Comment on "Predicting theater chair absorption from reverberation chamber measurements" [J. Acoust. Soc. Am. **91**, 1514-1524 (1992)]

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ABSTRACT

The relationship between the measured acoustic absorption coefficient of an array of theatre chairs and the ratio of the perimeter length to plan area of the array is considered. It is shown that the linear relationship measured by Bradley in a reverberation chamber and reported in "Predicting theater chair absorption from reverberation chamber measurements" [J. Acoust. Soc. Am. **91**, 1514-1524 (1992)] is to be expected from simple theory. This means that any non-linear influence of diffracted energy on the relationship is small. Bradley is also unduly harsh on the usefulness of a chair absorption measurement method involving screens. A sample result is given, showing that this method can predict *in-situ* theatre chair absorption with reasonable accuracy.

INTRODUCTION

In Bradley's paper[1], four methods of predicting auditorium seat absorption were evaluated, including that proposed by Kath and Kuhl[2]. Whilst the paper provided much useful data, it recommended a rather lengthy prediction method involving measurements of several different sizes of seating array. We have recently completed an investigation of the rather simpler method initially proposed by Kath and Kuhl, after presenting interim findings[3]. We will shortly submit a journal paper covering all our results in detail. This project involved comparing seating absorption measurements made in ten auditoria (by measuring reverberation time before and after seat installation) with measurements of the same seating in an ISO reverberation chamber. Our results demonstrate a high enough standard of accuracy for a practical test method, and we have evidence that contradicts Bradley's criticisms of it. We also have a different interpretation of the significance of Bradley's results of the variation of reverberation chamber seat absorption with sample size.

I. EFFECT OF SAMPLE SIZE

In the first part of Bradley's paper, one of the stated aims is to investigate whether an array of auditorium chairs conforms to the relationship

$$\alpha = \alpha_\infty + \beta E \tag{1}$$

where α is the absorption coefficient of a finite sample of chairs, α_∞ is that for an infinite sample, β is a constant, and E is the ratio of sample perimeter length to plan area. Bradley notes that the variation of α with E will depend on two factors: the absorption of the exposed sides of the array and diffraction at the array edges. Eq. (1) has been used several times before[4-7] to model the diffraction effect only for plane absorbers. For a three-dimensional absorbing block, however, it is easy to show that this linear relationship describes the variation due to the extra absorption of the sides, if diffraction is ignored.

Consider a rectilinear absorbing block of dimensions *w* x *l* in plan and of height *h* metres. When measured in a diffuse reverberation chamber, the total absorption is

$$A = A_p + A_s \tag{2}$$

where A_p is the total absorption of the plan (top) area and A_s is the total absorption of the four sides. If diffraction effects are ignored,

$$A_p = \alpha_\infty wl \tag{3}$$

$$A_s = 2\alpha_s h(w+l) \tag{4}$$

where α_s is the absorption coefficient of the sides of the absorber, assumed to be unaffected by diffraction and equal for all four sides.

If the absorption coefficient for the whole absorber is now calculated as a function of the plan area *wl* then Eqs. (3) and (4) may be substituted into (2) to obtain

$$\alpha = \frac{A}{wl} = \alpha_\infty + 2\alpha_s h\frac{w+l}{wl} \tag{5}$$

We now introduce the ratio of perimeter length to plan area,

$$E = \frac{2(w+l)}{wl} \tag{6}$$

Substituting Eq. (6) into (5) gives

$$\alpha = \alpha_\infty + h\alpha_s E \tag{7}$$

At a given frequency, $h\alpha_s$ will be a constant (β), so Eqs. (7) and (1) are equivalent. Hence, if an array of seats can be thought of as a block in this way and if the diffraction effects are small, then this relationship is a consequence of measuring different sizes of seating arrays with the sides exposed. Because Bradley did obtain such a variation for measurements of real seats over the range $1.4 < E < 2.4$ m^{-1} it seems that non-linear diffraction effects are indeed small over this range of E at least.

II. KATH AND KUHL'S METHOD

This method consists of placing a rectangular array of seats in the corner of a reverberation chamber and obscuring the exposed sides with screens. If diffraction effects can be neglected, then this method removes the variation of α with E. Bradley's criticisms of the method seem to be based on a measurement of a block of seats not in the corner, with all four sides partially obscured. One of his criticisms is that the screens add their own low-frequency absorption to that of the chairs. In our experience this is due to coupling between room modes and panel modes, producing a resonant panel absorber. One advantage of placing the array in the corner of the chamber is that only two screens are needed, so this anomalous absorption is halved. Another advantage of the corner placing is that any diffraction effect is also halved, as sound can now only diffract into the top of the array at the two edges not adjacent to the walls. This can be explained in terms of the array being mirrored in the two adjacent walls, effectively quadrupling its acoustic size. Values of E then result on the order of those found in auditoria. In our tests, an array of four rows of six chairs was used, with a plan area of 3.3 by 3.6 m. In the centre of the chamber, this gives E = 1.16 m^{-1}, but in the corner of the chamber, the effective value is 0.58 m^{-1}. In Bradley's paper, three of his four auditoria have a mean E of 0.8 m^{-1} and one has 0.6 m^{-1}.

The corner placing with screens allows an accurate measurement of the absorption contributed by the plan area of an array of seats. For the highest accuracy, the absorption of a particular layout of seating blocks in an auditorium is predicted by adding appropriate amounts of exposed front and side seat absorption to the reverberation chamber measurement. The front and side absorption coefficients are obtained from supplementary measurements of the seating array in the reverberation chamber with only one screen covering the side and the front of the array respectively.

One disadvantage of the corner placing is that a small correction must be added to the plan area of the array to take account of pressure doubling. The form of the correction is detailed in Kath and Kuhl's original papers[2,8,9]. Nevertheless, the method works well, and Fig. 1 shows a typical example of the agreement that is achieved between reverberation chamber and auditorium measurements. The auditorium seating absorption in Fig. 1 was calculated from reverberation time measurements in a rectangular concert hall with and without 468 of the 702 seats present. In the reverberation chamber the screens were the same height as the chairs, to exclude all side absorption without unduly changing any diffraction effects. A separately measured estimate of the screen absorption has been subtracted. It is thought that the discrepancy between the auditorium and screened data at 500 Hz is probably due to differences in diffusivity between the two sound fields - the effect of barrier absorption is negligible in this octave. Also shown is a reverberation chamber measurement made according to the traditional method with the seating array in the centre of the chamber without screens.

Thus, this method can both eliminate extra side absorption and achieve the right magnitude of E to make any diffraction effects close to the size of those in a diffuse auditorium. Of course, the screen absorption problem still exists, but increased accuracy can be obtained by measuring the screen absorption separately and subtracting it. This need only be done once for a series of measurements on different seats.

III. CONCLUSION

It has been shown that, for an array of chairs with sides exposed in a reverberation chamber, a linear dependence of absorption coefficient on the ratio of array perimeter length to plan area E is expected. This result was obtained from geometrical considerations and ignores diffraction. Bradley's experimental results demonstrating such a linear relationship therefore mean that any non-linear diffraction effects on chair absorption must be small, at least for $1.4 < E < 2.4$ m^{-1}.

Since diffraction effects can probably be ignored, the screen method of measuring seating absorption seems to offer a more realistic prescription for accurate technological testing than Bradley's method, which requires measurements of several different sizes of seating array. Fig. 1 is an example of the reasonable accuracy of the screen method, taken from a comprehensive study to be submitted shortly. The choice of test method seems particularly important if seating manufacturers are ever to be persuaded to include absorption data in their catalogues.

[1]J. S. Bradley, "Predicting Theater Chair Absorption from Reverberation Chamber Measurements," J. Acoust. Soc. Am. **91**, 1514-1524 (1992).

[2]U. Kath and W. Kuhl, "Messungen zur Schallabsorption von Polsterstühlen mit und ohne Personen," Acustica **15**, 127-131 (1965).

[3]W. J. Davies and R. J. Orlowski, "Methods of Measuring the Acoustic Absorption of Auditorium Seating," Proceedings of the Institute of Acoustics (U.K.) **12**(1), 299-306 (1990).

[4]E. D. Daniel, "On the Dependence of Absorption Coefficients upon the Area of the Absorbent Material," J. Acoust. Soc. Am. **35**, 571-573 (1963).

[5]T. ten Wolde, "Measurements on the Edge-Effect in Reverberation Rooms," Acustica **18**, 207-212 (1967).

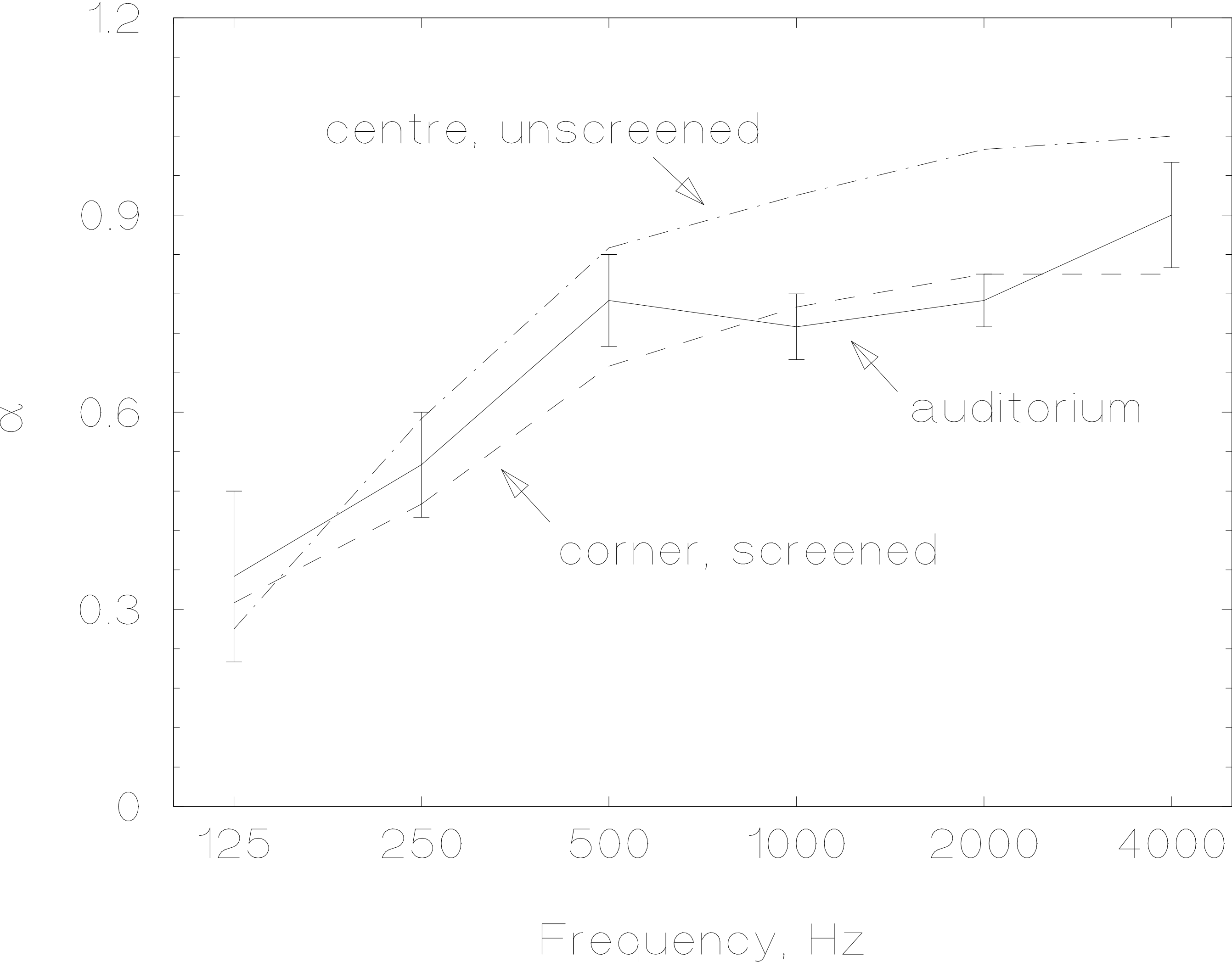
[6]H. Dekker, "Edge Effect Measurements in a Reverberation Room," J. Sound Vib. **32**, 199-202 (1974).

[7]T. W. Bartel, "Effect of Absorber Geometry on Apparent Absorption Coefficients as Measured in a Reverberation Chamber," J. Acoust. Soc. Am. **69**, 1065-1074 (1981).

[8]U. Kath and W. Kuhl, "Einfluss von Streufläche und Hallraumdimensionen auf den Gemessenen Schallabsorptionsgrad," Acustica **11**, 50-64 (1961).

[9]U. Kath and W. Kuhl, "Messungen zur Schallabsorption von Personen auf Ungepolsterten Stühlen," Acustica **14**, 50-55 (1964).

FIG. 1. Seating absorption measured *in situ* in an auditorium and by two different reverberation chamber measurement methods. The error bars represent ± one standard error.



1.2
0.9
0.6
0.3
0
α
centre, unscreened
auditorium
corner, screened
125
250
500
1000
2000
4000
Frequency, Hz