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Directional represantation of a clarinet in a room

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Abstract:
This article presents a study of the directional characteristics of a clarinet in the context of a real performance. Anechoic measurements of the directivity of a Bb clarinet have been done in the horizontal and vertical planes for isolated frequency tones. Results are discussed comparing the particular directivity of tones and the averaged directivity over the whole frequency range of the instrument. Room acoustic simulations with the measured and averaged directivities have been carried out for a concert hall as an example of a realistic application. Further developments will consider measurements with other instruments as well as auralizations and tests with an alternative sound radiation representation.

Keywords: musical acoustics, clarinet, directivity, room acoustic simulations

1. Introduction and goals

The directivity of musical instruments has been studied by several authors [1, 2, 3], Jürgen Meyer being probably the one who has contributed with more specific information about the radiation characteristics of musical instruments in a real performance situation [4]. The data on the directional characteristics of different classical music instruments provided by Meyer are mostly concerned with averages of the directivity over the whole performing frequency range of the instruments. Very little information is included about the directivity of instruments for particular tones, even though, as shown by Meyer, the directivity of instruments changes dramatically over the performing range. Most of the available data on the directivity of musical instruments used nowadays for room acoustic simulations and auralizations consider the averaged directivities from Meyer's results. Very few attempts have been made to use a different directional representation that would include the directivity changes of the musical instruments within the performing range [5]. On the other hand, experiments using room acoustics auralizations have shown that the directional representation of sources in room acoustic simulations is important and changes in their directivity can affect the perceived sound in a room [6]. For these reasons there is a need to better understand how large the variations of the directivity of musical sources are in a real performance situation and how important these variations can be both acoustically and perceptually.

The first goal of this study has been to measure and compare the particular directivities of a clarinet for particular tones and the averaged directivity over the whole compass. This has been done in order to compare the traditional representations (averaged directivity) with a more realistic representation of a performance situation (directivities of particular tones). The second goal has been to use the measured and averaged directivities for room acoustic simulations in order to evaluate their possible influence on the perceived sound according to different room acoustic parameters.

2. Directivity of the clarinet

2.1 Choice of instrument

The idea of making directivity measurements was inspired by the goal of achieving a comparison between the particular directivities of a musical instrument and the averages of the directivity over the whole compass. The instrument chosen for the directivity measurements was a clarinet in Bb, mainly due to its sound radiation characteristics as well as its large register possibilities [7]. The directivity measurements of the clarinet were planned and made in a way that would allow a study of the directivity of the instrument in a performance situation, always with the representation of the source in computer room simulations in mind. For this reason, it was very important to carry out simultaneous measurements and have a setup that could be used for other purposes such as simultaneous recordings for room auralizations [5]. It was also important to make the measurements using the whole performing range of the instrument in order to have the average and the particular directivities available for comparison.

2.2 Directivity measurements of the clarinet

The directivity measurements of the clarinet were carried out using simultaneous recordings of 13 microphones in the anechoic chamber at 45° intervals, considering a distance of 1.5 meters from the source and measured in octaves from 125 to 8000 Hz. The measurements were carried put using a 24-bit quantisation and a sampling frequency of 44.1 kHz. Single tones were measured over the whole compass of the instrument (44 tones) with a similar musical intensity played by the performer. Figure 1 shows the performer playing the clarinet in the anechoic chamber during the measurements and Figure 2 shows the measuring setup in the horizontal and vertical planes.

Fig. 1. **Clarinet player during the directivity measurement in the anechoic chamber.**

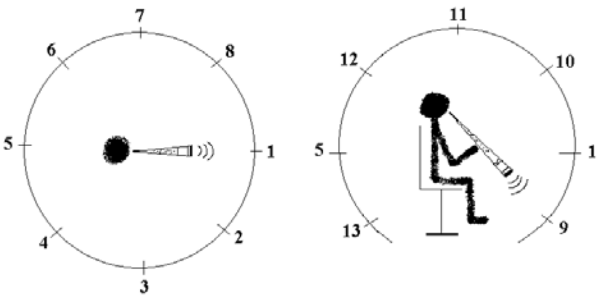

Fig. 2. **Setup for the simultaneous directivity measurements with 13 microphones. The left part of the figure shows the setup in the horizontal plane and the right part shows it in the vertical plane. Microphones 1 and 5 appear in both planes.**

2.3 Results

In order to compare particular directivities with the averaged directivity over the whole range, short samples of the sound of the tones were chosen and used as representative. Five different tones, with ascending pitches over the whole compass of the instrument, were considered for the comparisons with the calculated average. These tones with their respective fundamentals were: C4 (262 Hz), A4 (442 Hz), E5 (667 Hz), B5 (999 Hz) and E6 (1327 Hz). Figure 3 shows an example of comparisons between the averaged and the particular directivity for five ascending tones at 2000 Hz. The horizontal and vertical results were normalised to the level in the frontal microphone (microphone 1 in Figure 2) so as to correspond to the way the directivity of sources is represented in computer room simulations and in order to have a basis for comparison for later simulations. Figure 4 shows the graphs with the level differences between the particular tones directivity and the averaged directivity for the octave bands from 500 to 4000 Hz. In this case the curves were normalised to the level in the front and a suitable range of frequencies was chosen for comparisons (500-4000 Hz). The graphs displayed in Figure 4 show the filtering process over the fundamental of the tones.

The results in the horizontal plane show that the directivity differences increase with frequency. For most of the curves at 500 and 1000 Hz the level differences are within a range of ±5 dB, with some punctual exceptions where the difference can be up to 10 dB (C4, 270° at 1000 Hz and A4, 90°, 270° at 1000 Hz). At 2000 Hz, the directivity differences become greater within a range of ±10 dB, with some exceptions where the differences can be up to almost 30 dB (E6, 315°). At 4000 Hz the directivity differences are clearly significant within a range of ±20 dB.

In the vertical plane the differences become greater than in the horizontal plane and also less predictable within the same measured tone. The differences at 500 and 1000 Hz are within a range of ±15 dB with some particular greater differences in some cases (C4 for 135° and 315° at 500 Hz; A4 for 90° at 500 Hz; E5 for 90° at 1000 Hz). At 2000 Hz the differences are in a range of ±10 dB, while at 4000 Hz the differences are within a range of ±15 dB.

2.4 Discussion

The comparisons between the measurements of the directivity of the clarinet and the average show fluctuating differences that clearly increase with frequency. When comparing the directivity differences in the two planes it becomes clear that the differences are much greater in the vertical plane than in the horizontal plane. As shown by Meyer [4], in the vertical plane the clarinet becomes more and more directional towards the axis of the bell (315°) over 1000 Hz. This could make the particular directivities at higher frequencies have greater differences resulting in larger variations compared to the average. This could also mean that the changes at higher frequencies are more dramatic and that a different representation might imply severe consequences in the sound perceived in a room. To provide an example, one can consider tone E6 in Figure 3. In this case the instrument clearly becomes more directional in both planes. It may be assumed that in this case if the average representation were to be used in the auralization of a room instead of the particular directivity of E6, the instrument's directional characteristic would be transformed into something much more omnidirectional, raising the level in the front direction (0°) instead of the axis of the bell and also at the sides (45° and 315°) of the instrument. In an auralization these differences could be very noticeable if one considers a change in the direct sound of 6 dB and in the lateral reflections in almost 10 dB as seen in the figure.

Another interesting result of the comparisons is that they show that the pitch of the selected tones does not seem to affect the directivity differences in the horizontal plane. In the vertical plane an increase in differences can be noticed with the pitch of the tones. As stated before, the vertical plane seems to be much more unstable and dependent on the particular tones played.

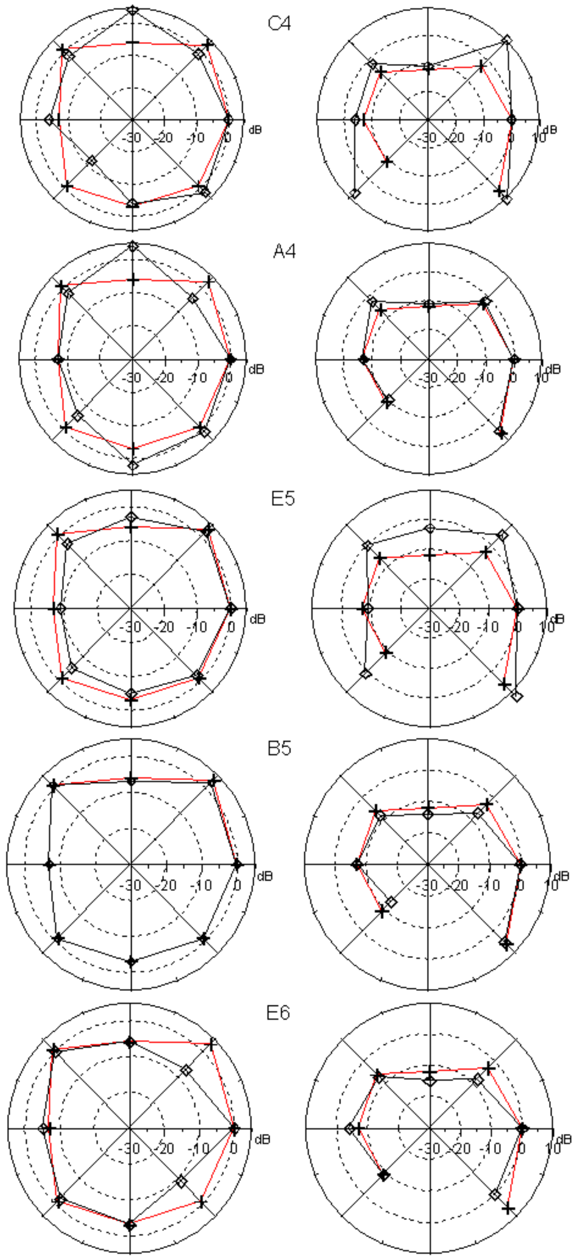

Fig.3. **Comparisons of the averaged and the particular directivities of the clarinet at 2000 Hz for different tones. Left: Horizontal Plane. Right: Vertical plane. The averaged directivity is plotted as crosses while the particular directivity is plotted as diamonds. The orientation is the same as in Fig.2 with the instrument pointing to the right.**

3. The sound of the clarinet in a room

3.1 Room acoustic simulations

As a way to get a more clear picture of how the directivity of a clarinet affects the sound in a room, computer room simulations were carried out with the measured directivities using the same power for the sources. The software used for the simulations was ODEON version 6.0 [8]. The purpose was to contrast the differences in the sound in the room using the traditional averaged representation of the directivity of the clarinet and the representation of particular ones. For this purpose the directivities of two of the five tones considered previously (C4 & A4) were used. The room simulations were carried out with a model of the concert hall ELMIA located in Jönköping, Sweden. The different directivities were simulated with the sources located in the normal position of the soloist on the stage, at a height of 1 meter from the floor pointing to the audience.

The first comparison was made between the grid response for the sound pressure level (SPL), calculated both with the averaged directivity and the directivity of the two tones respectively. Figure 5 shows the grid response for the SPL in the concert hall at 500, 1000, 2000 and 4000 Hz with the three directivities (average, C4, A4). As it can be seen in the figure, the simulations showed the SPL to be directly dependent on the directivity of the sources in most of the cases, while in some cases the directivity changes dramatically for the same tone filtered at two different octaves. In this case the directivity of the average maintains a good SPL homogeneity in the room compared with the tones for all the measured frequencies, except for 4000 Hz, where it is clearly worse. It is also interesting that the directivity affects the SPL on the stage, showing in some cases a great difference within a very short distance from the source.

A second comparison made with the simulation software concerned the clarity factor (C80). Figure 6 shows the grid response of the C80 in the room at the different frequencies, with the averaged directivity and the directivity of the tones. In this case the clarity also seems to be directly dependent on the directivity of the source and the differences seem to be more critical. When comparing the C80 with the averaged directivity and the ones of the tones, one can see that in some cases the C80 with the average directivity is clearly lower than the one of the tones (1000 and 4000 Hz). In the other cases it is similar or slightly higher. The C80 of the averaged directivity seems to be more symmetrical in the distribution in the room and also quite similar for 500, 1000 and 2000 Hz. One could say that the C80 with the averaged directivity is not necessarily much better than the one of the tones but more stable and predictable.

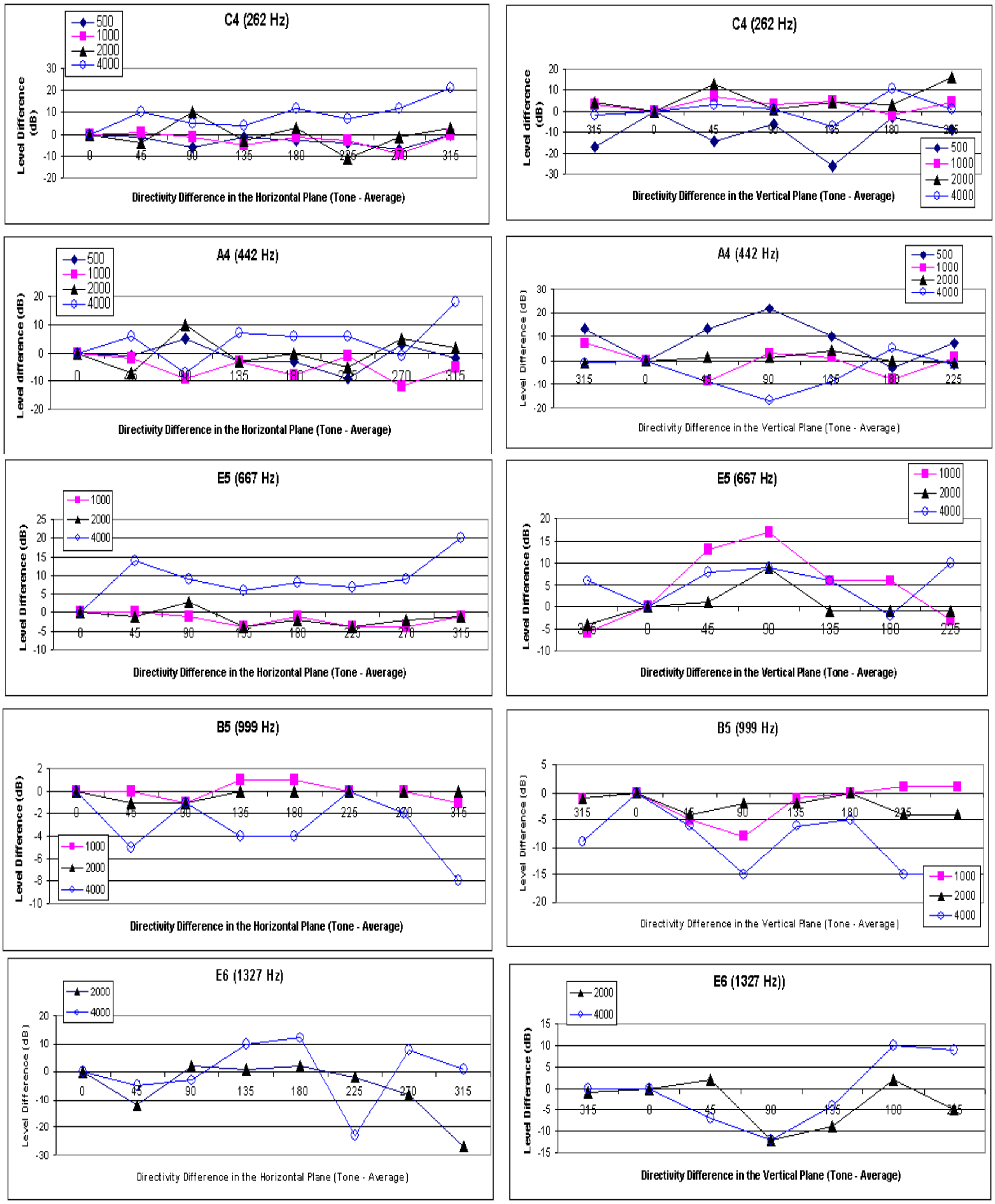

Fig. 4. **Directivity difference in the horizontal and vertical planes for five ascending tones of the clarinet when compared with the average. The left column of figures corresponds to the horizontal axis while the right column corresponds to the vertical axis.**

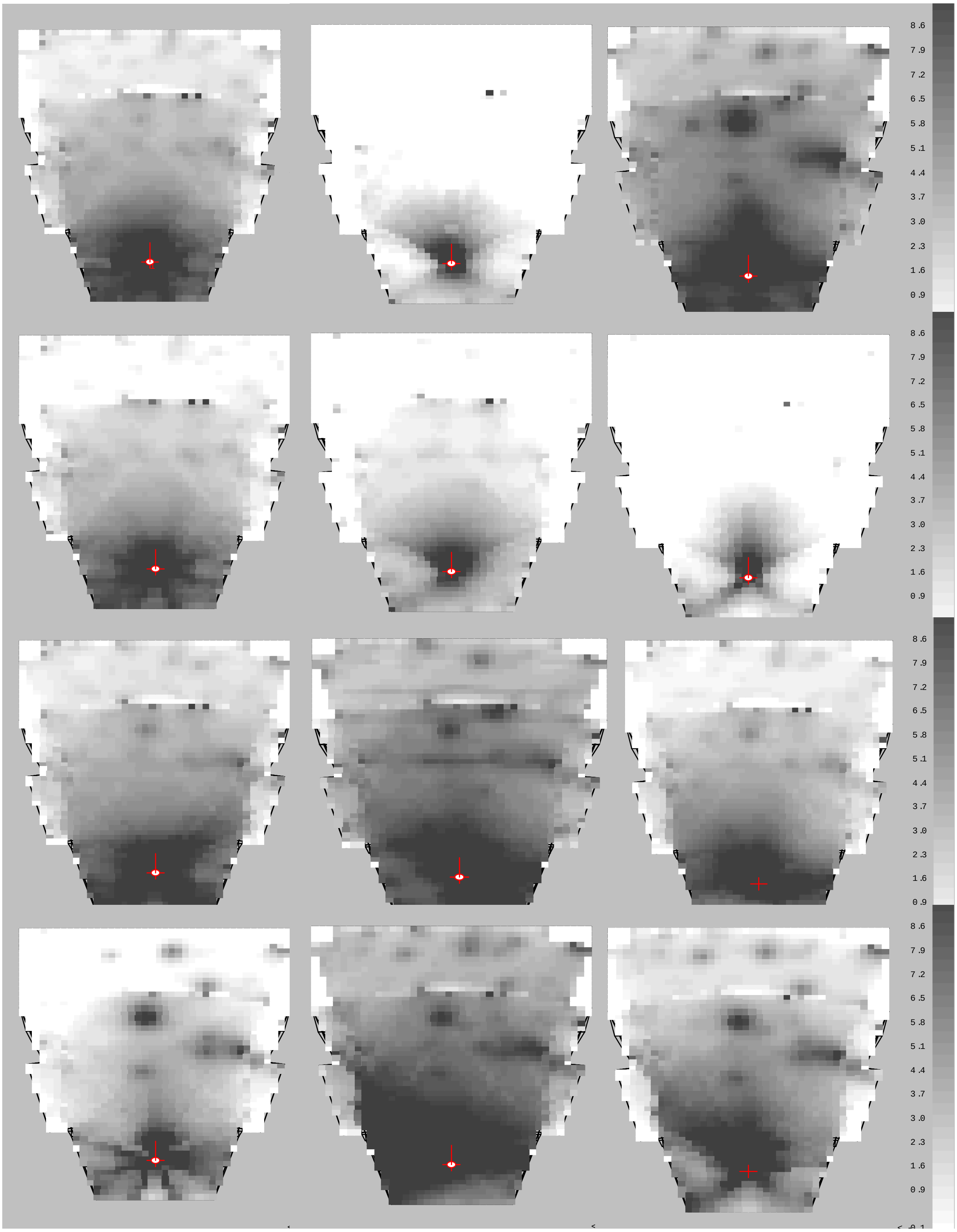

Fig.5. **Grid-response of the sound pressure level (SPL) with three different directivities at 500 (top), 1000, 2000 and 4000 Hz (bottom) at the ELMIA concert hall. The figures on the left correspond to the averaged directivity, the figures at the center to the first tone's directivity (C4) and figures to the right to the second tone's directivity (A4). The scale is relative and shown from 0 to 10 dB with white and black as the minimum and maximum values, respectively.**

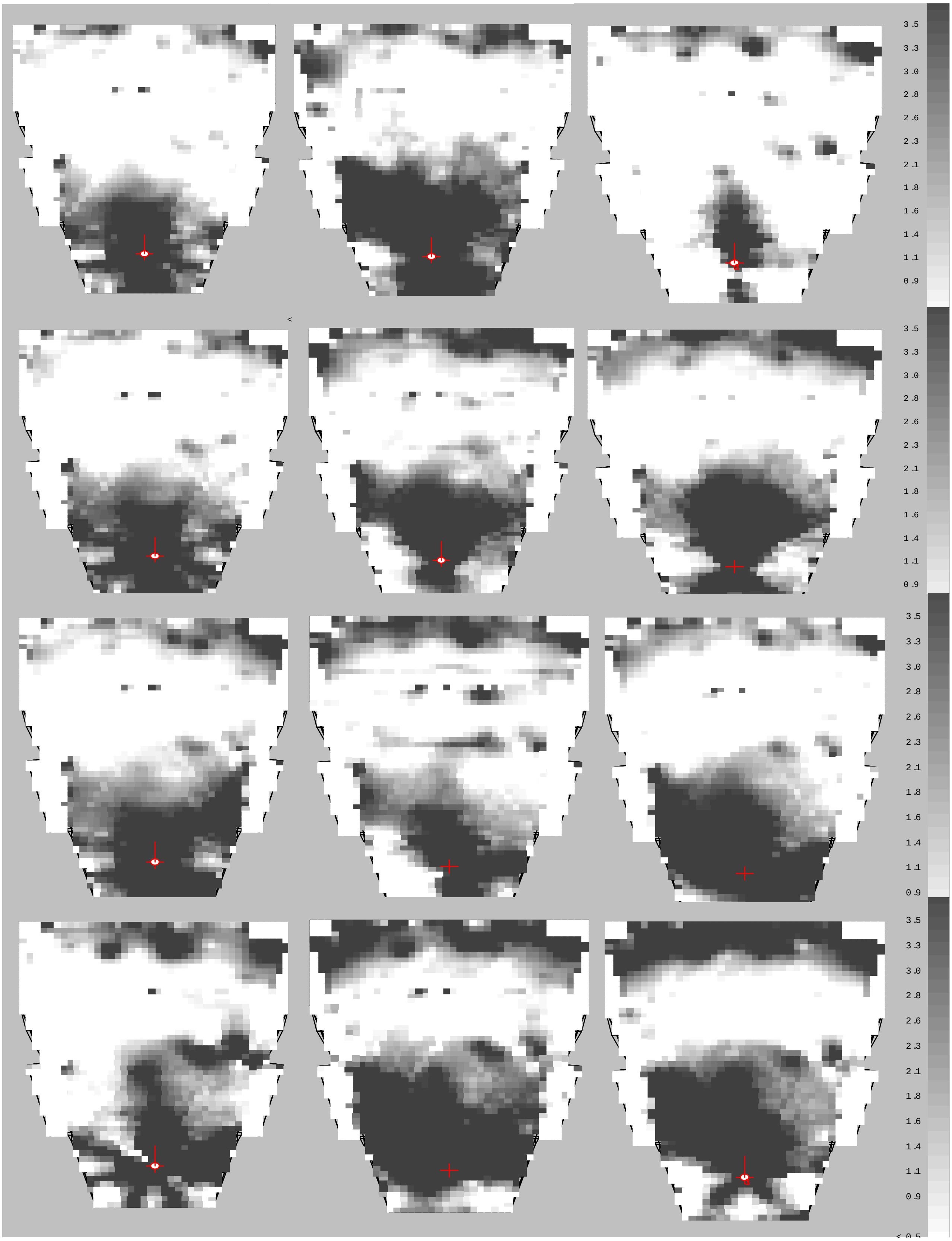

Fig.6.**Grid-response of the clarity (C80) with three different directivities at 500 (top), 1000, 2000 and 4000 Hz (bottom) at the ELMIA concert hall. The figures to the left correspond to the averaged directivity, the figures at the center to the first tone's directivity (C4), and figures to the right to the second tone's directivity (A4). The scale is shown from 0 to 4 dB with white and black as the minimum and maximum values, respectively.**

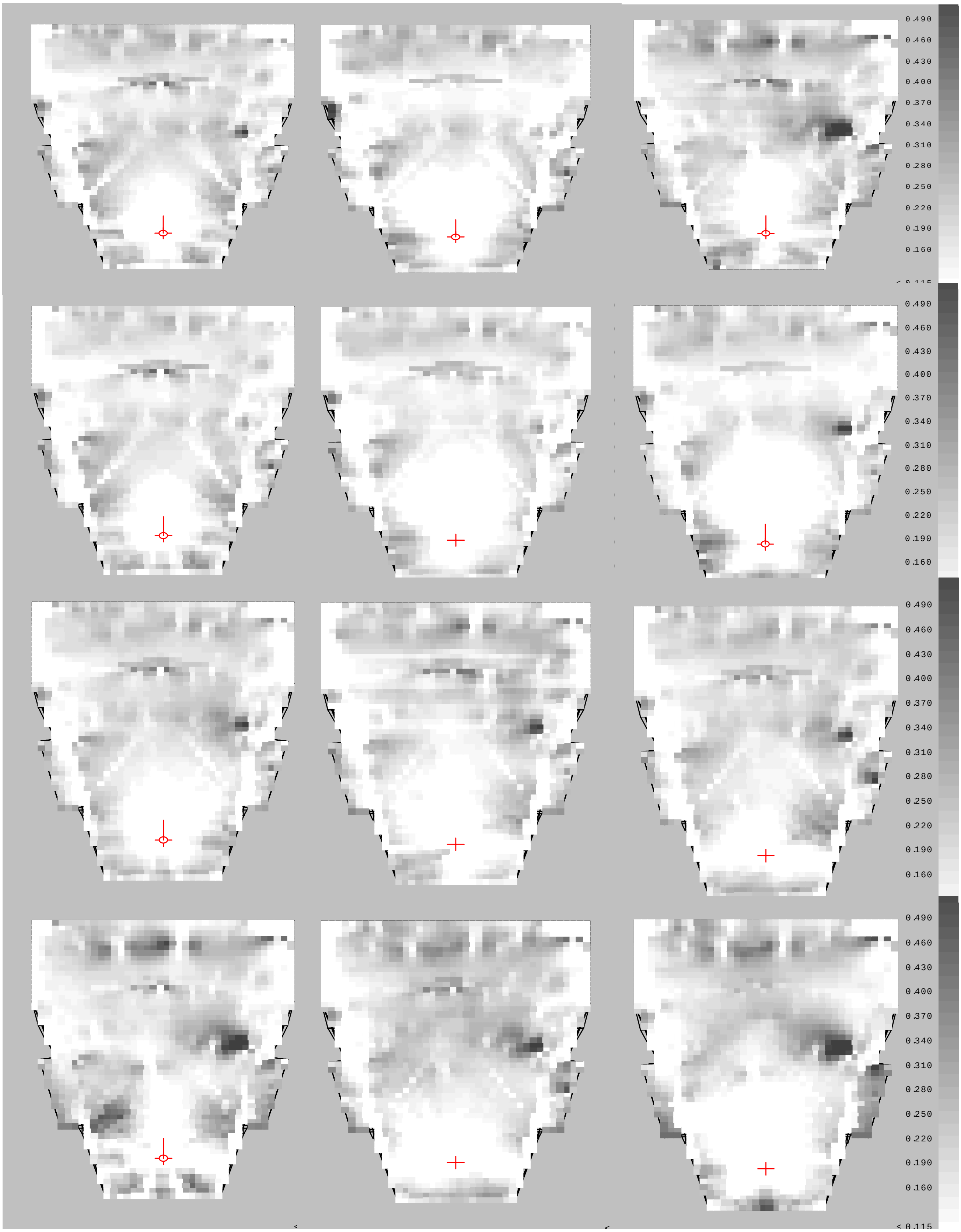

Fig.7. **Grid response of the Lateral Energy Fraction (LF) with three different directivities at 500 (top), 1000, 2000 and 4000 Hz (bottom) at the ELMIA concert hall. The figures on the left correspond to the averaged directivity, the figures at the center to the first tone's directivity (C4) and figures to the right to the second tone's directivity (A4). The scale is shown from 10% to 50% with white and black as the minimum and maximum values, respectively.**

The last comparison made with room simulations concerned the Lateral Energy Fraction (LF). Figure 7 shows the LF grid response in the room at the different frequencies with the averaged directivity and the directivity of the tones. In this case the simulations show that the LF is also dependent on the directivity of the source. The LF distribution in the room with the averaged directivity showed to be more stable and symmetrical than the one for the tones in most of the cases.

3.2 Discussion

The room simulations with the measured and averaged directivities showed that the changes in the directional pattern of the source clearly affect the SPL, C80 and LF in the room. The symmetry of the directivity in the horizontal plane of the sources affect the homogeneity of the simulated sound in the room in the horizontal plane, especially notorious for the C80 and LF. The changes of the directivity from one filtered frequency to the other were greater for the particular tones measured than for the averaged directivity. The importance of the symmetry and stability in the representation of a musical instrument in a room will need to be studied in detail in order to assert if the desired representation should resemble the directivity of particular tones, with differences in level and asymmetries in the sonic distribution in the room, or an averaged directivity which is more stable and less directional.

Further developments of the room acoustic simulations could consider comparisons of auralizations using the measured and averaged directivities used for the simulations. Other issues to be studied are the importance of the directivity representation of the source in the sound distribution on stage [9] and the importance of the changes of the directivity in the vertical plane in the representation.

4. Conclusions

The directivity measurements of particular tones of the clarinet differ significantly with the averaged directivity. These differences increased with frequency but not with the pitch of the tones and are much larger in the vertical plane than in horizontal axis.

Room simulations with the averaged and particular directivities of the clarinet showed that the changes in the directional pattern of the source clearly affect the sound distribution in a room. The symmetry of the directivity in the horizontal plane is important in the homogeneity of the simulated sound in the room. The averaged representation of the directivity implied in some cases a more even distribution of the acoustical factors than the one of the particular tones; in others it implied a more scattered distribution.

Aknowlegments

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References

1. **T. H. Rossing.** The science of sound. Addison-Wesley. Second edition. 1990.
2. **N. H. Fletcher & T. D. Rossing.** The physics of musical instruments. Springer-Verlag. New York. Second edition. 1997.
3. **J. Štepánek & Z. Otcenášek.** Sound Directivity Spectral Spaces of Violins. Proceedings of the International Symposium on Musical Acoustics. 2001. Perugia, Italy. P. 133-136.
4. **J. Meyer.** Acoustics and the performance of music. Verlag Das Musikinstrumenter. Frankfurt/Main. 1978.
5. **F. Otondo & J.H. Rindel.** New method for the representation of musical instruments in auralizations. paper submitted to the International Computer Music Conference, Gotemborg, Sweden. 2002.
6. **B.-I. Dalenbäck, M.Kleiner & P. Svensson.** Audibility of Changes in Geometric Shape, Source Directivity, and Absorptive Treatment-Experiments in Auralization. J.Audio Eng. Soc. 1993. Vol.41.P. 905-913.
7. **W. Piston.** Orchestration. W.W. Norton & Company. 1955. P.164-169.
8. "The Odeon home page." http://www.dat.dtu.dk/~odeon
9. **A. C. Gade.** Investigations of Musicians Room Acoustic Conditions in Concert Halls. Part I: Methods and Experiments. Acustica. 1989. Vol. 69. P.193-203