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INVESTIGATIONS OF STAGE ACOUSTICS FOR A SYMPHONY ORCHESTRA

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ABSTRACT
This investigation was made in collaboration with a professional symphony orchestra, with the goal of improving the acoustics at their home stage. A pre-study through questionnaires was conducted during a tour. The outcomes were used to design the first stage configurations, evaluated during the early part of a tuning week. Binaural impulse responses were measured for 14 configurations from five positions on stage to five musicians and to a dummy head in the audience. After performing seven pieces of music, all musicians judged the stage acoustics in a questionnaire. The music was recorded binaurally and the A-weighted sound pressure levels were evaluated. The musicians judged the sound level to be much lower in the final configuration. However, the binaurally measured sound pressure levels from the music played show very small differences. The measured sound level is probably mainly determined by the sound from the own instrument and the closest surrounding instruments. The judged level is probably based on the later arrived sound level and the character of the sound. Generally the judgements are highly scattered and the correlations between subjective judgements and standardized parameters like Support, Clarity, EDT, IACC etc is low.

1 INTRODUCTION
Much of the research on stage acoustics has been performed using simplified laboratory simulations. Both the simulated sound fields and the playing situations have been quite unrealistic and often only small ensembles have been used. Laboratory conditions give the possibility to have good control of different parameters. However, it may be difficult to draw general conclusions that are valid in real performance situations for a symphony orchestra.

One important issue is to make sure that the descriptions of parameters are unambiguous and fully understood by the musicians. Even if this is done, the preferences for musicians often differ quite a lot between different persons, even sitting next to each other playing the same instrument. Therefore, general conclusions should be made only when a large number of judgements from musicians are included.

Previous investigations have been made by Gade [1-2], Naylor [3] and recently Barron and Dammerud [4-5] who all have proposed different parameters (Support, Hearing-of-Others, Early Ensemble Balance) for objectively measure the stage conditions for the musicians.

2 BACKGROUND
The background of this investigation was a commission from Norrköping Symphony Orchestra to improve the stage acoustics in their concert hall De Geer. It was reported that the musicians have been complaining about high sound levels and problems of hearing each other. However, no systematic investigation of the musicians opinions of the stage acoustics in De Geer had been done. As a first step a pre-investigation was made during concerts in three other Swedish concert halls: Berwaldhallen (Stockholm), Stockholm Concert Hall and Folkets Hus in Motala. The same programme was first performed in De Geer. The results from the subjective judgements and the design of the stage enclosures of the three halls were then used in the planning of different measures which were tested during a tuning week at the home stage.

3 RESULTS

3.1 Subjective judgements of three halls
Directly after the concerts a questionnaire containing twelve parameters was distributed to all members of the orchestra. Since the acoustical memory is short the importance of answering the questionnaire directly

after the concert was stressed. The questionnaire contained twelve questions about sound level, hearing of others, balance between own and others, support of own instrument, support from the hall for the integrated orchestra sound, echoes or disturbing late reflections, low/high frequency balance, spaciousness, harshness, communication with the audience, background noise, etc. Each question included a scale for absolute judgement, a scale for comparison with their home stage, three categories of importance (less, rather, very important) and also a field for comments.

Berwaldhallen is the home stage for the Swedish Radio Symphony Orchestra with a seating capacity of 1300. The hall has a hexagonal shape. There is no canopy or reflectors above the stage. The Stockholm Concert Hall is the home stage for the Royal Philharmonic Orchestra seating 1800 people. The ceiling reflectors have lately been raised to a higher level. Both the Stockholm Concert Hall and Berwaldhallen have choir/audience balconies around the stage, high ceiling above and the stage integrated with the hall. Folkets Hus in Motala is a multi-purpose hall seating 400 people. This hall has a relatively small stage house with an orchestra shell which is not integrated with the auditorium. The De Geer hall with 1379 seats resembles a horse-shoe shaped opera hall with an almost closed stage shell with a large, deep stage and side walls angled only 9º (see figure 4-6).

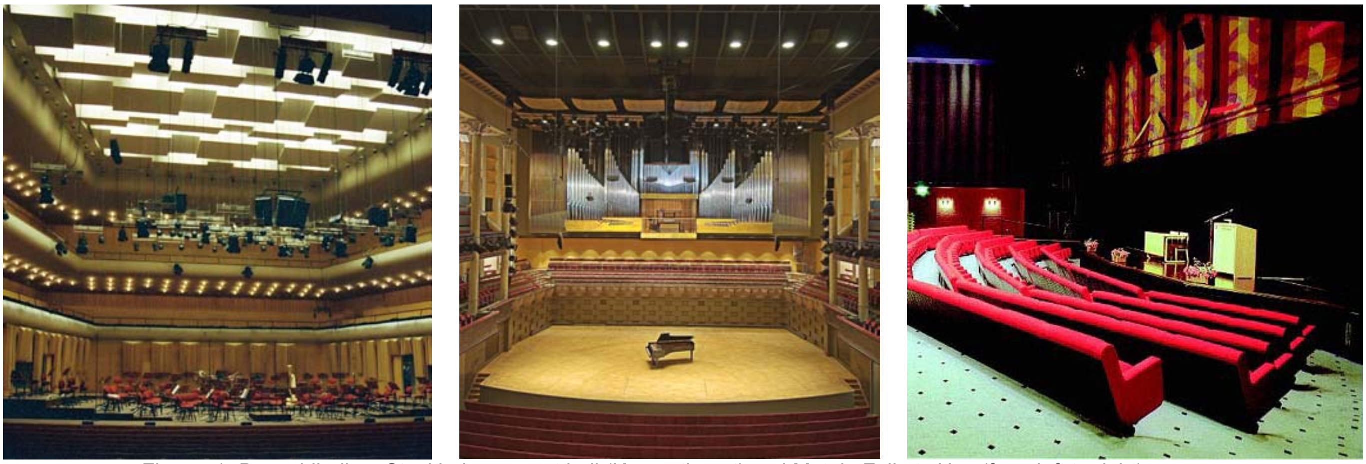

Figure 1.-Berwaldhallen, Stockholm concert hall (Konserthuset) and Motala Folkets Hus (from left to right).

The results show that the four most important questions were: How do you judge the hearing of others musicians regarding ensemble playing, precision and clarity? How do you judge the balance between the sound from other instruments and the sound from your own instrument? How do you judge the hearing of the soloist? How do you judge the sound level on stage? These questions (except the soloist question) were later used in a new questionnaire used during a tuning week at the home stage.

The scattering in judgements between musicians is quite high and in general not less within the same instrument group. When comparing to their own stage the scattering is even higher. One example of scatter diagrams for the judgements of the sound level in Berwaldhallen and the comparison with De Geer is shown in figure 2.

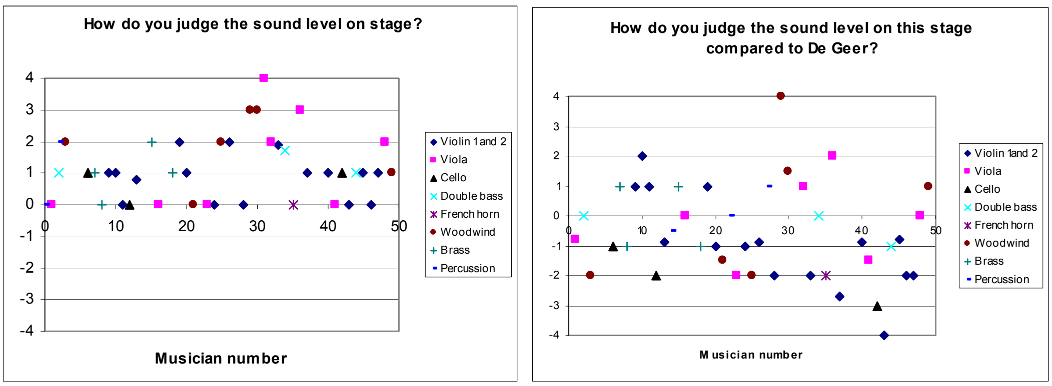

Figure 2. Left: Scatterdiagram of the judgements for the sound level in Berwaldhallen (-4 too low, 0 just right, 4 too high). Right: Sound level in Berwaldhallen compared with De Geer (-4 much lower, 0 the same, 4 much higher).

The scattering is lower for the judgement of balance, however when comparing with the home stage the scattering is still high. In figure 3 the average judgements of level, hearing of others and balance is shown. Hearing of others and balance are judged as “good” in Berwaldhallen and Stockholm Concert Hall. In Motala the balance is judged to have a little too much of others.

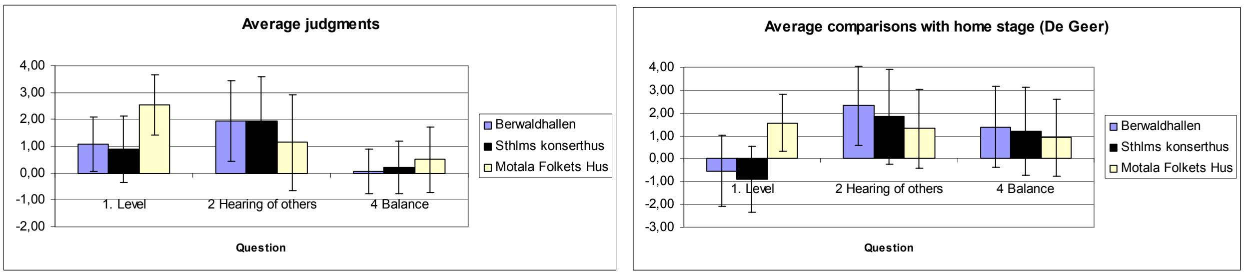

Figure 3. Left: Average of judgements of sound level (-4 too low, 0 just right, 4 too high), hearing of others (-4 very bad, 0 middle, 4 very good), balance own/others (-4 too little of others, 0 good balance, 4 too much of others). Right: Average values of the judged comparisons in the three halls with the home stage; level (-4 much lower, 0 the same, 4 much higher), hearing of others (-4 much worse, 0 the same, 4 much better), balance (-4 less of others, 0 the same, 4 more of others). Error bars are ± one standard deviation.

The questions are of course not independent of each other, therefore the comments are very useful for the interpretation. In De Geer there is for instance an uncertainty if the hearing of self is too high or if the hearing of others is unclear. Reading the comments, it is probably a combination of low clarity and too high level from others. Some sections of the orchestra are separated with long distances, which results in a low level of direct sound relative to reflected sound from the closed stage shell. Therefore, the sound from others is “muddy” and is difficult for the directional hearing to concentrate on the instruments you need to synchronise with (law of the first wave front).

3.2 Tuning week in the De Geer hall

Based on the findings from the pre-study different measures where planned for a tuning week together with the whole orchestra (78 musicians). The main purposes were to improve the hearing of others concerning ensemble, precision and clarity, achieve good balance between self and others and decrease the sound level. In other words, to achieve a clearer and less “mixed” and “noisy” sound character on stage. To work together with a symphony orchestra concentrating on stage acoustics for a whole week gave also the possibility to investigate the validity of objective parameters in full scale.

The first tests contained quite large differences such as with/without ceiling reflectors, with/without back-drop draperies etc. During the tuning week in total 14 stage configurations were tested. The initial and the final test configuration are shown in figure 4-5. In the final test the following changes were made:

- Absorptive heavy draperies were hung in front of the rear wall and in front of the side walls (appr. 3.5 m above the stage floor).
- Ceiling reflectors were opened on the sides and back leaving a central part which was heightened from appr. 7.7 to 8.2 m. In the stage tower above there was some absorptive textiles and diffusing fly bars etc. The front reflector was lowered from appr. 9.2 to 8.4 m and angled more horizontal.
- Screens in front of brass section (with absorption towards the brass) for attenuation of sound to the violas.
- The orchestra was moved forward towards the audience and the musicians were moved closer together (the brass section were initially sitting very far back).
- Six side reflectors (2x4 m) making the stage width smaller and angled towards the audience.
- Reflectors appr. 1.5 m behind each French horn.
- Small personal reflectors behind percussion players to improve hearing of others.

Figure 4. Initial (left) and final stage configuration (right) during the tuning week.

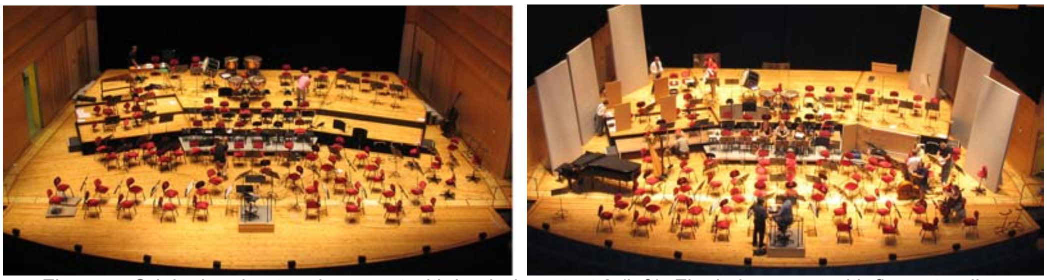

Figure 5. Original orchestra placement with back-drop, test 2 (left). Final placement with floor-standing reflectors and screens, test 14 (right).

For each test binaural impulse responses where measured from an omni-directional loudspeaker 1 m above the floor and 1 m in front of five musicians to binaural microphones on the same five musicians (Trumpet, Viola, Oboe, 2nd Violin, Cello) and to a dummy head in the audience, see figure 6. During the measurements, five musicians and all chairs, music stands and percussion were present on stage. After the measurements the whole orchestra played seven different pieces of music for appr. 20 minutes, which were recorded binaurally. Directly after the playing the 78 musicians (and four listeners) filled in the questionnaires. Only the three questions with the highest importance in the pre-study were used (level, hearing of others, balance own/others). By the end of each day the musicians were discussing in groups. Then the whole orchestra was gathered and the results from the group discussions were reported and noted. Totally, the 14 tests resulted in 420 binaural impulse responses (840 mono) and 3276 judgements on scales by the musicians.

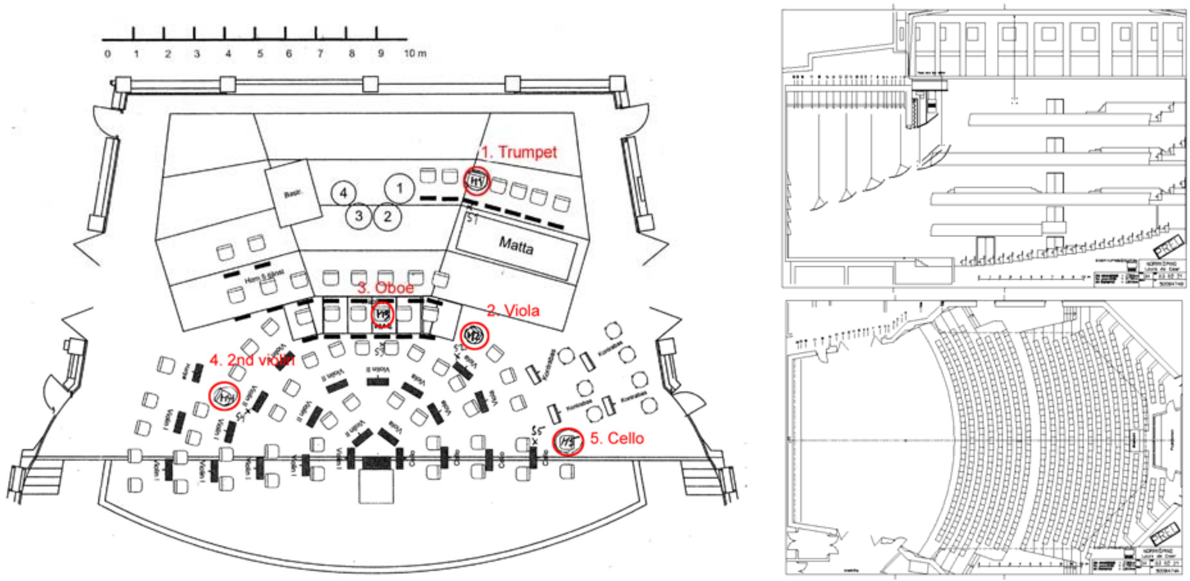

Figure 6. The De Geer hall. The five measurement positions on stage in the original placement of the orchestra (left). Cross section and plan (right). Note that the heights of the ceiling reflectors are not the one used.

The music played were excerpts from:
1. Mozart: Molto Allegro from Symphony no 40 (appr. 120 s)
2. Tjajkovskij: Suite from the Nutcracker, Dance Arabe, last bars of (appr 30 s).
3. Beethoven: Symphony no 5, from the beginning of the last movement (appr. 130 s)
4. Beethoven: Symphony no 5, from bar no 150 (appr. 70 s)
5. Brahms: Symphony no 1, end of last movement (appr 90 s)
6. Sjostakovitj: Symphony no 5, from slow movement (appr. 220 s)
7. Sjostakovitj: Symphony no 5, end of last movement (appr. 130 s)

The following parameters were derived from the impulse responses in octave bands: EDT, T_{30}, T_{20}, T_c, C_{50}, C_{80}, D_{50}, Strength, IACC (total, early 0-80 ms, late 80- ms) ST_{Early}, STI and MTF (for definition see [15]). Both individual measurements and averaged “others to own” have been analysed. However, the analysis of this huge material is not finished but some results are discussed below.

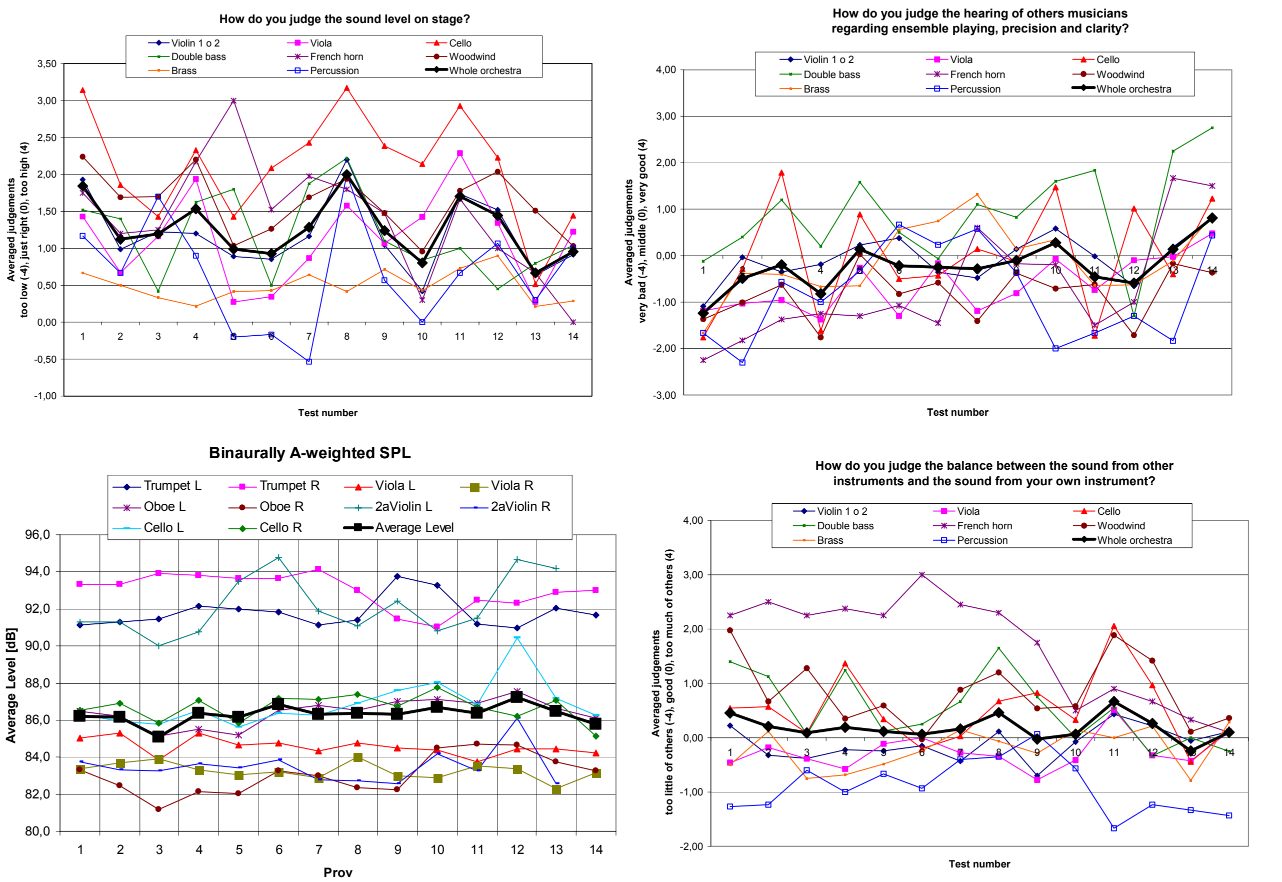

Figure 7. Mean values of judgements for test 1-14. Measured LAeq from music piece no 7 for left and right ear and total mean (lower left).

As shown in figure 7 the measured L_{Aeq} of the music piece with the highest level have a very small variation between the tests. The trumpet player and the left ear of the 2^{nd} violin have the highest L_{Aeq}. The viola player sitting in front of the brass section has almost 10 dB lower level than the trupet player.

DISCUSSION

From this study it is clear that the scattering of subjective judgements is high. This makes it more difficult to draw clear conclusions about the validity of objective parameters. Nevertheless, we have tried to interpret some results.

It is clear that the judgement of sound level have a very low correlation both to measured SPL from the music and the measured Strength. Measured mean values for each test vary very little. The only clear agreement between judged and measured sound level is averaged Strength from others which drops by 1.5 dB from test 1 to test 2 when the back-drop velvet is exposed. When measuring the music the own instrument and the strong instruments in the vicinity probably determines the SPL at the musicians ears. However, the musicians “filter” away the sound from their own instrument and probably judge the character of the sound which is more dependent on the fine structure of the early impulse response. A “muddy” sound is probably judged to have a higher level. Assuming this, one should expect at least some systematic agreement to D_{50}, C_{50}, STI, EDT or $IACCE_{0\text{-}80ms}$, but this is not the case.

In average the judged hearing of other gets better with side draperies exposed and without ceiling reflectors. However, some ceiling reflectors was kept above strings and woodwind to get better balance for the audience. In this study the support ST_{Early} seems to correlate very weakly to hearing of others and balance own/others. Lower values are often judged to have better hearing of others. The time window 20-100 ms means that reflections from objects closer than appr. 4 m is not included. For the judgements of balance reflections earlier than 20 ms is probably important. This is illustrated by the judgements of the French horn players who perceive a big difference when reflectors are placed close behind them. It is also highly probable that the level and delay time for the direct sound from others is important (not included in ST_{Early}). If the goal is to have a design parameter which is independent of the orchestra arrangement and nearby reflectors ST_{Early} could be useful. However, it must then be clarified that the reflections between 0-20 ms do not mask the influence of the later reflections. In the last test the averaged $IACC_{Early}$ from others are more equal (appr. 0.6). It seems that the higher $IACC_{Early}$ often is preferred for hearing of others, but this is not consistent.

For the dummy head in the audience (middle of the stalls) there is no variation in SPL from the music and the differences in the measured parameters are smaller than the just noticeable difference. However, subjectively there is a clear difference between the initial and final test in clarity, transparency and tone quality, for instance in the final test one can hear details such as double basses playing without vibrato and celli with vibrato. This indicates that the parameters used are probably too rough to detect these types of important differences.

Some more observations:

- Support ST_{Early} is decreased by appr. 1.5-2 dB in average and subjectively the hearing of others is increased from rather bad to rather good. This investigation indicates that ST_{Early} can not by its own explain the relative large subjective difference.
- Averaged Strength from others has a very small variation, less than 2 dB. The judged sound level variation is obviously much higher than indicated by Strength.
- When the orchestra is moved forward and put closer together and the brass section is moved appr. 2 m closer the violas (test no 5 to 7) the average $IACC_{Early}$ from others to the trumpet is increased from 0.4 to 0.6, Strength is increased 1 dB and ST_{Early} is decreased 2 dB. The judgements show that the hearing from others is increased and the balance becomes good. Judged level is almost the same. This indicates that further studies of binaural parameters could be useful.
- The music SPL for the 2^{nd} violin is very different for left and right ear. The left ear is appr. 10 dBA higher. Both the own instrument and the loudest of other instruments are exposed to the left ear mainly. However for the viola the difference is only appr. 1 dBA.
- As expected D_{50} and C_{50} are maximum when the orchestra is tightend.

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