COMPARISON OF DIRECTIONAL SOURCES IN SIMULATING A SOPRANO VOICE

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ABSTRACT

The study of the acoustical balance between the singer and the orchestra by means of room acoustical measurements has shown that the directional characteristics of the source are important. This investigation compares the directional characteristics of two loudspeakers used for room acoustic measurements in an historical opera house when simulating a soprano. Directivity measurements of a soprano singer were done in an anechoic chamber and used as a basis for comparison in room acoustic simulations of the Royal Theatre of Copenhagen. The influence of the directional sources in the distribution of the simulated acoustical parameters in the room was compared and evaluated with the distribution obtained from the soprano.

1. INTRODUCTION

One of the most outstanding acoustical characteristics of an opera house, which still is not sufficiently investigated, is the balance between the sound of the orchestra in the pit and the sound coming from the stage. Previous studies have shown that one of the important factors that affects balance measurements is the directivity of sound sources [1] [2] [3]. Considering the available normative to evaluate the acoustical qualities of an opera house, the ISO 3382, omnidirectional sources have to be placed both in the orchestra pit and on the stage.
In this study the effect of using other types of directivity loudspeakers, besides the dodecahedron omnidirectional source has been investigated. The goal has been determining which source is closer to the directional characteristics of a soprano's singer voice.

2. DIRECTIVITY MEASUREMENT

Directivity measurements of a soprano singer and two loudspeakers were performed in an anechoic chamber to be used for the room simulations in the opera house.

2.1. Directivity measurements of the soprano

Multi-channel anechoic recordings of a soprano singer were made with a setup of 23 microphones. The singer was rotated in four positions and measured with a resolution of 10° in the horizontal and vertical axes. The recordings were made at 24-bit quantization and 44.1 kHz sampling rate and the singer was asked to sing isolated tones in two octaves from A3 (220 Hz) to A5 (879 Hz). The recordings from the four positions were then used to construct the averaged directivity in the octave bands from 125 to 8000 Hz. Figure 1 shows the measured directivity of the soprano in the horizontal plane at 500, 1000, 2000 and 4000 Hz octave bands. Figure 2 shows the measured directivity of the soprano in the vertical plane at 500, 1000, 2000 and 4000 Hz octave bands.

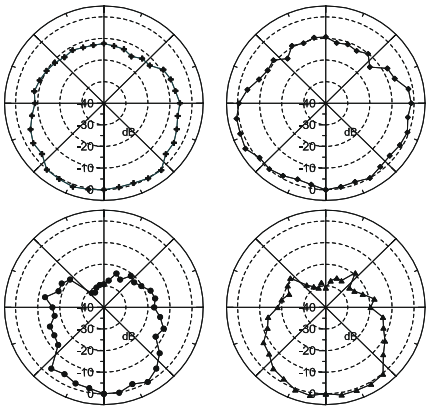

Figure 1: *Measured directivity of the soprano singer in the horizontal plane at 500 Hz (above-left), 1000 Hz (above-right), 2000 Hz (below-left) and 4000 Hz (below-right) octave bands.*

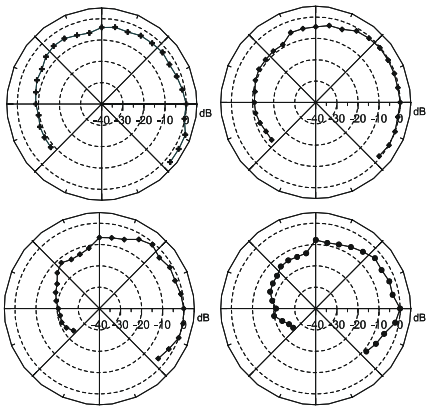

Figure 2: *Measured directivity of the soprano singer in the vertical plane at 500 Hz (above-left), 1000 Hz (above-right), 2000 Hz (below-left) and 4000 Hz (below-right) octave bands.*

2.2. Directivity measurement of the loudspeakers

The directivities of two loudspeakers were measured in an anechoic chamber following the traditional method of rotating the source in steps of 10 degrees in both vertical and horizontal axes with a single microphone. The two full range loudspeakers considered had different shapes in order to evaluate the influence of the loudspeakers cabinet. The first source was a 6 inch unit mounted in a rectangular wooden box of dimensions 20x20x15 cm. The second source was a dodecahedron omnidirectional source with a diameter of 35 cm. Each unit in the dodecahedron omnidirectional source was 5 inches and only one of the vertical units was measured and used for room acoustic simulation. Both sources were selected as representative of conventional loudspeakers that could be used in the context of balance measurements in rooms. The vertical and horizontal directivities of each of the loudspeakers proved to be the same. The directivity of the dodecahedron omnidirectional source was not measured and was assumed to be ideally omnidirectional. Figure 3 and figure 4 show the directivities of the two loudspeakers in the horizontal and vertical planes at 500, 1000, 2000 and 4000 Hz octave bands.

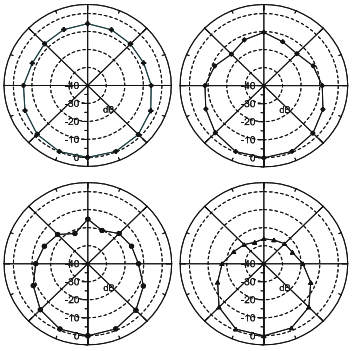

Figure 3: *Measured directivity of the wood box loudspeaker in the horizontal and vertical plane at 500 Hz (above-left), 1000 Hz (above-right), 2000 Hz (below-left) and 4000 Hz (below-right) octave bands.*

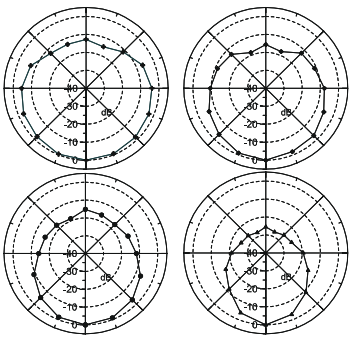

Figure 4*: Measured directivity of the dodecahedron omnidirectional source with just one frontal unit turned on. Horizontal and vertical plane at 500 Hz (above-left), 1000 Hz (above-right), 2000 Hz (below-left) and 4000 Hz (below-right) octave bands.*

3. SIMULATIONS

Room acoustic simulations were carried out on a model of the Royal Theatre of Copenhagen, using the software ODEON [4], in order to compare the directivities of the three acoustical sources with the soprano's one. Two different stage conditions were considered for the simulations: with stage set-up and without stage set-up. This was done in order to consider two realistic situations during the typical acoustical measurements in these kinds of theatres.

3.1. Method

The directivities of four sources were simulated in the theatre. The first source was a dodecahedron omnidirectional source (defined "OMNI"), the second was a rectangular wooden box (defined "Box"), the third was the dodecahedron omnidirectional source with only one unit turned on (defined "D1/12") and the fourth was the soprano's voice. Each source was simulated with the same power level in each octave band. This condition allowed for a comparison between the four different sources.

Three different source positions were chosen on the stage: **S1** at 1 m from the symmetric axis of the hall and 2 m from the fire curtain; **S2** at 1 m from the symmetric axis of the hall and 5 m to the fire curtain, and **S3** at 4 m from the symmetric axis of the hall and 2 m from the fire curtain, all of them at 1.5 m from the stage floor. These positions were considered as typical locations of the singer on stage. All of the four sources were simulated in each of the three positions (S1; S2; S3), one at the time. Due to the symmetry of the hall, positions in only one half of the room were simulated. 21 receiver positions (8 in the stalls and 13 in all the balconies) were selected. The Sound Pressure Level (SPL) simulated by the software in each receiver position was the parameter used to evaluate the similarity between the sources and the soprano's voice.

3.2. Results

An energetic average of the SPL obtained in each receiver's position for each single source, playing one at a time in the three different positions (S1; S2; S3) on the stage, was considered. The results are shown according to the distance between source and receiver in the room.

Two different behaviours were observed for each source in the hall: one in the stalls and another in the balconies. Because of this, the results will be divided between stalls and balconies.

The discussion has focused mostly on the 2 and 4 kHz octave bands, where the formant of the singer's voice is located [5] and where, according to Meyer [6], the voice's emission spectrum can be compared to the one of the orchestra.

Figure 5 shows the simulated energetic average of the SPL at different positions in the stalls, with stage set-up and without stage set-up. In the stalls there is a clear similarity between the behaviour of the two directivity loudspeakers in both the set-ups chosen (with and without stage set-up), while a different behaviour can be observed for the dodecahedron omnidirectional source. None of them proved to be significantly close to the behaviour of the soprano's voice.

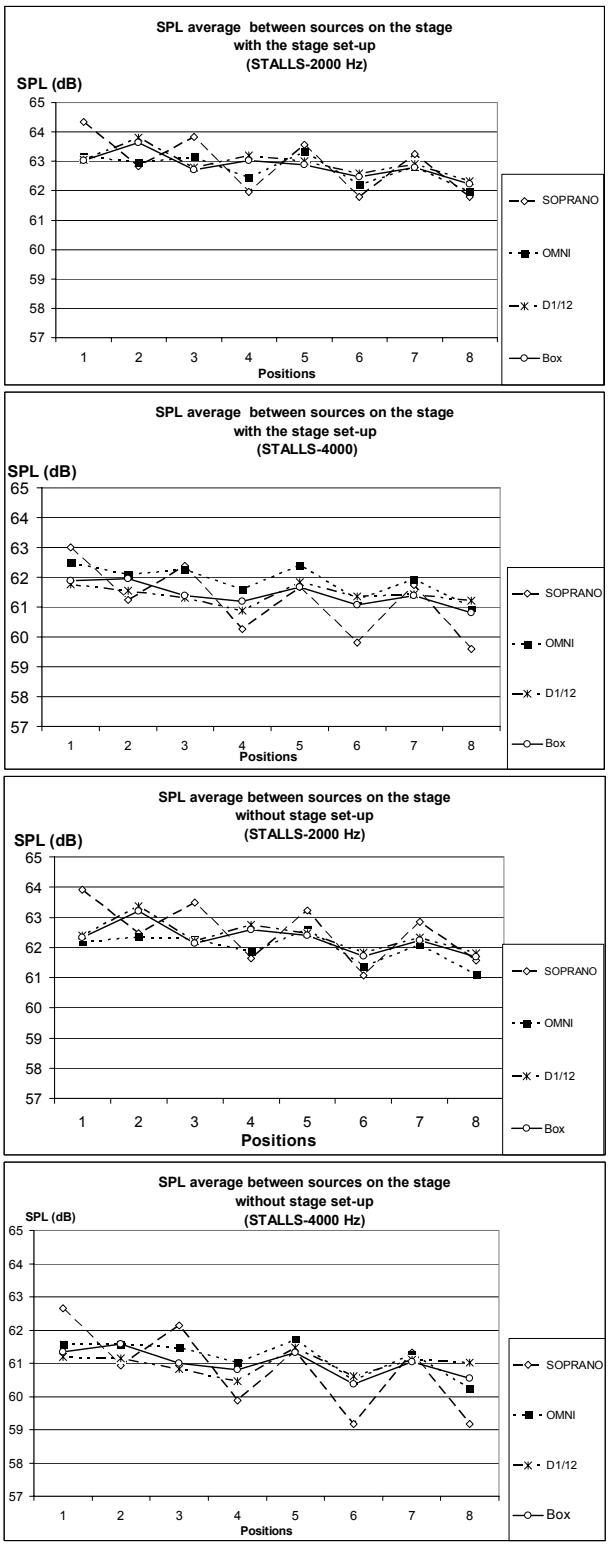

Figure 5: *Energetic average for different sources on the stage with the receivers in the stall. The first and the second are with stages set-up, the third and the fourth without stage set-up.*

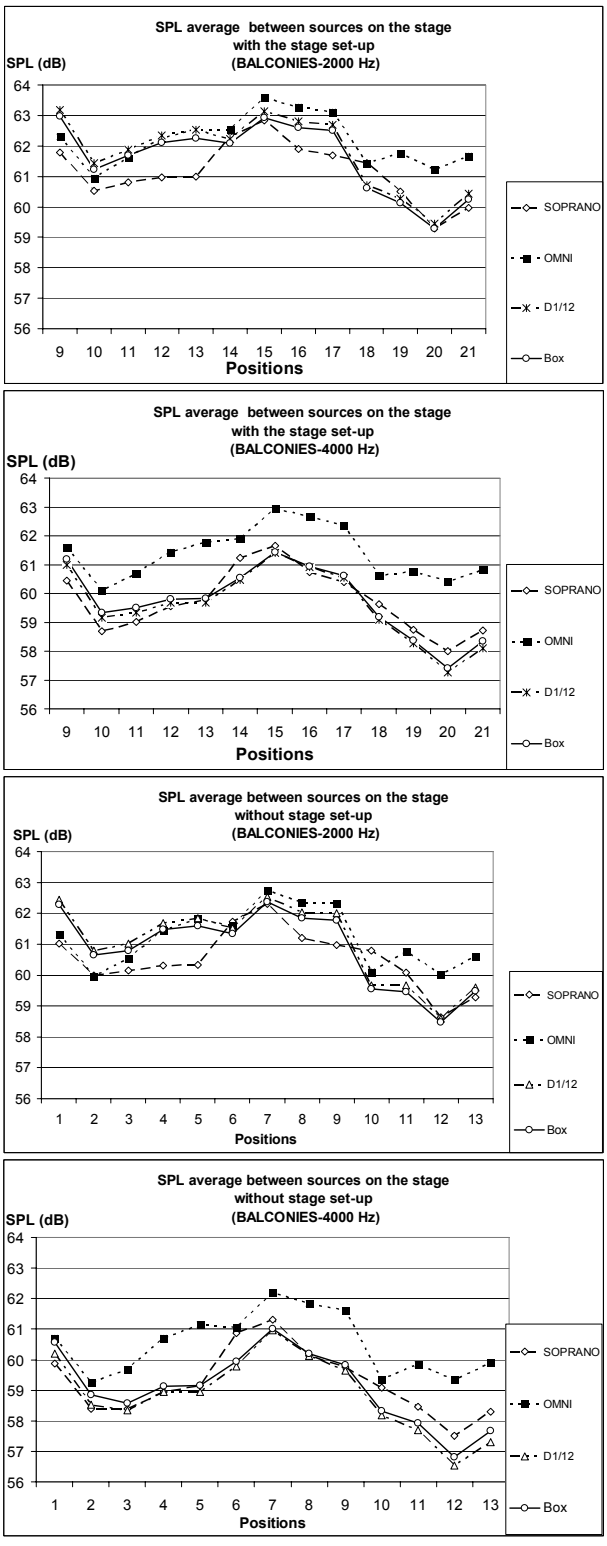

Figure 6: *Energetic average for different sources on the stage with the receivers all over the balconies. The first and the second are with stages set-up, the third and the fourth without stage set-up.*

Figure 6 shows the energetic average of the SPL at different positions in the balconies, with stage set-up and without stage set-up.

The behaviour of the two directivity loudspeakers and the soprano's voice are more similar in the balconies than in the stalls. At 2 kHz, in the receiver positions on the balconies, closer to the symmetric axis (positions 19-20-21), the dodecahedron omnidirectional source is stronger than the other sources. The similarity between the directivity sources and the soprano's voice is more evident at 4 kHz. On the other hand, the dodecahedron omnidirectional source seems to overestimate the soprano's voice by 2-3 dB.

The use of a stage set-up clearly increases the difference between the dodecahedron omnidirectional source and the other sources. This is due to the fact that early reflections are supporting the dodecahedron omnidirectional source more than the other sources, included the soprano's one.

3.3. Discussion

The significant discrepancies observed in the balconies at 2 and 4 kHz for the dodecahedron omnidirectional source seems to be based on two separate aspects. Firstly, this source spreads out more energy towards the balconies due to its uniform directivity distribution. Secondly, the stage tower's characteristics have more influence on the dodecahedron omnidirectional source behaviour than on the directional sources. This effect can be related to the omnidirectional characteristics of the source, an effect which is strongly influenced by the surfaces and the shape of the stage tower. Results obtained in other room models with different stage tower characteristics showed that, based on the same power level in each octave band, the dodecahedron omnidirectional source has a lower SPL over the entire hall than the other directional sources, including the soprano's voice.

4. CONCLUSIONS

The use of a dodecahedron omnidirectional source to emulate a soprano's voice in balance measurements can cause an over or underestimation of the soprano's voice. Simulation showed that the behaviour of the two full range loudspeakers was closer to the one of the soprano's voice compared to the dodecahedron omnidirectional source.

Despite the changes in the directivity and shape of the two full range loudspeakers, their acoustical behaviour in the room proved to be similar. This means that different full range loudspeakers are suitable to emulate a soprano's voice for the balance measurements purposes.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] Barron, M., "Auditorium acoustics and architectural design", E & FN Spon, London, pp. 333, 1993.

[2] O´Keefe, J., "Measurement of the stage to pit balance in four proscenium arch theatres", in Proceeding of IOA – Auditorium design of the millennium, Belfast, 1997.

[3] Pompoli, R. and Prodi, N., "A study on balance inside an historical opera house", in Proceeding of ICA2001, Rome, 2001.

[4] ODEON home page. http://www.odeon.dk

[5] Sundberg, J., "The acoustics of the singing voice", Scient. Amer. 236, 1977, pp 82.

[6] Meyer, J., "Some problems of opera house acoustics", in Proceedings of 12th ICA, Vancouver, 1986.

[7] "The DOREMI project home page." http://www.at.oersted.dtu.dk/~doremi/