Listener envelopment : an essential part of good concert hall acoustics

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The Executive Council decided in 1987 that several recent and newsworthy advances in acoustics should be selected each year for brief description in a format and in language which would be appropriate for publicizing progress in acoustics through science writers to the general public. Some of these short articles would also be submitted for possible publication in the annual Physics News published by the American Institute of Physics. All of the brief articles, to be solicited and selected by the President and Editor-in-Chief, would be published in our Journal. *The following two articles were selected in 1995.*

Listener envelopment: An essential part of good concert hall acoustics [43.55.Br]

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Just over a century ago, Sabine[1] took the first step toward quantifying the acoustical characteristics of concert halls with his famous equation for predicting the reverberation time in a room. Many other efforts to quantify various aspects of concert hall acoustics followed. These early studies concentrated on monaural (monophonic) attributes such as reverberance, clarity, loudness, and timbre. In the late 1960s the importance of binaural effects (i.e., effects that require both ears) was recognized as critical to achieving excellent concert hall acoustics. These binaural effects are usually referred to as spaciousness or spatial impression. Spaciousness was described interchangeably as either an apparent broadening of the source or the sense of being immersed in, or enveloped by, the sound of the orchestra. A strong sense of spaciousness was felt to be a characteristic of such halls as Vienna's Musikvereinssaal or Boston's Symphony Hall, which are renowned for their excellent acoustics.[2]

In his pioneering work on spaciousness, Barron[3] found that strong reflections arriving at the listener from the side and shortly after the direct sound increased the apparent width of the source. The recognition of the importance of such strong early lateral reflections helped to explain the success of narrow shoebox-shaped concert halls such as those in Vienna and Boston. This discovery led to a revolution in concert hall design and has been a key focus of research in concert hall acoustics for the past 25 years. Many newer halls have been designed with large reflecting panels to provide strong early lateral reflections. These new halls have generally been quite successful, but it is possible for such designs to produce an excess of clarity and a sense of insufficient reverberance.

Although the various early studies referred to the general concept of spatial impression, there was no attempt to distinguish between the various descriptions of spaciousness. New work[4,5] has now revealed that there are at least two distinct components to spaciousness and that each is related to different physical parameters. These components are a sense of listener envelopment, and an apparent broadening of the source. Although in the past the two terms have been treated as interchangeable, listeners perceive them as separate effects. As shown by Barron, the apparent width of the source is related to the strength of the early lateral reflections. However, the sense of being enveloped by the sound in a hall is now known to be related to the strength of later arriving lateral sound energy. Thus, to have a more nearly complete sense of spaciousness in a concert hall, it is necessary to have strong early and later reflections arriving from the sides of the listener.

The two components of spaciousness can be understood in terms of the workings of our hearing mechanism. Our hearing system tends to integrate, or add together, sounds that arrive soon after the direct sound. Early reflections in a concert hall are not heard as separate events, but are summed together with the direct sound and appear to come from the direction of the direct sound, which arrives first. Thus early lateral reflections simply tend to make the location of the source slightly ambiguous and cause the apparent width of the source to broaden. Conversely, later arriving lateral reflections are not integrated with the direct sound, but are both temporally and spatially separated from it. Thus, to the listener, the later arriving lateral reflections appear from all directions, thereby creating the sense of the listener being enveloped by the sound. This new understanding has led to the development of a physical measure that is a good indicator of the degree of listener envelopment.[5,6] The new measure, the late lateral sound level, measures the strength of the late reflections that arrive from the side. New work has also shown that higher levels of later arriving sound tend to mask the effects of the early lateral reflections. This suggests that the sense of listener envelopment created by later arriving lateral sound energy may be the more important component of spaciousness.

The importance of the later arriving lateral reflections further explains the success of classical shoebox-shaped concert halls and is expected to lead to further changes in approaches to concert hall design. It is now clear that in addition to various other requirements, the design of a successful concert hall must provide strong later arriving lateral reflections. These are necessary to produce the more nearly complete sense of spaciousness required for excellent acoustics.

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[3] M. Barron, "The Subjective Effects of First Reflections in Concert Halls: The Need for Lateral Reflections," J. Sound Vib. **15** (4), 475–494 (1971).
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[5] J. S. Bradley and G. A. Soulodre, "Objective Measures of Listener Envelopment," J. Acoust. Soc. Am. **98**, 2590–2597 (1995).
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