Qualification of balance in opera houses: comparing different sound sources

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The balance between singer and orchestra in opera houses has been receiving increasing interest in the recent years. This characteristics is in fact at the core of the functionality of opera houses and its tuning deserves great attention both in the qualification and in the design process. Unfortunately, a standardized method for the measurement of balance is still not available in the technical norms. In this work a set of data is measured in the Municipal Theatre of Modena and the use of omnidirectional and different directional sound sources to study the balance is investigated. In particular an antropometric sound source and two directional loudspeakers are compared and also two different omnidirectional sound sources are employed. Several combinations are obtained and the merits and the limits of the different measurement chains are presented and discussed. It is seen that a severe scatter of data may occur depending on the measurement chain. The results are also discussed in relation with former computer simulations in other theatres in order to fix the best available measurement chain for the qualification of balance.

1 Introduction

The balance between singer on the stage and orchestra in the pit was investigated as a subjective attribute [1] [2] and also results regarding its objective qualification [3] and control [4] were obtained in the recent past. In particular in [3] a computer model based approach was used to assess the measurement chain for the balance. In that work one omnidirectional source and two different full range loudspeakers (single unit) were compared with a simulated soprano. All of the sources where calibrated in the model to have exactly the same sound power in each octave band. The simulations showed that the directional sources are preferable to mimic a soprano voice and that the scatter of data between the proposed alternative solutions was limited (typically well within 1dB).

The present work intends to experimentally investigate other directional sources for the qualification of the balance. In particular two solutions based on two-ways loudspeakers are studied and compared with Caruso (CAR), which is a two way antropometric sound source developed at the Institut fur Technische Akustik in Aachen (Germany). It is in fact assumed that CAR has a directional performance which is closer to a human than that of conventional sources. In the present case several combinations of sources were studied inside an historical opera house in order to test the performance of the different solutions.

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The measurements took place in the Municipal Theatre of Modena, Italy, whose complete acoustical data were reported in [5].

2 The sound sources

The present study considers two omnidirectional sound sources and three directional sound sources. The former group consists of a commercial product (DOD_FE) and of a special source of optimized directionality consisting of three separated units (DOD_AC). The first directional source (CAR) is also a special device with two units for high range and low range respectively, whereas the remaining loudspeakers (called F11 and LEM) are both commercial devices belonging to different market segments. Table 1 resumes the main characteristics of the sources employed.

Before collecting the acoustical measurements in the theatre a preliminary session was performed with the aim of measuring the sound power of each sound source. The scanning sound intensity technique [6] was used and the devices were fed with white noise. The results are shown in Fig. 1 for the directional and the omnidirectional sources respectively.

The power output was optimized to achieve the best possible S/N ratio before distortion from each source. As a result the sources are not calibrated and it can be seen that the commercial ones tend to have in both cases a higher sound power.

Table 1: A list of the employed sound sources.

Name	Type	Notes
DOD_FE	Omnidirectional	Dodecaedron
DOD_AC	Omnidirectional	Composed of three units for low, mid and high range
CARUSO	Directional	Antropometric source with two units
F11	Directional	Two ways active audio pro monitor
LEM	Directional	Two ways PA active monitor

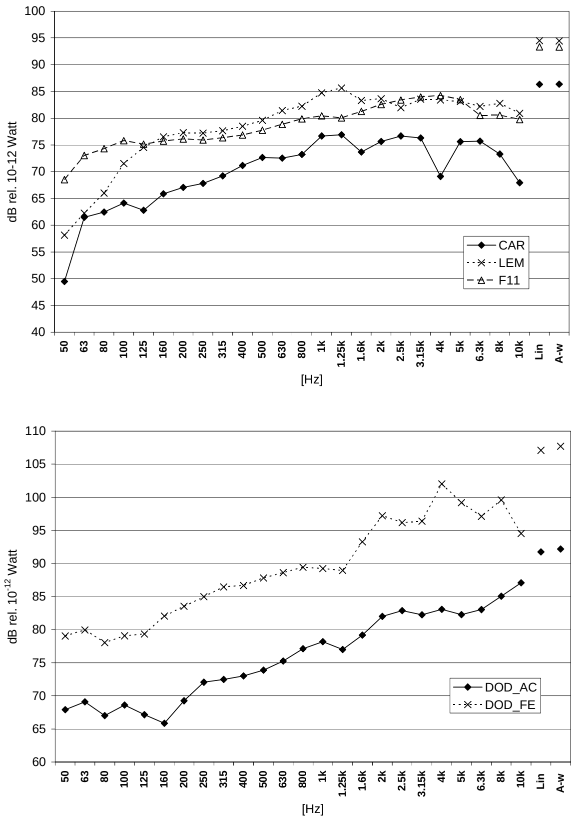


Figure 1: Sound power measurements for the omni sources (above) and the directional ones (below).

Moreover also the frequency responses show remarkable deviations in both groups. The directional characteristics of omnidiretional sources comply with the requirements of [7]. Apart from the LEM source, whose polar directivity patterns are shown in [1], the respective directional data for F11 and CAR were unfortunately not available.

3 Materials and methods

3.1 Positions of sources and receivers

Then the equipment was moved in the Municipal Theatre of Modena. A grid of sources was defined which consists of three positions on the stage arranged at a triangle vertexes and one position in the orchestra pit. The stage positions were actually selected in a previous study as being representative of the most important variance of acoustical parameters in an historical theatre. As described in Fig. 2, eight receivers were selected, half in the stalls and half in the boxes on the same side of the hall.

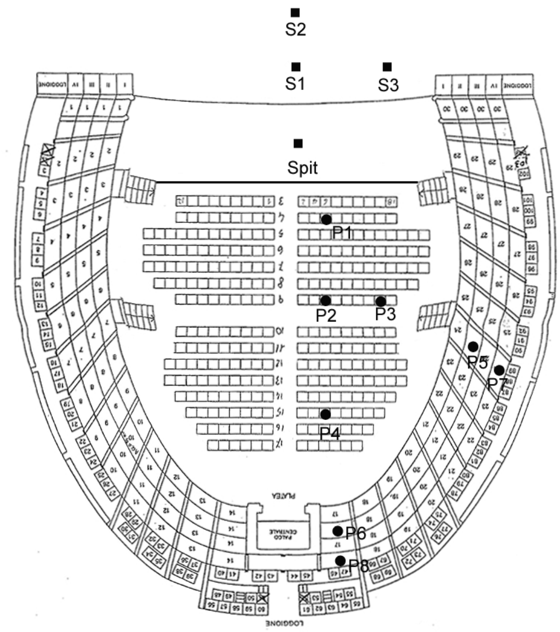


Figure 2: The plan of source and receiver positions in the Municipal Theatre of Modena.

3.2 Measurement procedures

Basically the directional sources were swapped between the stage positions and the omnidirectional ones occupied both the stage and the pit locations. For each source configuration a complete grid of receivers was measured. The source signal consisted in a piece of steady state white noise that exactly reproduced the already measured power emission.

The sound level at each receiver position was sampled by means of a B&K2260 analyzer. Table 2 summarizes the number and location of source-receiver combinations. The height of sources was 1.2m in the pit and 1.5m on the stage whereas the receivers where set at 1.2m box in the stalls and in the boxes.

Table 2: Summary of source receiver combinations - "s" is for stalls and "b" for boxes.

Source	DOD_FE	DOD_AC	CAR	F11	LEM
S1	4s 4b	4s 4b	4s 4b	4s 4b	4s 4b
S2	4s 4b	4s 4b	4s 4b	4s 4b	4s 4b
S3	4s 4b	4s 4b	4s 4b	4s 4b	4s 4b
So.pit	4s 4b	4s 4b	-	-	-

4 Experimental results

The sources were not calibrated to have the same sound power since this might impair their S/N ratio in the field. The basic quantity to be used in comparing the performance of the different solution was the difference L_P - L_W . From the norm [7] one can verify that this quantity coincides with the strength G – 31 dB only in the case of omnidirectional sources. Should the source be directional, the figure to be added to get G deviates from 31dB depending on the specific polar directivity pattern and on the frequency characteristics. Anyway, for the scope of this work the above L_P - L_W difference allowed to perform a comparative study for the two groups of sources. In particular the absolute L_P - L_W differences were averaged upon the positions: for the omnidirectional sources this procedure outputs the proper differences of G values. On the other hand the L_P - L_W averages applied to the CAR, LEM and F11 sources were the only robust level measurement that can give information on the different interaction of each source with the same room.

4.1 Values of level differences

A first data set is shown in Fig. 1, where the averaged absolute level differences between the two omnidirectional sound sources are reported, together with the respective standard deviations. This plot is measure of the reproducibility of the omni sources over the whole group of 32 combinations of source and receiver positions. The results are in fairly good agreement though a remarkable deviation can be found both in the range close to 1.6kHz and for very low and high frequencies. This information is important since it is seen that the qualification of G might suffer from the choice of the omnidirectional source, and the averaged overall A weighted bias is about 1.2 dBA.

Then the averaged absolute L_P - L_W differences between the three directional source are reported in Fig. 4 and the related standard deviations are showed in Fig. 5. The course of the plots in Fig.4 show that in the frequency range from 100Hz to 800Hz the three sources are fairly in agreement.

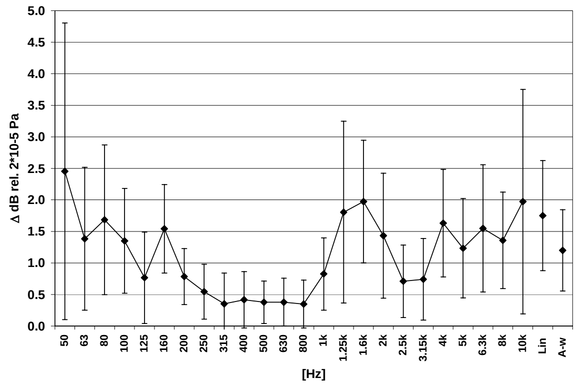


Figure 3: Averaged absolute level differences between DOD_FE and DOD_AC.

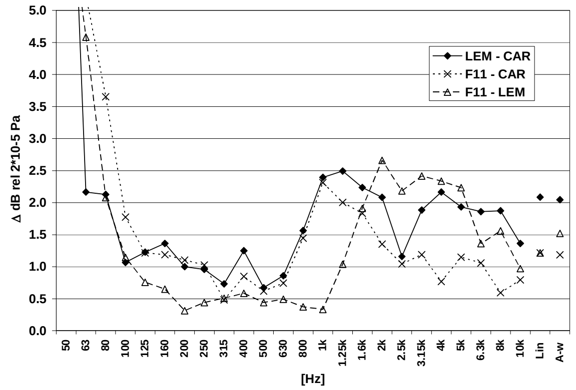


Figure 4: Averaged absolute level differences between CAR, F11 and LEM.

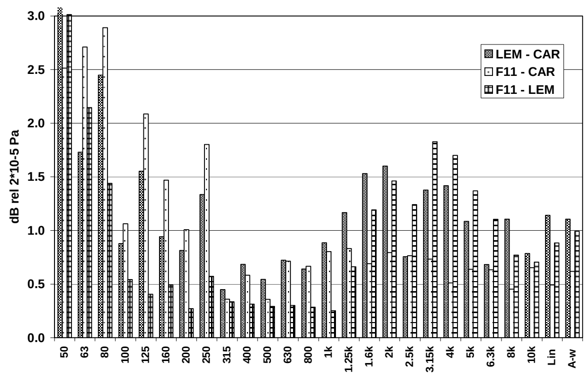


Figure 5: Standard deviations of the differences shown in Fig. 4.

On the other hand the behaviour of each of them has substantial deviation from the others both in the lower range and even more markedly in the higher range. In particular this was not expected for the couple F11 – LEM, since they are conceptually similar. The overall data show that CAR is closer to F11, probably thanks to a better match in the higher frequency range. The A – weighted differences of this couple is quite the same as that of the two omni sources tested above.

The standard deviations in Fig. 5 do confirm this findings and a noticeable scatter of data is found respectively for CAR in the lower range and for LEM in the higher.

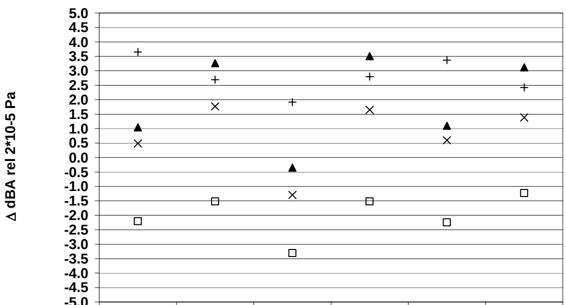
4.2 Values of balance B

The same data set was later analyzed for different combinations of omni and directional sources. To obtain a physical evaluation of the balance between stage and the orchestra pit a simple relation was implemented, that is:

$$B = (L_P - L_W)_{\text{STAGE}} - (L_P - L_W)_{\text{PIT}}\ .\ \ [\text{dB}] \quad (1)$$

This equation coincides with the difference of G values from stage and pit when the source is omnidirectional. In the other cases this is the same experimental formula commonly accepted, which is generally employed with omni and direct. sources having the same sound power.

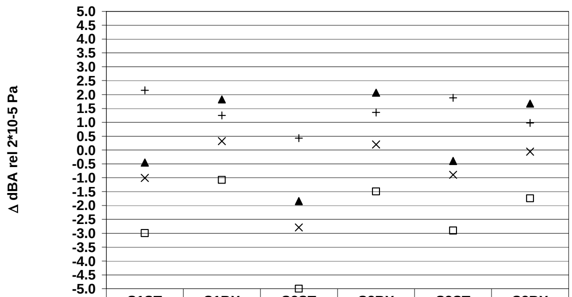
The data reported in Figures 6 and 7 are averages of B values (overall A weighted) in the stalls (ST) and in the boxes (BX) calculated for several arrangements of sources. In particular the plots show the comparison of four items. Taking Fig. 6 as model, the first item is the balance measured when the omni source DOD_ FE is placed both in the pit and on the stage. The other three items relate to conditions where, keeping DOD_FE in the pit, the stage source are CAR, F11 and LEM respectively. Exactly the same concept applies to Fig. 7 with the only difference that the omni source DOD_AC is used there.



	S1ST	S1BX	S2ST	S2BX	S3ST	S3BX
□ Dod_fe - Dod_fe	-2.2	-1.5	-3.3	-1.5	-2.2	-1.2
× Car - Dod_fe	0.5	1.8	-1.3	1.6	0.6	1.4
▲ F11 - Dod_fe	1.0	3.3	-0.3	3.5	1.1	3.1
+ Lem - Dod_fe	3.7	2.7	1.9	2.8	3.4	2.4

Figure 6: Average values of B for combinations of directional sources and DOD_FE.

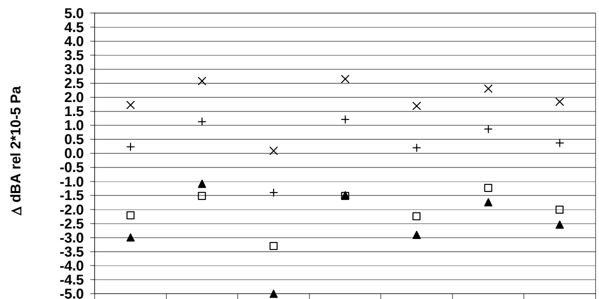
First of all when the omni source is used both for pit and stage the values are lowest. In fact the directional sources are all facing forward thus emitting sound mostly on the half space where the receivers are located. In particular for this reason a bias close to 3dBA is found both in the stalls and in the boxes between the DOD_FE – DOD_FE and the CAR – DOD_FE conditions. What is more surprising is that F11 and LEM do not follow the same rule. In fact, while in the boxes their behaviour is similar (differences between the two are close to or smaller than 1dBA) in the stalls their distance is much larger (nearly 2.5dBA). This unfortunately means that substantial discrepancies are to be expected in the results for the qualification of B depending on which of the two sources is used.



	S1ST	S1BX	S2ST	S2BX	S3ST	S3BX
□ Dod_ac - Dod_ac	-3.0	-1.1	-5.0	-1.5	-2.9	-1.7
× Car - Dod_ac	-1.0	0.3	-2.8	0.2	-0.9	-0.1
▲ F11 - Dod_ac	-0.4	1.8	-1.8	2.1	-0.4	1.7
+ Lem - Dod_ac	2.2	1.3	0.4	1.4	1.9	1.0

Figure 7: Average values of B for combinations of directional sources and DOD_FE.

The same conclusions are drawn also by examination of Fig. 7. In this case the bias between the omni DOD_AC and CAR is a little compressed (near 2dBA).



	S1ST	S1BX	S2ST	S2BX	S3ST	S3BX	avg
□ Dod_fe	-2.2	-1.5	-3.3	-1.5	-2.2	-1.2	-2.0
× Dir Dod_fe	1.7	2.6	0.1	2.7	1.7	2.3	1.8
▲ Dod_ac	-3.0	-1.1	-5.0	-1.5	-2.9	-1.7	-2.5
+ Dir Dod_ac	0.2	1.1	-1.4	1.2	0.2	0.9	0.4

Figure 8: Comparison of the behaviour of DOD_FE and DOD_AC.

Finally Fig. 8 shows a comparison of the two omni sources in the calculation of B. It is clearly seen that when the omni sources are used in the pit and in the stalls the B values are well reproduced (with just one exception in the S2ST column). On the other hand the use of directional sources imply a bias which, as seen before, can be primarily traced back to the specific characteristics of the sources employed.

5 Discussion

The above findings further clarify the topic of qualification of opera houses with respect to the balance between singer and orchestra. The results obtained with the different measurement chains show that even two ways loudspeakers conceptually similar can produce scattered data. In this context the tridimensional directionality and the frequency responses play a paramount role. Both these characteristics are depending for the matching of woofer and tweeter units in that sources, and this cause of variance in technology and design probably makes these types of sources unsuitable for the present scope. On the contrary full range single unit speakers were demonstrated earlier to be more regular, since minor deviations in the polar pattern are found when just one mid-range woofer is working. On the other hand the frequency range covered by two-ways speakers is usually larger and more power is provided in the higher range. Both these benefits seem limited in comparison with the present drawbacks. It is also interesting to note that the antropometric source gave in both cases an almost fixed bias which could be in principle corrected for, by taking the omnidirectional source as a reference.

Moreover the work demonstrated that the sound power calibration of the sound sources to the same octave band level is not necessary, given that the power of each one is known. This issue is relevant because in practice it is rather difficult to meet this requirement without affecting the S/N ratio. This was not an issue in previous computer simulations where, by using power calibrated sound sources, the value of B was just their sound level difference in the hall.

Furthermore the results for balance obtained in this work are mostly based on overall dBA values. The limits and the merits of this approach to stage and pit mixing are discussed in [1].

Finally some other features can be considered when directional sources of different kind are employed to mimic a singer. In particular it is believed that also the trend of other acoustical parameters shall be checked in view of reproducing with the loudspeaker a sound field with features as similar as possible to that of a singer. In this respect in Appendix the reverberation time, the clarity and the interaural crosscorrelation obtained by means of the F11, LEM and omni DOD_FE are compared with those obtained with the CAR source.

6 Concluding remarks

The present work investigated the performance of two-ways directional loudspeakers as sound sources to be used in the qualification of balance in opera houses. The results show a large variability due primarily to polar directivity which makes it unreliable the use of such devices for the this scope. As expected, the use of just one omni source gave quite reproducible results. Anyway previous researches showed that a singer is better reproduced by a directional source. This study demonstrated that the source to be used has to be a single unit full-range loudspeaker. It is hoped that accumulation of such data will allow in the near future to establish a shared approach to the balance measurements. The procedure will hopefully become a protocol to be inserted in the relevant technical norm.

Acknowledgments

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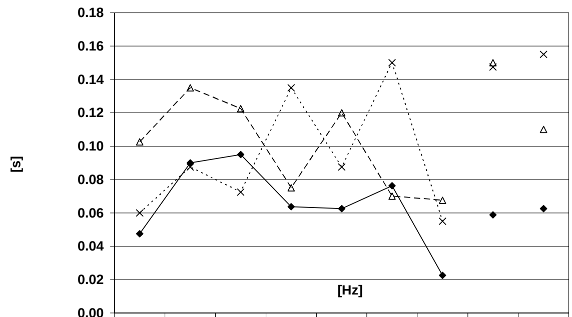
Appendix

Together with sound level measurements also impulse responses were taken in subset of source – receivers combinations by means of the sine sweep technique. In this case an omnidirectional microphone was employed and the elaborations were done by a dedicated software.

Figure 1A shows that the EDT differences between the target CAR source and a typical source like LEM can be equal or even bigger than those with an omnidirectional source. The deviations are bigger than 5% which is usually set as the just noticeable limen for detectability.

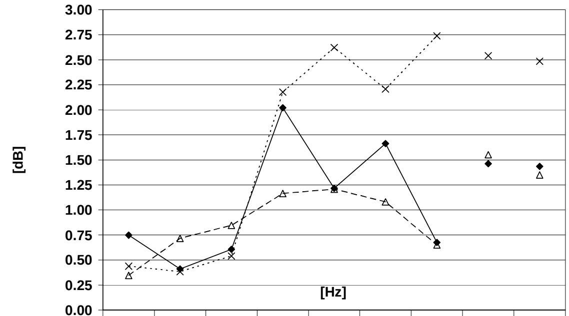


	125	250	500	1000	2000	4000	8000	Lin	A
CAR_F11	0.05	0.09	0.10	0.06	0.06	0.08	0.02	0.06	0.06
CAR_LEM	0.06	0.09	0.07	0.14	0.09	0.15	0.06	0.15	0.16
CAR_DODFE	0.10	0.14	0.12	0.08	0.12	0.07	0.07	0.15	0.11

Figure 1A: Averaged absolute differences between EDT values of CAR source and the others.

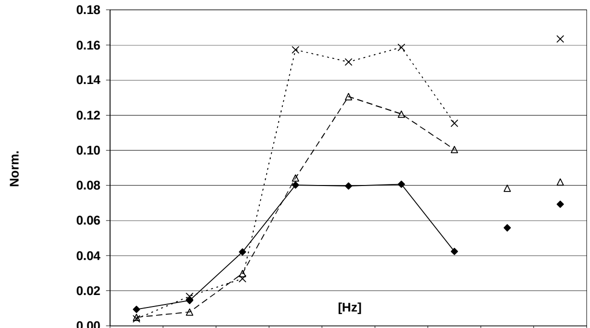
In Fig. 2A the same comparison is shown for the parameter clarity for music C80. Though DOD_FE, CAR and F11 seem to work at the same way in the wide band, there are indeed remarkable deviations in the mid and higher range. This is much more critical for LEM, probably due to a excess of frontal power output compared to both CAR and F11.

As a confirmation of this last finding Fig. 3A reports the IACC differences. Here the behaviour of the sources is better understood. The CAR is more similar to F11 than to LEM or DOD_FE.



	125	250	500	1000	2000	4000	8000	Lin	A
CAR_F11	0.75	0.41	0.61	2.02	1.22	1.66	0.68	1.46	1.44
CAR_LEM	0.44	0.38	0.54	2.18	2.62	2.21	2.74	2.54	2.49
CAR_DODFE	0.35	0.72	0.85	1.17	1.21	1.08	0.65	1.55	1.35

Figure 2A: Averaged absolute differences between C80 values of CAR source and the others.



	125	250	500	1000	2000	4000	8000	Lin	A
CAR_F11	0.01	0.01	0.04	0.08	0.08	0.08	0.04	0.06	0.07
CAR_LEM	0.00	0.02	0.03	0.16	0.15	0.16	0.12	0.19	0.16
CAR_DODFE	0.00	0.01	0.03	0.08	0.13	0.12	0.10	0.08	0.08

Figure 3A: Averaged absolute differences between IACC values of CAR source and the others.