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Review

Review of objective room acoustics measures and future needs

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ABSTRACT

ISO 3382-1 describes a number of objective room acoustics parameters that are generally accepted as useful for rating some specific aspects of concert hall sound fields. They include measures of decay times, energy ratios, measures of sound strength and several quantities related to the spatial aspects of sound fields. In most cases there are details of the measures, or their application, that raise questions. In general, there has not been a lot of practical research to explore how best to develop and use these objective measures to evaluate conditions in concert halls. For some well established measures such as Early Decay Time (EDT), we are not really sure how best to calculate their values. For other measures such as energy ratios, modifications are often proposed but without the support of subjective evaluations of the proposed changes. In other cases, such as measures of spatial impression, two approaches have been suggested, but their relative merits are not well understood. It is easy to propose ever more complex measures, but it is much more difficult to demonstrate their general utility. On the other hand, some commonly described characteristics do not have accepted related objective measures. Many more important and more general problems relate to the need, for design criteria in terms of each quantity, and for an improved understanding of just noticeable differences for each measure. This paper discusses each measure illustrating particular problems with measurements in various halls.

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1. Introduction

Since the 1950s a number of room acoustics measures have been developed to describe various aspects of room acoustics characteristics. This paper gives a review of those parameters intended to describe conditions at audience seats for musical performances. The various room acoustic parameters have developed as a result of our understanding of the special importance of early-arriving reflections [1–3] and the realisation that reverberation times only give an indication of one aspect of room average acoustical quality. Many of the more accepted room acoustics parameters are now defined in Normative Appendices to the ISO 3382-1 standard [4], but are not an integral part of the main body of the standard. It

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is still a reverberation time standard with some helpful optional Appendices.

The work of Haas [1,2] reintroduced the importance of early-arriving reflections to the perceived acoustical qualities of rooms. Joseph Henry [5] had first understood their importance in the 1850s, but with Sabine's introduction of his reverberation time equation, the importance of early reflections was forgotten for many years. After Haas, subsequent research explored the perceived effects of combinations of reflections [3] and Thiele [6] proposed Deutlichkeit as a measure of definition or clarity. Deutlichkeit (D_{50}) is an energy ratio of the energy in the early-arriving reflections (in the first 50 ms after the direct sound) to the total energy in an impulse response. Somewhat later Reichardt [7] proposed C_{80} as a measure of clarity for musical sounds and others suggested variations such as C_{50} that is now preferred as a measure of clarity for speech sounds. C_{50} values can be exactly related to equivalent D_{50} values, i.e. $C_{50} = 10\ \log\{D_{50}/(1 - D_{50})\}$. C_{50} and C_{80} are both energy ratios of the early-arriving to later-arriving reflections expressed in decibels with early time intervals of 50 and 80 ms respectively. Not liking the inflexibility of the abrupt divisions between early and late-arriving sounds, Kürer [8] proposed the Centre time T_S as an alternative clarity measure. T_S is calculated as the centre of gravity of the impulse response.

At the same time as some of the developments of clarity measures, Atal et al. [9] showed that perceived reverberance was better related to decay times measured over the first 160 ms of decay for synthesized non-linear decays. For decays in halls, a measure of the decay time from the first 15 dB of the decay curve was used but was less successful than the results for the synthesized decays. This was adapted to the Early Decay time proposed by Jordan [10] and obtained from a best fit straight line to the first 10 dB of decay. It has been found to be a successful indicator of perceived reverberance in a number of studies [11–13]. However, there is no evidence of systematic studies to establish the optimum decay range for best assessing reverberance.

In the seventies and eighties various measures of spatial impression were proposed. Early work by de Villiers Keet [14] showed that the perceived width of the sound source was enhanced as the cross correlation of the signals at the two ears of a listener decreased. Barron and Marshal [15,16] demonstrated the importance of early-arriving reflections arriving at the listener from lateral directions and they related perceived spatial impression to the (early) lateral energy fraction (LF_{early}). Although initial work attributed source broadening and listener envelopment to early-arriving lateral reflections, work in the nineties [17–19] showed that listener envelopment was mostly due to late-arriving reflections and was enhanced when they arrived from the side of the listener. That is, spatial impression was seen to have two components, apparent source width (ASW) and listener envelopment (LEV).

In the seventies two comprehensive German studies were carried out to determine the relative importance of various room acoustics measures to listeners' perceptions of acoustical quality [20,21]. They used two different techniques to reproduce concert hall sounds in the laboratory. Subsequently Barron [11] evaluated the relative importance of various aspects of concert hall sounds by administering questionnaires to a panel of expert listeners at seats in British concert halls. More recently, Beranek and Hidaka have produced a number of publications [12,13,22,23] relating acoustical measurements in a large number of well known halls to ratings of the halls from Beranek's interviews of conductors and other knowledgeable listeners. Although there are common conclusions from these more comprehensive studies there are also many differences as to which parameters are most important and the relative importance of each parameter.

Clearly much more research is needed to unravel the many complex relationships between listeners' perceptions and room acoustics parameters. These could eventually include new comprehensive studies to determine the relative merits of various measures as components of overall acoustical quality of concert halls. However, much new work is also needed to better understand how best to choose among the measures we do have and how they might be refined to better evaluate conditions in concert halls. Specific needs will be discussed in the following sections for each group of room acoustics parameters.

2. Problems with existing measures

Table 1 summarises the room acoustics measures currently defined in ISO 3382-1 that are intended to evaluate conditions at audience seats in halls for musical performances. These are broken down into four groups listed in the first column: decay times, sound strength, clarity measures, and measures of spatial impression. Problems related to each group of audience parameters will be discussed in the following four subsections.

2.1. Decay times

Reverberation time (T_{60}) is a physically important parameter that relates to the average properties of a room. It is generally accepted that perceived reverberance is better related to the Early Decay Time (EDT). It is tempting to dismiss the separate importance of EDT values because many studies have shown T_{60} and EDT values to be very highly correlated (see Table 2). EDT values are determined from a best fit straight line to the first 10 dB of sound decays and can vary from seat to seat in a large auditorium, indicating changes in perceived reverberance. Although EDT and T_{60} values are generally very similar, in some cases they can be remarkably different and in these cases the EDT values indicate some unusual properties of the acoustics of the hall (see Fig. 1). We must be careful in dismissing quantities just because on average they are strongly correlated with other parameters. Clearly EDT and T_{60} values have quite different and important uses.

Table 1
Summary of audience parameters from ISO 3382-1.

Type of measure	Measures	Notes
Decay times	T_{60}, reverberation time	Physically important
	EDT, Early Decay Time	Subjectively important
Sound strength	G, Strength	Hall effect on sound levels
Clarity measures	D_{50}, Definition	Clarity of speech
	C_{50} Clarity	
	C_{80} Clarity	Clarity of music
	T_S Centre time	
Spatial impression	LF_{early}, Early lateral energy fraction	Apparent source width
	$IACC_{early}$, Early inter-aural cross correlation	
	GLL, Late lateral sound level	Listener envelopment