Improve localization accuracy and natural listening with Spatial Awareness

While you probably don't even notice them, your localization skills make everyday tasks easier: like finding your ringing phone or focusing on a speaker.[1] Your brain locates sounds by using spatial cues: the time of arrival to each ear, the level at each ear and the frequency shape. One of these cues, frequency shape, is extremely dependent on personal anatomy, and your brain is accustomed to hearing sounds via the unique geometry of your ears.

Given this information, it's no wonder that hearing instruments impair localization. While they make sounds loud enough to hear, they also interfere with the frequency cues our brains rely on. Directional responses may help or may further destroy these cues. Plus, there's the question of which microphone strategy is best: a tight and focused beam, omnidirectional or something entirely different?

This paper will outline the strong relationship between ear shape and localization, and how we can improve the patient experience by focusing on what is natural and providing a more realistic sound experience.

Authors
Betty Rule, Hon. B.Sc. Experimental Physics
Senior Product Manager
Favorite sound: my family's laughter

Nancy Bunston, M.Cl.Sc., Reg. CASLPO
Corporate Audiologist
Favorite sound: waves breaking on the shore

Carolina Rubiano Galvis
Senior Validation Specialist
Favorite sound: the heart beat

Jesse Sinclair, MClSc, Aud(C)
Corporate Audiologist
Favorite sound: my children laughing

Leonard Cornelisse, M.Sc.
Hearing Scientist; Manager, Hearing System Engineering
Favorite sound: live jazz music

How does localization work?

It was many years ago (1907) that researchers discovered how Interaural Time Differences (ITDs) and Interaural Level Differences (ILDs) play a major role in locating sounds.[2] But it wasn't until much later that we realized the importance of the exact shapes of our ears. Edgar Shaw was one of the first to carefully analyze how the angle of incidence impacts the sounds we hear (see Figure 1). The frequency shape of a sound when it reaches our eardrums will differ depending on where it comes from in relation to us.[3] Figure 2 expands on Shaw's angle of incidence research, to show how unaided ears respond to sounds arriving from 360 degrees around the listener. It shows that the right ear focuses on sounds to the front-right, whereas the left ear focuses on sounds to the front-left. Together, they produce interaural frequency information that helps us with localization. When combined, ITDs, ILDs and frequency shape give us an overall sense of our environment, and help us to pinpoint where sounds are located.

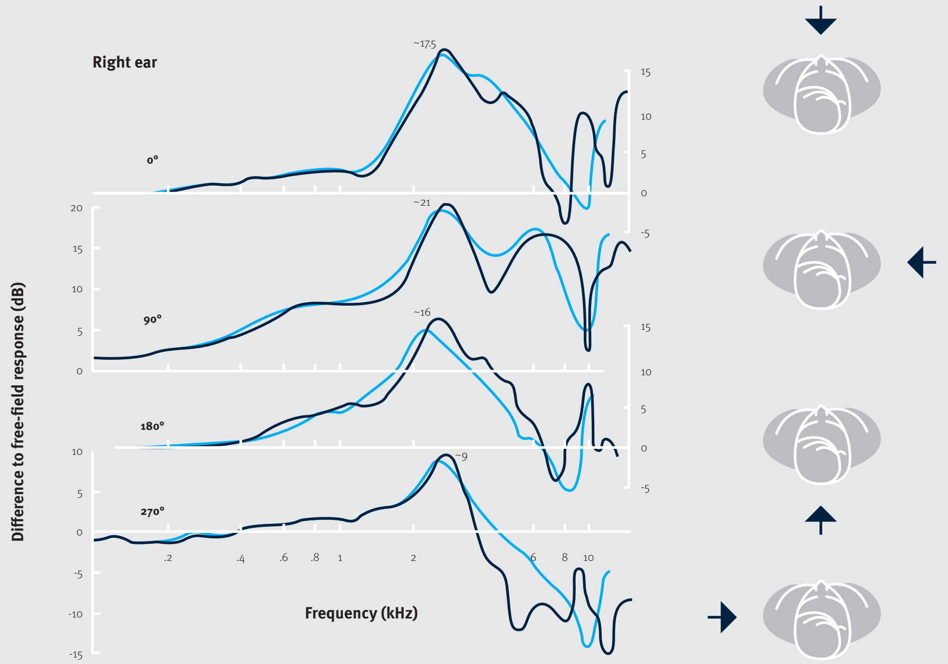

Figure 1 – Edgar Shaw was one of the first to show how the angle of incidence greatly impacts the frequency shaping of sounds. These graphs show the great difference location can make on the right ear's detection of sound.

KEMAR response

Shaw data

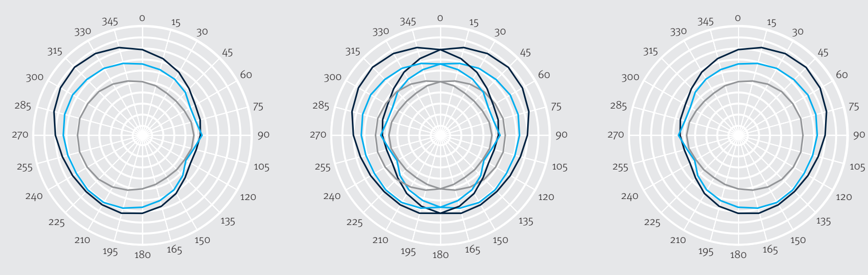

Figure 2 – Response to frequency information, for both the left and right ears. By combining the information from both ears, the brain gains a better awareness of the overall environment.

High frequency

Mid frequency

Low frequency

The importance of ear shape

Our ears are designed to help us identify where sounds come from. Shaw was also a pioneer in determining the relationship between our physical features and how they shape the sounds we hear at different frequencies and angles. His foundational research revealed that the head, torso and neck, pinna, concha, ear canal and eardrum play significant roles in shaping the sounds we hear.[4]

From Figure 3, we can see that the ear canal and eardrum are responsible for the first main peak in the natural response. The ear canal is a tube made of soft sides, and enclosed by soft material (the eardrum). This shape gives the average ear canal a resonant frequency around 2.5 kHz. However, not everyone's ear canal is the same shape. A shorter tube would create a higher sound, giving it a higher resonant frequency. Generally speaking, people with shorter ear canals tend to have a higher peak in their REUG (Real-Ear Unaided Gain). Having a longer ear canal creates a lower resonant peak.

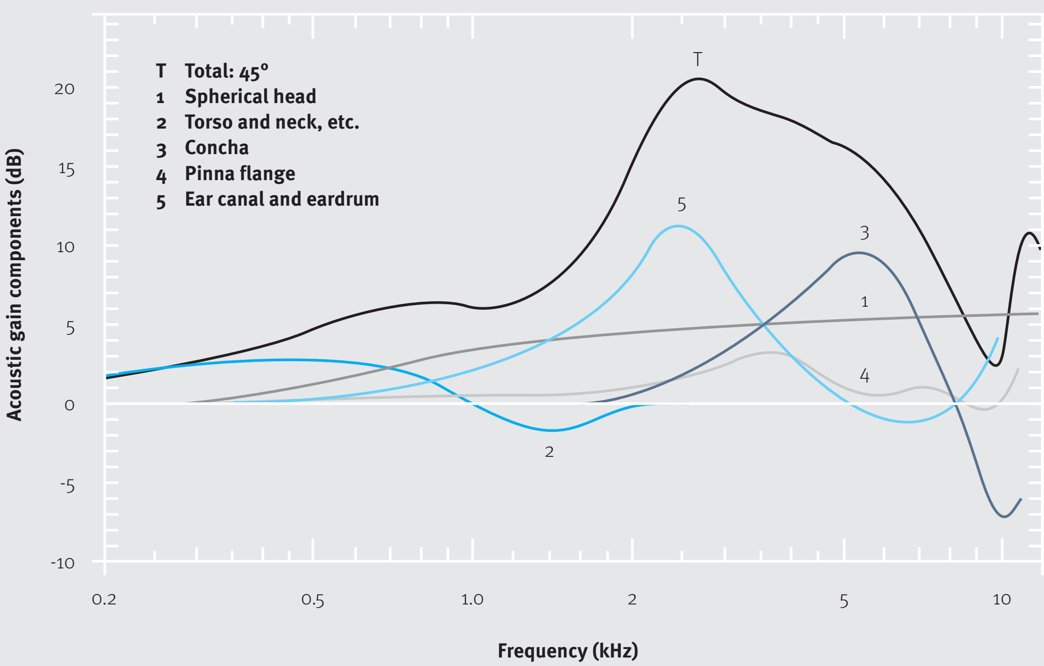

Figure 3 – Edgar Shaw exposed how different aspects of human anatomy impact sounds arriving at the eardrum. This graph shows the impact for sounds approaching the head from 45 degrees in the horizontal plane.

Since we each have unique ear geometry, every individual is acclimatized to assessing sounds with their own unique frequency response. Using someone else's ears would impair your ability to locate sounds. Of course, using someone else's ears is a ridiculous concept. But it's an accurate comparison for those who rely on hearing instruments—and something that traditional directional microphones alone don't address.

The challenge with hearing instruments and ear shape

Essentially, the placement of hearing instrument microphones cuts ear shape out of the localization equation. The worst case is the BTE (behind-the-ear) hearing instrument, which picks up sounds from behind the pinna instead of at the eardrum. This changes the frequency shape of sounds from what a patient is accustomed to hearing (see Figure 4). An inaccurate perception of a sound's frequency shape can lead to an inaccurate perception of its location. A patient might feel that sounds are jumbled together, instead of having a specific source location. Or they may even perceive that the sounds are coming from inside their own head. Either is an unnatural, confusing experience.

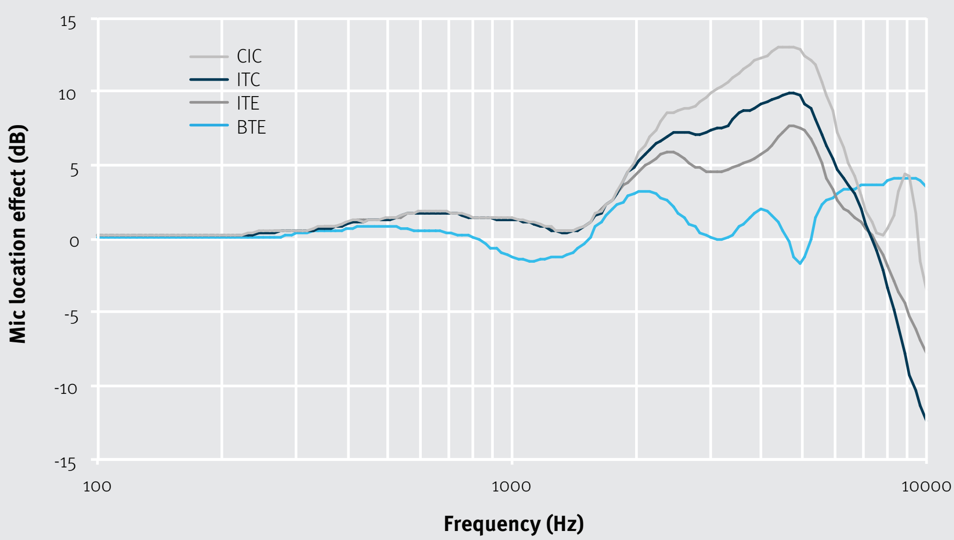

Figure 4 – Measurements of microphone location effect (MLE) for four styles of hearing instruments show the significant difference microphone placement makes. In low frequencies, the hearing instruments have very similar responses to sounds that are picked up at the eardrum. This is because the head has the biggest impact on the low frequency sounds, not the pinna. The placement of the microphone around the ear becomes much more important in high-frequency sounds, where the shape and reflections of the pinna and ear canal are key to providing localization cues.

Pushing the boundaries on directional microphones

At Unitron, we are passionate about creating technologies that help patients solve their biggest complaints. And localization is one of them. That's why we've gone beyond standard directional microphones. Our Tempus™ platform includes several technologies that make it easier to localize sound by providing more natural, realistic listening experiences.

Pinna Effect

To make the hearing instrument experience more natural and realistic, Unitron hearing instruments use a mild directional response, called the Pinna Effect, to mimic the experience of an unaided pinna. Depending on frequency, Pinna Effect provides a varying directional response. In lower frequencies, it's more omnidirectional, where the head has the biggest impact on those long wavelengths. It gradually increases to an approximate cardioid pattern in the highest frequencies. When the Pinna Effect was introduced, field trial subjects reported the feature to be "more natural" than the more basic omnidirectional option used in past platforms.[5] This was the beginning of the drive toward a more realistic sound experience.

Spatial Awareness

While the Pinna Effect improved naturalness for patients, we knew it could be more precise. The slight differences between the Pinna Effect and the unaided ear could still impact a patient's ability to localize sounds. To improve the patient experience further, we assessed how the differences in individuals' pinna shapes affected their ability to localize sounds. See Figure 5 for a sample of the results.

The majority (~80%) of adult pinnae matched KEMAR adult ears quite well. We knew that if a hearing instrument could precisely mimic KEMAR's shape, it would produce a more realistic response for most patients—which could greatly improve localization.

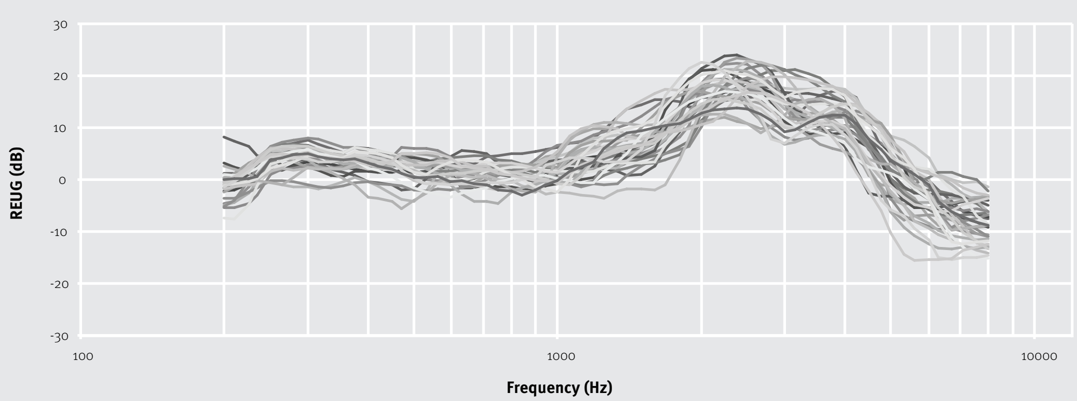

Figure 5 – An example of REUG measurements of 32 adult ears, which were used in the analysis of the impact of differently shaped pinnae on sounds reaching the eardrum. KEMAR ear measurements were primarily based on the average of 12 males and 12 females by Burkhard and Sachs[6] with some input from Henry Dreyfuss'[7] measurements.

This research led us to create our Spatial Awareness feature. Hearing instruments driven by the Tempus platform use a 33-channel directional processor to better match the natural frequency response of the KEMAR adult ear from 360 degrees. This ultra-detailed directional response varies by frequency. Like the Pinna Effect, Spatial Awareness is omnidirectional in the low frequencies. However, as the frequency increases, the response changes for the left and right ear to match the focus direction of KEMAR. By matching Spatial Awareness to KEMAR, we are able to closely match the natural responses of most adult pinnae.

To test the validity of this match, 38 field trial subjects performed a localization task to test Spatial Awareness.[8] The subjects, between the ages of 32 and 87, with mean age of 66 and binaural mild to moderate sensorineural hearing loss, were fitted with Tempus hearing instruments (24 experienced, 14 new to hearing instruments). The testing was performed in a sound room with 4 speakers evenly spaced 90 degrees apart. Target speech was randomly presented from a speaker at 0, 90, 180 or 270 azimuth degrees in quiet, with no visual cues. After each presentation, subjects were asked to rate their perception of speech direction and rate the naturalness.

A response was considered correct if speech was perceived from the correct direction, and was not heard as being inside the head. Subjects exhibited some front/back confusion at the initial fitting, although this improved after three weeks of acclimatization (see Figure 6) and was better than other results from the literature.[9] This confirmed our hopes for Spatial Awareness: the majority of subjects could localize sounds quite well, as shown in Table 1, and showed an improved sense of their surroundings (see Figure 7).

Table 1 – Percent correct responses with Spatial Awareness

	Initial fitting	After 3 weeks
Front	70%	81%
Back	56%	68%
Left	86%	86%
Right	83%	90%

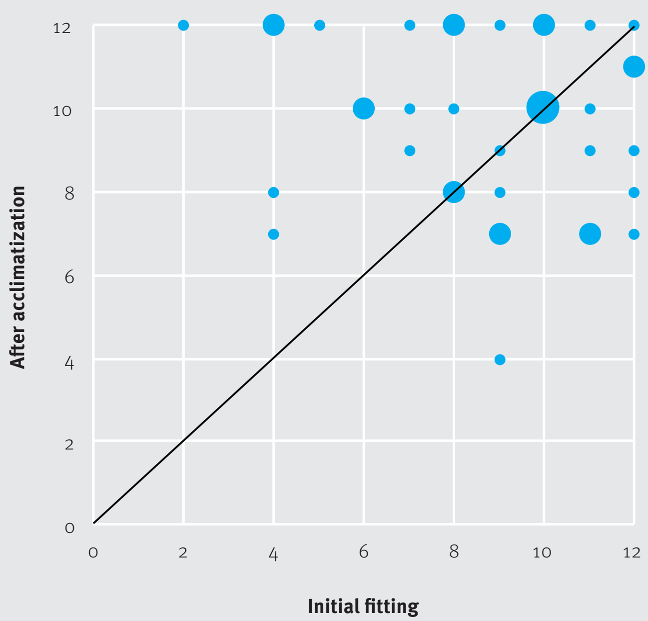

Figure 6 – Localization improvement in quiet, for 12 randomized localization tasks (4 front, 4 back, 2 right, 2 left). This graph compares each subject's ability to correctly identify location at each session. Six subjects achieved perfect scores at the initial fitting; this increased to 12 perfect scores after acclimatization.[8]

After each test, subjects were asked to provide ratings for naturalness. Again, the results confirmed our hopes for Spatial Awareness: 34% agreed, and 66% strongly agreed, that the speech sounded natural. These responses were similar for each of the four target directions.[8] Subjects not only improved their localization abilities, they also found the sound quality to be natural.

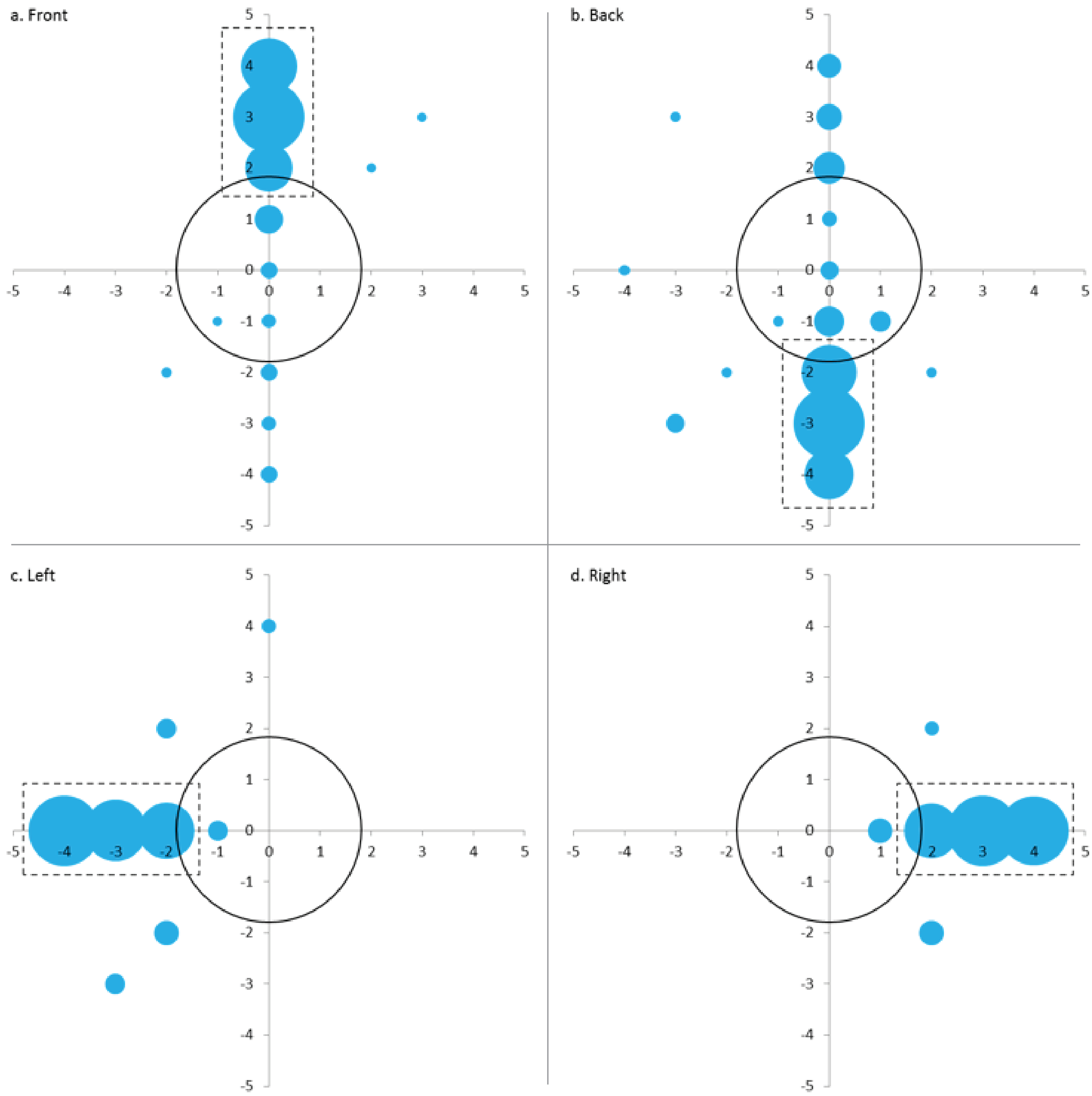

Figure 7 – Accuracy in subjects' ability to correctly identify the location of speech, at both the initial fitting and post-acclimatization. The larger circles indicate a larger number of responses for that location. Responses within the black circle were heard as being inside the head. Responses within the dotted lines were considered correct and represent the majority of responses from the tests.[8]

Personalized Spatial Awareness

Our tests confirmed that Spatial Awareness does improve localization in adults. But we could do even better—providing a more accurate solution for patients whose ear geometry doesn't match KEMAR.

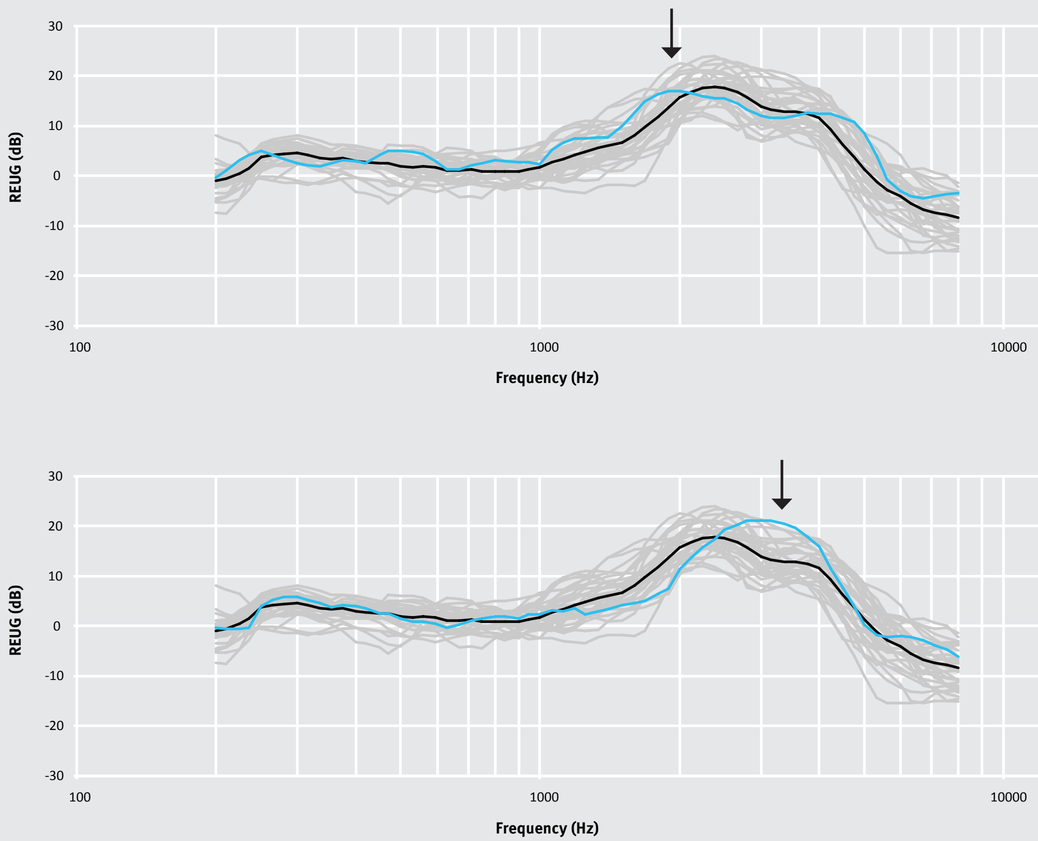

Figure 8 – Measured REUG responses showing average, lower and higher ear canal peaks in the frequency response. The black line indicates the average REUG. The blue lines are examples of subjects who had REUGs that were lower or higher than average.

To determine the best frequencies for personalizing Spatial Awareness, we used REUG measurements from 32 ears (see Figure 8). The measurements fit into three categories: those that matched the average REUG of KEMAR (~80%), those with lower-than-average peaks and those with higher-than-average peaks. To better personalize the feature, additional details were gathered on the two categories that didn't match KEMAR.

Using this data, two Personalized Spatial Awareness settings were created to account for differing ear shapes. If a patient's ear canal is longer or shorter than typical, these options can make localization more accurate, and provide a more natural experience.

Let’s bring ear shape into the localization equation

Our brains rely on the specific shape of our ears to locate sounds via frequency response information. Until now, hearing instruments haven’t fully addressed this aspect of localization. In fact, their placement and traditional microphone strategies impair a patient’s ability to locate sounds and gain a sense of their environment. It’s an unnatural and confusing experience.

After extensive research and testing, our latest technologies are making localization easier. By acknowledging the personalized nature of localization, we drove change in hearing technology, and created a better, more realistic listening experience.

For many years, these solutions have been beyond our reach. Until now.

Unitron is making leaps in localization technology with our Spatial Awareness feature, driven by the Tempus platform. Contact your representative to learn how Tempus is a game-changer in localization.

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