Oliver Masciarotte

Brain of the Beholder

The following lends a general explanation of psychoacoustics.

FOR THOSE PEOPLE who are fortunate enough to have unimpaired hearing, there is a rich world of sounds and sensations that constantly color our perception of reality. Our hearing mechanism is quite good at telling us about our physical surroundings though this information usually becomes part of the sum of all of our sensory input and goes unheeded.

For example, think about what is called the Cocktail Party effect. Say you're holding a conversation in a crowded room. It's a simple matter to mentally filter out extraneous noises or other conversations and concentrate on the speech of interest. Another simple luxury of life is the ability to close your eyes and precisely determine the location of a nearby sound source. These feats of signal processing depend on the physical makeup of our hearing apparatus and the way our brain processes auditory information. Though we can't compete with a bat or porpoise when it comes to auditory information processing, we can put our ear/brain combination to good use as audio practitioners if we are aware of our limitations. Thus, a general understanding of psychoacoustics can surely come in handy.

In the 1930s, several folks were involved in research that laid the foundation for much of our current understanding of hearing. A good deal of this research was conducted at particular universities and corporate facilities like Bell Laboratories. The questions of how and why people hear the way they do were mostly unanswered questions. These questions fall under the heading of psychoacoustics which is defined as the study of the brain's perception of, and response to, all aspects of sound (Woram). Let's look at some of the aspects of this subject that immediately affect us and see what conclusions can be drawn.

Our brain perceives a certain frequency of sound as a particular pitch sensation. If there are several other frequencies present in some complex harmonic structure,

Oliver Masciarotte is a faculty member of Miami University.

that will usually alter only the timbre of the sound. The interesting thing to note is that pitch changes with changing intensity (Stevens). Least affected are frequencies around 1,000 Hz. Below approximately 1,000 Hz, perceived pitch goes down as intensity is increased. Predominantly low frequency sounds go flat as they get louder while predominantly high frequency sounds behave in an opposite manner, they seem to go increasingly sharp as they get louder. This is not the kind of stuff my college professors would call "intuitively obvious."

Another interesting aspect of hearing is the fact that the perceived timbre of a sound changes as the sound is made louder or softer. Two researchers, Fletcher and Munson, averaged the responses of a group of test subjects and graphed this phenomenon as a family of curves showing frequency vs. (perceived) "equal loudness" (Fletcher and Munson). What these curves or contours show is that as a sound's intensity approaches the threshold of hearing, as it is made quieter, our sensitivity to high and low frequencies gets progressively worse. Using 1,000 Hz as a reference we find that, at low intensities, frequencies below 800 Hz and above about 4,000 Hz must be of much higher intensity to be perceived as equally loud as 1,000 Hz. Near the threshhold of hearing a 40 Hz tone must be more than 50 dB greater in intensity to be perceived as loud as a 1,000 Hz tone. That is 100,000 to one increase in intensity! These equal loudness curves also show that human hearing is most acute between 3,000 and 4,000 Hz. It is no surprise that human speech lies predominantly in the 1,000 to 4,000 Hz range. Our hearing apparatus has become finely tuned for interpersonal communication.

While we're on the subject of frequency response, I'd like to talk about one of the mechanisms that allows us to determine the location of a sound source. Let's try a thought experiment (after Mehrgardt & Mellert) whereby we take a tiny microphone and carefully place it at the entrance to the ear canal of a willing test subject. This should be a calibrated microphone with known frequency response. We then place a wide range loudspeaker driven by a linear amplifier, again with known frequency response, in front of our test subject. The microphone output is sent through a preamp to a spectrum analyzer to provide frequency versus amplitude data, and pink noise is applied to the amplifier/loudspeaker. Now we can determine the frequency response of the subject's head/outer ear combination. With that accomplished, we move the loudspeaker slightly in an arc with the subject's head at the center of the arc. Again we measure the response and continue to move the speaker around the head, graphing as we go. What we come up with is a family of curves that show a strange thing. The ear "sees" a different frequency response depending on the sound source's lateral angle around the head. At 8,000 Hz where the wavelength of the sound is significant relative to the dimensions of someone's head, the variation is + or - 10 dB! Two factors make this experimental result, performed by various researchers in the past, less hideous than it seems. One is the fact that the ear canal itself acts as an acoustical filter with a frequency response that alters the response variations created by the head and outer ear. The other consideration is that we are born with this complex acoustic filter and it has become part of our day to day existence.

I must mention one last quirk of our hearing mechanism that is of interest to the audio professional. At those same frequencies that we observe wide lateral variations in frequency response, from about 3,000 Hz to 8000 Hz, there is also a gradual change in the perceived height or elevation of a fixed source located on a horizontal plane with a listener's head (after Roffler and Butler). As frequency goes up, the source seems to come more and more from above. At frequencies above 8,000 Hz, the perceived elevation rapidly diminishes until it seems to be back on a horizontal plane at 10,000 Hz. Stranger and stranger....

The one word I have repeated several times in this discussion is "perceived"—the key to this subject. The four phenomena I have mentioned: changing pitch with changing intensity, the Equal Loudness curves, changing timbre with different lateral angles and, different perceived elevations at different frequencies all work together to unconsciously inform us of where a sound source is located. We can also use these hearing mechanisms to our advantage to paint a sound picture as real or bizarre as we could imagine. Also by keeping the principles of psychoacoustics in mind we can avoid violating the laws that govern how we hear. Next time we will talk about the more obvious ways that our brain derives location information and discuss how we can manipulate information to create specific effects:

(1) from Woram, Recording Studio Handbook, Elar, 1982
(2) from Stevens, Journal Acoustical Soc. of America, Vol. 6, No. 3, 1935
(3) Fletcher & Munson, J. A. S. of A., Vol. 5, No. 2,
(4) Mehrgardt & Mellert, J. A. S. of A., Vol. 61, No. 6
(5) Roffler & Butler, J. A. S. of A., Vol. 43, No. 6. ■