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Acoustic feedback for performers on stage – return from experience

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Abstract

When working with musicians on the acoustics of concert stages, the commonly used set of acoustic criteria is insufficient to describe all aspects and problems. Orchestra musicians have clear requirements: hearing themselves, hearing others and hearing the room. While some commonly used acoustic criteria like ST1, Reverberation Time T and G_{late} (measuring late room response) can be helpful in understanding some of the problems encountered, other aspects like loudness and directions of arrival (of early sound as well as late sound) also need to be taken into consideration.

Experiences from recent projects concerning optimization of stage acoustics will be given. In addition, findings from these experiences can help in setting rooms with coupled reverberation chambers as well as acoustic reflectors above the stage. Another aspect that often tends to be neglected is the question of orchestral balance (for audience members but equally for musicians on stage) that can strongly be influenced by acoustic design decisions.

Keywords: room acoustics, concert hall design, stage acoustics, feedback for performers

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1 Introduction – requirements for performers on stage

Room acoustic quality of concert halls has been studied for several decades, first concentrating on the listeners in the audience. The multi-dimensional aspect of room acoustical quality is well-established (see for example Sabine [1], Beranek [2], Barron [3], Kahle [4] or Lokki [5]) and correlations between objective criteria (for example those identified in ISO 3382) and the different perceptual factors have been studied. More recently, attention has been focused on the room acoustic quality parameters for musicians on stage (for example Gade [6], Dammerud [7], Skalevik [8], Ueno [9]). While the needs of performers seem clear and will be detailed below, the sole criterion commonly used for describing the acoustic quality on stage is the objective criterion ST1, relating to the energy reflected back to the source in the time interval 20ms – 100ms. Proposals have been made for other objective criteria but mostly with relatively limitated success. In the absence of successful objective acoustic criteria, architectural and/or spatial criteria have been proposed by Dammerud [10], for example the height/width ratio on stage or the notion of competing reflections vs. compensating reflections. The aim of this paper is to discuss the underlying acoustic criteria, from the notion that the requirements for musicians on stage can in fact be defined relatively easily and clearly.

Supposing a large symphony orchestra on stage, and following Dammerud, the requirements for musicians on stage can be summarized as follows:

1. Hearing oneself;
2. Hearing others;
3. Hearing the room.

These, apparently very simple, requirements should be discussed in some more detail:

1. Hearing oneself: already this simple statement that a musician must be able to hear himself or herself is not that straightforward. One's sound must not be too soft, nor too loud – and to a certain degree the requirement for "help" from the room is instrument-specific. A string player and a woodwind player must be able to hear themselves even in major *tutti*, for intonation and tone colour. Brass and percussion instruments, on the other hand, require less "help" from the stage environment, as otherwise their own sound will mask the sound of any other players, especially the sound from the strings and woodwind (and, if present, from the soloist).
2. Hearing others has numerous aspects: for string players (and to a lesser degree woodwind and brass) hearing the section is important, and the section needs to be in balance with one's own sound, otherwise ensemble is difficult in terms of timing, intonation and tone colour blend. Other typical problems of hearing other instruments

include cross-stage communication for strings (stage left to stage right: Vl1 to Vc in the American setting, Vl1 to Vl2 in the Classical setting, etc.), woodwinds not being able to hear strings while the brass and percussion are playing, and finally, for brass and percussion sections, hearing the strings and woodwinds.

3. Hearing the room: this is a requirement for performers on stage that is often forgotten, thinking that hearing oneself and the other musicians is sufficient for ensemble playing. Experience shows that this is not the case, or at least not sufficient for ideal working conditions. Musicians need feedback from the room for several reasons: first of all, they need assurance (and reassurance) that their sound is indeed being projected and heard in the last row of the hall. Often musicians call this aspect "ease" of playing: if they can hear a room response they know that they can be heard, and communication with the audience can be established and overplaying can be avoided. Secondly, the hall return provides feedback about ensemble playing and balance: are all woodwinds balanced in the hall return? To give an example: if the oboe is louder than all other woodwinds in the hall return, this provides a highly useful cue for the oboe player who – even subconsciously – will adapt their playing accordingly. Feedback is a necessary part of music-making: musicians are trained via (and for) feedback loops, both as individual players and in ensembles. The same of course holds for singers, who generally find intonation much easier when room feedback is present. Finally, the hall return is feedback for the musicians in the simplest meaning: it is the projection of the hall onto the stage, allowing musicians to hear "what is going on in the hall".

Before describing several case studies in more detail, two examples will be given that illustrate the importance of "hall feedback" for musicians:

- Sibelius Hall in Lahti is highly appreciated both by audience members and by musicians. Yet there is a rather strong and clear echo on stage – from the rear wall and the rear wall corners of the top balcony – which has been noticed (and complained about) by many acousticians, technicians and engineers. The sound engineers of the Finnish Radio were some of the first to notice the echo, and they were quick to install a curtain track and several individual curtains. Yet, if you go there for a concert of a classical orchestra today, you will find that… the curtains are stored away in a storage pocket. The author has tried himself after a concert, first clapping hands and then playing the viola: the echo is evident when clapping hands, with the distance to the rear wall slightly more than 30m the delay is more than 150ms; but when playing the viola… the echo is highly appreciated and contributes very positively to a good hall response and hall feedback.
- Stavanger Concert Hall (Fartein Valen Hall) has both a moveable ceiling and a cloud of suspended reflectors above the stage. The suspended reflectors (typical height 14m) are moderately sized (average dimension 2m), plan coverage is slightly less than 50% and the reflectors extend a little beyond the actual stage surface. In order to create homogeneous coverage, all reflectors are convex curved, which makes reflected energy back to the stage relatively constant with respect to tilt. The suspended reflectors were

designed with a tilt of approximately 5° in order to increase projection from the stage towards the hall, but after installation by the contractor prior to the first test rehearsals the average tilt was in effect 0° (so horizontal). Between rehearsals, the reflectors were adjusted to the originally planned 5° tilt. After rehearsal with the adjusted reflectors, musicians stated “we do not know what you did to the hall in detail, but never change back – we love it”. What had changed for the musicians was the hall response, with the tilted reflectors they could hear the hall reverberation much more clearly than before, and highly appreciated this fact: hearing the reverberation “of the hall” and not the reverberation “of the stage” was and is important to them.

As shown by these examples, reflections “outside” the range measured by the parameter ST1 are important to musicians’ well-being on stage. A beneficial hall response, and the direction of arrival of the late reverberation is important for musicians.

2 Return from experience – general trends

2.1 ST1

Just as the optimal loudness (amplification) G of a concert hall depends on the musical work performed, optimum values for ST1 are equally highly influenced by the orchestral forces present on stage. Concerning the 1,400-seat *Stadtcasino* in Basel, Beranek in [2] indicates that the hall is not ideal for the large symphonic repertoire, quoting Herbert von Karajan (“the volume of large orchestras is smashing”) and Dimitri Mitropoulos (“too small for full orchestra”). Staying with historic halls in Switzerland, to a lesser degree the same holds for the *Tonhalle* in Zurich and *Victoria Hall* in Geneva: both halls are on the small side for large symphony orchestras and therefore not ideal for very big orchestral works like the later symphonies by Gustav Mahler.

The original work on ST1 performed by Gade was based on two halls in Copenhagen: the 1,780-seat Tivoli Concert Hall (acoustic volume less than 13,000m^3) and the 1,080-seat (former) Danish Radio Concert Hall with an acoustic volume of 12,000m^3. Both halls have a relatively compact stage enclosure and it is therefore not surprising that the ST1 values measured by Gade were relatively high. Furthermore, the preferred stage had higher ST1 values than the less preferred hall. Perhaps in part due to the history of the research on stage acoustics and in part due to the chosen name “support”, there has been a tendency to believe that “the more support, the better”. The sometimes quoted “preferred range” of ST1, of between -11dB and -13dB, already seems high to this author, and some researchers and acousticians even propose -9dB as a preferred value, which corresponds more to good conditions for chamber music than for large symphony orchestras.

As will be shown later in this paper, experience from recent projects tends to indicate that most problems with on-stage acoustics are due to *too much* sound rather than *not enough* support. It is interesting to note that other studies corroborate this finding. In his initial studies, Gade [6] indicates that in the Tivoli Concert Hall, some musicians felt that they were lacking contact with the reverberation from the auditorium, as the rather shallow stage enclosure provides abundant early reflections. Ueno [9] found that a very high level of early reflection energy was disliked by most musicians because it masked the reverberation, made the room sound “small” and was not actually contributing to Support.

In this context, it is interesting to note the ST1 values for some recent concert halls.

The average ST1 on the stage of the 1,500-seat Fartein Valen Concert Hall in Stavanger (acoustic volume in the measured configuration 20,000m^3) is -12dB. The hall is considered by musicians as providing close to ideal listening conditions both for medium-sized and large-sized symphony orchestras.

The average ST1 on the stage of the 2,400-seat Philharmonie de Paris, as measured by Marshall Day Acoustics in the setting preferred by the Orchestre de Paris, is -15dB, and once again the hall is highly appreciated by musicians, especially for large symphonic works.

2.2 Reflector height

The quest for “the more support, the better” has lead to overhead acoustic reflectors above the stage, sometimes in the form of big acoustic canopies and sometimes as smaller “reflector clouds”. While their usefulness for providing reflections back to the stage is proven, we generally find that they are often placed too low in the room and above the stage. In addition, whenever possible, reflectors should contribute to projection from the stage towards the hall – reducing loudness levels on stage and increasing the hall response for musicians on stage.

In the Philharmonie de Paris, the preferred height for the canopy (by the Orchestre de Paris) is 15m above stage. The canopy is slightly convex curved and horizontal, as in a surround hall the question of projection to the audience is more difficult.

In the KKL Lucerne concert hall, clarity and on-stage hearing for large symphony orchestra is better with the canopy (horizontal and flat) at a height of 15m above stage than with a height of 14m above stage. This has been confirmed by listening tests with several symphony orchestras.

In Fartein Valen Hall, Stavanger, the preferred height of the smaller, quite convex curved reflectors is a minimum of 14m above stage, for large symphony orchestras. For chamber music, the reflectors are lowered to about 12m.

In Casa da Musica, Porto, the (convex curved) canopy was raised (by 3m) and tilted (for projection), leading to improved clarity and on-stage hearing conditions.

In Stockholm Konserthuset, one of the first steps in improving the acoustic settings of the hall was to slightly raise and tilt the existing, rather small, reflectors above the stage. After adding cross-stage communication reflectors on the choir balcony fronts, another acoustic rehearsal with the musicians showed a clear preference for a yet significantly higher setting of the over-stage reflectors, with musicians indicating that they felt that “a lid was taken off”, suggesting that the lower reflector setting could create a compressed sound on stage.

These observations are especially interesting when put into context with the findings by Dammerud concerning the importance of the height/width ratio, indicating a clear preference by musicians for tall and narrow stages: low stage enclosures are problematic as they can lead to a compressed sound and a dense sound field – dense in the sense of making it difficult to hear details and therefore reducing clarity.

2.3 Variation of ST1 across stages

When ST1 is discussed for concert stages, most of the time the only parameter given is the *average* of ST1 for all measured source positions – and not for individual source positions. Even less discussed is the variation of ST1 across the stage – which, in the opinion of the author, is possibly even more important than the absolute value (or average value) of ST1.

Arau, in two papers on the stage acoustics of the Auditori concert hall in Barcelona [11,12], discusses the question whether the support parameter ST1 is a sure method to forecast stage acoustics and concludes that Gade's criterion is a necessary but not a sufficient condition. In Arau's measurements of stage support in the Auditori Barcelona, he obtains an average value of -14,8dB and claims that this value is close to those observed in other concert halls with good reputation concerning on-stage acoustics (which, on a basic level, is correct, see above). When looking into more detail, however, one can see that the ST1 values vary significantly and systematically across the stage: ST1 is around -18dB in the strings zone, -14dB in the woodwind zone and -11.5dB in the percussion zone. The following figure shows the distribution of ST1 across the platform:

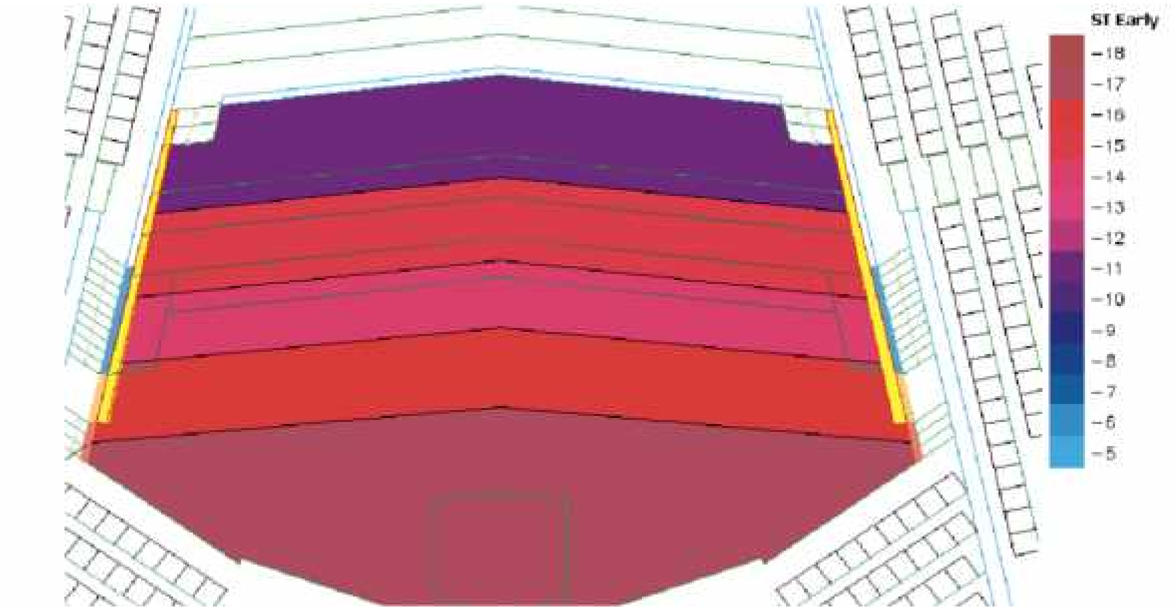

Figure 1: ST1 by zones on the stage of Auditori Barcelona. Reprinted from reference [12]

It should be clear that the above distribution of ST1-values across the stage is neither good for on-stage hearing conditions nor for orchestral balance: the increased ST1 values around the brass and percussion instruments indicate that there is less absorption around the brass and percussion than around the strings, therefore most likely the brass will be too loud in the hall as well, creating problems of orchestral balance. Secondly, and even more importantly in the context of this paper, the additional reinforcement of the brass and percussion instruments creates an overly loud brass sound on stage – in the framework of Dammerud, there is an abundance of *competing* reflections from the brass on stage!

In projects adjusting halls and improving stage acoustics, adding absorption around the brass and percussion has nearly always lead to improved stage acoustics: reducing the loudness of the brass sound on stage makes it possible for the woodwinds to (finally!) hear the strings seated in front of them, rather than the string sound being masked by the brass sound. In addition, reducing brass loudness makes it easier for musicians to hear and perceive a hall response, creating a better connection between the stage and the hall. And, finally, reducing brass loudness on stage generally improves perceived clarity on stage, as has been clearly pointed out by musicians.

As indicated in the introduction, strings (and to a certain degree woodwinds) need more “support” and reinforcement than the brass and percussion players. For this reason, ST1 for brass and percussion should be lower or, at most, equal to ST1 for string positions (which is in fact quite difficult to achieve on most stages).

Measurement results for both the concert stage in Fartein Valen Concert Hall, Stavanger, and Philharmonie de Paris show a relatively uniform distribution of ST1, with values for brass and percussion very close to those for string positions.

2.4 Direction of reverberation

Excessive reflections and reverberation from around and behind concert stages can have a negative influence not only on orchestral balance but also on on-stage hearing conditions for musicians (see as well [13]).

The new concert hall for the Bochumer Symphoniker, due to open in October 2016, is a 950-seat shoebox concert hall with an acoustic volume of over 14,000m^3 in order to accommodate full symphony orchestra repertoire. Due to the small seat count and comparatively large volume, it was planned from the beginning that some of the variable sound absorbing elements would be used even for non-amplified orchestral concerts. Due to delays in construction works, the first acoustic test rehearsal in the hall took place with no curtains installed, with a reverberation time of just under 3s. With no curtains in place, there was clearly excessive reverberation (but at the same time good clarity) and excessive loudness, but also a lack of openness and a slightly compressed sound. Adding moderate amounts of absorption behind the stage and on the upper rear wall behind the choir balcony relieved saturation, allowing reflections from the upper volume to be heard which increased the perceived ceiling height and created acoustical openness, still with a reverberation time of around 2.5s. Other curtain locations were tried, but the back wall behind the musicians gave the best results both on stage and in the audience.

The findings suggest that the reduction of competing reflections is important for revealing the full spatial room response and avoiding the saturated and compressed sound on stage.

After a recent renovation of the Grieghallen in Bergen, musicians complained that on-stage hearing conditions had severely deteriorated, while acoustic measurements indicated few changes when compared to the situation before the renovation. It turned out that during the renovation all curtains in the flytower *behind and above* the acoustic shell had been removed and only some of the curtains had been put back. As a result the stage house reverberation "outside" the shell was longer than the reverberation of the auditorium. The response from the stage house created excessive reverberation on stage: not in length, but in level – the delayed arrival of energy back from the stage house sounded like it came from "on stage". In addition, the acoustic response on stage had become too dense, making hearing on stage more difficult. Adding absorbing curtains in the stage house and reducing the gaps in between the orchestra shell elements eliminated the delayed response from the stage house and not only significantly improved on-stage hearing conditions but also increased the definition and clarity of all orchestra groups in the hall. Reverberation was then increased in the audience chamber by removing variable acoustics curtains – increasing reverberation time beyond what it had been with the resonant stage house and at the same time maintaining the improved clarity. This finding suggests that the direction of reverberation has a strong influence not only on perceived spaciousness but also on other aspects like clarity and subjective distance to the musicians.

The same effect was observed when an electronic reverberation system was installed in the Stockholm Concert Hall [14], first as a temporary test and then as a permanent system. In this 1800-seat concert hall, home of the Royal Stockholm Philharmonic Orchestra, a semi-transparent technical grid had been installed during a previous renovation and suspended below the entire ceiling. The technical grid was identified as the reason for a lack of reverberation, and it was decided to first test an electro-acoustic enhancement option to cancel the attenuation of sound passing through the grid. Natural reverberant sound is picked up with microphones high in the hall and fed to loudspeakers above the technical ceiling grid, in various locations across the length of the room. During trials with the final system, it was found that loudspeakers above and behind the stage had a tendency to reduce clarity and to increase the subjective distance to the performers, while loudspeakers above the back of the hall enhanced envelopment without deteriorating clarity.

3 Conclusions

Just like the perception of room acoustical quality for listeners, stage acoustics quality is multi-dimensional, which means that several different aspects need to be addressed when talking about stage acoustics.

Possibly even more than for audience, musician preferences can be directly linked to working requirements: musicians have to (i) hear themselves, (ii) hear others and (iii) hear the room response.

While there are several perceptual factors, there is only a single commonly accepted objective criterion for stage acoustics quality, the support parameter ST1, and more work in the definition of further adapted criteria is welcome in this respect.

Concerning the factor of “hearing oneself”, for symphony orchestra less “support” by the room is required than often quoted in literature. Large concert halls like the Philharmonie de Paris have ST1 values in the vicinity of -15dB and are highly appreciated by musicians.

Concerning the factor of “hearing others”, musicians listening to colleagues are using the cocktail party effect for perceptual unmasking – and any element making the cocktail party effect more effective is beneficial in this sense. Once again, more research would be welcome in this respect; the current research indicates that reduction of (unwanted) loudness of brass and percussion instruments is helpful for simplifying the use of the cocktail party effect. The same holds for added projection from the stage into the audience chamber, as this reduces loudness levels on stage.

Concerning the factor of “hearing the room”, this aspect has too long been neglected in the research and case studies show that this is as much a requirement for musicians as self and ensemble hearing, and an important factor in musicians’ preference. When dealing with room response, the direction of the room response needs to be taken into account: the hall response should be perceived as frontal by the musicians, i.e. come from the part of the room that is opposite to the stage.

Setting the acoustical characteristics of the stage surroundings not only influences on-stage acoustic conditions but equally the result for listeners in the audience chamber. Reflective surfaces and excessive reverberation at the back of the stage, especially surrounding the brass and percussion instruments can create problems with orchestral balance and can decrease source presence and source clarity. Case studies discussed in this paper seem to indicate that our brain prefers acoustics that facilitate stream segregation: source presence should originate from the real location of the sources, i.e. from the stage (with lateral reflections augmenting apparent source width), while room presence should surround the listener and originate from a location away from – but not beyond – the stage.

The findings discussed in this study have consequences for developing optimum settings for variable rooms, for example those with reverberation chambers: reverberation from behind the stage makes reverberation more frontal, increases the subjective distance to the sources and decreases subjective room height, while reverberation from around the audience (and from lateral reverberation chambers) maintains clarity and source proximity while at the same time maximizing listener envelopment.

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