Can reverberation enhancement systems change perception of other room acoustic aspects than just reverberation ?

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ABSTRACT

In order to test the possibilities of early reflection/reverberation enhancement systems to create the illusion of a hall having a size and shape different from (often larger than) the physical hall at hand, a mock up of an enhancement system was created in an acoustically modified university auditorium. In this setup dummy head recordings were made for different settings of reverberation and early reflection parameters. Some of these recordings have been used for listening tests, in which seven subjects judged level, apparent source width, apparent room width, degree of envelopment and apparent distance to the source through pair comparisons. Besides a strong influence on perceived level, the results also indicated clear effects of the reverberation level and reverberation time on perceived room width and envelopment.

Introduction

When use of reverberation enhancement systems is considered, the ambitions often go beyond creating a more reverberant version of the physical hall at hand - to create the illusion of a hall, which is different from it with respect to size (often larger) and geometry. This implies a demand for the system to be able to modify the early reflection sequence in a realistic way, i.e. without creating reflection levels that are unnaturally high (stemming from an attempt to mask the natural reflections with the system reflections).

To test whether such an interval of reflection levels exists, a reverberation enhancement system was designed and installed in an acoustically modified auditorium at our university. Since this auditorium was only available for a limited period of time, dummy head recordings were made for a large number of different settings of reverberation and early reflection parameters for later subjective experiments. In the following, the setup and the results of preliminary listening experiments will be described.

The physical room and necessary modifications

The auditorium used for the experiments has a rectangular plan with dimensions 16 m x 12 m (see Fig. 1). The 170 folding chairs behind narrow fixed tables are arranged in eleven rows on a sloping floor, whereby the ceiling height varies from 5.4 m in the front to about 3.3 m in the rear part of the room. The seats and back rests are upholstered. When empty the seats can stay in their horizontal position, so it is possible to maintain high absorption in the empty hall for these experiments. The acoustically hard suspended panel ceiling is subdivided into differently slanted sections for even distribution of early reflections over the audience area. The walls are wood panelling with air cavity behind. In the rear wall there are slits between the boards. The floor is wood parquet on joists with a slightly raised part near the black board wall.

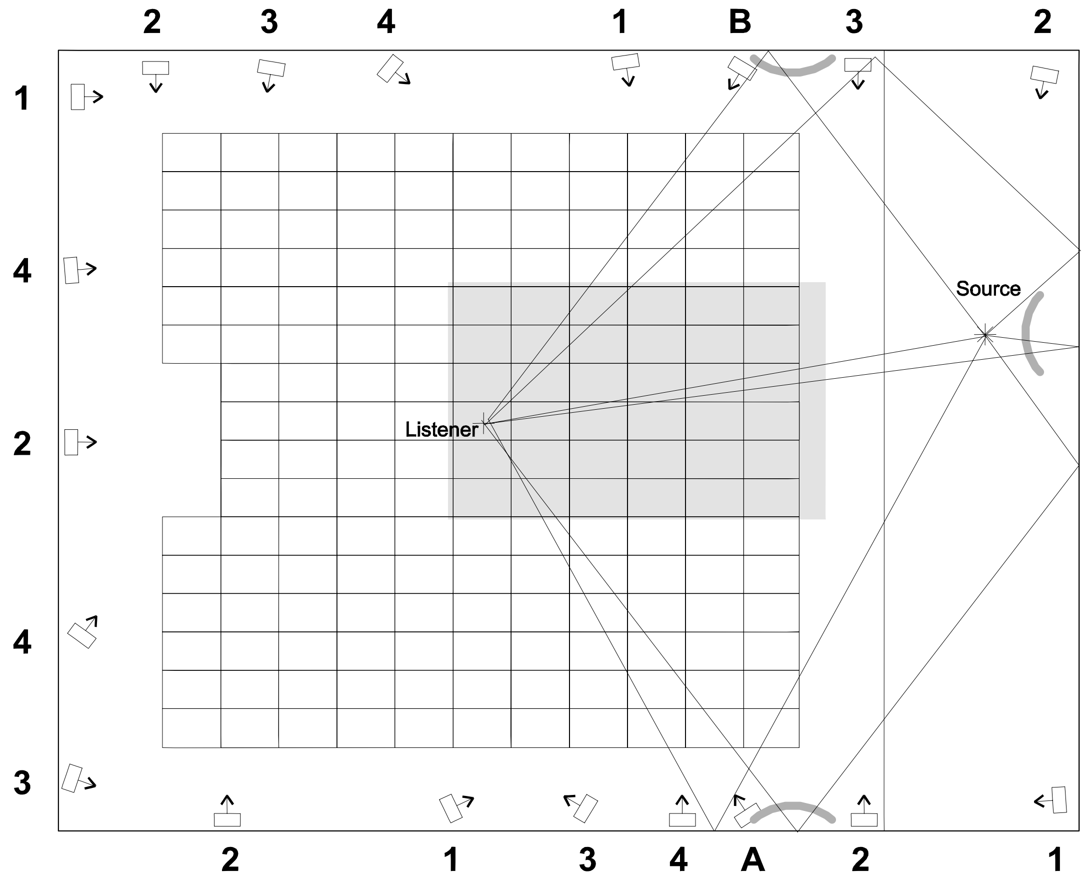
In this hall, a single listener position was chosen in the middle of the audience area. A Brüel and Kjær Dummy head was placed in this position for recording of the sound field created by the room and enhancement system together.

In order to have the artificial reflections determine the perceived “size” of the room, it is important to reduce the most dominant natural reflections, so that they will not mask those created by the enhancement system. In the case of the hall used here, it is primarily the strong reflection from the fairly low ceiling, which could be a serious limitation for simulating a reverberant hall - which naturally would have a high ceiling. Therefore this reflection was subdued by suspending 100 mm thick mineral wool batts about 50 cm below the ceiling covering a 3.4 m x 6 m area of the reflecting ceiling between the source and the dummy head “listening” position. Additionally, 75 mm mineral wool batts fixed to curved masonite boards were placed in front of the geometrical reflection points for the two first order side wall and two second order rear wall/side wall reflections (see Fig. 1). Due to the floor slope and the absorption properties of the rear wall, no primary reflection from this wall needed to be considered. The reflecting table areas close to the dummy head position were covered with 75 mm mineral wool batts.

Reverberation time in the treated auditorium was about 0.5 Sec. at 125 Hz, increasing to about 0.9 Sec. at 1000 and 2000 Hz. The efficiency of the reflection attenuation treatment was monitored through recordings of impulse responses using a MLSSA-system and a shot gun microphone.

The enhancement system

Fig. 1: Plan of the auditorium with source and listener positions and enhancement



loudspeaker positions indicated (small open rectangles with arrows). Loudspeakers with numbers 1 - 4 were used for reverberation, while A and B generated reflections as along the paths shown between source and receiver. The shaded areas indicate extension of sound absorption treatment: rectangle under ceiling and arches in front of walls.

The enhancement system consisted of seventeen loudspeakers emitting reverberation and two loudspeakers emitting early lateral reflections. All loudspeakers were 5" full range units in closed three litre boxes. The reflection and reverberation components were generated by three TC Electronic M2000 reverberation units each containing two separate DSP channels. One unit was used to generate 2 x 2 early reflections, while the remaining two units were used to generate reverberation. Since the algorithms did not contain any time variance, the four reverberation channels were not uncorrelated. However, by setting the start delays for the reverberation slightly different in the four channels and by mixing the four to five loudspeakers connected to each channel, it was possible to create a reverberant sound field, which subjectively was judged as being highly diffuse.

The signal fed to the system came from a cardioid microphone placed in front of the sound source, which was an omnidirectional dodecahedron loudspeaker reproducing anechoic recordings of solo guitar music and female speech. The microphone was placed only one metre from the acoustic centre of the source in order to avoid feedback setting a limit on obtainable enhancement levels. This way, the signal to be processed by the system contained less “room information” compared to common practice in such systems, where the microphones are often placed 5 to 10 metres from the sources. However, this was regarded of less importance in this context.

Experimental variables

With this system it was possible to simulate different delays and levels of the four early lateral reflections as well as different reverberation times and levels. The idea was to combine these variables so that they corresponded to the sound field in halls of different widths, different volumes and different reverberation times relative to the already physically modified auditorium.

The differences in hall width were implemented so that they corresponded to a change from 50 % to 200 % (in 25 % steps) relative to the width of the auditorium. The four reflections simulated were first order side wall reflections plus second order rear- + sidewall reflections from both sides (see Fig. 1). The electronic delays and levels were selected so that they gave the correct values for spherically attenuated reflections from hard walls at the listener position in the middle of the hall but slightly off of the centre axis. A 2.5 kHz lowpass filter with moderate slope was applied to the reflections, since this produced a more natural sound. A B&K dummy head was placed in this position to record the sound fields.

The level and decay rate, T, of the reverberation were chosen to correspond to realistic changes in volume and/or absorption area, e.g. caused by the changes of width mentioned above or by changes in ceiling height. Recordings were made with T-settings on the processors from 0.4 to 2.4 Sec. in 0.4 Sec. steps. To aid in setting up realistic relative levels, G, a prediction model based on measurements in a large number of existing halls [1] was used. Naturally, as also discussed in [1], G should be reduced when attempting to simulate a larger hall. Of course this is not possible as long as enhancement systems can only add sound energy to the room; but at least G does not need to increase as much as if only the amount of absorption had been reduced in a hall of fixed volume. As a test of the applicability of the model, G from the model was calculated to be less than 0.5 dB off of the measured value of 12.0 dB in the auditorium without enhancement.

The subjective experiments

Two subjective experiments were carried out with this system. In the first one, a), only the hall width was changed (50 %, 100 %, 150 % relative to the physical width), while the reflection level was changed -2, 0 or +2 dB around the level corresponding to the spherical attenuation from a hard, plane wall surface. In a real hall, such a variation could arise due to absorption or focussing - or the fact that there are more than just two reflections coming from each side wall. No artificial reverberation was added in this experiment, since one could argue that if the seating and rear wall absorption areas change proportional to the variation in width, then the V/A-ratio and subsequently T would remain the same.

In the second experiment, b), the idea was to simulate different hall volumes with different reverberation times. Consequently, both level and decay rate of the reverberation were selected as variables. Levels -2, 0, +2 dB relative to the “natural” G-values in the physical room and T-values of 0.8, 1.2, 1.6 Sec. were selected on the processors, while values of hall width (from 75 to 200 % relative to the physical width) were chosen to suit the different hall volumes that would correspond to combinations of the two reverberation variables. (The measured G- and T-values were very close to the numbers listed above.)

The different combinations of variables for the two experiments, which were selected from the much larger set of dummy head recordings produced in the auditorium, are shown in Table 1 a) and b) respectively.

Experiment a): changes in room width

		Reflection level relative to spherical attenuation		
		-2 dB	0 dB	+2 dB
room	50 %	a1	a2	a3
width	100 %	a4	a5	a6
rel. 12 m	150 %	a7	a8	a9

Experiment b): changes in room volume/T

		Reverberation time setting in processor		
		0.8 s	1.2 s	1.6 s
Reverb.	- 2 dB	b1	b2	b3
level	0 dB	b4	b5	b6
	+ 2 dB	b7	b8	b9

Table 1: Combinations of variables used in the two experiments; a): effects of changes in simulated hall widths and b): effects of changes in hall size and absorption area.

In both experiments, seven subjects scaled differences between pairs of sound fields along five subjective axes: level, apparent source width, apparent room width, degree of envelopment and apparent distance to the source. The level aspect was included as a separate scale in order to observe what influence this obvious parameter had on the responses along the other scales. The pair comparison experiments were carried out using a computerized presentation system, in which the 20 Sec. long stimuli were stored as Wave files. The responses were delivered as pencil markings on scales printed on the questionnaire sheets, from which the position of the markings were read manually with a simple ruler. From the pair comparison results, the total scores for each of the sound fields were calculated.

Experimental results

At the time of writing this paper, only preliminary analyses of the data have been carried out. (Hopefully more details can be revealed during the presentation.). Significant correlations between objective variables and subjective responses appeared as shown in Table 2.

Experiment a): changes in room width

Objective param. Subjective resp.	Level G meas.	Width setting
Level	**0.88**	**- 0.72**
Room width		
envelopment	(0.28)	- 0.34
Source width	0.35	(- 0.29)
Source distance	(-0.26)	

Experiment b): changes in room volume/T

Level G meas.	Reverb. <u>level</u> set.	Reverb. <u>time</u> set.	Width setting
0.53	**0.80**		**-0.52**
	0.50	**0.74**	
(0.25)	**0.54**	0.37	
(0.29)			(-0.26)
	(0.31)	**0.62**	

Table 2: *Correlations between subjective responses and objective variables or objective measures. Significance levels are indicated as follows:* ***< 1/10%*** *, <1%, (<5%).*

Regarding the room width experiment, it is interesting to notice, that changing the four early lateral reflections did not have any influence on the perceived width of the room. On the other hand, the results of the second experiment reveal, that it was possible to change the perceived width: increasing the level and duration of the reverberation - which in this experiment came after 40 - 60 ms and primarily from lateral directions - also increased the impression of the room width.

Despite the absence of influence on perceived room width, the correlations indicate that the early reflections have some perceptive effects, primarily on the perceived overall level: the larger the width the lower the reflection levels and the lower the perceived level. However, it should be remembered that in experiment b), the change in width was confunded with the changes in the reverberation parameters and so it is difficult to point out which variable is actually responsible for the result. In the width-experiment a), where no reverberation component was added or changed, the early reflections also influenced the degree of envelopment to some degree.

In both experiments a strong and not surprising relationship is seen between perceived level and measured G.

The objective parameter primarily responsible for the variation in perceived envelopment is seen to be the setting of the reverberation level - i.e. the level of the late components in the impulse response - a result very much in line with the results of Bradley and Soloudre [2], who also found that the early reflections were mainly responsible for the apparent source width. In these experiments, only weak (but consistent) indications of this relationship are found - again most likely because the four variable early reflections only contained a small portion of the total impulse response energy.

Finally, it is seen that the impression of source distance increases with increased reverberation time - not a surprise either; but nice to see confirmed.

Concluding remarks

As the building of the setup and the subjective experiments all had to fit within the tight schedule of a master thesis project, certain shortcomings had to be accepted. A more efficient attenuation of the natural side wall reflections and more effort in simulating more of the side wall reflections in halls of different width might have resulted in more clear results regarding the influence of such reflections. For instance, better control of the early reflection sequence - including extension of the time interval before the onset of the artificial reverberation - might have illuminated more clearly the distinction between apparent source width and envelopment, and to which degree control of these aspects requires absorption treatment of reflecting surfaces in the physical hall - besides installation of the enhancement system of course.

However, the results obtained seem to confirm that the method applied here in obtaining the stimuli can provide meaningful results. Therefore, with the large material of stimuli recordings now available, we hope to be able to find further interesting results in new subjective experiments.

References

[1] A. C. Gade: ” Possibilities and limitations in the use of Reverberation Enhancement systems for small multi purpose halls. Proceedings of 15th. ICA, Trondheim, Norway, June 1995, Vol. II, p. 465-468.

[2] J. S. Bradley and G. Soloudre: “The influence of late arriving energy on spatial