
# SoundRecover2 for Pediatrics: Audibility where it matters most

**The potential benefit of a new adaptive version of non-linear frequency compression (NLFC) that permits the use of lower compression ratios and higher cut-off frequencies was evaluated in a study with children. This study compared hearing performance, including audibility and speech recognition, to outcomes obtained with the original NLFC algorithm. The findings suggest that the new adaptive version of NLFC results in improved access to high-frequency speech sounds and improved recognition of speech sounds and monosyllabic CVC words without detriment to speech recognition. This new adaptive NLFC processing, termed NLFC-2, constitutes the basis of SoundRecover2 from Phonak, introduced in 2016.**

## Introduction

Phonak first introduced non-linear frequency compression (NLFC) with SoundRecover in 2008, offering a solution for restoring audibility of conventionally unaidable high-frequency sounds. NLFC found in SoundRecover compresses high-frequency acoustic inputs to a lower frequency. For children, this technology has the potential to provide access to important high frequency sounds for speech acquisition and recognition, including fricatives such as /f/, /s/, and /sh/.

A review of research studies examining the benefits of this form of hearing aid signal processing for children with hearing loss shows that SoundRecover can improve speech recognition when proper verification is conducted (Glista & Scollie, 2012; Glista et al., 2009; Glista, Scollie, & Sulkers, 2012; Wolfe, Caraway, John, Schafer, & Nyffeler, 2009; Wolfe et al., 2010; Wolfe et al., 2015). Although the benefits of SoundRecover are well documented, strong NLFC compression parameters (e.g. high compression ratios and low cut-off frequencies) may produce substantial distortion to the original speech signal rendering it unpleasant up to unintelligible (Hillock-Dunn, Buss, Duncan, Roush, & Leibold, 2014).

In response to this limitation, a second generation of NLFC, NLFC-2, was developed. The primary difference between the original NLFC and the adaptive NLFC-2 is that the NLFC-2 algorithm is not static, but depends adaptively on the energy distribution of the input sound. NLFC-2 also possesses a second cut-off frequency which “protects” low-frequency sounds, such as vowels and voiced consonants. In the NLFC-2 processing scheme, inputs below the lower cut-off frequency are always left intact (i.e. linear processing is applied). Inputs above the upper cut-off frequency are subject to frequency compression. In the middle-frequency area between the lower and the upper cut-off frequencies, the processing depends on the momentary energy distribution in the input signal. In this frequency area, the system adaptively and instantaneously determines whether frequency compression will be active or not.

If the upper cut-off frequency of the adaptive NLFC is set appropriately, the lower cut-off frequency can be set well below the 1500 Hz limit of the original algorithm. The formant relationship for vowels will not be adversely affected, because with the adaptive algorithm, the frequency compression for mid-to high-frequency acoustic inputs is only active if these input components have a significant energy with respect to the simultaneously present low-frequency components. The use of a lower cut-off frequency in turn allows for the use of a lower compression ratio, which will result in less alteration of the spectral shape of mid- and high-frequency phonemes and environmental sounds.

For the purpose of this study, the original version of NLFC (found in the first generation of SoundRecover) will be referred to as NLFC-1 and the adaptive NLFC (found e.g. in SoundRecover2) will be referred to as NLFC-2. The objective of this study was to evaluate the use of an adaptive algorithm for non-linear frequency compression for children.

## Methodology

### Participants

Fourteen children served as participants. All children had been previously diagnosed with hearing loss ranging from mild to moderate in the low frequencies to severe to profound in the high frequencies. The mean age of the children was 11 years, 6 months (range: 6 to 17 years old). All subjects were previous users of NLFC-1 and native English speakers, with receptive and expressive spoken language aptitude within two standard deviations of age-referenced norms.

Children with auditory neuropathy spectrum disorder, retrocochlear hearing dysfunction, cognitive/neurological disability and/or illiteracy (that would preclude participation in questionnaires or closed-set speech recognition tasks requiring phonemic awareness) were excluded from the study.

### Hearing aid fitting procedure

All participants were fitted binaurally with a prototype of the Phonak Naída Q-90 behind-the-ear (BTE) hearing aid with multiple NLFC algorithms. In situ probe microphone measures with measured real-ear-to-coupler difference values were used to ensure that the output of the hearing aids matched the DSL v5.0 target (+/- 2 dB) for the target speech signal presented at 55, 65, and 75 dB SPL while NLFC was disabled. Active feedback cancellation was enabled in every participant's hearing aids and an acoustic feedback calibration and assessment was conducted prior to probe microphone assessment.

### Study design

The study was conducted across three phases. Each phase spanned a duration of 4-6 weeks. Within each of the phases, the participants used one of the three types of NLFC: NLFC-1, NLFC-2A, and NLFC-2B. Because all subjects were experienced users of NLFC-1, NLFC-1 results are considered fully acclimatized. Auditory performance with each NLFC-2 processing was measured at the beginning "acute" and after completion of the respective phase (4-6 weeks).

1. NLFC-1

Each participant's initial NLFC-1 settings were identical to what had been used in their own hearing aids prior to the study. Their original NLFC-1 settings were determined by a verification and fine tuning protocol previously described by Glista et al. (2009). Probe microphone measures were conducted with NLFC enabled to ensure that a recorded /s/ phoneme spoken by a female and presented at 65 dB SPL was sufficiently audible (i.e. the compressed signal met or exceeded the DSL v5.0 target at the destination frequency) with the original NLFC-1 settings. The strength of the NLFC-1 compression was fine-tuned if the /s/ phoneme was inaudible.

Two settings of the NLFC-2 processor were chosen to be compared with NLFC-1.

2. NLFC-2A

The NLFC-2A was designed by the following criteria for each subject based on the corresponding audiogram. The maximum NLFC-2 output was determined from the intersection of the subject's hearing threshold and the hearing aid maximum power output with NLFC disabled. In addition the intersection point of 80 dB SPL speech with the hearing threshold was used to fix the upper cut-off frequency. This ensures that the broadest possible harmonic range of speech is protected by the NLFC-2 processor for each individual participant.

3. NLFC-2B

The NLFC-2B setting was chosen to lie between the NLFC-2A setting and the NLFC-1 setting. For each subject, the same maximum NLFC output as in their NLFC-1 setting was used. In comparison with their NLFC-2A setting, the lower cut-off was set higher (with a stronger compression ratio) and the higher cut-off was set lower to achieve an audible bandwidth closer to the fine-tuned NLFC-1 setting. This setting was selected in an attempt to allow investigating whether the subject preferred an NLFC-2 fitting which was closer in terms of compressed sound quality to what they were used to with NLFC-1.

### Outcome measures

Open-set speech recognition in quiet was evaluated with three different measures: the University of Western Ontario (UWO) Plurals Test (Glista & Scollie, 2012), the Consonant-Nucleus-Consonant (CNC) monosyllabic word recognition test (Peterson & Lehiste, 1962), and the Phonak Phoneme

Perception Test (PPT) (Schmitt, Winkler, Boretzki, & Holube, 2016).

## Results

### UWO Plurals Test

Average performance on the UWO Plurals Test across the five test conditions is shown in Figure 1.

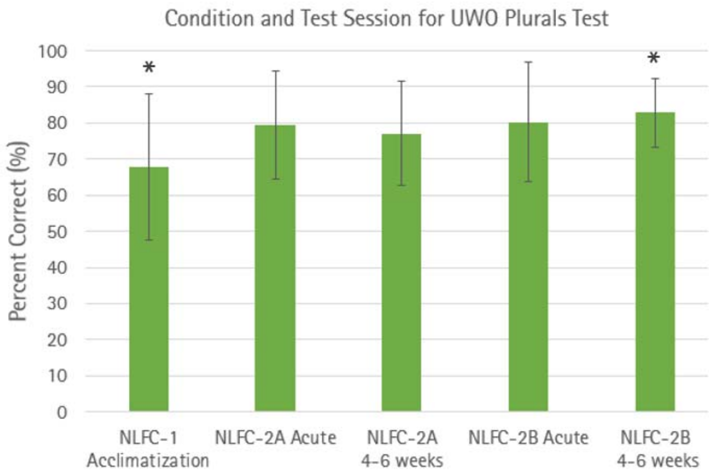


**Figure 1: Mean scores in percent for the UWO Plurals Test across the NLFC conditions. * Statistically significant: p=0.02.**

This graph shows that NLFC-2B scores (4-6 weeks after fitting) were significantly better than NLFC-1 (i.e. SoundRecover) scores.

### CNC Word Recognition Test

Average word recognition performance across the five NLFC test conditions (for 50 dBA and 60 dBA presentation levels) is shown in Figure 2 and 3 respectively.

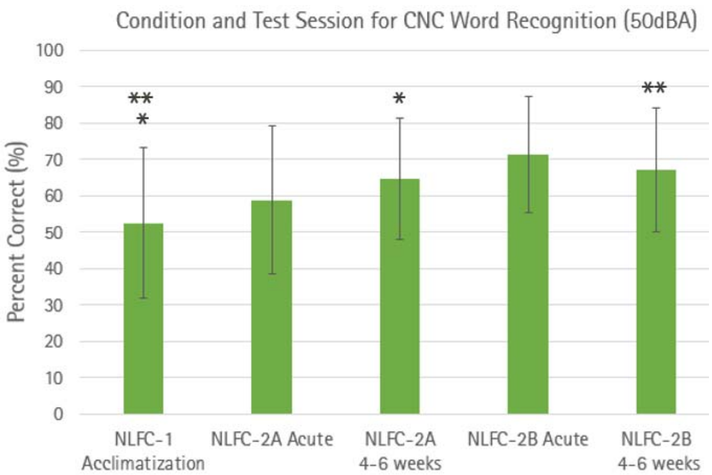


**Figure 2. Mean scores in percent correct for the CNC monosyllabic word recognition test across NLFC conditions for the 50 dBA presentation level. * and ** Statistically significant: * p = 0.005 ** p = 0.004**

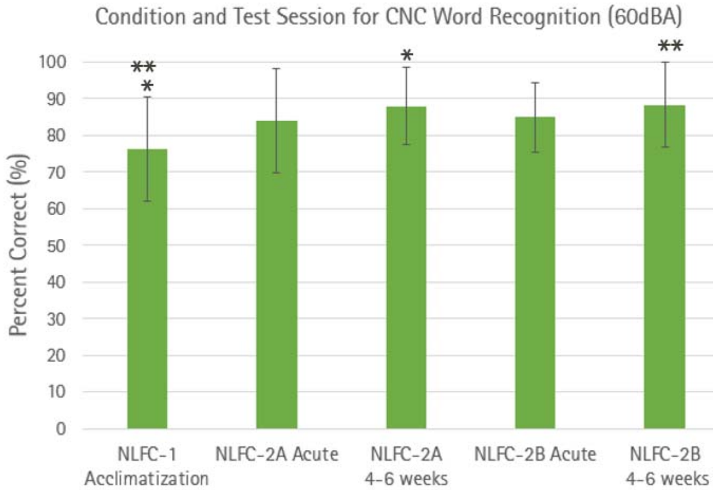


**Figure 3: Mean scores in percent correct for the CNC monosyllabic word recognition test across NLFC conditions for the 60 dBA presentation level. * and ** Statistically significant. * p = 0.005 ** p = 0.004**

Figures 2 and 3 indicates that for both the 50 and 60 dBA presentation levels, NLFC-2A (4-6 weeks) and NLFC-2B (4-6 weeks) mean scores were significantly better than NLFC-1 (i.e. SoundRecover) scores.

### PPT Detection Thresholds

There were no significant differences between the NLFC processing conditions; however, there were decreases of up to 4 dB SPL in average detection thresholds in the NLFC-2B relative to the NLFC-1 and NLFC-2A conditions for several of the stimuli.

### PPT Recognition Thresholds

The average recognition thresholds across the test and stimuli conditions are shown in Figure 4.

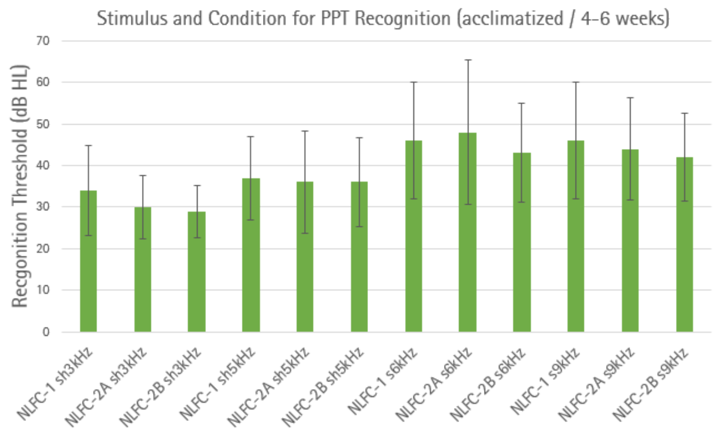


**Figure 4: Average recognition thresholds on the four PPT stimuli for NLFC-1 (acclimatized) and NLFC-2 (4-6 weeks after fitting).**

There were no significant differences between the NLFC processing conditions for all four stimuli; however, the recognition thresholds for all investigated phonemes decreased (i.e. became better) for the majority of subjects with NLFC-2B after 4-6 weeks of use.

## Discussion

The results of this study indicate that the use of adaptive NLFC allows for better detection and recognition of high-frequency speech sounds when compared to performance obtained with the original version of NLFC. Additionally, there are no signs of a detriment in speech recognition with the use of adaptive NLFC.

Although not all findings were statistically significant, there was a trend of slightly superior performance with the intermediate version of NLFC-2, NLFC-2B. The adaptive function of NLFC-2 together with the use of the newly introduced second cut-off frequency is the primary mechanism that allowed for the provision of a lower cut-off frequency relative to what has been typically used with NLFC-1.

This study does possess some limitations. First, performance was not evaluated in noise. It is possible that NLFC-2 may improve speech recognition in quiet, but does not result in any change in speech recognition in noise. Second, NLFC-2 settings were based on the NLFC-1 settings the children were using at the onset of this study. It is possible that greater NLFC-2 benefit could have been observed if NLFC-2 parameters would have been further optimized on an individual basis using a combination of objective (e.g. probe microphone) and subjective measures. Moreover, it is possible that in the current study the advantages of NLFC-2 relative to NLFC-1 may have been underestimated because acclimatization to NLFC-2 processing was likely not complete after only 4-6 weeks of use. Third, performance with NLFC-1 and NLFC-2 was not compared to performance without the use of NLFC. Previous research has indicated that children who have hearing losses similar to the audiometric profiles of the participants in this study typically perform at least as well, and in many cases better, with NLFC-1 than they do without NLFC (Glista et al., 2009). However, that was not measured directly in this study, so conclusions regarding the benefit of NLFC-2 relative to conventional processing cannot be clearly established.

## Conclusion

NLFC-2, the base algorithm for the adaptive SoundRecover2 processing scheme, was compared to NLFC-1, the original SoundRecover frequency lowering algorithm, to evaluate audibility and speech recognition associated with the use of an adaptive non-linear frequency compression in children.

The results show that when compared to performance of the original version of NLFC (e.g. SoundRecover), the use of adaptive NLFC:

- improves access to high-frequency speech sounds
- improves the recognition of monosyllabic CVC words
- does not result in detriment in speech recognition

In addition, long-term users of conventional NLFC (e.g. original SoundRecover) were able to successfully switch to adaptive NLFC without a long period of acclimatization.

## References


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