

GN Otometrics, April 2007

Best Practice #1 **Verifying Audibility in Dynamic Hearing Instruments**

Change in the World of Hearing Instrumentation

The use of digital technology in hearing instruments has changed the way we verify that speech is audible and dynamic features are functioning properly. Linear hearing instrument amplified all sounds equally. Digital hearing instruments are dynamic, changing the amount of amplification based on the input they receive from the environment and the location of sound. The traditional way of performing real ear measurements is not effective with these new hearing instruments. These new devices have many dynamic features that influence the way in which we should verify the fitting. The new features include but are not limited to:

1. Directionality

Directionality incorporates two or more microphones into the hearing instrument. By monitoring the time difference for the signal to reach the front and back microphones, the direction of the signal can be determined. In directionality mode the hearing instrument will suppress signals presented from the rear and or side.

Patterns of directionality vary, with the hypercardioid and adaptive being the most commonly utilized. The hypercardioid provides less amplification to sounds from behind and to the side of the individual and more amplification to sounds in front of the individual. The pattern of directionality remains the same for all settings. With digital hearing instruments, adaptive directionality can be implemented. This means that the hearing instrument changes the pattern of directionality it is using to best fit the environment based on the input it receives. It is constantly assessing the sounds from the environment and determining the pattern of directionality that will give the individual the best signal to noise ratio.

2. Noise Reduction

Noise reduction assesses the characteristics of the incoming signal using many features such as amplitude modulation to estimate the speech to noise ratio. If it does not match speech characteristics in one or more frequency bands, then it is considered noise and the gain of the input in that frequency band is reduced. There are many different algorithms designed by hearing instrument manufacturers to achieve noise suppression. Since these algorithms function differently, you are not guaranteed that an artificial speech signal will successfully fool the instrument into identifying it as speech. Therefore, it is important that real speech is used to verify that speech is audible in the hearing instruments with noise suppression.

3. Feedback Suppression

Feedback suppression assesses the feedback path as a function of frequency. If feedback is present, it will reduce the gain or phase-cancel the feedback at this particular frequency. For phase cancellation, a digital filter is created that has the same frequency and amplitude as the feedback but has opposite phase. When the feedback and the filter are added together, the feedback will be canceled out.

4. Wind Noise Reduction

Wind noise reduction assesses the spectrum of the input using advanced algorithms to determine if a low frequency noise is present due to turbulent air flow. If the algorithm identifies the presence of low frequency broadband noise, the hearing instrument will reduce the gain at these frequencies.

Verifying the Dynamic Hearing Instrument using the Correct Stimulus

Digital hearing instruments change their processing scheme based on input from the environment and the location of sound. The dynamic, interactive features of digital hearing instruments need a dynamic stimulus to verify digital hearing instrument fitting. Incorrect stimulus selection can result in mistakes in hearing instrument fitting. The best dynamic stimulus, which changes rapidly in frequency, amplitude and phase, is SPEECH. In addition, a SPEECH stimulus is the best option for verifying that speech will be audible for the following reasons:

1. Stimulus of Interest to the Wearer of the Hearing Instrument

Speech is usually the most important signal to the individual wearing the hearing instrument; therefore, using a speech stimulus to verify the fitting assures that the most

important signal is audible. The speech stimulus can be a pre-recorded speech file or a recording of the individual's spouse or family member.

2. All Dynamic Features On

With traditional real ear measurements that utilize a swept tone or noise stimulus, the dynamic features of the hearing instrument are turned off in order to avoid the hearing instrument identifying the stimulus as noise and reducing the gain during the verification procedure. With speech measurements, all the dynamic features can be left on during verification of fitting. This is optimal because verification of the fitting should be representative of how the individual is wearing the hearing instrument and how it is performing in the individual's environment.

Choosing the correct stimulus is important when verifying the dynamic features of a digital hearing instrument. Some hearing instruments have algorithms that detect speech, using a music stimulus may result in a very different outcome if trying to ensure that speech is audible. On the flip side, if the individual enjoys listening to music, verifying that music is audible and pleasing to the individual using a music stimulus would be appropriate. Similarly, a noise stimulus should be used to verify that noise suppression is functioning appropriately. A live speech recording is beneficial for verifying the feedback suppression. See "Verifying Hearing Instrument Dynamic Features" for further details.

Considerations when Verifying Audibility and the Manufacturer Algorithm Recommendations

1. Vent Size on Closed Fit Hearing Instruments and Open Canal Hearing Instruments

Before making fine adjustments to the fitting, make sure the assumption of the vent is set correctly in your manufacturer's fitting software. For open canal hearing instruments, some high frequencies may leak out into the reference microphone. This leakage does not affect the output of the stimulus but can affect the level of the VU meter. The effect on the VU meter is directly related to the severity and configuration of the audiogram. Open Canal Hearing Instruments affect the VU meter minimally at the high frequencies (~ <2 to 3dB). If the stimulus selected contains more high frequency energy, more of an effect may occur. See "Verifying Open Canal Hearing Instruments with AVS" for further details.

2. First Fit versus Fine-Tuning

For most manufacturers, programming the hearing instrument to the first fit under-amplifies the high frequencies in comparison to the recommended audibility area (i.e. customized speech banana) of the AVS. The gain recommended by the first fit is intended to allow the individual time to acclimate to the hearing instrument. Therefore, after the individual has worn the hearing instrument for a period of time, fine-tuning to increase the hearing instrument gain to fit the audibility area may be needed.

3. First-Time User versus Experienced User

For some manufacturer's fitting software, there is an option to program the hearing instrument based on whether the individual is a first-time hearing instrument wearer or has worn a hearing instrument previously. For a first-time wearer, the starting point of the recommended gain is often lower than needed for full speech audibility, in order to focus on comfort. After the individual has worn the hearing instrument for a period of time, fine-tuning to increase the hearing instrument gain to fit the audibility area may be needed.

Understanding the Speech Banana

1. Origination of the Speech Banana

The speech banana in AVS for the normal hearing listener is based on research from Mueller & Killion¹. The speech banana is a representation of the long term average speech spectrum and represents the average intensity of speech as a function of frequency². The long term average speech spectrum was collected in 1/3 octave bands. This is important when verifying the fitting and will be expanded upon later. The speech letters are displayed on the speech banana. There are published speech bananas based on several different languages. The speech banana in your system was determined by a group of experts in your country.

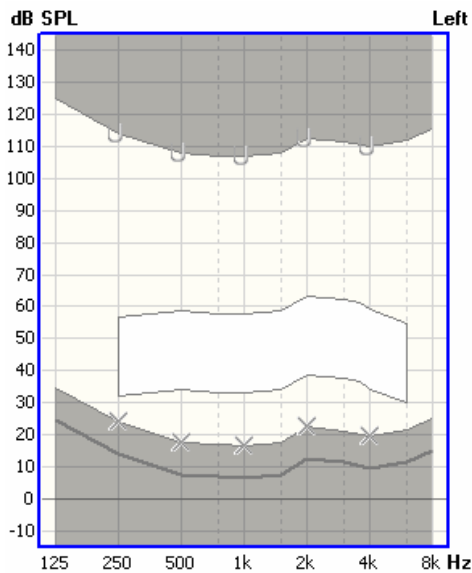
2. Audibility Area (Customized Speech Banana)

The audibility area displayed for the hearing impaired individual is based on the speech banana for the normal listener. The algorithm in the software modifies the normal speech banana based on the audiogram of the specific individual being fit with the hearing instrument.

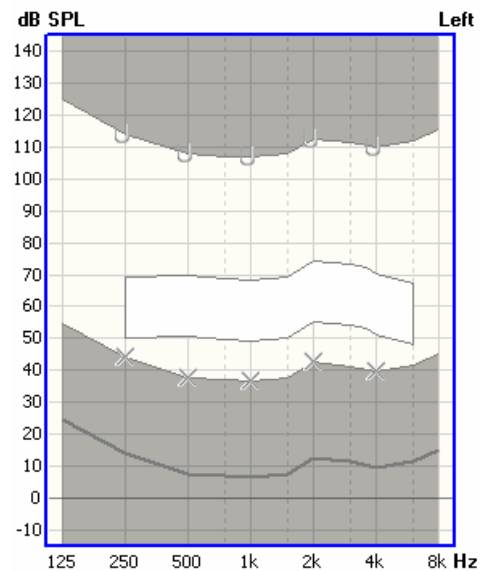
Below are 4 SPLograms representing the audibility area (customized speech banana) for a 10 dB, 30dB, 50dB and 80dB flat hearing loss.

The SPLogram displays dB in sound pressure level on the y axis and frequency on the x axis. The user can choose to use the SPLogram or an audiogram (dB HL) for displaying the audibility area and patient thresholds. The SPLogram is recommended because it is often easier for the patient to understand that soft sounds are at the bottom of the graph and loud sounds are at the top of the graph. The thresholds for the left ear are displays by "X"s and the uncomfortable loudness levels are displayed by the "U"s. The box in the middle represents the audibility area and the grey line at the bottom of the graph represents the SPL thresholds for a patient with hearing within normal limits.

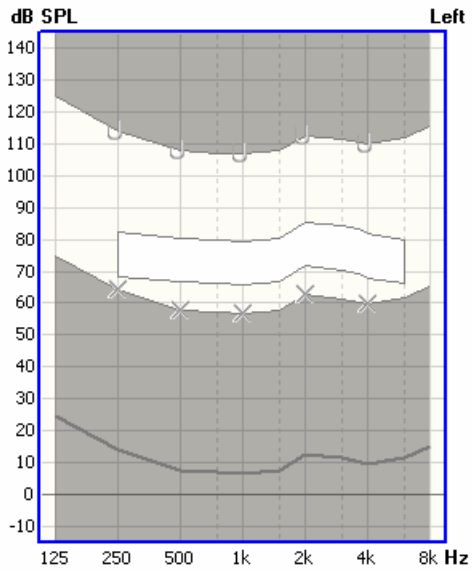
To determine the audibility area for an individual with hearing loss, the speech banana is increased in intensity and compressed to fit within the individual's dynamic range. Note that as the hearing loss becomes greater, the distance between the threshold and the lower curve of the audibility area is reduced.



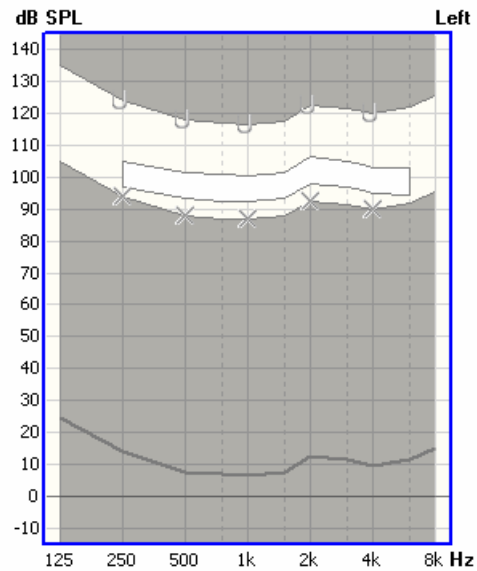
10dB Flat Hearing Loss



30dB Flat Hearing Loss



50dB Flat Hearing Loss

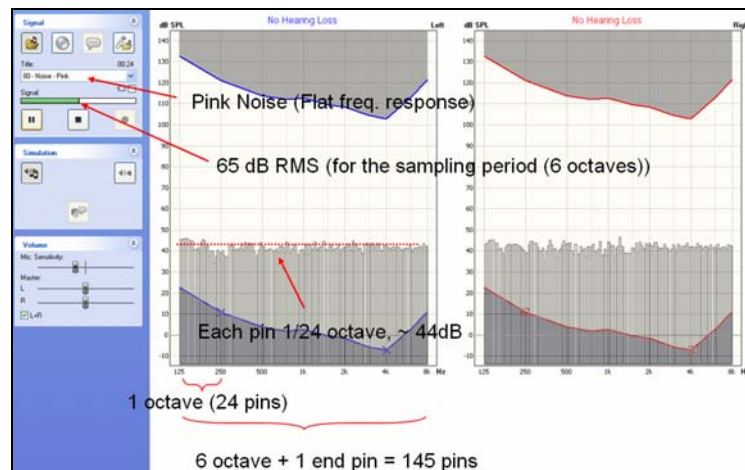


80dB Flat Hearing Loss

3. Audibility Area is the Target for Verifying Speech

Understanding the FFT Response

The RMS VU meter is the sum of energy over the whole frequency range of 125 to 8000Hz (6 octaves). There are 24 pins per octave and 1 end-pin for a total of 145 pins. When two pins are added together, this doubles the energy and results in +3dB increase. By adding all the pins together the energy increases +21 dB.



If a 65 dB SPL Pink Noise signal is presented. Each pin displays ~44 dB.
 $RMS\ of\ 6\ Octaves = 44 + 21 = 65\ dB\ SPL$

Broadband correction should be "On" (located under Tools, Options, General) and will result in an additional +9 dB. The speech banana was originally created with 1/3 octave analysis of speech. Broadband correction should be "on" when using broadband signals. The correction makes the "24 Points per Octave" spectrum fully comparable with the 1/3 octave speech banana.

Fitting to the Audibility Area

The goal of verifying a hearing instrument fitting is to assure that soft speech is audible, moderate speech is comfortable and loud sounds are tolerable.

- a. To verify that soft speech is audible, it is recommended that the speech file be delivered at 50 or 55dB SPL on the VU meter and the response curve be at the lower level of the audibility area (i.e. customized speech banana). If the response curve does not meet the recommendation, it is recommended that the gain rows be modified until the response curve is adequate. Refer to your hearing instrument manufacturer; to determine which gain rows should be modified to meet the recommendation.
- b. To verify that moderate speech is comfortable, it is recommended that the speech file be delivered at 65 or 70dB SPL on the VU meter and the response curve be covering the audibility area. If the response curve does not meet the recommendation, it is recommended that the gain rows be modified until the response curve is adequate. Refer to your hearing instrument manufacturer; to determine which gain rows should be modified to meet the recommendation.
- c. To verify that loud sounds are tolerable, it is recommended that the airplane file be delivered at 90dB SPL on the VU meter and the FFT peaks not exceed the UCL values. If the response curve does not meet the recommendation, it is recommended that the gain rows be modified until the response curve is adequate. Refer to your hearing instrument manufacturer; to determine which gain rows should be modified to meet the recommendation.

Verification of Audibility Recommendations

Proper fitting techniques assure that what is measured is accurate and valid. The following are tips:

1. Patient Location

The patient should be 18 to 36 inches from the speaker and with the reference microphone inside an imaginary circle with a 3ft diameter. The patient should be 0

degrees or 45 degrees azimuth to the speakers. The tester should not be inside this circle. Walls to the side and behind the patient should be at least 5 feet away from the speaker in order to reduce reverberation.

2. Proper Probe Placement

Placing a probe tube into the ear and measuring the SPL in the ear canal is a valid and scientific measurement. However, the probe tube must be placed properly:

- a. Approximately 28mm for females, 30mm for males and 20mm for children past the tragal notch or 5mm from the tip of the earmold or hearing instrument.
- b. The probe tube can also be secured to the earmold or hearing instrument using “Comply Wrap” or similar wrap.
- c. A substance like “Otoease” can make insertion of the probe tube easier and more comfortable for the patient.

3. Open Canal Hearing Instruments

Open Canal hearing instruments are designed for individuals with minimal to no low frequency hearing loss. If the response curve in the low frequency range does not match the audibility area, it is not recommended that the hearing instrument gain be increased in order to fit to this area. The Open Canal hearing instrument is designed to let the low frequencies leak out of the ear; therefore, by trying to fit the low frequency region of the audibility area will ultimately lead to distortion and the individual will not be satisfied with the sound quality of the hearing instrument. See “Verifying Open Canal Hearing Instrument with AVS” for further details.

4. Steeply Sloping or Severe High Frequency Hearing Loss

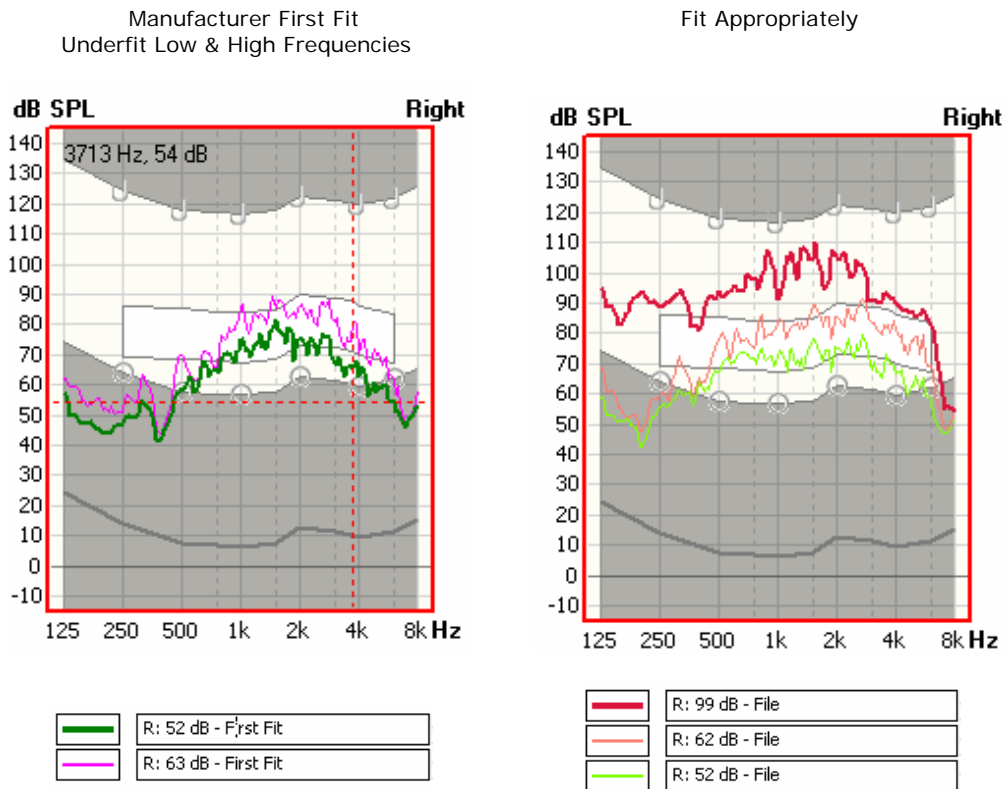
If the response curve in the high frequency range does not match the audibility area, it is not recommended that the hearing instrument gain be increased in order to fit to this area. By trying to fit the high frequency region of the audibility area will lead to feedback and off-frequency listening effects causing distortion and the individual will not be satisfied with the sound quality of the hearing instrument.

5. Stimulus File

The stimulus files we recommend for fitting a hearing instrument to the audibility area are: Babble, Café (this stimulus file has more high frequency energy), ICRA signals (see appendix for list and description), or recorded reading of the Rainbow Passage.

The left SPLogram shows a curve collected using a 52 and 63 dB Babble stimulus. This graph displays that by using the manufacturer "First Fit" there is not enough gain from the hearing aid to make speech audible for the low and high frequencies. This hearing aid did have a medium sized vent.

The right SPLogram shows 3 curves collected using a 52dB and 62dB Babble stimulus and a 99dB Airplane stimulus. The gain of the hearing instrument shown in the left panel was increased for the low and high frequencies; however, remember the medium sized vent allows for some low frequency leakage. The bottom curve demonstrates that soft sounds are audible, the middle curve demonstrates that conversational speech is comfortable, and the top curve demonstrates that loud sounds will be tolerable.



References

1. Mueller HG, Killion MC (1990) An easy method for calculating the articulation index. *Hear J* 43(9): 1-4.
2. Olson WO, Hawkins DB, Van Tassel DJ (1987) Representations of the Long-Term Spectra of Speech. *Ear Hear* 8(5)Sup: 100S-108S.

Appendix

ICRA (International Collegium of Rehabilitative Audiology) Stimulus Files

URGN-M-N	Unmodulated male weighted noise. Normal effort. Level: L_{ref}
URGN-M-R	Unmodulated male weighted noise. Raised effort. Level: $L_{ref}+5.7$ dB
URGN-M-L	Unmodulated male weighted noise. Loud effort. Level: $L_{ref}+12.1$ dB
3BSMN-F-N	3 band female weighted speech modulated noise (3bSMN). Normal effort. Level: L_{ref}
3BSMN-M-N	3 band male weighted speech modulated noise (3bSMN). Normal effort. Level: L_{ref}
2PB-1F1M-N	2 persons babble. 1 female 3bSMN + 1 male. Normal effort. Level: L_{ref}
6PB-N	6 persons babble. Normal effort. Level: $L_{ref}+4.7$ dB
6PB-R	6 persons babble. Raised effort. Level: $L_{ref}+10.7$ dB
6PB-L	6 persons babble. Loud effort. Level: $L_{ref}+17.2$ dB

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