THE QUEST FOR THE CORRECT BALANCE BETWEEN “HEARING ONESELF”, “HEARING OTHERS” AND “HEARING THE ROOM” ACROSS ROOMS OF DIFFERING VOLUME

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ABSTRACT

On-stage hearing for musicians is a multi-dimensional puzzle, involving “hearing oneself”, “hearing others” and “hearing the room”, requiring an appropriate balance between these three aspects so that they do not excessively mask each other. In terms of objective criteria, the three aspects are somewhat correlated yet differently influenced by the acoustic volume and the reverberation time of the room. For concert halls, in order to maintain an appropriate balance of the different aspects, it will be shown that the absolute values of support parameters like ST_{early} should be volume-dependent, so equally dependent on the audience size (and not only as a function of orchestra size). Rehearsal spaces, generally having a significantly smaller acoustic volume than concert halls, do not physically allow to completely reproduce on-stage hearing conditions of a larger concert hall. What should the acoustic design then be for a typical size orchestra rehearsal room when the client wants “the same acoustic conditions as on stage”? Theoretical considerations will be given as well as return from practical experience.

Keywords: *On-stage hearing, Stage Acoustics, Perception, Acoustic Criteria*

1. INTRODUCTION

In concert performances of musical ensembles, it is vital that musicians have good listening conditions so that they can deliver the best performance, without any acoustical obstacles. To achieve excellent stage acoustics, there are multiple aspects to consider, all of which must be in balance, with no particular aspect dominating:

1. Each musician must be able to hear her or himself properly. This means that they can hear themselves sufficiently but not to the point that their own sound masks that of the others;
2. Each musician must be able to hear all other musicians on the stage properly and in balance, even those seated on the other side of the stage. This is particularly important for instrument groups where there is often detailed interplay, for instance between the string groups (1st violins, 2nd violins, violas, cellos and double basses);
3. The acoustics from certain instrument groups must not be too loud, so that they do not mask the sound of other instruments. Typically, excessive loudness and excessive reverberation from the percussion and brass can be problematic on orchestra stages, resulting in poor listening conditions for the entire orchestra;
4. The musicians should receive a structured and sufficiently audible “room response” so that they hear that their sound is reaching the last rows of audience and so that they can judge the orchestral balance. This involves generating multiple reflections with different delay times from the audience part of the hall back to the stage.

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In his seminal papers, A.C. Gade [1-3] studied on-stage listening conditions through measurements and experiments with musicians in existing halls, starting out by differentiating "hearing oneself" and "hearing others", respectively to be measured by criteria ST1 (now generally called ST_{early}) and Early Ensemble Level (EEL).

ST_{early} is calculated from the ratio between the early reflection energy (within 100ms, excluding the floor reflection) and the direct sound (including the floor reflection) in an impulse response recorded on stage with a distance of only one meter between the source and receiver, see Eqn. (1):

$$ST_{early} = G_{(20ms\text{-}100ms)} - G_{(0ms\text{-}10ms)} \quad (1)$$

EEL is calculated from the ratio between the early energy received from the distant source (within 80ms) and the direct sound (including the floor reflection), the latter recorded on stage with a distance of only one meter between the source and receiver, see Eqn. (2):

$$EEL = G_{other\ (0ms\text{-}80ms)} - G_{self\ (0ms\text{-}10ms)} \quad (2)$$

Gade later abandoned the use of EEL, his data not supporting the differentiation between ST_{early} and EEL, and proposed to use the parameter ST_{early} both for "hearing oneself" and "hearing others", in the latter case using the ST_{early} value for the other source. As a reason for this simplification, Gade argues that ST_{early} is a measure of the amplification of each source on stage and that the amplification of a specific source location will be similar for all receiving positions on stage.

Naylor [18] found the balance between the sound level of the other player(s) and the level of one's own instrument to be of prime importance: OTHER – SELF should be such that the player is able to hear both signals well, allowing to achieve ensemble.

J. J. Dammerud [5-6] could not confirm any strong correlation between ST_{early} and on-stage hearing conditions in his work on objective measurements and subjective evaluations of several professional European orchestras. In his data, correlations with objective criteria were generally weak, better correlations were observed with geometrical parameters such as height-to-width ratio, indicating an influence of directional aspects on on-stage hearing. In his analysis, Dammerud introduced the very useful notion of *"competing reflections"* vs. *"compensating reflections"*, indicating that the differing needs for the various instruments groups on stage need to be taken into account. Furthermore, Dammerud observed a relatively strong correlation of positive aspects such as "projection", "bloom" and "overall impression" with audible feedback from the hall, through reflections and reverberation. He found that the most popular stages have a late sound level G_{late} (G after 80ms) approximately 2 dB above the level of G_{late} within the stalls section [6-7].

2. DISCUSSION

Naylor's findings highlight the importance of "correct balance" between "hearing oneself" and "hearing others" while Dammerud's findings add the importance of "hearing the hall" to the list, a finding the author can strongly confirm from practical experience. Furthermore, Dammerud's conclusion on the importance of relative level of late sound on stage with respect to the late sound in the main audience area indicates that optimal stage parameters are not independent of the size of the concert hall. Finally, the notion of "amplification of a specific source location on stage" introduced by Gade has implications when considering the strongly variable sound levels of different orchestra instruments. All these aspects are discussed in the following subsections, using Dammerud's notion of "compensating reflections" vs. "competing reflections". For the sake of discussion it seems appropriate to use ST_{early} notwithstanding its limitations, as it is still the most widely used parameter for on-stage acoustics.

2.1 ST_{early} as a function of instrument

Sound power levels of brass and percussion instruments are significantly higher than those of string instruments and woodwinds, with differences exceeding 10dB (see Meyer [8], Kahle [9] or Rindel [10] on the Norwegian standard NS8178). It is not by coincidence that the louder instruments are generally placed at the back of the stage (i.e. with a maximum distance from the conductor and most audience members). Those instruments do not need additional reinforcement from close-by reflecting surfaces and therefore, to use Gade's terminology, the amplification of the brass and percussion area of the concert platform should be lower (or clearly not stronger) than elsewhere on the stage. This means that, ideally, ST_{early} should be lower for the brass and percussion than for woodwinds and strings. In practice this turns out to be difficult as those locations are closer to the room boundaries than for example the woodwinds in the center of the stage. Strings as well as woodwinds require support and amplification of their sound, the same holds for the soloist position next to the conductor.

The conclusion is that ST_{early} should be either slightly stronger for the front of the stage and slightly weaker at the back of the stage, or be uniform throughout the stage. An increase in ST_{early} for brass and percussion is to be avoided.

2.2 Self vs. others as a function of instrument

Strings need support and amplification as they are the weakest instruments (though largest in numbers). Equally importantly, strings need "cross-communication reflections", as the physical distance between string players placed stage left and string players stage right is quite large, yet they need to play together and must be able to perceive the string section on the other side of the stage. Vertically inclined choir balcony fronts, allowing to create cross-communication reflections above the heads of the musicians (as discussed by Dammerud) are very helpful in this respect, and return from experience shows that strings prefer these reflections to be as strong as possible. For example, during an acoustic test with the Royal Stockholm Philharmonic in Konserthuset Stockholm, flat plexiglass panels were preferred by string players (for cross-communication reflections) over curved wooden panels with 10% chord, i.e., radius of curvature of approximately 5m. During the same test, convex-curved wooden panels (radius of curvature approximately 3m) were preferred over straight plexiglass panels by the brass and percussion players (both for cross-communication and self-hearing).

Woodwinds equally need support and amplification, due to their moderate sound levels (and numbers) and due to their location in the middle of the orchestra, generally furthest away from reflection surfaces. Overhead reflectors can be helpful (or even be required) in this case, ideally ensuring an acoustic return to the musicians as well as projection from the woodwinds into the main audience zones, allowing woodwinds "to get over" the orchestra. The location of the woodwinds is especially critical when it comes to "hearing others", as they are located in between the strings and the brass. Hearing strings is required for ensemble playing and additional reflections from string instruments are therefore beneficial. The contrary holds for the brass, often located directly behind and with a directivity towards the woodwinds. The direct sound of brass instruments is sufficient for being heard by the woodwinds (and often already considered as being too loud), meaning that any additional reflections are detrimental as they will act as "competing reflections", masking the string sound. This is generally the biggest problem concerning on-stage hearing for woodwinds: that they cannot hear the strings any longer when the brass starts playing. Interestingly, it should be noted here that not only early reflections from brass to woodwinds will enhance masking of strings, but equally diffuse reflections, late reflections and reverberation from brass and percussion on stage. Late, reverberated energy, as well as diffuse reflections from a source 10dB louder than other sources can and will have a non-negligible masking power.

Brass and percussion instruments need less amplification, but they do need acoustic feedback, both from the stage enclosure and from the hall. In Stavanger Concert Hall [11], the wall behind the brass and percussion players is an acoustically transparent surface, made from wood slats, more than 50% open. An acoustic curtain is located behind this acoustically transparent surface, creating an acoustically absorptive stage back wall, except for the top 80cm, where the wood slats cover the solid, reflective balcony front. During an acoustic test, additional absorption was added behind the brass and percussion instruments, inserting absorbing foam between the wood slats covering the balcony front. All listeners (including brass and percussion players) agreed that the orchestra sound and balance was improved by this added absorption close to the brass and percussion instruments. The absorption was left in place after the test, with the consequence that, over time of about two years, brass players were playing increasingly loudly, probably as the diminished feedback forced them to increase their own sound levels. After two years, it was decided to partially remove the additional absorption strips in order to increase the acoustic feedback loop back to the brass and percussion players. Acousticians need to take into consideration that their design decisions can have an impact on the playing style and internal balance of the resident orchestra, while guest orchestras will most likely only marginally be affected by these choices. For resident orchestra musicians, the playing levels of individual musicians (and instrument groups) will be influenced by the feedback loop to the musicians (from the stage enclosure and from the hall) as well as by the relative loudness levels at the conductor's position.

Furthermore, brass and percussion players need reflections from all other musicians of the orchestra, including reflections originating from behind them, both for timing cues and in order to feel acoustically part of the ensemble. Brass players do appreciate cross-communication reflections, facilitating the timing between brass instruments located stage left and brass instruments located stage right, but generally they prefer them at a lower level than the strings (curved reflectors preferred over straight reflectors during the test in Stockholm, see above). With respect to "hearing others", it is interesting to note that any reflections back to oneself as well as late reverberation (from any instrument) will be part of "competing energy", equally for brass and percussion instruments, increasing masking and reducing the audibility of the remainder of the orchestra.

Just as for ST_{early} levels, the back of the stage should ideally be softer in reverberation level than the front of the stage; return from experience indicates that increased reverberation levels at the rear of the stage should be avoided.

2.3 STearly as a function of hall size

Dammerud's finding that the most popular stages have a late sound level G_{late} (G after 80ms) approximately 2 dB above the level of G_{late} within the stalls section indicates a preference for a good coupling between the stage area and the audience area: musicians and audience members like to be "in the same room", with the sound from the stage projecting well into the audience area – and the hall reverberation projecting back onto the stage. In order to perceive the hall reverberation on stage, the on-stage reverberation level can only be moderately stronger than the hall reverberation level. The musicians' preference can therefore be interpreted as a rejection of proscenium arches separating the orchestra from the audience, but equally as a rejection of overly resonant and reverberant stages that make it difficult to hear the room response.

The strength of the reverberant field in the audience area is determined in first approximation by the size of the hall (number of audience members) and the reverberation time of the hall. Using Barron's revised theory [12-13], it can be calculated that a hall with twice as many audience members (i.e. twice as much absorption area) will, for the same reverberation time, have a late sound level G_{late} that is reduced by 3dB – both in the audience area and on stage. This implies that, if one wants to maintain a balanced relationship between "hearing oneself", "hearing others" and "hearing the room response", as suggested in this article, the strength of the on-stage support (and on-stage reflections) should be dependent on the late reverberant sound level of the hall – and therefore be dependent on hall size and reverberation time.

To create ideal, balanced conditions, on-stage support needs to be stronger for smaller and more reverberant halls and needs to be softer for larger and less reverberant halls.

This line of thought actually helps to explain the sometimes contradictory recommendations concerning optimal values for ST_{early} found in the literature. Gade's initial proposal of an ideal range between -11dB and -13dB has been questioned as being too high, with other successful concert halls measuring at significantly lower ST_{early} values. The lowest observed value for a successful concert hall was measured on the stage of Concertgebouw Amsterdam, where the stage conditions are known to be "difficult" or "borderline acceptable". The measured ST_{early} value for Concertgebouw Amsterdam of 17dB (-18dB in some publications) can therefore be considered as an absolute lower limit of acceptance. Gade's proposed range of between -11dB and -13dB may well have been significantly influenced by the halls used for most of the practical experiments: Tivoli Concert Hall and the (old, no longer used) Danish Radio Concert Hall. Both halls have an acoustic volume of only slightly above 10'000m^3 (corresponding to roughly 1000 seats in a modern configuration) and are no longer used as concert halls, as musicians found them to be excessively loud.

Whether the relationship between preferred ST_{early} levels and hall size is strictly inversely proportional, and whether the reverberation time and reverberation level need to be taken into account, is a question for further research, ideally as a mixture between practical tests on real stages and laboratory conditions. But what seems clear from the above discussion is that optimal ST_{early} levels not only depend on orchestra size, but equally on hall size as well as probably the reverberation level (more than the reverberation time) of the hall.

2.4 ST1 in Orchestra Rehearsal halls

The acoustic volume of typical Symphony Orchestra Rehearsal rooms – unless when the orchestra is rehearsing in the actual concert hall – is generally situated in the range between 2500m^3 and 5000m^3, i.e. between half and one quarter of the volume of the halls used by Gade for his study. If one follows the logic of this article that the balance between hearing oneself, hearing others and hearing the room should be maintained, the implication for an orchestra rehearsal room would be that – for the same reverberation time – ST_{early} would need to be between 3dB and 6dB stronger than the values suggested by Gade, as G_{late} will be between 3dB and 6dB stronger. This is generally not feasible and acoustically not a good idea, as it would lead to excessive sound levels and potential hearing damage [14].

The first parameter to change (in order to get things "back on track") will then be the reverberation time: a reduction in reverberation time leads to a reduction in G_{late} and therefore allows lower – and more typical – values of ST_{early} while maintaining energy balances. In the case of an orchestra rehearsal room, a lower reverberation time may actually allow creating acoustic conditions that are more similar to the conditions on concert stages than maintaining reverberation time. This statement is confirmed by practical experience: the smaller the volume of the orchestra rehearsal room, the lower the highest acceptable reverberation time. The author has worked on (symphony orchestra) rehearsal rooms where the musicians found any reverberation time over 1.0s to create inacceptable acoustic conditions. Otherwise the – relatively small – room became excessively loud and on-stage hearing conditions became inadequate. The price for the beauty of the long reverberation time is not only excessive loudness, but a reduction in hearing of others.

The second factor that can be used is to decrease reverberation level while maintaining reverberation time, by geometric shaping. If one manages to "park" late reverberation under the ceiling rather than on stage at ear height, the audibility of the reverberation tail is increased (the room is "waking up") while masking is minimized. Absorption in orchestra rehearsal rooms should therefore ideally be placed low in the room, as much as possible, and not be coming down from the ceiling. Vertically inclined wall panels that send reflections upwards towards the ceiling can further help to decrease masking while increasing late reverberation in the upper part of the room.

Thirdly, it needs to be taken into consideration that masking levels will, by definition, be larger in a smaller room. Useful reflections, for example cross-communication reflections between stage right and stage left therefore need to be at least as strong if not stronger in a rehearsal room than in a concert hall. This applies both to the strings and the brass cross-communication reflections. Reverberation levels – as well as the energy of diffuse reflections – should be reduced as much as possible, to minimize masking levels. Concerning feedback from the hall, where possible this is still a useful element of the acoustic response and highly appreciated by the musicians. A sufficiently large empty area behind the conductor is beneficial, meaning that violins do not "play into a wall directly next to them. In one rehearsal room project of the author, the architects managed to add the volume above a storage room located behind the conductor to the acoustic volume of the room. This pushed the upper half of the rear wall back by some 4m, creating a significantly later reflection back to the musicians that provides the acoustic sense of a hall response. With the increasing use of reverberation systems, this "hall response" could equally be created electronically – not as reverberation from everywhere in the room, but as reverberation from a non-existing audience area located behind the conductor.

Finally, as already indicated above, the maximum allowable reverberation time in an orchestra rehearsal room (or generally ensemble practice room) will depend on the sound power level of the ensemble and therefore on orchestra size (see as well Rindel [10] on the Norwegian standard NS8178). For loud ensembles, for a given volume the maximum reverberation time needs to be limited to avoid excessive sound levels. For rooms used by different ensemble sizes (and ensembles with different loudness levels), this suggests a variable reverberation time: for smaller, less loud ensembles the reverberation time can be allowed to be longer, creating a "nicer sounding room". Larger ensembles need less amplification, but smaller ensembles need more amplification, suggesting that in orchestra rehearsal rooms (and ensemble rehearsal rooms used by different groups) ideally both the reverberation time and the ST_{early} stage parameter should be variable. This would allow ST_{early} to be set according to reverberation time, as the logic of this article suggests that a longer reverberation time requires ST_{early} levels to be higher in order to be "in balance" with the room response Variable acoustics in ensemble rooms and orchestra rehearsal rooms should mean variability of reverberation time (and reverberation level) as well as variability in the support parameter.

3. CONCLUSIONS

Concerning the value of ST_{early}, both research and return from experience indicate that the *homogeneity* of ST_{early} across the stage is even more important than the absolute value(s). Higher values of ST_{early} for the brass and percussion instruments should be avoided as this leads to *competing reflections* as well as increased reverberation levels, making it difficult or impossible for the woodwinds to hear the strings. Highest values for ST_{early} should be sought for the soloist position and the strings, ideally including strong cross-communication reflections between stage left and stage right for the front of the stage. Concerning the ideal values of ST_{early} as a function of hall size, the recommendation by Dammerud should be followed that G_{late} on stage should be approximate 2dB louder than G_{late} in the main audience areas. This recommendation implies that ST1 values should be approximately 2dB lower for very large concert halls (2000 seats or slightly above) when compared to halls of 1000 to 1200 seats. Hearing oneself, hearing others and hearing the hall need to be considered together, aiming at an appropriate balance that allows musicians on stage to hear "all they need" in order to judge their performance and receive adequate feedback.

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