Linear Frequency Transposition: An Individual Approach to Choosing a Start Frequency

Denise M. Keenan, M.A.
Widex Office of Research in Clinical Amplification, Widex USA

INTRODUCTION

Traditionally, patients with a high frequency hearing loss have been a challenge for audiologists to satisfy completely. Reaching the sufficient audibility in the high frequencies without the wearer experiencing the occlusion effect has been the major obstacle. The use of open-fit instruments eliminates the problem of occlusion. However, even with the sophistication of active feedback cancellation, the openness of the fitting will limit the maximum available gain to approximately 40 dB. This amount of gain may not be enough for some hearing aid wearers. Furthermore, some patients with "dead" regions cannot tolerate the amplification of the high frequencies because of distortion within the hearing system. In either case, an alternative solution may be warranted to assist these individuals so the information contained in the high frequencies becomes audible again.

AUDIBILITY EXTENDER (AE)

One alternative solution is to move the unaidable high frequency sounds to an area where there may be more usable hearing to the individual. The Audibility Extender in the Inteo hearing aid linearly transposes high frequency sounds to a lower frequency region for ensured audibility.

The Audibility Extender (AE) identifies a "start frequency" above which sounds will be transposed. The AE will then determine the region with the highest intensity above the start frequency or "source" octave. The sounds within the "source" octave region will be linearly transposed one octave lower to the "target" region and mixed with the original, un-transposed signals and amplified based on the individual's degree of hearing loss.

The default start frequency in the Audibility Extender is chosen by taking the lowest frequency that has a 70 dB HL threshold and an audiogram slope between 500 Hz and 4000 Hz that is greater than 10 dB per octave. Generally, this default setting is optimal for most (80%) patients. However, in some cases, depending on how much usable hearing is available along the slope of the audiogram, the default start frequencies may not be the most optimal.

The Importance of an Optimal Start Frequency

The start frequency is critical to the usefulness of the AE. If the start frequency is too low, areas that may have been "aidable" are now transposed instead. This may result in poorer speech intelligibility in the transposed condition. If the start frequency is set too high, areas that are unaidable may not be transposed. The sounds in that area may still remain inaudible. The different scenarios are summarized in Figure 1.

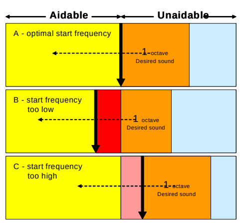

Figure 1: Three hypothetical choices for the start frequency (shown by dark downward arrow). (A) The optimal start frequency is chosen. The aidable region is amplified, whereas the unaidable region is transposed and becomes audible. (B) A lower (than optimal) start frequency is chosen. Some of the aidable region (in red) is not amplified but transposed. (C) A higher (than optimal) start frequency is chosen. Some of the unaidable region (in pink) remains unaidable.

Determination of Customized Individual Start Frequency

A customized approach is used to estimate the start frequency in order to account for the individual variations. In this approach, a recorded /s/ sound at 30 dB HL is used as the stimulus. This sound contains energy around 4000 Hz to 6000 Hz and is difficult to hear for most people with a high frequency hearing loss. It is assumed that if the wearers can hear and identify this particular phoneme at its typical presentation level, they should be able to hear and identify most, if not all, of the English language speech sounds.

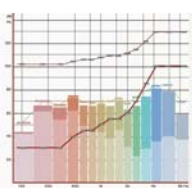

Figure 2: Master Program /s/ sound could not be identified

The following procedure may be used to determine the start frequency.

1. After verification of an optimal fit with the master program, the recorded /s/ sound may be presented in sound field at 30 dB HL one meter from the test subject. The (in)audibility of the /s/ is also verified on the Sound Tracker (Figure 2)
2. The AE program was activated with the highest start frequency (6000 Hz). Again, the recorded /s/ sound is presented as in step 1 (30 dB HL at one meter).

START FREQUENCY (cont.)

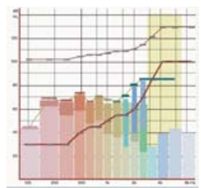

Figure 3: Custom start frequency; /s/ sound identified

3. If the patient is unable to hear and identify the /s/, the gain of the transposed signal (AE gain) could be adjusted in 1 dB steps up to 14dB max.
4. If the maximum AE gain is reached and the subject continues to not be able to identify the /s/ sound, the next lower start frequency should be attempted (4000 Hz). (Figure 3)
5. This systematic procedure continued until the patient is able to hear and identify the /s/ sound without distortion.
6. If a patient is unable to identify the /s/ at any start frequency, a recorded /sh/ sound may be used instead following the same procedures. The /sh/ sound has dominant energy from 2000 Hz to 4000 Hz.

CASE STUDY SUBJECTS

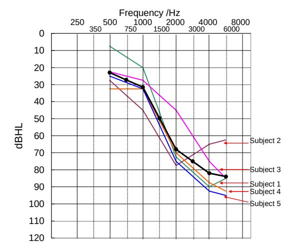

Figure 4: Audiogram for research participants; right and left ears averaged together. Group average shown as black line.

Five native English speaking subjects aged 54 to 83 years (mean age of 68 years) were evaluated for this report. These subjects were part of a larger study that evaluates the efficacy of the Audibility Extender. The average of their right and left ear audiograms can be seen in Figure 4 with the average of all subjects in black. Four of the five test subjects were experienced hearing aid users. The subjects were seen every two weeks for three visits.

These test subjects were chosen as "case studies" because they could not identify the /s/ sound at a soft level of 30 dB HL with the master program. In addition, their individually determined start frequencies were different from the default start frequencies as seen in Table 1. Test subjects whose default start frequencies coincided with the individually chosen start frequencies were not reported in this report.

Table 1: Default start frequencies and individually determined start frequencies

	Default Right	Default Left	Custom Right	Custom Left
Subject 1	2500 Hz	2500 Hz	4000 Hz	4000 Hz
Subject 2	2500 Hz	6000 Hz	4000 Hz	4000 Hz
Subject 3	3200 Hz	6000 Hz	4000 Hz	4000 Hz
Subject 4	3200 Hz	2500 Hz	4000 Hz	3200 Hz
Subject 5	2500 Hz	2500 Hz	3200 Hz	3200 Hz

Evaluation of Performance

Several tests were used to evaluate performance. These tests included:

1. **Edgerton-Danhauer Nonsense Syllable Test (NST)** presented at 30 dB HL and 50 dB HL. This test consists of two lists of 25 bisyllables in a consonant/ vowel/ consonant/ vowel (CVCV) context with six randomizations for each list. This test was chosen because it has been shown not to have any learning effect even when given multiple times. It may also be more challenging for people with a high frequency hearing loss. The NST lists are based on items having similar difficulty for sensorineural listeners rather than on phonetic balancing or frequency of usage in the language.

2. **Subjective evaluation of birds, music and speech**. Ten sound samples of each stimulus category (birds, music, speech in sentences) were presented to the test subjects at 50 dB SPL. The subjects were asked to rate the sound quality of the sample on a 1-10 scale with 1 being the poorest score and 10 being the best score. The subject rated each sample with each hearing aid program (master and AE). The order of the programs was randomized so that the same program was not always rated first or last. The subject was not informed as to which program they were listening to. Preference between the two programs was determined by the program with the highest rating for each particular sound sample.

RESULTS

Nonsense Syllable Test (NST)

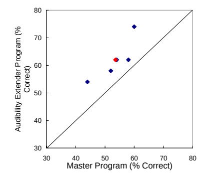

Figure 5a: NST consonant results at 50 dB HL

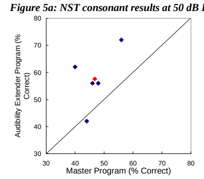

Figure 5b: NST consonant results at 30 dB HL

Figure 5a shows the consonant results for all five subjects (average in red) at a 50 dB HL presentation level at the first visit. All subjects were able to identify more consonants with the AE program than with the master program.

- The average score on consonant identification at a 50 dB HL presentation level was approximately 9% better with the AE program than with the master program.
- One subject improved by as much as 14% with the AE program over the master program.

Figure 5b shows the consonant results for all five subjects (average in red) at a 30 dB HL presentation level at the first visit. All but one subject were able to identify more consonants with the AE program than with the master program.

- The average score on consonant identification was 11% better with the AE program over the master program at a 30 dB HL presentation level.
- One subject had very similar performance with both programs (around 43-45% correct).
- One subject's consonant identification improved by 16% with the AE program and another subject improved by as much as 22% with the AE program

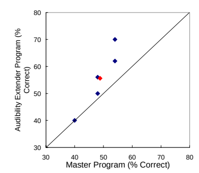

Figure 6a: NST consonant results at 30 dB HL for Visit 2

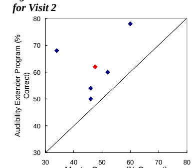

Figure 6b: NST consonant results at 30 dB HL for Visit 3

Figure 6a shows the consonant results for all five subjects (average in red) with a 30 dB HL presentation level at the second visit.

- The average score was approximately 7% better with the AE program than with the master program.
- Two subjects had very similar performance between the two programs at this visit.

Figure 6b shows the consonant results for all five subjects (average in red) with a 30 dB HL presentation level at the third visit.

- The average identification of consonant sounds improved by as much as 15% with the AE program over the master program.
- One subject's performance improved by 18% with the AE program and another improved by as much as 34% with the AE program over the master program.

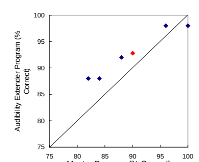

Figure 7a: NST vowel results for 50 dB HL

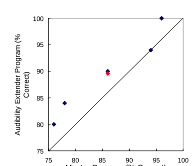

Figure 7b: NST vowel results for 30 dB HL

Figure 7a and 7b show the vowel results for all five subjects (average in red) at a 50 dB HL and a 30 dB HL presentation level respectively at the first visit.

- All but one subject identified more vowels with the AE program than with the master program.
- This subject had excellent performance in both programs (above 95%).
- Similar performance was seen in the subsequent visits two and three with vowel identification.
- Scores were around 80-90% correct for both programs.
- This indicates that vowel identification was not negatively affected by linear frequency transposition.

RESULTS (cont.)

Subjective Evaluation

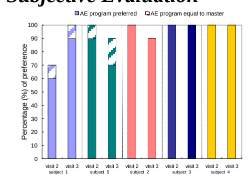

Figure 8: AE program preference on subjective evaluation of birdsong samples presented at 50 dB SPL for visit 2 and visit 3

Figure 8 shows the preference for the AE program over the master program for the ten birdsong samples over two visits.

All five subjects preferred the AE program over the master program for most, if not all of the stimuli.

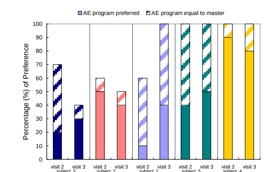

Figure 9: AE program preference on subjective evaluation of music samples presented at 50 dB SPL for visit 2 and visit 3

Figure 9 shows the preference of the AE program over the master program for ten music samples presented at 50 dB SPL over two visits.

Three subjects showed a consistent preference or improvement in preference for the AE program.

Two of the test subjects showed a slight decline in preference for the AE between visits.

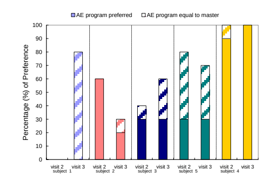

Figure 10: AE program preference on subjective evaluation of speech samples (sentences) presented at 50 dB SPL for visit 2 and visit 3

Figure 10 shows the preference of the AE program over the master program for ten speech sentences presented at 50 dB SPL over two visits.

Most of the subjects either preferred or could not tell a difference between the programs for at least half of the speech samples.

Interestingly, subject 1 initially had no preference for the AE program while listening to speech. At the follow up visit, he had more difficulty distinguishing between the two programs and had at this point virtually no preference (80% of the samples were rated equally).

Subject 4 had a clear preference for the AE program over the master program at each visit and for all other types of stimuli including speech.

DISCUSSION

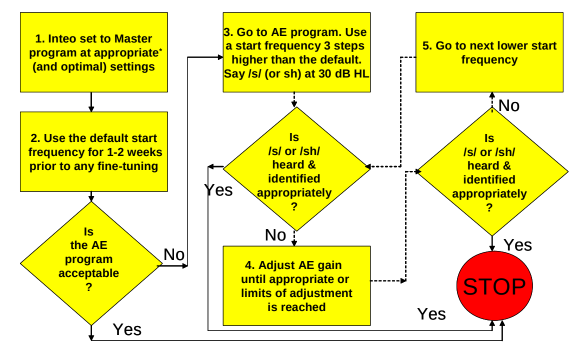

Figure 11: Flow chart for suggested AE start frequency determination

This report showed that by using the audibility of the /s/ or /sh/ sound as a criterion to determine the start frequency on the Inteo Audibility Extender, we were able to provide additional audibility of high frequency sounds to the hearing aid wearer while accounting for individual differences. This resulted in an improved consonant recognition in quiet and appreciation of everyday sounds such as birdsongs and music listening. Based on our experience, a suggested fitting procedure was developed as seen in Figure 11.