Criteria for evaluating the performance of linear frequency transposition in children

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One of the most challenging hearing loss configurations that audiologists face in working with children is a precipitously sloping sensorineural hearing loss (SNHL), such as that resulting from treatment with ototoxic agents. This audiometric configuration often limits access to high-frequency (HF) acoustic cues, which may interfere with the child’s ability to learn to categorize sounds into their morphological contexts and to eventually reproduce them.

It has been shown that high-frequency acoustic cues impact speech-recognition abilities even for normal-hearing children. Children with hearing loss are more affected by limited HFs in terms of speech recognition, and may also exhibit errors in morphology such as plural markers and verb tense (e.g., cow vs. cows and jump vs. jumps).

Fortunately, amplification options suitable for such a challenging hearing loss configuration may be available. One example is the linear frequency transposition algorithm utilized in the Widex Inteo, called the Audibility Extender (AE). Clinicians treating children with such hearing losses may consider these strategies when conventional amplification fails to provide sufficient HF information for the perception of high-frequency speech sounds, such as /s/. Because of the uniqueness of this processing algorithm, the typical evaluation protocol applicable to conventional hearing aids may require modification when it comes to assessing performance with the AE.

In this article, we describe the evaluative measures used to validate the performance of the AE algorithm for two children. They are 2 of a group of 10 children whose performance with the AE was systematically studied. Results of the group as a whole, which were similar to the cases described herein, will be reported in the future. These cases are presented because they describe evaluative tools and performance of children with different hearing loss configurations, in different developmental stages, and with different test-taking, attention, and reading skills.

LINEAR FREQUENCY TRANSPosition

Linear frequency transposition (LFT) is an example of a novel application of frequency lowering. In this approach, a frequency region (called the “source frequency”) above a particular “start” frequency is targeted for transposition. Typically, the source frequency is either unaidable (because of a potential “dead” region) or unreachable (because of inadequate gain/output).

Once activated, the spectral peak within the source region is 4000 Hz, sounds in the 4000-Hz region are lowered to 2000 Hz. Using this technique preserves the harmonic relationship between the original and the transposed signals for simple stimuli. In this manner, high-frequency (HF) cues can be made available to the child without introducing unnecessary distortion. For a more detailed description of LFT as used in the Widex Inteo AE, see Kuk et al.

Studies have been conducted to examine the efficacy of the AE algorithm in adults. For example, Kuk et al. found that adults with a precipitous HFSNHL fitted with thin-tube open fittings demonstrated subjective benefits for the AE as well as improvements in consonant identification. As much as a 10%-15% improvement in consonant scores was realized following an acclimatization period of 2 to 4 weeks.

Korhonen and Kuk (in press) found that the Inteo AE creates acoustic cues that normal-hearing listeners with a simulated hearing loss at and above 1600 Hz can be trained to use without negatively affecting identification of vowels and voiced consonants.

EVALUATING BENEFIT IN CHILDREN

Audiological considerations

In evaluating the efficacy of amplification, including that of the LFT algorithm, the clinician’s main concern is to determine if new HF cues are available to the child. This can be done by measuring the aided hearing sensitivity, speech recognition, and identification of environmental sounds. In addition, subjective preference for LFT may be compared when such information can be obtained reliably.

Sensitivity measurements are important in LFT fittings because the goal is to provide the child with access to high-frequency information, including low-level, high-frequency information that may not be audible with conventional amplification. To that end, the aided thresholds may contribute sensitivity information of importance in evaluating non-linear devices. Only when the aided thresholds indicate that the child has auditory access to soft HF information can the clinician be assured of the potential for improved speech recognition.

The ability to recognize HF speech information is generally measured by administering HF word lists or nonsense syllable tests. In addition to testing at a conversational input level, testing at soft input levels should be included in order to identify improvements in recognition of soft
HF speech sounds. Improvements in awareness of HF environmental sounds can also indicate if the LFT strategy affects the child’s everyday life positively. Children and their parents should be encouraged to chronicle information about new auditory experiences in a hearing aid diary. Checklists of HF environmental sounds for parents or older children may also provide this information.

Speech considerations

Receptive and expressive language tests, vocabulary tests, and articulation tests are useful in determining if a hearing aid strategy for a child has a positive impact in the short term. However, these measures will not reveal if a new amplification strategy is affecting the child’s speech production in the short-term.

It is critical that auditory training be provided when LFT is used. It can help the child link the new auditory cues to the sounds the child produces and to establish and reinforce the sound/symbol link when reading aloud. The overall goal of the auditory training program is for the child to detect, discriminate, and produce the required speech sounds. Auditory training may take the form of games that focus on the perception and production of target phonemes, such as /s/, /f/, /z/, /sh/, /ch/. During these sessions, children are required to listen and produce the required speech sounds in word or sentence forms, depending upon the nature of the activity.

For very young children a clinician should closely monitor the child’s speech production of new HF sounds. Also, clinicians should complete communication inventories with the help of the child’s parents. For older children, the clinician may also be interested in monitoring the accuracy of production of problem sounds, especially those most likely to be affected by access to new HF acoustic cues, such as voiceless fricatives.

A full analysis of the child’s production repertoire in terms of frequency and accuracy of production would involve hours of transcription of recorded speech samples. In a clinical setting this would be unrealistic. However, clinicians can select and monitor the sounds that are most likely to be impacted by new HF auditory information, such as /s/ and /z/.

For example, a child may be asked to describe a picture using key words containing /s/ and /z/ phonemes in various positions. It may also be useful to measure carryover into reading since additional HF speech cues could potentially stimulate a sound/symbol connection prior to its becoming apparent in conversational speech.

The clinician should also be interested in how parents and other professionals view the child’s speech production and related progress. Communicating with teachers and/or educational itinerants can help in this regard.

Case examples

The following case studies illustrate the application of audiological and speech perspectives in evaluating the efficacy of the AE algorithm in school-aged children.

CASE STUDY 1: “LE”

LE’s hearing loss is secondary to cisplatin treatment for adrenal cortical carcinoma. Treatment began when she was 6 years of age and lasted 2 years. LE is now 13 years old and healthy. Her audiogram is shown in Figure 1.

Prior to her trial with LFT, she used two-channel, high-power digital BTEs. Although LE “graduated” from speech therapy and was being seen infrequently for maintenance only, her articulation score on the Goldman Fristoe Test of Articulation (GFTA) indicated an age-equivalence of 5.5 years. She is also approximately 3 years below age level on global speech-language assessment tools. For these reasons, her clinicians decided she may be a good candidate for LFT.

Sound field threshold testing with LE’s own hearing aids indicated aided audibility within the slight/mild hearing loss region for the low frequencies and in the moderately severe/severe range for the higher frequencies. She was fitted with IN9 hearing aids binaurally with the AE feature enabled. Her aided thresholds with the Inteo AE (Figure 2) showed aided thresholds in the normal-to-mild hearing loss range across frequencies (filled triangles).

Since LE had good reading and attention skills, the California Consonant Test (CCT) was selected to evaluate her recognition of HF speech sounds. An example of a stimulus item is the word “leaf.” The three choices in addition to the correct response are “leash,” “leak,” and “lease.” The CCT may be especially useful for identifying errors in patients with HFN-SHL.

The 100-item test was administered in a recorded format at 30 and 50 dB HL in each hearing aid condition. Results of LE’s baseline CCT word scores with her own HAs were 28% and 56% at 30 dB HL and 50 dB HL, respectively. LE was recorded reading a four-paragraph passage entitled “Ice Cream.”

Recordings were later transcribed and LE’s /s/ and /z/ production was analyzed.
The accuracy of her production of these two targeted phonemes was 79%. For the conversational speech sample, LE answered questions about pictures with key words with /s/ and /z/ in various positions. The sample was recorded until 50 /s/ and /z/ phonemes were collected, which was on average a 5-minute recording. Her conversational speech sample indicated an 85% accuracy rate for /s/ and /z/ phoneme production.

Additionally, the subject reported that she was hearing new environmental sounds such as elevator bells, soda “fizzing” in a glass, the telephone ringing from another room, and feedback from her hearing aid when she held it in her hand. LE continues to use the AE, and her speech and hearing professionals are monitoring her progress.

CASE STUDY 2: “CS”

CS is an 8-year-old male whose early history included 5 days of seizures after birth and prophylaxis with streptomycin for suspected meningitis. He was diagnosed with a moderate-to-severe SNHL 2 weeks after birth and fitted with hearing aids at 6 months of age. This child’s audiogram is displayed in Figure 5.

CS was using five-channel, high-power digital BTEs prior to his trial with LFT. He is mainstreamed in the classroom where he uses an FM system. He receives speech/language therapy daily at school. CS’s speech was not very intelligible; his GFTA age equivalent score was 3.8 years. He has frequent omissions and distortions including for /s/ and /z/ sounds. In addition, his global speech and language assessment indicates age-equivalent scores just over 2 years below his chronological age.

Since CS reads below grade level, an open-ended nonsense syllable test was administered to assess speech recognition. A recorded version of the Edgerton-Dan- hauer nonsense syllable test (NST) was administered at 30 and 50 dB HL with his own HAs.11 The NST is a 25-item test of nonsense syllables in the CVCV format.

Responses were recorded and later transcribed by a speech-language pathologist. Reading and conversational speech samples were also recorded and transcribed. CS and his parent were surveyed re: environmental sound awareness. CS’s parent reported that with his own hearing aids CS was unable to hear many environmental sounds, including the telephone ring from another room.

Results with his own HAs indicated that at 30 dB HL, not only was CS unable to recognize initial and medial consonants, but he was also scoring very poorly on...
scores improved, but his consonant scores while using his own HAs.

/z/ phonemes accurately in reading and were still very poor. CS produced /s/ and vowel recognition. At 50 dB HL his vowel scores continued to improve after 6 weeks of use. At the fitting of the AE, recognition of both consonants and vowels improved dramatically and immediately at 30 dB HL. CS’s vowel- and consonant-recognition scores continued to improve after 6 weeks of use. At 50 dB HL, his consonant scores improved dramatically over scores with his own HAs and continue to do so after 6 weeks of use. Again, this suggests some degree of acclimatization with the AE feature.

Accuracy of production of /s/ and /z/ also improved dramatically after 6 weeks of use for reading and conversation. CS improved from 40% to 80% in the production of /s/ and /z/ in a reading aloud task. For conversation, he improved from 60% to 85% in accurately producing the /s/ and /z/ phonemes. CS continues to use the AE, and his clinicians plan to reassess his progress regularly.

### CONCLUSION

Linear frequency transposition may improve speech re-cognition of individuals with a high-frequency hearing loss that is either unaidable or unreachable by conventional acoustic amplification. The two cases described in this paper illustrate successful AE use in children. In both cases there is improved consonant recognition as well as improvement in HF fricative production after 6 weeks of use of LFT.

Auditory training may be a useful “fuel” for successful LFT fittings. A thorough evaluation of a child’s progress with LFT may necessitate a modified assessment protocol from both audiological and speech perspectives. Additionally, audiologists and speech-language pathologists should collaborate to identify and validate changes with LFT in speech perception and production skills and to monitor progress over time.

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**REFERENCES**


