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PRESENTS

Subjective and objective measures of relevance for the description of acoustics conditions on orchestra stages

by Anders Christian Gade

Abstract

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Based on communication with a number of researchers and practitioners active in this field, such a unified set of objective and subjective data will be proposed and discussed in this paper.

Toronto, Canada
International Symposium on Room Acoustics
2013 June 9-11

Subjective and objective measures of relevance for the description of acoustics conditions on orchestra stages

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ABSTRACT

Even after more than three decades of research, we still have quite limited knowledge about how to describe and evaluate the acoustics of orchestra stages. This became clear after a comparison of results from several studies which seemed to indicate that objective parameters correlating with subjective evaluations differ depending on the stimuli (halls) applied in the study. A likely reason for this is that the number of degrees of freedom in hall design is much larger than the number of halls investigated in each study. If this is true, the only way to obtain sufficiently data for truly significant statistical results to appear is to pool results from relevant existing and future studies in an open data base; but this requires that the same type of subjective and objective data can be made available in a compatible format from these studies. Based on communication with a number of researchers and practitioners active in this field, such a unified set of objective and subjective data will be proposed and discussed in this paper.

1 INTRODUCTION

In the author's presentation on the current state of knowledge on orchestra stage acoustics during the previous ISRA conference (In Melbourne 2010) [1], it was concluded that:

Existing results based on scientific experiments in simulated sound fields in the laboratories are of limited value, since they lack realism - primarily by not having included the complex sound components produced by other orchestra members. These – as well as the playing subject's own sound – should be realistically convolved with direction dependant impulse responses corresponding to different halls of interest for the experiments to be realistic.

On the other hand, results from experiments carried out under realistic conditions, i.e. with full symphony orchestras on real stages, have not been unanimous in pointing out neither 1) which objective acoustic parameters are of importance nor 2) which stage designs are preferable.

The lack of consensus among different field experiments in existing halls is likely to be caused by the fact that in all such experiments the number of important physical variables in the halls were much too large compared to the number of halls investigated in each study. Thus, in all of the studies which we could find by 2010, the number of halls from which reliable data could be harvested was less than 10, which probably left too few degrees of freedom for common variables to appear as significant across these studies.

Also identification of subjective acoustic parameters in musicians' judgments has turned out to be difficult. Apparently orchestra musicians' ability to separate different subjective aspects in their evaluations is very limited. This implies that they will probably react on those variables which cause the strongest – and in the situation the most important - subjective changes without the subject (or the experimenter for that matter) being able to identify the decisive subjective parameter.

Consequently, all of our existing investigations from real halls are most likely severely limited by confounding of both objective and subjective variables. The only way to change this situation is to obtain sufficient data to overcome the lack of degrees of freedom – and preferably from experiments carried out in real halls. However, such a project is probably beyond the capacity of any individual researcher, consultant or institution, and few would have the opportunity to work with a sufficient number of halls and orchestras (don't even think of the costs of hiring a symphony orchestra for such a purpose).

On this background the author's ISRA 2010 paper concluded: "Therefore, researchers and consultants must unite in an effort to collect sufficient data on musicians' evaluation of halls as well as on objective parameter values and architectural descriptions from these halls. This can only be done if we agree on a minimum set of questions to be included in every new subjective survey of halls and on a minimum set of objective date to be measured and collected as well."

The intention in this paper is to present guide lines for acquiring objective and subjective data when investigating acoustic conditions on orchestra stages – be it for research or consulting purposes. We hope that researchers and consultants will use these guide lines and share their data so that these can be pooled and be subjected to common analysis. This work has been fueled by communication with a number of colleagues since 2010 and by studying recently published work on the subject.

2 IDEAS SINCE 2010

2.1 Objective parameters

In response to [1] and personal communication after the ISRA 2010 conference, Dammerud has written a note [2] with his suggestions for collection of objective and subjective data on orchestra stages. The objective data covers both architectural features of the halls and measured acoustic data (although his confidence in the latter is limited). Regarding the acoustic data, Dammerud suggests Late Strength, G_{late}, Clarity, C_{80} and Reverberation Time, T_{30} to be the parameters of highest relevance. Measurement of C_{80} and T_{30} is described in ISO 3382-I [3], while G_{Late} is defined as:

$$G_{late} = 10\ lg\frac{\int_{80ms}^{\infty} p^2(t)dt}{\int_0^{\infty} p_{10}^2(t)dt} = G + 10lg\left(\frac{10^{C_{80}/10}}{1+10^{C_{80}/10}}\right). \quad (1)$$

Thus, G_{late} is the energy of all reflected energy after 80 ms measured relative to the direct sound energy from the omni directional source when placed 10m from the microphone in an anechoic environment. Likewise, the Early Strength covering the direct sound and early reflection energy can be defined as:

$$G_{early} = 10\ lg\frac{\int_{0ms}^{80ms} p^2(t)dt}{\int_0^{\infty} p_{10}^2(t)dt} = G + 10lg\left(\frac{1}{1+10^{C_{80}/10}}\right). \quad (2)$$

In both equations, the last term shows how G_{early} and G_{late} can be derived from C_{80} and Strength, *G*. *G* is also defined in ISO 3382-I. Please notice that in ISO 3382-I *G*, C_{80} and T_{30} are mentioned for measurement in the audience area only; but one can equally well carry out these measurements with the microphone as well as the source placed on the stage.

Dammerud also suggests measurement of the Support-parameter ST_{late} (also defined in ISO 3382-I), but only for reference to all the data from halls, where this parameter has already been measured. Dammerud claims that *STearly/late* measurements are less accurate than measurements based on Strength, *Gearly/late.* The author does not quite agree to this as described in [1], which also discusses other objective parameters which had been suggested by 2010.

G_{early} and G_{late} could well be measured at a source-receiver distance of 1m (and still with a direct sound reference corresponding to 10 m distance); but it makes more sense to measure these parameters at larger distances (Dammerud suggests distances between 6 and 13m as indicated in Fig. 2), whereby one can hope to measure the actual efficiency of early and late sound transmission within the orchestra. (This was also the intention behind “Early Ensemble Level”, *EEL*, see [1] for details).

For longer source-receiver distances, $ST_{early/late}$ is not an alternative, because the direct sound in the recorded impulse response can no longer be relied on as representing the source power due to increased influence of both floor reflection (arriving closer to the direct sound) and the increase attenuation of both direct sound and floor reflection caused by furniture standing between source and receiver. Therefore, a parameter - like *G* - relating to a source calibration obtained during different conditions (either in free field, in the hall with transducer positions allowing separation in time of the direct sound from the reflections or in a reverberation room) has to be used.

During involvement with projects at the Technical University of Denmark, DTU, we have also considered using *G* as a measure of Support in small music rooms e.g. for music practicing, where the distances to walls and eventual furniture are too small to fulfill the requirements for correct *ST*-measurements. The idea was also implemented in projects on speaker comfort [4], where a head and torso simulator acted as both source and receiver.

If *G* is to be used for measuring propagation over larger distances on stages, it is – at least in principle – a drawback that it does not include the negative influence of the delay of the direct sound (as *EEL* did!). However, Wenmaekers [5] has suggested a way to take this into consideration. Using the ST_{Early} parameter as a starting point, he suggests a modification called $\mathrm{ST}_{\mathrm{Early,d}}$ in which the upper limit of the integration interval for useful reflections is reduced according to the time it takes for the direct sound to reach the receiver:

$$ST_{early,d} = 10\, Log\left(\frac{\int_{10}^{103-delay} p_d^2(t)dt}{\int_0^{10} p_{1m}^2(t)dt}\right). \tag{3}$$

A similar approach could be taken when measuring G_{early}.

Correspondingly, for measurements of G_{late} and ST_{late} over larger distances, the start of the integration interval for the late reflection energy could be set to 83-delay and 103-delay respectively. This would be relevant when using these parameters for estimation of masking by the late sound; but for measurement of Support, it wouldn't matter.

Wenmaekers [5] also gives a fine review of recently suggested objective measures for stages and makes comments on the influence of frequency band on the possibility to separate direct sound and first reflections from each other. Thus, for the octave bands higher than 125 Hz he suggests inclusion of reflections already from 10ms (instead of 20ms) in order to capture energy from surfaces closer to the transducers than 4m. On eight orchestra stagers (without furniture!), he measured the influence of different time intervals and source-receiver distances on the values obtained for ST_{early} and ST_{late}. He found that neither changes in the time intervals for reflection integration nor in the source-receiver distance had significant influence on the ranking of the eight halls by these parameters; but especially $ST_{early,d}$ varied significantly with source-receiver distance. Compared to ST_{early} measured at 1m distance, $ST_{early,d}$ obtained at larger distances seemed to correlate better with interviewees general preference for those halls, that had high early reflection levels on stage. Still, Wenmaekers concludes that more detailed studies on the subjective relevance of the various versions of the parameters are needed.

The desire to measure stage conditions for performers using *G* and to measure transmission over longer distances is also reflected in recent work by Ranjbari [6]; although he measures *G* without distinguishing between the early and late part and with a slightly different perspective: to measure the self-other balance of orchestra musicians.

Wei-Wha Chiang (who also participated in the stage acoustics session in Melbourne 2010) has also shared his views on needs for further research [7]. He suggests using *ST* and *EEL* "with certain modifications" (e.g. exclusion of the direct sound) for measurements on orchestra stages.

When measuring ST_{early} at short distances, it will be relevant to exclude the direct sound in the numerator in order to make the parameter more sensitive to changes in the room conditions (the early reflection properties); but for large distances – and measurement of communication efficiency between players in an orchestra - it is more relevant to include the direct sound, whereby its possible attenuation by furniture (and perhaps even musicians) will be detected in the measurement.

Separating the early and late energy in *G* (and *ST* for that matter) seems highly important as well: the early energy from others is useful for ensemble, while the late part provides support to one's own instrument; but the late part also influences the total orchestra loudness which may mask hearing of oneself as well as the useful early sound from others.

From the above it is seems that objective parameters already defined in ISO 3382-I are of main interest: G_{early}, G_{late}, ST_{early}, ST_{late}, C_{80}, T_{30} for acoustic measurements on orchestra stages. However, the author would like to suggest Early Decay Time, *EDT* as well, since the difference between *EDT* and T_{30} on stage is a good indicator for a coupled volume situation between the stage end and the main hall volume. All of these parameters are already implemented in most commercially available software for room acoustic measurements and are well known to most researchers and consultants. Of course, one can add further data obtained with other parameters – including modified versions of those from ISO3382-I - but it is less likely that a sufficient amount of data for such not widely accepted parameters will be collected within a foreseeable future.

2.2 Measurement positions

ISO 3380-I, Dammerud and the present author agree that measurements should be made on furnished stages without musicians present. Conditions without furniture are not relevant and opportunities for measurements with a full orchestra resent are rare.

ISO 3382-I suggests source-receiver heights of either 1.0 m or 1.5m. In the author's view, the 1.0m height is preferable, since this will increase the sensitivity of the measurement to detect the reduction of propagating attenuation by furniture(/musicians) caused by a sensible riser layout.

With source receiver distances larger than 1m, it becomes relevant to report G_{early} and G_{late}, from individual position combinations instead of only position averages as in the case of ST_{early}.

ISO 3380-I suggests measurement (of each parameter) in at least 3 positions; but with modern fast equipment, this should be extended to at least 5.

The general positions which have been used by the author for many years are shown in Fig. 1. $ST_{early/late}$ is measured in S1 (typical soloist position), S2 (between the viola and celli groups) and in S3 (left most position in second row of wood winds/ clarinet), and since about 1990 we also included P1 (flute leader), P2 (between 1st and 2nd violins) and P3 (rightmost position in second row of wood winds/ double bassoon).

EDT, *C* and T_{30} was originally measured with the source in S1 and the microphone in P1 and likewise in S2-P2 and S3-P3, but these days we also use other combinations to extend the number of measurements. The distance between source and receivers are normally between 6 and 9 m in all combinations. These position combinations could also be used for measurement of $G_{early/late}$ as well.

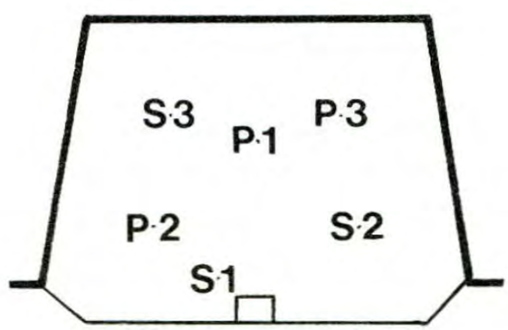

Figure 1: general layout of stage measurement positions according to Gade.

Dammerud [2] has suggested a slightly different layout of positions as shown in Fig.2; but it appears questionable not to choose any positions further from the stage front than 7m. Even moderate sized orchestras often occupy a floor space of depth approaching 12 to 15m (mainly because there is a deep wish to keep a substantial distance between woodwinds and brass and between brass and timpani/percussion). Besides, the conductor's rostrum is often placed a couple of meters back from the stage front, and the orchestra will always be placed relative to this position. It is therefore suggested to increase the Y-coordinates somewhat (but still using the fixed stage front as a reference). Anyway, if the positions in Dammerud's layout are adjusted as suggested here, at least the position averaged values will probably not differ much from those obtained using the scheme in Fig. 1.

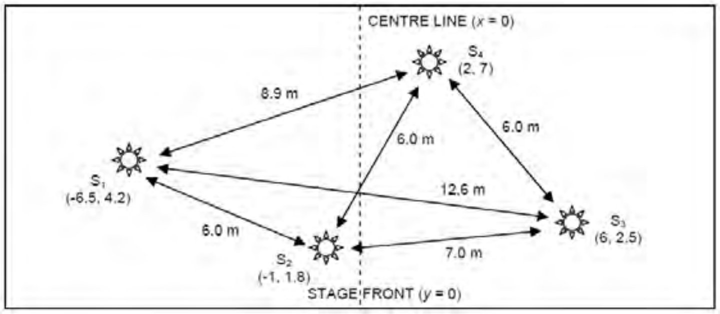

Figure 2: Suggested measurement positions on stage according to [2].

The Suggested frequency range for stage measurements is the 1/1 octave bands between 125 Hz and 4000 Hz. Lower frequencies will not be emitted by portable omni directional (*dodecahedron*) sources, and higher octaves will be too dependent on source directivity and orientation. (The sound source directivity should fulfill the specifications in ISO 3382-I). Our custom for ST_{early} measurements is to look at the 250Hz to 200 Hz octaves only and average these.

2.3 Architectural data

In general, Dammerud found only poor correlation between subjective responses (from interviews) and objective acoustic measures, whereas geometrical parameters gave better results. Among these the more important ones are illustrated in Fig. 3 below.

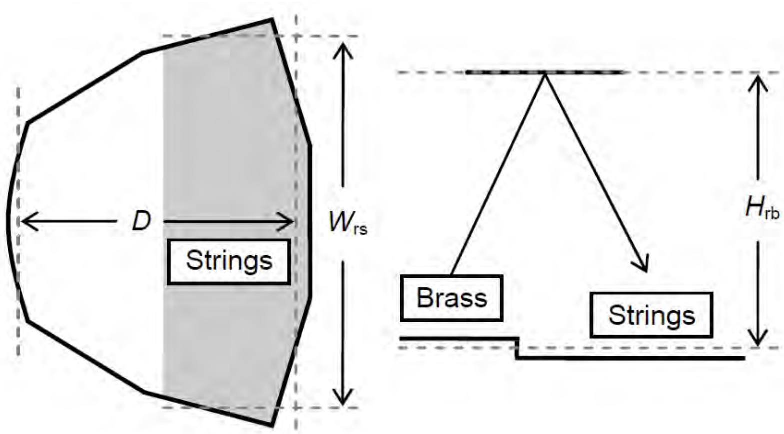

Figure 3: Suggested geometrical dimensions to be recorded from orchestra stages according to Dammerud [2].

From our experience gained from measurements in many halls (more than 60 by now), the author has developed a habit to record the geometrical parameters shown in Table 1.

Table 1: Geometrical parameters of relevance

Symbol	Description
Pwidth	Average distance between side walls on stage (= W_{rs})
Ph,refl	Average height to reflectors over stage (= $H_{rb)}$)
Prelf,perf	Average coverage of suspended reflectors
Ph,ceil	Average height to ceiling on stage
Pdepth	Average distance from stage front to rear wall on stage (=D)
Pwall,ang	Angle between side walls on stage
Pceil,ang	Angle of ceiling over stage
Pelev	Height of stage front above main floor
Parea	Useable stage area
Risers	Sketch of riser areas with levels
V	Hall volume
Misc. regarding the auditorium	Main auditorium dimensions, No. seats, No. balconies, proximity of side balconies to the stage, distance from stage front to last seat row, visibility of the auditorium rear wall seen from the stage

Of course, submission of scaled plan and section drawings of the hall will give access to all the above plus any other geometrical parameter of future interest. Drawings may also show the riser area and heights used as well at the location of the measurement positions. A few photos would also be welcome.

2.4 Subjective data

First of all, musicians whose opinions are collected should have played in the halls they evaluate several times, otherwise they are unlikely to give a detailed judgment. One should also be aware that they may have biased opinions about the acoustics or their home hall – particularly if they do not have fresh experiences from regularly performing in other halls. The following list of factual information to be supplied for each musician is a modified version of Dammerud's suggestions [2]:

Subject identification (initials, number or name).
Instrument played.
Years of experience (as a professional musician).
Name of the hall assessed.
Approx. number of times you have performed in this hall.
Number of other halls in which you perform on a regular basis.

Typical position on the stage (marked on a sketch printed on the questionnaire form)
Orchestra arrangements normally being used in this hall (American, German).
If sitting on a riser, how high is it?
Are screens or hearing protection used against sound from loud instrument(s) nearby?
The music played during test session (if questionnaire is filled in immediately after playing).

It is strongly recommended that subjective data are collected based on a recent playing/listening experience, since data obtained in retrospect are less reliable due to our short acoustic memory and a risk of less control with the objective conditions under which the assessment was formed.

The subjective parameters to be included in a questionnaire could be chosen from the following list (being a fusion of aspects suggested by Dammerud and by the author). For each hall or hall configuration tested, the judgment of each quality should be made not as a comparison test but as an absolute scaling along a semantic differential scale consisting or either a continuous line or a row of tick boxes with short guiding descriptions at the end points (as suggested in brackets below). The wording should not be excessive in order not to promote the subjects using only the central part of the scale. Still, the subjects should be instructed to consider the end points as their personal experience limits (like: the worst/best I have ever experienced).

Sense of acoustic communication with the main auditorium (weak - strong).
Sense of reverberant response, 'bloom' or 'resonance' (weak – strong).
Support from the room to one's own sound production (weak – strong).
Ability to hear all the other groups in the orchestra (easy - difficult)
Ability to hear members of one's own group (easy - difficult)
Ability to hear oneself (easy - difficult)
Overall level (too weak - too loud)
Instruments which were too loud.
Instruments which were difficult to hear.
Disturbing delays or echoes. (none - very disturbing)
Timbre related to one's own instruments or the orchestra sound (dark/dull - bright/harsh)
Ease of varying the dynamic expression (easy - difficult)
Background noise (none - very disturbing)
Positive aspects of the acoustic conditions
Negative aspects of the acoustic conditions
Which of the above mentioned aspects are of primary importance to you when playing in this hall - for better or for worse.
Overall acoustic impression, OAI (very poor - very good).
Other comments

OAI should be listed at the end of the questionnaire to avoid a premature conclusion which might influence the judgment of all the more detailed responses (the so-called 'halo effect').'

The above list may be reduced to suit the target of the specific experiment and to avoid fatigue and confusion in cases where only a limited number of judgments are actually relevant.

3 DISCUSSION AND CONCLUSIONS

Much more could be said and discussed regarding the above recommendations; but it is the hope of the author, that a unified approach to data collection from acoustic experiments on orchestra stages somewhat in line with the description in this paper (which is still open for discussion!) will be an important step towards further advancements of stage acoustics. More specifically, there is a need for more knowledge to answer at least the following three questions:

1. Can improved direct sound distribution through the use of (half circular) risers compensate for a lack of early reflections and vise versa?
2. What are the time limits for the ratio between clear (early) sound components and blurring reverberant levels on stage, and how is this controlled by the architectural design?
3. Which communication paths are the most important ones between musicians on orchestra stages?

Some of the answers will inevitably interact with the layout of the orchestra, the performance practice and the instrumentation in the score played; but hopefully some significant factors related to the architectural design of the hall alone can be found – simply because the hall is harder to change if not found optimal than e.g. the layout of the orchestra.

Based on the above, the idea is to set up a web page with suggested detailed guide lines for measurements, questionnaire forms and the possibility to submit results. It is with great joy that it can be announced that Magne Skålevik msk@bs-akustikk.no has agreed to host this web page on his acoustics portal: http://www.akutek.info/index.htm. Before the aural presentation of this paper, we hope to be able to show bits and pieces from this web page.

ACKNOWLEDGMENTS

The author is grateful to the colleagues who have shared their ideas in this process and to Magne Skålevik for his willingness to put his web page at the disposal for this cause.

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