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The acoustical characterization of orchestra platforms and uncertainty estimation of the results

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ABSTRACT

Measurements have been carried out on furnished orchestra platforms in four concert halls in Italy in order to describe the sound field perceived by musicians. The heterogeneous nature of the orchestra suggested a procedure able to take into account the mutual hearing between instrumental sections. The measured parameters were the early, late and total support, the reverberation time, the early decay time and the clarity index. A part of the study has been devoted to the measurement uncertainty estimation. The source directivity and the small displacements of the microphone influence the early decay time to a great extent while the on-platform spatial variability affects both the early decay time and the clarity index. Per-section early support shows differences that render the overall spatial mean inappropriate to describe the stage as a whole. For the other parameters an overall mean platform value can instead be suitable, even though, for the case of clarity a more evident group variability is observed. The values of late support, reverberation time, early decay time and clarity index, proposed in literature as suitable measures of reverberance for musicians, are not all intercorrelated, indicating that not all these parameters can be associated to the same subjective impression.

1. Introduction

In recent years, in the architectural acoustics context, more attention has turned towards the issue of acoustic conditions on orchestra platforms and how the acoustics for the performers might be improved. The musicians have to play in a correct and expressive way and for this reason they need both support from the hall [1] and to balance their own performance with the sound of the other musicians [2].

Much has been said about the acoustical characterization of spaces for the audience, but insufficient agreement and no specifications exist concerning performers' spaces, such as orchestra platforms, orchestra pits and rehearsal rooms. At the time of writing the present paper the main reference Standard regarding performance spaces was ISO 3382:2000 [3], recently substituted by the ISO 3382-1:2009 [4]. The older version focused on the acoustical characterization of auditoria according to subjective listener aspects and only in the draft of the revised version, ISO/CD 3382-1:2004 [5], to which the authors referred, an Annex proposed two stage measures for the acoustic evaluation of the orchestra platform.

The reason for this lack of references about acoustical parameters for musicians is perhaps due to the difficulty of achieving reliable correlations with subjective assessments, which are often few and heterogeneous. Since the early 1970s', research has focused on the relationships between physical characteristics and psychoacoustic judgments; some works concerning stage acoustics have mainly focused on laboratory experiments in simulated sound fields [6–9] while others have carried out in-field experiments [10–13]. In a simulated sound field, it is difficult to create a realistic environment and to involve a sufficiently high number of subjects to represent all the orchestra sections. In real halls, it is difficult to cover wide ranges of acoustical conditions and to control the influence of other factors on subjective judgments, while it is possible to investigate the complex interaction of the different instrument sections of the orchestra, which until now, has not been taken into account.

1.1. Stage measurements by others

A first rigorous in-field stage acoustical characterization survey was carried out by Gade [10] and it involved extensive measurements in nine Danish and ten British concert halls. In his work, he described a procedure that included three sets of measurement positions on furnished platforms. One omni-directional source was located in a typical soloist positions and in correspondence to the

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celli and the woodwind instruments with the microphone placed at 1 m from the source and at a height of 1 m from the floor. He measured the "Support" parameters called ST1 and ST2, which are the no longer used versions of ST_{early} and ST_{total} [12], and CS, which is clarity C80 [1] measured at a distance of 1 m from the source, and which was soon substituted by the similar ST_{late} measure (see also Section 4.1.1). The ST1 and ST2 support parameters were based on the ratio between the sound energy reflected back from the room in time intervals of 20–100 ms and 20–200 ms, respectively, relative to the direct sound energy (including the floor reflection). Other parameters, such as the centre time (T_s), the early decay time (EDT) and the reverberation time (T), were also measured for each source position at three microphone positions corresponding to the solo oboist, between the first and second violins and at the far right in the second row of the woodwinds. The distances between the sources and microphones were between 6 and 8 m. The low/high frequency EDT ratio, named EDTF, was also proposed. Arithmetical averages were taken for the 0.25–2 kHz octave bands for all the parameters except T, for which an octave band range of 0.5–2 kHz was chosen, and over different positions on the platform.

Chiang et al. [11] evaluated the stage acoustics of five rectangular multi-use concert halls with a platform areas of between 49 and 269 m^2. Four stage configurations for chamber music (front vs. centre and with vs. without side reflectors) were considered for each hall, and measurements were taken at two locations for each configuration. One source position was located behind the instruments, further back, and the other to the left of the instruments, at the side. The parameters were derived from the impulse response which was taken 1 m away from the omni-directional source at a height of 1 m from the furnished stage (floor). Early and Late Support parameters (ST_{early} and ST_{late}), together with additional measures, such as the early-to direct energy ratio (ED100), reverberation time (T20), early decay time (EDT), strength (G), clarity (C80) and centre time (T_s), were obtained. ED100 is similar to ST_{early}, but has an integration window of 7–100 ms that can account for the early energies provided by a relatively small stage envelope. All the data were averaged over 0.25–2 kHz octave bands and over the different positions on the platform.

Jeon and Barron [12] carried out ST_{early} measurements in eight positions on an empty stage in a large fan-shaped hall in Seoul. The stage area was 270 m^2, the average width was 22 m and the ceiling was at a height of 14–15 m. Source and receiver heights of 1.2 m were used and all the quoted values were over the 0.5–2 kHz octave bands. The highest values of about −15.0 dB were measured for positions at the rear of the stage. Lower values were measured for positions further forward on the stage and minimum values of about −24.0 dB were measured for the positions close to the audience area.

Dammerud and Barron [13] carried out stage measurements and subjective surveys in four halls in Britain. The platform areas were in the 111–189 m^2 range and had an 18.0–27.0 m width range and a mean height range of 9.6–19.0 m. Among others, they measured the ST_{early} and ST_{late}, T, EDT, G, C80 and T_s acoustical parameters, with chairs on the stage. The source–receiver distances ranged from 1 m, for the support parameters, to 9.0 m for the other measurements, with a minimum distance of 4.0 m. The lowest ST_{early} was obtained in the narrower hall with the highest ceiling, with a small reflector at a height of 9.0 m.

1.2. Present study

The studies reviewed above presented results for objective measures as averages of measurements made at different positions on the platform. None of these papers considered the uncertainty estimation of the experimental data.

The current paper presents the results of a measurement procedure that was drawn up to perform the acoustical characterization of orchestra platforms, with the aim of detecting differences, if present, in acoustical conditions among the main instrumental sections. This is particularly important for an orchestra playing on a stage, which is made up of different instrumental groups with different features and different active roles in the performance.

The measurement positions on the orchestra platform were chosen to correspond to the main orchestra sections. The protocol included both measurements with a microphone 1.0 m from the source, for the support parameters, and, for other parameters, sets of measurements with a source and a microphone to represent the mutual hearing between the orchestral sections.

An overall spatial average value was obtained to describe the stage as a whole, while a per-section value was calculated averaging all the measurements for a fixed microphone position (hearing section) and the different source positions (playing sections), with the exception of support parameters for which a unique value was obtained for each section.

As far as the choice of the acoustical parameters is concerned, the measurement procedure is based on Committee Draft ISO/CD 3382-1 [5] and the previously cited literature, particularly with reference to those parameters for which correlations with subjective attributes have been established [10,13–15].

A measurement procedure has been defined in such a way that it gives comparable and reproducible results when carried out by different researchers. With this aim, all the possible causes of variability were considered in advance to define the procedure. Contributions attributable to the measurement equipment and to the measurement procedure were therefore investigated in order to estimate the associated uncertainty.

On the basis of measurements on four auditorium stages, the order of magnitude of the uncertainty contributions for the measured parameters has been obtained, even though the values cannot be generalized because of the small number of case studies. The uncertainty has been assessed for each single measurement, the per-section and the whole stage measurements, which were carried out according to the proposed procedure.

2. Orchestra configurations on the stages

Symphonic orchestras usually have seven main instrument groups: violins, violas, celli, double basses, woodwinds, brass instruments and percussion.

The orchestra has evolved over the years and has had different arrangements on the platform, until the present 'American' arrangement (see Section 4.2) which is generally preferred throughout the world. From the point of view of the audience, violins are on the left and celli on the right, while violas are in the middle and double basses are behind the celli. Woodwinds are behind the strings, in the middle of the stage, and brass partly behind the woodwinds and partly towards the back near the percussion section, which is usually on the left.

The first and second violins are the most numerous sections in the orchestra, and these are followed by violas, celli and double basses. There are usually eight to twelve woodwind and brass instruments and from two to six percussion players.

3. Case studies

Measurements have been carried out on the orchestra platforms of four concert halls in Italy, the G. Agnelli, A. Toscanini and G. Verdi Conservatory Auditoria, in Turin, and the Sanremo Casino Theatre, in Sanremo. Table 1 lists the main features of the halls and Fig. 1 shows pictures of the orchestra platforms.