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ROOM ACOUSTIC CONDITIONS OF PERFORMERS IN AN OLD OPERA HOUSE

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Proposed objective criteria related to the acoustic conditions for instrumentalists and singers have not received a sufficiently wide consent yet. In spite of this situation, it is the opinion of the authors that the measurement of existing criteria is useful for analysis and comparison. This paper reports the results of various acoustic measurements carried out in the Teatro di San Carlo, Naples-Italy, with the aim of obtaining objective information about its acoustics for performers. A first set of measurements was carried out when the theater was fitted for a symphonic concert and a second one when it was fitted for an opera performance.

1. INTRODUCTION

Research work in the area of "good acoustics" for listeners in a concert hall has produced a wide knowledge about the link between objective descriptors of the sound field in a hall and the subjective impression arising in a concert listener. However, the acoustic conditions suitable for performers are not known with the same confidence. It is not by chance that some musicians having acoustics knowledge have paid attention to this subject (see, e.g., references [1–4]). It is reported that sometimes musicians complain that their own instrument, and those of their colleagues as well, are difficult to be heard during *ensemble*. On occasion they feel a lack of room response. Besides these, further kinds of discomfort could be mentioned. Notable laboratory studies aimed at understanding the features of the sound field preferred by performers have shed some light only over specific aspects about this topic (see, e.g., references [5–8]). For instance, some investigation has been carried out about the preferred direction, delay and level of a single reflection for a particular performer. Although precious, this information could not be translated directly into manageable objective criteria of a certain validity.

To the knowledge of the authors an attempt toward this aim had been made by Jordan [9]. He was of the opinion that for an instrumentalist on the platform of a concert hall, it is not important if a single sound reflection reached him along a particular direction with a particular delay and level. Rather, he thought that the performer takes advantage of the diffuse sound energy he receives within a reasonably short time span, say 35 ms, after the direct sound. Therefore, Jordan

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proposed the early energy balance (EEE) as an objective criterion related to the comfort of the performer on the stage of a concert hall. This parameter was obtained from the impulse response measured with a non-directional sound source and a microphone, both located on the stage, at a mutual distance larger than the critical distance of the room. EEB was calculated as the ratio in dB of the energy in the first 35 ms and the energy of the direct sound in the first 5 ms. Sadly, owing to his death, Jordan could not arrive at defining a desirable range of values for EEB. He could only suggest that higher values are better than lower ones. The values of EEB he measured in eight concert halls were in the range 2·6–11·7 dB, averaging 6·2 dB.

Further descriptors for the comfort of the performer, that were based on energy fractions, were proposed later by Gade [10, 11]. During the subsequent decade little progress has been reported. The state of knowledge appears to be worse when opera performance is considered. However, it is the opinion of the authors that, despite the inherent uncertainties, it is useful to report measured values of proposed objective criteria for performers in halls that are well known and/or typical. This may help the analysis for understanding what objective features influence already reported (and/or future) judgements of musicians, singers and conductors about their general feeling of comfort while performing in the above-mentioned class of halls.

2. ACOUSTIC CRITERIA FOR PERFORMERS IN A CONCERT HALL

Gade carried out an extensive investigation about the acoustic condition suitable for musicians on the orchestra platform in a concert hall [10, 11]. His subjective/objective study was based on experiments performed both in the laboratory with synthetic sound fields and in the field with musicians playing in real halls. Although results were at variance as regards the individuals preference, Gade found a set of objective parameters ... "which predict the judgement of the "average performer" very well". These parameters stemmed from an averaging of the subjective data over positions, individuals and instruments.

Eventually, the author proposed a set of objective parameters including $ST1$, $ST2$, EDT and $EDTF$ as relevant measures of the room-acoustic conditions for performers in a concert hall. He suggested also a range of optimal values for some of them, e.g., $ST1 = -12 \pm 1$ and $ST2 = -9 \pm 1$ $ST1$ and $ST2$ were related to the subjective attribute *Support* which corresponds to the feeling of the musician that he/she can hear his/her instrument without forcing it unduly. The use of $ST2$ was suggested as preferable when describing the support for soloists. ST_{late} was the objective descriptor of the subjective attributes *reverberance* and *dynamics*. The first one takes into account the sensation of sustain of the tones just played and the bridging of tones played in succession. The second one was thought to be linked to the sensation that the room is responsive to the dynamic intentions of the player (piano, mezzoforte, etc.). The STs are energy fractions calculated from the pressure impulse response measured at a point 1 m from a non-directional sound source placed in succession at three key locations 1 m over the orchestra platform. The author suggested that the stage should be fitted with music stands and chairs, but located within a 2 m distance from the sound and the microphone. Also, the latter should be placed 1 m above the floor. The sound source locations chosen as typical were: (1) the soloist positions, (2) a position at the middle of the right-side area—between the violas and cellos—and (3) a position far left in the second row of winds. The basic definitions of the objective supports were

$$ST1 = 10 \log \frac{E(20, 100\ \text{ms})}{E(0, 10\ \text{ms})} \quad \text{in dB}, \tag{1}$$

$$ST2 = 10 \log \frac{E(20, 200\ \text{ms})}{E(0, 10\ \text{ms})} \quad \text{in dB}, \tag{2}$$

$$ST_{\text{late}} = 10 \log \frac{E(100\ \text{ms},\ \infty)}{E(0, 10\ \text{ms})} \quad \text{in dB}. \tag{3}$$

$E\ (\cdots)$ stands for the time integral of the squared pressure signal of the impulse response between the time limits reported in the brackets. In all three definitions, $t = 0$ is the arrival time of the direct sound. The STs were measured as averages for the octave bands centered at 250, 500, 1k and 2k Hz. A single value for the considered stage was obtained by a further averaging with respect to the sound source locations.

Also, EDT, the reverberation time evaluated from the average slope of the first 10 dB of a sound level decay, was reported to be a measure of *reverberance*.

The combination

$$EDTF = \frac{EDT_{250} + EDT_{500}}{EDT_{1k} + EDT_{2k}} \tag{4}$$

was found to be a good measure of the subjective attribute *timbre*. This attribute was related to the sensation caused by the room on the tone color of the instrument, on the balance in level in different registers of the instrument and on the tonal balance among various instruments in ensembles.

A few years latter, Gade [12] reported further experience about the use of the above-mentioned parameters. He found that $ST1$, renamed as early support ST_{early}, had revealed itself as a successful descriptor of the ease of hearing other orchestra members. The former parameter EEL, specifically conceived for the purpose, had failed in real concert hall use. $ST2$ use was dropped and the total support ST_{total} was adopted for describing the support of the room to the musician playing his own instrument. The original ST_{late} was modified slightly and was assumed to be still a descriptor of the *reverberance*. For convenience, the last definitions of the objective supports are as follows:

$$ST_{early} = 10 \log \frac{E(20, 100\ \text{ms})}{E(0, 10\ \text{ms})} \quad \text{in dB}, \tag{5}$$

$$ST_{total} = 10\log\frac{E(20,\,1000\ \mathrm{ms})}{E(0,\,10\ \mathrm{ms})} \quad \text{in dB,} \tag{6}$$

$$ST_{late} = 10\log\frac{E(100,\,1000\ \mathrm{ms})}{E(0,\,10\ \mathrm{ms})} \quad \text{in dB.} \tag{7}$$

As supposed by Gade, the difference between ST_{late} and ST_{early} may be useful for describing the degree of masking of ensemble information by excessive reverberation.

3. OBJECTIVE CRITERIA FOR THE COMFORT OF PERFORMERS IN AN OPERA HOUSE

The requirements for the comfort of the instrumentalists should be satisfied in any case. It is not hard to accept that the above-reported objective parameters retain their validity when the orchestra performs in an opera house, whether on the stage platform or in the pit. However, the performance of an opera, e.g. of the Italian style, poses further problems concerning the comfort of singers. In the following, only two aspects related to room acoustics and singer comfort are just mentioned.

It is well known that the balance between the singer and the orchestra is an important issue of opera performance, both for the listener and for the singer. Now and then the singer complains about the orchestra sound overpowering his/her voice. Within certain limits this is an aspect under the control of the conductor and the musicians but some instruments cannot be played softly at will (e.g., winds). Room acoustics also play their role in projecting excessive orchestra sound from the pit to the singer. To the knowledge of the authors no objective/subjective study has been published yet with the aim of finding an objective criterion to quantify the above-mentioned effect that disturbs the singer. At least in part, the annoyance of the singer might be caused by the orchestra sound masking his/her own voice, especially when trying to get in tune. Tentatively, the relative amount of sound transmitted from the orchestra pit to the stage could be quantified by the objective descriptor *EEL* that was introduced by Gade in connection with the subjective feeling of *Hearing each other* on an orchestra platform. To describe the overpowering effect a parameter $EEL_{pit\text{-}stage}$ could be defined as

$$EEL_{pit\text{-}stage} = 10\log\frac{E_{stage}(0,\,80\ \mathrm{ms})}{E_{pit}(0,\,10\ \mathrm{ms})} \quad \text{in dB,} \tag{8}$$

where E_{pit} (0, 10 ms) is obtained from the sound pressure impulse response at a location 1 m from an omnidirectional source in the pit; E_{stage} (0, 80 ms) is obtained from the impulse response to the same source pulse at the singer's head location on the stage; $t = 0$ is the arrival time of the direct sound 1 m from the source in the pit. Originally, the equality of the lower limits of the integrals was deemed to take into account timing aspects related to the synchronization of the performers. In the present context the integration interval (0, 80 ms) of the squared pressure at the singer's head location is taken also as a rough approximation to the integration time of the ear for the loudness of music. As done for the STs, also the parameter is measured as an average in four octave bands.

Although not measured yet in the Teatro di San Carlo, it is worth considering another objective parameter related to the comfort of singers on the stage. When performing most critical soloistic passages, opera singers often stand in the frontal area of the stage facing the audience. Because of the directivity of the sung voice, they cannot get a good support as the early sound reflected by the surfaces near the proscenium is feeble. Of necessity, the singers must take advantage of the delayed reverberant sound coming from the auditorium. Probably, professional singers develop a sense of ease of singing related to the feedback from the main hall. This might be supported by the results of the study of Marshall and Meyer [13] who concluded '...that "ease of ensemble" for singers is inseparable from questions of singing comfort and that both are controlled by reverberant conditions. Energetic early reflections do contribute positively if they are early enough but at 40 ms delay reduce preference well below that of a reflection-less reverberant field'. By comparing the reverberation times used by Marshall and Meyer in their artificial sound fields with those found or suggested usually for an opera house, one might accept that the late energy in the impulse response, as measured at the front of the stage in a real-world opera house, contributes positively to the comfort of the singers in any case. In this regard, a candidate objective descriptor could be ST_{late} measured with a sound source approximating the directivity of the sung voice.

4. MEASUREMENTS IN THE TEATRO DI SAN CARLO

Classical/symphonic concerts and opera as well are regularly performed in the Teatro di San Carlo. Depending on the type of performance, the orchestra plays on the stage or in the pit. Therefore, two sets of measurements were carried out in the unoccupied theater.

The first one was performed on the occasion of a symphonic concert. In this instance the orchestra pit had been covered completely by a sliding wooden floor. Chairs and music stands had been arranged classically for musicians on the enlarged stage floor and on riser. A high flat curtain, made of thin wood covered with an adherent velour, had been erected behind the proscenium arch with the aim of reducing the acoustic coupling between the stage-house volume and the volume of the auditorium.

The second set of measurements was carried out on the occasion of an opera performance. The pit was open almost completely, except a narrow belt over a few chairs and a timpani set as shown in Figure 1. The stage-house was fitted with the scenery for the particular performance.

In the first fitting a dodecahedron loudspeaker was placed at the three key positions over the orchestra platform as suggested by Gade. The sound source was fed with a maximum length sequence (MLS) signal generated by an MLSSA

Figure 1. A view of the orchestra pit of the Teatro di San Carlo fitted for an opera performance.

analyzer [14]. Impulse responses were obtained at a distance of 1 m from the geometric center of the loudspeaker at four points placed around each sound source location symmetrically, as depicted in Figure 2. Instead of one, four receiving points for each source point were considered with the aim of averaging out some residual directivity effect of the loudspeaker and the effect of scattering along a specific direction from nearby objects, if any.

Similar measurements were carried out by placing the dodecahedron in the pit when the theatre was fitted for the opera concert. Figure 3 shows the three locations of the sound source in the pit and the four microphone locations around each one.

The sound source being in the pit, further impulse responses were recorded on the stage platform at four locations at a height of 1·6 m in order to calculate $EEL_{pit\text{-}stage}$ (see Figure 3). In this instance the loudspeaker at the three locations in the orchestra pit radiated the same sound power as when impulse responses were measured at a distance of 1 m.

The calculation of the objective supports, and that of $EEL_{pit\text{-}stage}$ as well, were carried out by prefiltering the relevant wide-band impulse responses in the frequency range corresponding to the octave bands from 250 Hz to 2 kHz (177–2828 Hz). This was done in order to reduce errors related to the time windowing of the octave band filtered responses. In fact, the time smearing of the response filtered in the lowest octave band made difficult the correct choice of the integration limits of the squared pressure responses. RT, EDT and $EDTF$ reported herein were obtained from the same impulse responses that yield that STs.

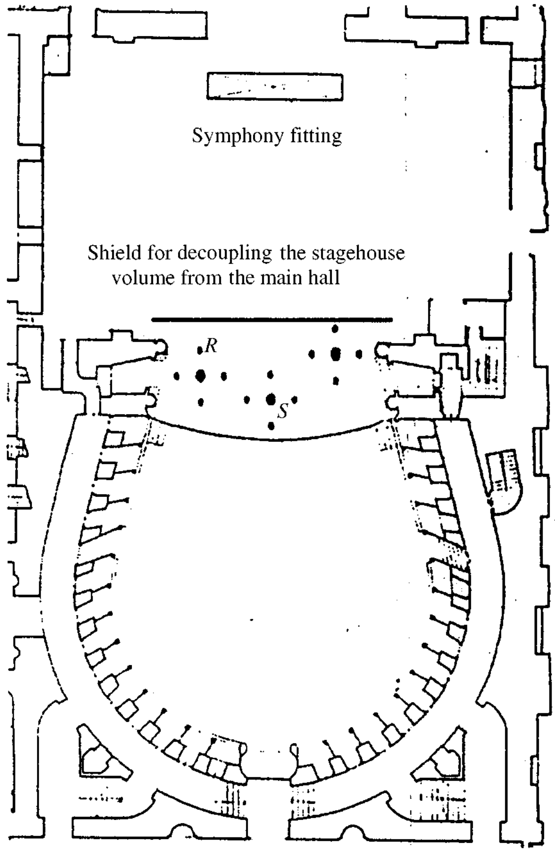

Figure 2. Plan of the Teatro di San Carlo fitted for symphonic music performance. *S* is a sound source location and *R* is a microphone location.

5. RESULTS

Table 1 shows the four-octave band space-averaged values of the measured parameters for the performers. In particular, $EEL_{pit\text{-}stage}$ is the mean value obtained by averaging the 12 values corresponding to the 12 couples of sound-source/receiver defined by joining each source point in the pit with the four receiving points on the stage.

6. CONCLUSION

The average values of the objective parameters reported in Table 1 point out that the performing conditions of musicians are quite different in the two theatre settings and orchestra location. As regards the early support in symphony setting, ST_{early} appears to be on the low side with respect to the values measured by Gade in concert halls. On the contrary, when opera setting is considered, musicians receive an objective early support that seems a bit in excess. This can be explained by

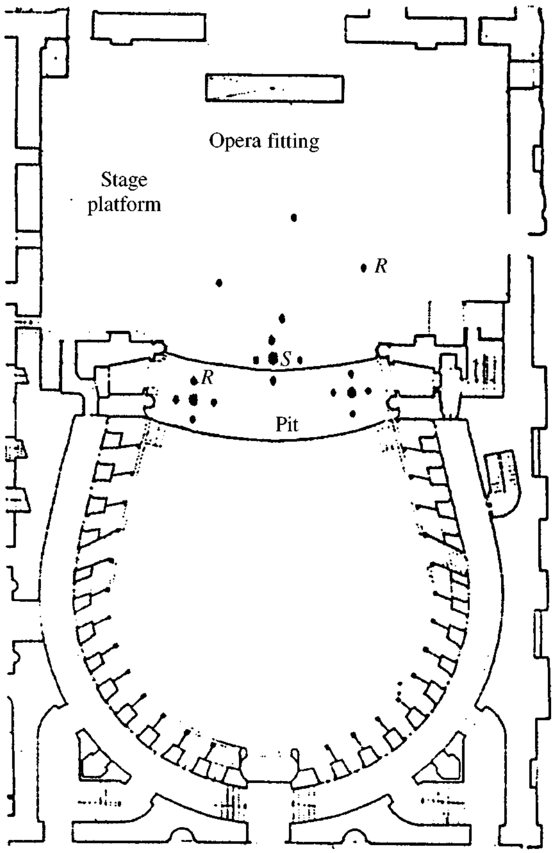

Figure 3. Plan of the Teatro di San Carlo fitted for an opera performance. *S* is a sound source location and *R* is a microphone location.

TABLE 1

Objective parameters for performers measured in the Teatro di San Carlo, Naples-Italy

Stage fitting (source location)	ST_{early} (dB)	ST_{total} (dB)	ST_{late} (dB)	EDT (s)	$EDTF$	RT (s)	$EEL_{pit\text{-}stage}$ (dB)
Symphony (stage)	– 14·4	– 13·6	– 21·4	0·06	1·33	1·76	—
Opera (pit)	– 6·8	– 6·5	– 17·9	0·21	0·78	0·99	– 18·4

considering that in the symphony setting the orchestra is located at the forefront of the enlarged stage. In this instance most of the direct and early sound is projected into the auditorium where it is absorbed effectively. When the orchestra plays in the pit, which is lined with thick wood, much early reflected sound can fill the incomplete enclosure determining a higher early support.

A similar reasoning can explain why the late support is low on average and still lower when the orchestra performs on the stage platform in the symphony setting. This emerges also from the consideration of the low values of EDT measured at 1 m from the sound source.

No interview of musicians performing in the Teatro di San Carlo has been carried out yet, but it is expected that, on the average, they will find their room-acoustic condition a bit uncomfortable especially when performing symphonic works on the stage platform.

If musicians will complain of a lack of *support*, *dynamic* and *reverberance* when performing symphonic works on the stage platform, the use of demountable orchestra shell will be suggested. In the event the average objective supports measured in the orchestra pit will correspond with a certain degree of discomfort, an investigation aided by the comments of the musicians will be carried out to spot causes and possible remedies.

As regards the overpowering effect of the orchestra in the pit, nothing can be seriously argued now from the single average $EEL_{pit\text{-}stage}$ measured in the Teatro di San Carlo. The authors are confident that the measurement of this parameter in other opera houses, associated with subjective judgements of opera singers, can shed some light on this aspect of the comfort of the performer.

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