post-acclimatization

Table 1. Testing paradigm and goals across this study of auditory acclimatization.

Phonak Naida IX SP BTE hearing aids were programmed using prescriptive targets and clinical protocols from the Desired Sensation Level (DSL) method version 5.0a (Bagatto et al. 2005) and iPFG fitting software. Volume control, digital noise reduction (DNR) and automatic program selector features were disabled in the every-day listening program. A separate program for listening in noise was included in the hearing aid fitting process, with a frequency response that closely matched that of the first program. Noise reduction features were enabled for the noise program only. The Audioscan Verifit® VF-1 was used to measure aided responses for speech across soft, average and loud inputs, as well as to assess the maximum power output (MPO). A fit-to-targets evaluation was first completed with NLFC disabled. Once an appropriate fit-to-targets was achieved without NLFC, it was then enabled in the fitting software. Fine-tuning of the NLFC setting was completed using advanced verification measures (Glista and Scollie 2009) – further details are included below. A setting of 1600 Hz cut-off and 4:1 compression ratio was chosen to provide audibility of mid- to high-frequency sounds, with NLFC starting below the suspected dead region. Figure 1 displays long-term average speech spectrum (LTASS) with frequency-lowering active, residing between approximately 1600 Hz (the point at which NLFC begins) and 3000 Hz. A more precise description of the electroacoustic effects of NLFC using advanced measures will follow.

Advanced electroacoustic measurements included the use of frequency-specific "speech bands" (Glista and Scollie 2009). These filtered speech stimuli, available in the Audioscan Verifit® include bands of high-frequency speech energy at specific center frequencies including 4000 and 6300 Hz. Results suggest that speech energy in the 4000 Hz region is lowered to approximately 1700 Hz

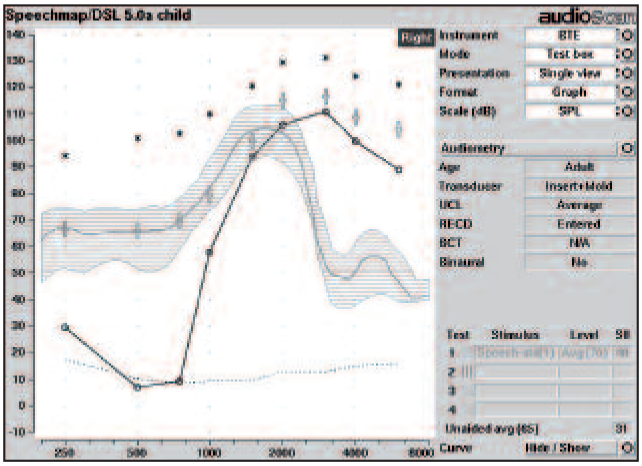

Figure 1. Aided verification results for the long-term average speech spectrum (LTASS) measured using an input level of 70 dB, with NLFC enabled.

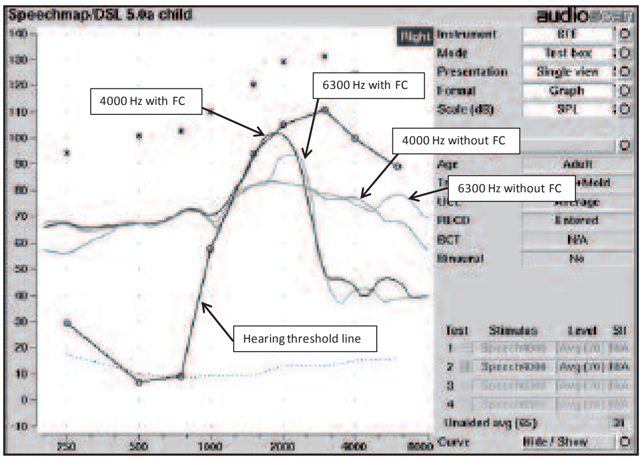

Figure 2. Verification results for filtered speech bands measured at 4000 and 6300 Hz using an input level of 70 dB SPL, with and without NLFC enabled.

when NLFC is enabled in this fitting. This lowered energy is amplified to approximately audiometric threshold (Figure 2). However, the speech energy at 6300 Hz is not audible, despite being lowered to approximately 2500 Hz. Further adjustments to achieve audibility for 6300 Hz were not possible. Overall, these measures show the frequency-lowering effects of NLFC, and indicate that audibility of speech energy up to at least 4000 Hz may be possible.

In past work, we have verified NLFC fittings using live voice productions of /s/ and /ʃ/ rather than the speech band approach shown in Figure 2 (refer to: Scollie, Glista, Bagatto and Seewald 2007; Glista, Scollie, Bagatto et al. 2009). Both approaches may have value. Live voice productions are not calibrated, and therefore may have test-retest variation. Also, isolated fricatives do not contain vowel energy, and therefore may differ in how they engage the compression of a multichannel system. The speech band test signal has the advantage of being calibrated and thus highly replicable, and also contains significant vowel energy. However, the bandwidth of the isolated speech band in the "speech band" test signal is narrower than the frication bands of /s/ and /ʃ/, and therefore may not fully reflect the audibility of naturally produced frication bands, nor whether the frication bands of /s/ and /ʃ/ are overlapped. Therefore, we are also showing results for live voice productions of /s/ and /ʃ/ measured with the same hearing aid fitting in Figure 3. We note that the lower-frequency portions of the fricative bands are audible in the 1500 Hz region, and that some separation between the levels and peaks of /s/ and /ʃ/ are observed. One purpose of this case study is to evaluate whether partial audibility of high-frequency speech cues provides speech perception benefit, when compared to a fitting that provides no audibility of these cues; this is evaluated as a function of acclimatization time. Although not shown here, this hearing aid fitting provides no audibility of either /s/ or /ʃ/ without NLFC enabled, much like what is shown for 4000 Hz and 6300 Hz speech bands in Figure 2.

Case Study Results

Speech recognition and detection results for this case are shown in Figure 4. Each pane represents a different outcome measure, excluding the top right corner pane, which displays test ear hearing thresholds.

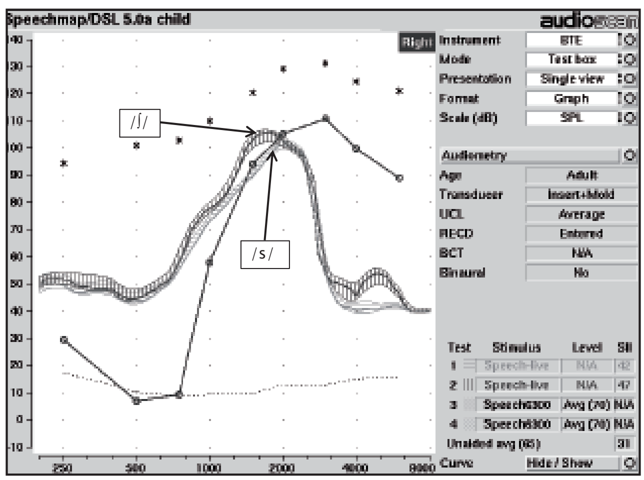

Figure 3. Verification results for measures of live productions of /s/ and /ʃ/, using a moderate speaking level, with NLFC enabled.

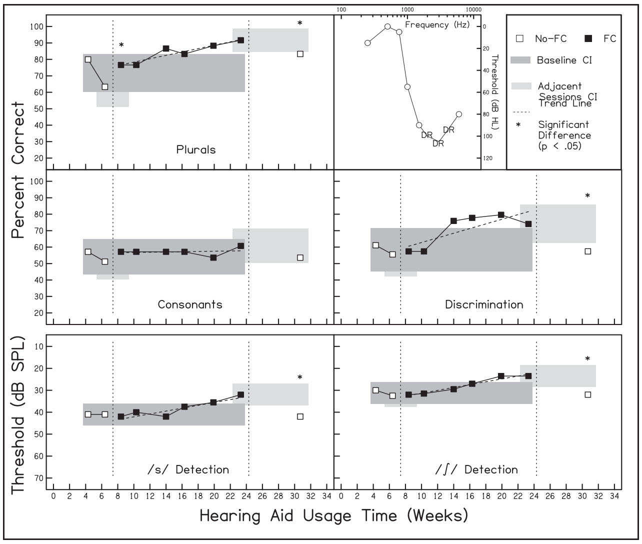

Figure 4. Speech recognition, discrimination and detection results displayed as a function of acclimatization time in weeks. Each pane represents a different outcome measure, excluding the top right corner pane, which displays test ear hearing thresholds. DR is marked in the place of hearing thresholds where dead regions are suspected. Vertical, dashed division lines separate data by experimental phase in the order of: baseline results (using open squares), treatment results (using closed squares), and withdrawal results (using open squares). Shaded regions display 95% confidence intervals around average baseline scores, denoted with "Baseline CI", and final baseline/treatment scores, denoted with "Adjacent Sessions CI."

Vertical, dashed division lines separate data by experimental phase in the order of: baseline results, treatment results and withdrawal results. Shaded regions display 95 % confidence intervals around average baseline scores, and final baseline/treatment scores. Significant NLFC benefit from baseline to treatment was found for plural recognition, /s-ʃ/ discrimination and detection of /s/ and /ʃ/. Participant comments made in the treatment phase of the study included new audibility of bird songs, household appliances (e.g., microwave beeps), and warning signals at school (e.g., the bell and fire alarm). Significant NLFC benefit from treatment to withdrawal was found on all measures, with the exception of the consonant recognition task. Within the treatment period, large and consistent improvements were found on all measures except the consonant recognition task. Significant acclimatization trends were found for the plural recognition task and both detection tasks. Two types of acclimatization trends are present in the data: gradual improvement over time indicated on the plural recognition task and both detection tasks, and large improvement after approximately 6 weeks on the discrimination task.

Discussion and Clinical Implications

This article presents a case study of auditory acclimatization following the fitting of NLFC hearing aids for a child with a steeply sloping hearing loss and "high frequency" dead regions. Careful consideration was taken in the experimental design of the study to ensure a high level of experimental control. Although it is not possible to generalize findings from one case study across all pediatric listeners, the results provide evidence of auditory acclimatization to newly audible high-frequency sounds following NLFC hearing aid fitting. Specifically, a period of acclimatization time was needed prior to observing significant NLFC benefit (i.e., 6 to 8 weeks). With NLFC enabled, most sounds presented during initial outcome measure testing would have been entirely novel to this listener, relative to her previous, long-standing hearing aid fitting. For this reason, it is probable that an acclimatization time was required to: a) determine meaning related to novel high-frequency sounds, and b) associate these cues with specific phonemes (to be able to recognize and/or discriminate sounds). It is likely that the time course and magnitude of acclimatization to newly audible speech sounds would be different across listeners presenting with unique hearing loss configuration and hearing aid fittings.

Verification measures alone do not explain the large degree of NLFC benefit obtained for tasks involving audibility of /s/ sounds (i.e., plural recognition and /s/ detection). Verification measures were used to estimate audibility of sound for a specific frequency region or for isolated speech sounds; however, they cannot capture the exact spectral energy associated with the experimental stimuli. It is possible that this listener learned to use the partial audibility provided for frication cues (Figure 3), and/or alternative cues in the frequency-lowered speech signal. The significant withdrawal effect reported across four out of the five tasks suggests that benefit change over time can be attributed to novel speech cues introduced with NLFC hearing aid processing, as opposed to practice effects. This finding relates to an underlying principle of single-subject research: when a stable data trend in the treatment phase is followed by an immediate and abrupt change in level/trend in the withdrawal phase, we can conclude a functional change has occurred based on the treatment of interest (Gast 2010).

This case illustrates the application of modified hearing aid verification and validation procedures that have been developed specifically for frequency lowering technology. For example, verification procedures now include high-frequency, speech-based stimuli to assist with optimization of NLFC settings on an individual basis (Glista and Scollie 2009). However, electroacoustic measures do not tell us if a child benefits from signal processing, and cannot address acclimatization effects. Measures of speech sound detection and recognition designed to evaluate perception of high-frequency sounds can help determine whether a listener is receiving benefit from a new hearing aid fitting. Results from this case study suggest that it may be important to administer speech perception testing on more than one occasion and after allowing a period of acclimatization for listeners wearing NLFC hearing aids. Repeated validation measurement has potential utility in the fine-tuning of NLFC settings on an individual basis. Further research is needed to determine the time course of acclimatization following NLFC hearing aid fitting in a larger group of participants.

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