6.13.5 Distance Cues

How do we know how far away a sound source is? Suppose I set up two loudspeakers in a room behind an acoustically transparent but visually opaque screen. The first speaker is 3 meters in front of you and I play a sound at intensity *I*. Suppose I then switch to a second speaker at twice the distance and play the same sound with the same intensity *I*. You'd have no trouble telling which was the closer sound source: because of the inverse square law, the intensity of the direct signal arriving from the far speaker is $I_d = I/4$; therefore you hear the second speaker as farther away.

But suppose we do a second experiment where I secretly increase the intensity of the far speaker to $4I$, so that now $I_d = 4I/4 = I$, and repeat the procedure. Though the inverse square law cue is now gone, you will still correctly tell me which speaker is the far one and will perhaps also mention that I appear to have made the far one louder. How did you figure that out?

For every sound, your hearing judges not just the intensity of the direct signal I_d but also the ratio of the direct signal intensity to the attendant reverberant signal intensity *R* as a cue for distance. In the first experiment, we're pumping the same intensity *I* into the room from either speaker; therefore the average reverberant intensity in the room is *R* no matter which speaker plays. Reverberant energy is distributed uniformly throughout the room quickly after a sound starts. But meanwhile the direct signal intensity went from *I* in the close speaker to $I/4$ in the far one. Thus, your ear judged that

$$\frac{I}{R} > \frac{I/4}{R}$$

and reasoned that if the reverberation intensity *stayed the same* but the direct signal intensity *went down,* then the second speaker must be farther away.

However, in the second experiment, the intensity in the room goes from *I* to $4I$. Therefore the amount of reverberation in the room likewise goes from *R* to $4R$. But meanwhile the intensity of the direct signal that you heard remained the same. (Because I quadrupled the intensity of the distant speaker, the direct signal strength you experience from either speaker is identical.) Thus, your ear judged that

$$\frac{I}{R} > \frac{I}{4R}$$

and reasoned that if the direct signal intensity *remains the same* but the reverberant intensity *increases,* the sound must be both farther away *and* louder.

We can confirm that your hearing is factoring reverberation into its cue for distance by repeating this experiment in an *anechoic chamber*. As the name implies, it is a room that is so padded that it produces no echoes, depriving you of the reverberation cue. This time you would experience the second experiment as ambiguous and wouldn't be able to tell which speaker was farther away.

Another distance cue is based on the fact that high frequencies are absorbed more quickly by air than low frequencies. The greater the distance, the more the high frequencies in a signal are attenuated. The effect is more exaggerated with greater humidity. So even in a large space without echoes—like a flat desert—you can still tell relative distance because your hearing has a built-in sense of how much air absorbs high frequencies.