Hearing the Music in Boston and Leipzig

This article previews a short lecture on the acoustics of Boston Symphony that this writer will deliver during a free public symposium at the Boston Public Library next Tuesday February 7th from 6 to 7 pm. The symposium celebrates the collaboration between the Boston Symphony Orchestra and the Gewandhaus orchestra in Leipzig Germany.

My goal is to illustrate the features in the Boston Symphony Hall that may be responsible for its fine acoustics, and compare it with its famous predecessors in Leipzig, the Altes Gewandhaus, where Handel, Haydn, Mozart, Beethoven, Mendelssohn, Brahms, and many others composed or performed, and the Neue Gewandhaus, which in 1885 replaced the earlier hall.

Boston Symphony Hall (BSH)

BSH – built in 1900 with 2650 seats, a volume of 663,000 cubic feet and a reverberation time of 1.9 seconds; widely thought to be one of the best halls in the world.

Why?
The first Gewandhaus had 400 seats and a reverberation time of 1.3 seconds. The acoustics were reputed to be excellent. The short reverberation time kept clarity high. The unusual seating arrangement preserved the bass in the direct sound. Handel, Haydn, Mozart, Beethoven, Mendelssohn, and Brahms composed and/or performed in this space.

The Neue Gewandhaus was completed in 1882, had 1560 upholstered seats, and a reverb time 1.55 seconds. The acoustics also were considered to be excellent. Along with the Boston Music Hall, built in 1852 with 2625 seats, the Neue Gewandhaus was one of the models for the design of BSH. It was narrower than BSH, and had risers onstage.
What architectural features create great acoustics?

There are three major roadblocks in our quest to understand hall acoustics. First, sound quality in halls depends on where you sit. There are always some wonderful seats, and some that are less wonderful. Second, our perceptions are multimodal, and our eyes usually dominate. If we can see a performance clearly, we are convinced that we are hearing it clearly. Third, our abilities to remember subtle but important sonic differences are extremely limited. In the field of audio we have found that to reliably compare two similar sounds it is essential to be able to switch back and forth with a gap of less than a few seconds.

Many attempts have been made to study hall acoustics. A standard method has been to distribute questionnaires to listeners before a concert, asking them to describe or rate the sounds. None of these experiments asked them to close their eyes. And these questionnaires were almost always filled out after the performance.

Laboratory reproduction of hall sounds has been fraught with serious oversimplification, and in my view has resulted in more error than progress. Recording of concerts with a microphone shaped like a human head has also been tried, but measurements made by this method simulated an orchestra with only one or two loudspeakers.

Fortunately, better methods are beginning to be used. Our own work has simplified the problem of binaural recording, where the microphone is shaped like a human head with ears. Measurements made this way in halls can now be heard with music in a laboratory and analyzed for how individual reflections change perception.

Tapio Lokki and his group have developed a system for emulating an orchestra that uses 17 loudspeaker pairs arranged on stage, one pair for each instrument. Measuring the response from each speaker pair to a concert seat, and then reproducing that sound in a laboratory with anechoic recordings of each instrument, result in a realistic reproduction of the original hall. The sounds from different seats and halls can be instantly compared.

Lokki has measured a large number of European halls with this system, and has conducted listening tests with many subjects. He has found that three, and only three, distinct perceptions explain the variance in preference:

1. Loudness,
2. Bass, and
3. A previously unreported perception he named “proximity”, the sense of being acoustically close to the performers.

Everyone likes all three perceptions, but young listeners tend to prefer loudness over proximity, while older listeners tend to prefer proximity over loudness.

Proximity is an under-recognized perception. It is the auditory sense of being close to the source of the sound. When sounds from an orchestra have proximity you can localize each section and hear each line even in a complex scene.

Proximity is not new, only newly named. Drama directors have known about it at least since the early Greeks, and cinema directors demand it for dialog in movie theaters. When a sound is proximate, it is easier to localize and separate from noise and other sounds. We believe that proximate sounds demand attention more strongly than aurally distant sounds.
Loudness

The direct sound from an orchestra gets quickly softer as you move away from the stage. Sounds that do not hit the audience directly bounce around and become reverberation. Reverberation is nearly constant in level throughout the hall. It supplies most of the loudness we hear.

In Boston Symphony Hall there is plenty of open volume above the audience for the sound to bounce around in before it is absorbed. Thus the reverberation is late, and strong. There is plenty of loudness in all the seats.

Note the large volume above the audience, and the close spacing of the seats.

This graph shows how seatback diffraction reduces bass frequencies in the direct sound at row DD seat 11.
Bass is diffracted away from the direct sound as it travels over the audience. In many seats the bass frequencies come only from reflections and reverberation. Because the reverberant level in BSH is strong, there is plenty of bass in all the seats.

Only the sound that does not hit the audience directly contributes to later reverberation. Some modern halls feature prompt reflections from the ceiling, beating down on the audience area. The result in our experience is reduced bass, loss of loudness for seats farther away from the orchestra, and little sense of the hall as a space.

**How does the ear detect proximity?**
The sounds we hear from speech and music seem to be continuous. But they are actually composed of regular pulses of air pressure, created by the burst of pressure when the vocal cords open or the bow lets go of the string. When our ears can detect these regular pulses, we perceive the sound as proximate, and neural filters tuned to the periods of these pulses can separate these sounds from others.

The picture above is the sound of my voice speaking “one two three”. The regular pulses are easy to see. This sound has proximity: one two three.

Neural filters tuned to the frequency of these pulses can separate a particular individual speaker from others and from noise. Such filters match the period of the pulses within about a tenth of a percent. We believe our acute sense of pitch evolved to separate voices in complex environments.

When we add early reflections the pulses are no longer regular. The sound is muddy and distant: one two three with reflections.

**Reverberation and proximity**
Proximity predicts the ability to localize a sound source, and the possibility of following its musical line. We like to hear the onsets of notes!

To localize and hear a sound as proximate, the ear and brain must detect the pulses in the direct sound of a syllable or note before reflections randomize them. Detecting the direction of the direct sound takes at least several periods of the pulses in the waveform (50 to 100 milliseconds). If reflections come too soon, and are too strong, the pulses are randomized, and the neural filters cannot separate them. All sounds blend together.
Onsets of sounds can also be masked by reverberation from previous sounds. Sabine developed the concept of *reverberation time* to explain this masking. When reverberation is both strong and lasts a long time, sounds will blend together.

But a long reverberation time can be beautiful if the reflections and reverberation arrive after the 50-100 milliseconds the ear needs to detect the pulses that identify the direct sound. The sound then is localizable by the amplitude differences between the two ears, and the time delay between the pulses in the two ears.

Sounds that are separable and localizable become “proximate” and are easier to hear and understand. Because of the high volume of the space above the audience in large halls like BSH, reflections and reverberation build up slowly. There is time for onsets to be heard even at large distances from the stage. Many seats have good proximity, though not all.

**The Limit of Localization Distance: LLD**

In most halls there is a distinct distance from the stage where all sound sources blend together into a single diffuse image. We call this the limit of localization distance, or LLD. When a listener is beyond LLD, proximity is lost.

We can find LLD by simply walking away from the stage with eyes averted during an orchestra warmup or rehearsal. Beyond a certain distance we can no longer localize individual instruments or small groups of players.

The perception is not subtle. When we pass LLD, the difference in the auditory ability to separate and localize individual players is dramatic. The sound goes from clear to blended in the space of about one meter, or one row of seats. LLD has not been recognized before in this way because it is not audible if you have your eyes open. If you see the people talking, or watch the players playing, you are sure you are localizing them distinctly. There is no question about whether they are close or far away. They are exactly where you see them.

We often demonstrate LLD by walking away from two loudspeakers playing anechoic recordings of the first and second violin parts of a Mozart aria. At some distance (LLD) we can no longer tell which violin is playing which part. There is no visual cue from the loudspeakers. Experimenters must use their ears. [Mozart Alternating Violins](#)

**Architectural features in BSH limit the earliest reflections from stage to audience, increasing LLD**

The halls in Leipzig, the Musikverreinsal in Vienna, and the Boston Music Hall all had no stage house. In Boston Symphony Hall (BSH) Sabine put the orchestra in a stage house. The design is unusual. The sides and ceiling of the stage are slanted so the first reflections are directed into the hall, heading toward the ceiling and the back wall. They do not travel to the audience on the floor. The upper back wall of the stage is covered by an absorptive organ. In addition, the ceiling of BSH is high and coffered. Some of the high frequencies that might interfere with proximity are directed back to the stage.
But the side walls near the floor in BSH are problematic. The arrows in the picture above show how the walls direct prompt double reflections into the audience on the floor.

**Typical stage houses are not like BSH!**

The Jordan Hall stage house is deep, and the sides and ceiling slant very little. In the past it had curtains to minimize the earliest reflections. The stage worked well for nearly 100 years.

The proscenium curtain was removed in 1997 during a renovation. The effect on LLD was dramatic and unfavorable. A few years ago Lee Eiseman and I replaced the proscenium curtain with moving blankets. LLD went from row I on the floor to the back wall. At the Acoustical Society meeting in Boston last May there were several papers which described the beneficial effects of adding curtains to problematic stages. The idea is coming back into favor.
Impulse responses measured with a binaural microphone can be reproduced by convolving them with anechoic recordings of individual instruments. The reproduction of these measurements in a laboratory is very similar to live recordings from the same seats.

We measured seven seats in about 40 minutes. Seat 11 in row DD is beyond LLD. The sound is muddy. Proximity is not present. mozart DD 11 with reflection. But when we electronically delete the double reflection from the right side wall, the sound becomes clear and beautiful. mozart DD 11 no first reflection
Can Boston Symphony Hall be improved?

Adding discrete absorption on the lower side walls would significantly increase LLD and the number of very good seats in that area.

Notice that the direct sound of the woodwinds and brass from the current stage is blocked by the strings and sometimes by the piano. Risers for the back half of the orchestra would improve the proximity of many instruments for the audience on the floor.

Side wall reflections in the Leipzig Neue Gewandhaus

The arrows in the picture above show that the first-order reflection from the lower side walls to the audience floor was blocked by the people on the platforms next to the walls. The reflection from the underside of the first balcony may also have been blocked. Note risers on the stage.
Chris Blair and Paul Scarborough’s Schermerhorn Symphony Hall in Nashville (built 2006, with 1844 seats) has gorgeous sound in a great many seats. It is similar to BSH, but has no stage house. Note that as in the Leipzig Neue Gewandhaus the audience along the bottom of the side walls blocks the reflections from that surface to the floor. The stage has risers for the woodwinds.

What about the current Leipzig Neue Gewandhaus?
The new Leipzig hall is built in the currently popular round style, with the orchestra spread out on a semicircular platform. I heard Janine Jansen play the Prokofiev Violin Concerto No. 2 from this seat in row K. The performance was fantastic. The soloist and the front of the orchestra were very clear, and the sound was engaging. But most of the instruments toward the rear of the platform lacked proximity.

In the front of the balcony overlooking the stage, the sound is not particularly loud, and the instruments in the rear of the orchestra are beyond LLD.

The website for the new hall claims the hall is wonderful because every member of the audience has an excellent view of the musicians.

**Does a great hall have to be a shoebox?**

I recently heard a performance from this seat in the Cologne Philharmonie, a bowl-shaped amphitheater. The sound was loud enough, had great bass, and was crystal clear. This hall has a very good reputation in Europe.