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ACOUSTICAL EVALUATION OF DIFFERENT ACOUSTIC CONDITIONS IN THE QUEEN'S HALL – THE ROYAL LIBRARY, COPENHAGEN

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ABSTRACT
The acoustical characteristics of the stage of the Queen's Hall in Copenhagen was investigated for different setups, which allow the acoustics of the hall to be varied. The aim of the measurements was to assess the influence of the different setups on the main acoustic parameters for the stage, both as a function of frequency and source and receiver positions on the stage. The Just Noticeable Difference is considered in the discussion in order to evaluate the relevance of the above aspects for the parameters variation.

INTRODUCTION
The Queen's Hall is a 530 m^2 concert hall seating from 384 up to 600 people. The width and the length are about 18 m and 29 m, respectively and the ceiling height is 10 m. The hall has efficient acoustic variable systems that allow changing the reverberation time between 1.1 and 1.9 second at 1000 Hz. This is possible with a total variable area of 400 m^2 consisting in 250 m^2 of sliding panels with cloth covered mineral wool which can be hidden behind the "saw teeth" side wall pockets, plus 150 m^2 of curtains on the end walls. Figure 1 shows a plan of the hall.

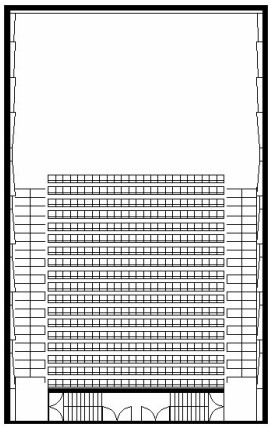

Figure 1: Plan of the Queen's Hall, Copenhagen.

MEASUREMENTS

Instrumentation and measurement conditions
The used measurement equipment was a dodecahedron loudspeaker of diameter 50 cm designed and manufactured at the Technical University of Denmark (DTU), a ½ inch omni-directional condenser microphone fitted on a sound level meter B&K type 2215 which acted as pre-amplifier, plus a HP portable computer with sound card and DIRAC software v. 3.1.

The environmental conditions were not measured, nevertheless, because the relative limited time employed for the measurements, they are considered constant during all the data acquisition. The stage was empty without any furniture during the measurements session and

only the two present writers were in the hall. A wood 40 cm height temporary riser, to accommodate a chamber group of musicians, laid on the floor, the dimensions of which were 8 m by 6 m. All the measurements presented here were carried out on the wooden riser.

Procedure

The acoustical measurements were carried out for each of the setups of the acoustics, described in Table I in which also the abbreviations used to indicate each setting is listed. In particular, the variable acoustic elements made it possible to introduce absorbing surfaces around the stage and/or in the audience area. Besides, tilted reflector surfaces could be deployed on the side walls in the stage area with the purpose of assisting ensemble.

The source and microphone were positioned at 1 m height and only a single measurement was made in each source-microphone configuration. An exponential sweep signal of 5.94 second length was used for the data acquisition, the gain of which was set in order to not saturate the system. Four positions were marked up on the stage, numbered 1 to 4. These were combined for a total of eight source - microphone combinations for each parameter. However, for the support parameters [1], measured with the microphone placed at 1 m distance from the source position, only the four positions were recorded. The used measurement setups are listed in Table II.

Table I.- Description of the acoustic setups

Acoustic setup	Abbreviations
no absorbers at all	NoAbs
no absorbers at all, stage reflectors	NoAbsRefl
side panels, curtains in the hall, stage reflectors	HAbsRefl
side panels, curtains in the hall, curtain behind the stage, stage reflectors	HAbsStCRefl
side panels, curtains in the hall, without reflectors and curtains in the stage	HAbs
side panels, curtains in the hall, curtain behind the stage	HAbsStC
side panels, curtains on stage, side panels and curtains in the hall	StAbsHAbs
side panels, curtains on stage, without absorbers in the hall	StAbs

Table II.- Measurement setups

	R1(-2,1)	R2(3.5,3)	R3(-3,5.5)	R4(0,3)
S1(-2,1)	S1R1 (support)	S1R2	S1R3	-
S2(3.5,3)	S2R1	S2R2 (support)	S2R3	-
S3(-3,5.5)	S3R1	S3R2	S3R3 (support)	-
S4(0,3)	-	S4R2	S4R3	S4R4 (support)

Figure 2 shows a detail of the stage plan with the measurement positions, indicated with Cartesian coordinates in meters referred to the point (0,0) at the mid point on the front of the wood riser; the source positions were then indicated with the capital letter `S´ and the number corresponding to the position, and the microphone position in an analogous way using the capital letter `R´, as listed in the cited Table II.

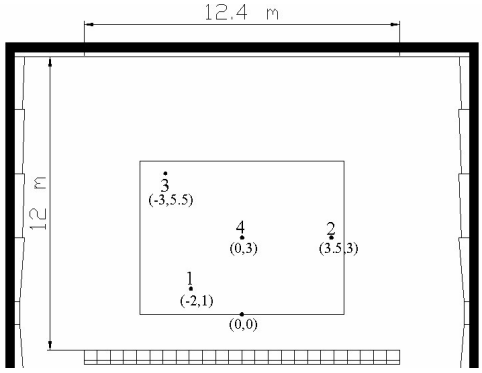

Figure 2: Plan of the measurement setups.

In order to evaluate the 'sound strength' parameter, G, measurements in the reverberant room were carried out with the same equipment, to perform the system calibration using the diffuse field method. The used reverberant room located at DTU has a volume of 210 m^3. Three source positions were chosen on the floor and three microphone positions for every source positions were used; for a total of 9 setups. The positions were chosen randomly on the room floor.

DISCUSSIONS

The above described measurement setups on the stage aimed at investigating the influence of different acoustic conditions on the stage parameters. The parameters, considered significant to describe the musicians' needs [2], are calculated from the impulse response measured on the stage. They are listed in Table III, with the symbols and the corresponding Just Noticeable Difference (JND), as specified in the ISO/CD 3382-1 [3]. The JND's are also indicated as the smallest division of the ordinate scale of the following graphs for comparison.

Table III.- Measured parameters

Measured parameters	Symbol	Just Noticeable Difference (JND)
Reverberation Time	T30	Rel. 5%
Early Decay Time	EDT	Rel. 5%
Early Support	ST_{early}	1 dB
Late Support	ST_{late}	1 dB
Clarity	C80	1 dB
Sound Strength	G	1 dB
Centre Time	t_s	10 ms

Reverberation Time

The average value of the reverberation time measured in all eight position combinations for each room configuration is shown in Figure 3, in order to compare the different acoustic conditions. It is possible to notice that the reverberation time changes for the different acoustic setups in a perceivable way, however the patterns vs. frequency keep similar shapes. In the case of T30, the limited variation of the parameter with the position allows using the spatial average as a legitimate operation to obtain single numbers.

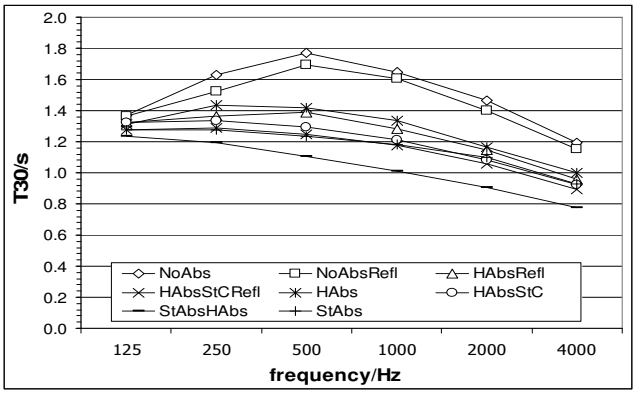

Figure 3.- Values of T30 for different acoustic setups.
The unit of format of the T30 scale is the relevant JND

Early Decay Time

Analogous results are obtained for the Early Decay Time and shown in Figure 4. Also in this case, the change of the acoustic conditions seem to have a high influence on the parameters values. Figure 5 shows the calculated average of the values at 500 Hz and 1000 Hz, as specified on the ISO/CD 3382-1 [3] for each position. It is seen that the main effect is due to the different acoustic conditions. The differences due to source and microphone positions are smaller, so that spatial averaging is justified also in this case. It is hence possible to notice, that for EDT the variance with the positions on the stage is quite high, in many case larger than the JND.

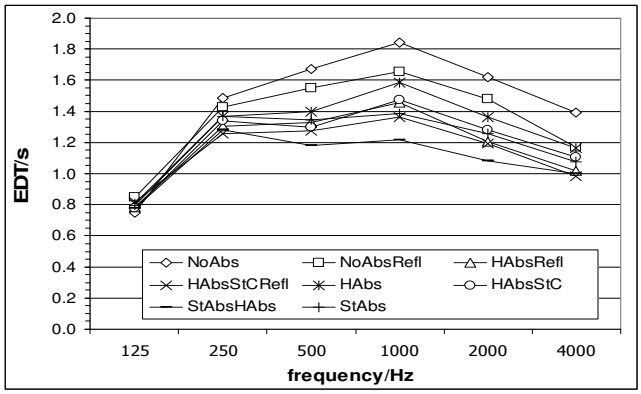

Figure 4.- Averages of EDT for different acoustic setups.

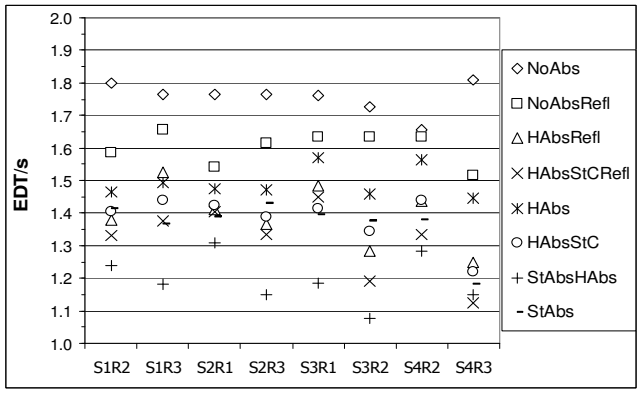

Figure 5.- Frequency averaging of EDT for each acoustic setups and position.

Early Support

In the case of the Early Support, the value of the parameter is specifically referred to the chosen position on the stage and not to the stage as a whole, so in this case, the average operation is not a proper process to elaborate the data. Figure 6 shows the single number averaging from the 250 Hz to the 2000 Hz central frequency band [3], obtained in order to compare the different acoustic setups for each position on the stage. In general, the acoustic changes have an important influence on the values of the early support. The change of the absorbing conditions in the hall seems to have a strong influence on the results in particular in positions S3R3 and S4R4. These positions are in general more sensitive to the acoustic changes, whereas S1R1 is less influenced. This is not easy to explain; nevertheless, it is evident that the position is also an important parameter influencing variations of this index.

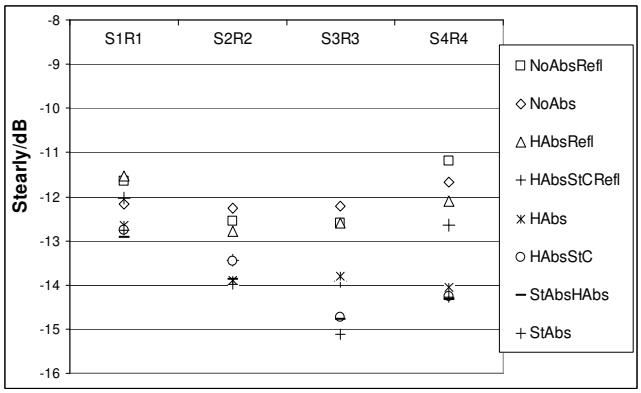

Figure 6.- Values of ST_{early} for different acoustic setups.

Late Support
In the case of the late support, analogous considerations than for ST_{early} can be stated. Figure 7 shows the frequency averaged values for this parameter.

Both the early support and the late support values are found to be within the typical range specified in the ISO/CD 3382-1 [3].

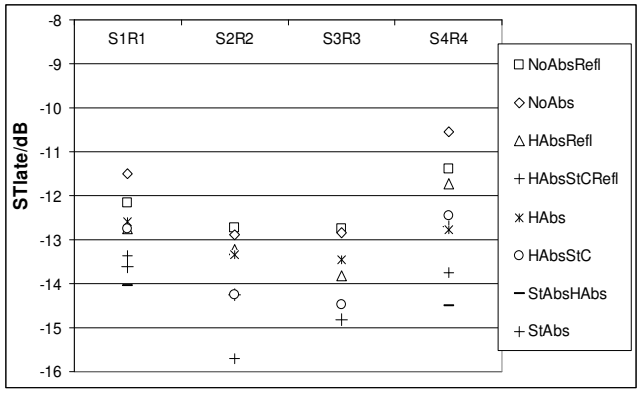

Figure 7.- Frequency averaged values of ST_{late} for each acoustic setup and position.

Clarity
From the analysis, the parameter 'Clarity' is visibly influenced by the positions of the source and the receiver on the stage, for all the acoustic setups. Figure 8 shows the frequency averaged numbers for C80, calculated over the octave bands with centre frequencies 500 Hz and 1000 Hz [3].

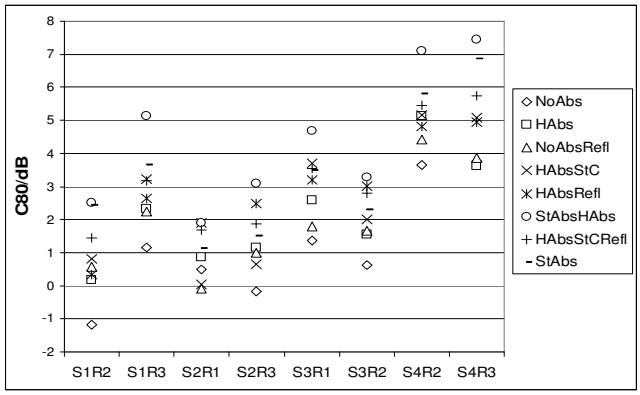

Figure 8.- Frequency averaged values of C80 for the different acoustic setups and positions.

It is particularly interesting to observe that the variation among the positions on the stage are, for the most part of the setups, higher than the Just Noticeable Difference, which is indicated as the division of the ordinate scale of 1 dB. Moreover, while for S1 there is an evident effect of the receiver position, the remaining results seem to depend mainly from the source position.

Sound Strength
In the case of the sound strength similar elaboration were carried out and in Figure 9 the single number average values over the central frequency bands 500 Hz and 1000 Hz are shown [3].

As before the main effect could be considered as due to the acoustic characteristics, significant position differences being evident only for the source position S4 and, maybe, for the source – microphone setups S2R3 and less for S3R2.
Figure 10 shows the values of G vs. the frequency for the different acoustic setups. It is possible to notice that the higher influence of the acoustic changes occurs in particular at high frequency.

This is expected, because the change of the absorbing surface in the hall have its stronger effect on the high frequencies.

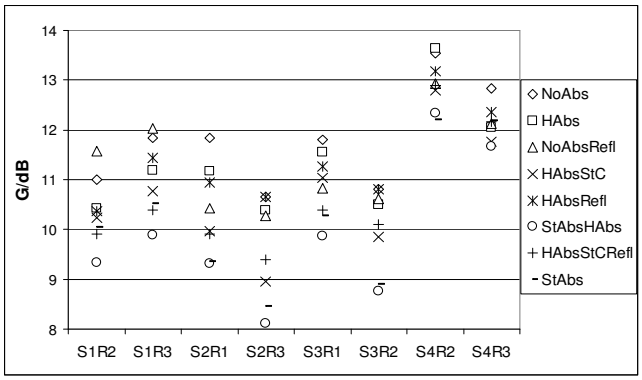

Figure 9.- Single number frequency averaging of G for the different acoustic setups.

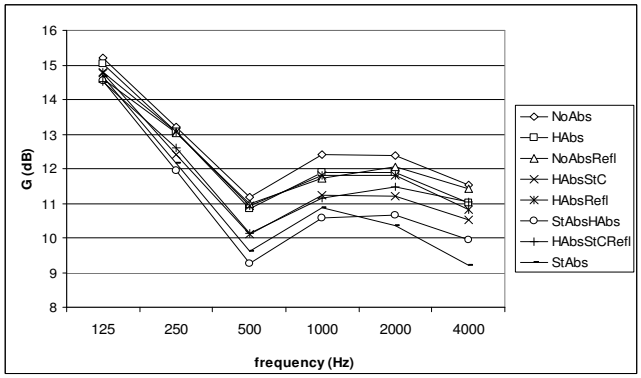

Figure 10.- Spatial average values of clarity for the different acoustic setups.

Conclusions

Measurements were carried out on the stage of the Queen's Hall in Copenhagen. The hall is characterized by the possibility to vary the acoustic conditions achieving many different acoustic setups. The aim of the measurements was to investigate both the influence of the acoustic changes and of the different source and microphone positions on the stage, on the parameters values.

The Reverberation Time and the Early Decay Time have similar behavior with respect of the source and microphone positions, while the support parameters, ST_{early} and ST_{late}, show clear effects only for the S3R3 and S4R4 positions, S1R1 being at the threshold of the JND. The parameter variations with the source in S4 position are more evident for the clarity parameter, C80, and the sound strength, G.

The differences are, in the most part of the cases, larger than the Just Noticeable Difference.
It is interesting to notice that in most cases the variations seems strongly influenced by the position of the source, whereas only in few cases, the microphone position seems to have a significant effect.

References:

[1] A. C. Gade: Practical aspects of room acoustic measurements on orchestra platforms. 14th International Congress on Acoustics, Beijing, China, September 3-10 (1992)
[2] A. C. Gade: Investigation of Musicians' Room Acoustic Conditions in Concert Hall. Part II: Field Experiments and Synthesis of Results. Acustica **69**, (1989) 193-203
[3] ISO 3382 Acoustic-Measurement of the reverberation time of rooms with reference to other acoustical parameters. (1997)
[4] M. Barron: Using the standard on objective measures for concert auditoria, ISO 3382, to give reliable results. Acoustic. Sci. & Tech. **26, No.2** (2005)