Proceedings of The Institute of Acoustics

SPATIAL IMPRESSION IN CONCERT HALLS - IS IT A GUARANTEE OF EXCELLENT ACOUSTICS?

M. BARRON

DEPARTMENT OF ARCHITECTURE, UNIVERSITY OF CAMBRIDGE

INTRODUCTION:

Early lateral reflections in concert halls are now considered by many to be a characteristic of the best concert hall acoustics. This paper reviews the history of the effect of early lateral reflections, called here 'spatial impression' and assesses the evidence relating to its subjective importance in concert halls. The story begins with two casual observations.

In 1952 Meyer and Schodder /1/ were experimenting with a simulation system and reported that "the presence of a second loudspeaker creates an apparent enlargement of the spatial extent of the primary source and with a delay of some 10ms also a certain 'reverberance'". Interestingly the extensive Gottingen experiment did not pursue this further.

A second intriguing mention is to be found in the first edition of 'Acoustics, Noise and Buildings' /2/ in 1958 where they say that "the rectangular hall ... in addition has a possible advantage that there is more cross-reflection between parallel walls which may give added fullness".

EARLY STUDIES OF SPATIAL IMPRESSION

In 1966/7 there are suddenly four mentions of the effect. One source for the realisation that lateral reflections might be important was probably the New York Philharmonic Hall. Beranek had concluded from his study of world concert halls /3/ that the delay of the first reflection, known as the initial-time-delay-gap, was the most important factor determining preference. The Philharmonic Hall, due to suspended cloud reflectors, had an optimum initial-time-delay-gap but nevertheless had serious problems. It is a short step from this observation to the realisation that the virtue of older classical concert halls might be the strong early lateral reflections. West /4/ found that there was a significant correlation between the ratio of height to width (or cross-section ratio) in halls and their subjective rating; high narrow halls, which produce strong lateral reflections, were preferred.

Independently but simultaneously Marshall /5/ proposed that the presence of early lateral reflections was the primary characteristic of concert halls with the best acoustic reputations. His paper makes several perceptive observations regarding the nature of the subjective effect: he notes that lateral reflections produce a sense of envelopment in the sound and involvement with the performance but most interestingly he observes an interrelation with loudness. Marshall also considers that the relative arrival time of lateral and frontal reflections is critical, which again leads to the concept of the cross-section ratio of a hall being a determinent of quality.

Two further papers in 1968 introduced two additional fundamental characteristics. Marshall /6/ stressed that low frequencies played a particularly crucial role in the effect and Keet /7/ demonstrated both that a cross-correlation type measure can be used as an objective measure and provided evidence that the effect was a function of loudness.

STUDIES WITH A REFLECTION SIMULATOR

The effect of early lateral reflections is straightforward to simulate with loudspeakers in an anechoic chamber. The effect is one of apparent source broadening; as lateral reflection level is increased the music also gains body and fullness and creates a certain degree of envelopment for the listener. An investigation into the subjective effects of a single lateral reflection /8/ showed that the effect occurs for reflection delays greater than 5 ms and that with a simple simulation spatial impression is the only positive reflection effect. Subsequent experiments showed that reflection delay was otherwise relatively unimportant; contrary to West and Marshall, mentioned above, it is the relative <u>level</u> rather than the relative <u>delay</u> of ceiling (or frontal) and lateral reflections which is important. Further it appears that all early reflections contribute and their contribution to the lateral sound is determined by the angle, ϕ, the reflection sound makes relative to the line through the listener's ears. As an objective measure the early lateral energy fraction, L_f, is proposed /9/:

$$L_f = \frac{\sum_{t=5\,ms}^{80\,ms} r \cos\phi}{\sum_{t=0}^{80\,ms} r} , \qquad (1)$$

where r is reflection energy, including in the divisor the direct sound energy. t = 0 corresponds with the arrival time of the direct sound. Further it was shown the L_f is a linear measure of the subjective effect. The frequencies relevant to spatial impression are considered those below 1.5kHz; removal of lateral energy below 200 Hz, for instance, severely reduces the spatial effect.

THE LEVEL FACTOR

Keet /7/ was the first to demonstrate that in a reproduction of a "stereophonic" recording the perceived source width increased with reproduction sound level. Kuhl /10/ has conducted listening tests with artificial head recordings and found that the recordings can be attenuated by different amounts in different halls before spatial impression is no longer audible. This is due to two factors: the different proportions of lateral sound (i.e. L_f in equation (1)) and the different loudness of the original recordings. The effect will be strongest in 'forte' music passages and inaudible in 'piano' passages. However for equivalent sound sources the sound level will be different in different halls. Measurements by Lehmann and Wilkens /11/ of six large German halls gave a difference of 8dB in level for an identical source.

If the degree of spatial impression is a function of two quantities, it is clearly important that we know the relative importance of each. Unfortunately this remains to be determined, apart from a preliminary estimate in reference /9/ based on Keet's results that an increase in loudness of 4.5dB corresponds to one difference limen for spatial impression. What it means however is that large halls generally miss out as far as spatial impression is concerned both due to weak lateral reflections and low sound levels.

DESIGN FOR HIGH SPATIAL IMPRESSION

Initial investigations suggested that the room cross-section ratio was related to the degree of spatial impression (S.I.) in a hall. With the revision of the criterion to include all early reflection energy, it is apparent that in simple rectangular spaces, at least, the height of the hall is not important. This comes about because the proportion of sound from the side is the same for ceiling and non-ceiling reflections. A dependence on width for simple rectangular spaces can be shown however, so this replaces the cross-section ratio criterion. The preference for narrow halls is not however an especially useful guideline if one is required to design a large hall.

The requirement is for strong lateral reflections and minimal frontal reflections. Preferably also these reflections should arrive on paths remote from the audience; with low frequencies being critical for S.I., the attenuating effect around 150-200 Hz for sound passing at grazing incidence is very relevant. Cornice reflections are thus very important in a rectangular space. In classical halls with side balconies reflections from the balcony soffit and side wall increase S.I. for seats in the stalls. Since reflections opposite the listener's ears are most effective, a reverse-splay is much preferable to a fan-shape in plan. Deep reveals on side walls which prevent lateral reflections are undesirable. Schroeder /12/ has proposed ceiling designs which reflect energy onto side walls and eliminate a direct ceiling reflection.

In large halls promising designs involve segmented audience areas surrounded by lateral reflecting surfaces or the inclusion of large inclined reflecting panels. The most radical designs to date for high S.I. are in New Zealand, in Christchurch /13/ and Wellington.

DOES HIGH SPATIAL IMPRESSION GUARANTEE EXCELLENCE?

The high acoustic reputation of narrow classical halls and smaller halls in general as well as the poor reputation of fan-shaped halls clearly gives support to the importance of spatial impression. Further the two German studies using artificial head recordings in one case support and in the other do not contradict the importance of S.I. In the study by Gottlob and Siebrasse /14/ a high correlation with preference was found both with hall width and a cross-correlation measure of spatial impression. In the Berlin study /11/ no physical measure of S.I. was included but one physical measure strongly correlated with preference was loudness, which is of course a contributory factor for spatial impression. The first hall designed specifically to provide S.I. /13/ has gained a very good reputation.

It is naive to suggest that spatial impression is the only missing characteristic of all lessthan excellent modern halls. Designing for high S.I. is, however, on present evidence a safe expedient which should gain better reputations for good acoustics in future halls. The current acoustic survey of British auditoria promises to provide much data to further illuminate the importance of spatial impression.

SPATIAL IMPRESSION IN CONCERT HALLS

REFERENCES

1. E. MEYER and G.R. SCHODDER 1952 Nachr. Akad.Wiss.Göttingen Math.-Phys. Klasse No.6, 31-42. Über den Einfluss von Schrallrückwürfen auf Richtungs lokalisation und Lautstärke bei Sprache.
2. P.H. PARKIN and H.R. HUMPHREYS 1958 'Acoustics, Noise and Buildings'. Faber, London.
3. L.L.BERANEK 1962 'Music, Acoustics and Architecture'. John Wiley, New York.
4. J.E. WEST 1966 J. Acoustical Society of America 40, 1245. Possible subjective significance of the ratio of height to width in concert halls.
5. A.H. MARSHALL 1967 J. Sound and Vibration 5, 100-112. A note on the importance of room cross-section in concert halls.
6. A.H. MARSHALL 1968 J. Sound and Vibration 7, 116-118. Levels of reflection masking in concert halls.
7. W. de V. KEET 1968 6th Int. Congress on Acoustics, Tokyo, E-2-4. The influence of early reflections on the spatial impression.
8. M. BARRON 1971 J. Sound and Vibration 15, 475-494. The subjective effects of first reflections in concert halls - the need for lateral reflections.
9. M. BARRON and A.H. MARSHALL 1981 J. Sound and Vibration 77, 211-232. Spatial impression due to early lateral reflections in concert halls: the derivation of a physical measure.
10. W. KUHL 1978 Acustica 40, 167-181. Räumlichkeit als Komponente des Raumeindrucks.
11. P. LEHMANN AND H. WILKENS 1980 Acustica 45, 256-268. Zusammenhang subjektiver Beurteilungen von Konzertsälen mit raumakustischer Kriterien.
12. M.R. SCHROEDER 1979 J. Acoustical Society of America 65, 958-963. Binaural dissimilarity and optimum ceilings for concert halls: more lateral sound diffusion.
13. A.H. MARSHALL 1979 J. Sound and Vibration 62, 181-194. Aspects of the acoustical design and properties of Christchurch Town Hall, New Zealand.
14. D. GOTTLOB 1973 Ph.D. Dissertation, Georg-August - University of Göttingen. Vergleich objektiver akustischer Parameter mit Ergebnissen subjektiver Untersuchungen an Konzertsälen.