RENOVATION OF THE CONCERT HALL DE DOELEN, ROTTERDAM, THE NETHERLANDS EARLY REFLECTIONS STRENGTH AND STAGE ACOUSTICS

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1 INTRODUCTION

The main hall of De Doelen, Rotterdam, the Netherlands, is a concert hall for classical music with a volume of about 27,000 m³ and a seating capacity of 2242. In 2009 the hall will be renovated and as a part of the renovation design, research has been done on the room acoustics. Despite the very good reputation of the main hall acoustics[1,2], possible improvements are investigated within the scope of the renovation. One of the aspects under investigation is the stage acoustics.

When opened in 1966, the main concert hall in De Doelen, was fitted with six canopies above the stage platform[3,4], see figure 1. Their function was twofold:
- to provide a large part of the audience with early reflections;
- to create good ensemble conditions for the musicians on stage.

Despite good reviews after the opening, a few years later the canopies were removed, because they caused unwanted reflections at the recording microphone positions just below the canopy. Since then, a significant percentage of the orchestra is not completely satisfied with the acoustic conditions on stage. During the design process of the renovation, possibilities to re-introduce a stage canopy and influences of shape and materials are investigated.

The investigations consist of 5 parts:
a) acoustical measurements in the main hall
b) subjective research into the perception of the stage acoustics by the musicians
c) scale model research
d) computer modeling
e) laboratory measurements

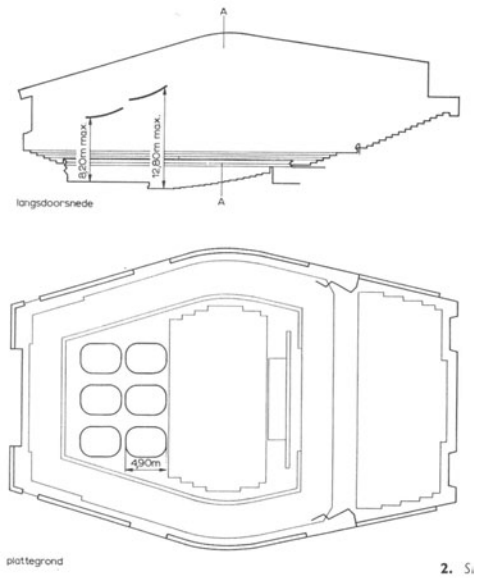


Figure 1. Vertical and horizontal section of the main hall De Doelen, 1966

This paper focuses on parts b) to d).

2 THE QUESTIONNAIRE

In order to obtain a good overview of the opinions concerning the stage acoustics, the musicians of the Rotterdam Philharmonic Orchestra were asked to fill out four questionnaires. They were asked to give their opinion on their own playing conditions, the ensemble conditions, the stage and hall acoustics in general. An overview of the questions is given in the annex at the end of this paper.
The questionnaires were handed out after rehearsals in De Doelen (twice), in De Singel (Antwerp) and in Het Concertgebouw (Amsterdam). The response was about 50%, 30% and 25% respectively. The purpose of the second questionnaire on De Doelen stage was to investigate if the musicians had changed their opinion after a rehearsal and concerto in another hall, which didn't appear to be the case.

The questionnaire was anonymous, but the musicians were asked to specify his or her instrument so the answers can be related to a position on stage. To compare the subjective opinions with acoustic parameters, the answers were given a score from minus 3 to plus 3 in the data processing. The goal of this subjective study is to compare the results of the questionnaire with the results of the acoustic measurements that have been performed. This should give a direction to investigate the influence of possible alterations of the stage surroundings, like the canopy above the stage.

From the questionnaires the most important conclusion on loudness and intelligibility is that the musicians of the Rotterdam Philharmonic Orchestra judge that De Doelen Main hall has:
- low loudness en intelligibility at the front positions of the stage, especially for the strings;
- high loudness from the rear position of brass and percussion to the other instrument groups.

The stage of De Singel is judged to be louder than De Doelen.

The timbre in De Doelen of the loud and high-frequency-instruments (brass and violins) is judged as rather shrill, the low-frequency instruments are judged as rather dead/woolly. Both De Singel and Het Concertgebouw do not give this judgement, although also in De Singel the brass and percussion are judged as loud and too shrill as well.
As for Het Concertgebouw, the musicians of the RphO were very enthusiastic about the stage conditions. Because this contradicts the general opinion of the musicians of the Concertgebouw Orchestra, the results of the questionnaire of Het Concertgebouw are used in a reserved manner.

Improvements of the acoustic of De Doelen stage are focussed on an increase of loudness and intelligibility of the strings and to reduce the shrill character of the hall and make it sound warmer.

3 MEASUREMENTS

The goal of the measurements was to objectively describe the stage environment and, if possible, to correlate it to the subjective judgement of the musicians.

The measurements are performed according to ISO 3382 and in the unoccupied halls with orchestra furniture on stage. The stage risers were in the position equal to rehearsal and concerto.
The impulse responses between source and microphone were measured at the following locations:
- at a distance of 1 m in the middle of the instrument groups;
- from source location 1 (cello's) to the middle of the other instrument groups;
- from source location 2 (trumpets) to the middle of the other instrument groups;
- from source location 16 (leader) to the middle of the other instrument groups.
- from source location 1 and 2 to audience locations (not described in this paper).

The middle positions of the instrument groups were chosen according to the orchestra formation of the concertoes on January 17th and 18th, which is the American arrangement.

If not mentioned otherwise, the presented results of the measurements are averaged over the octave bands 500 to 2000 Hz.

De Doelen is a large hall, which results in relative late reflections from the walls and ceiling. At the stage there are early reflections from the marble wall that surround the stage and the parterre. The impulse responses measured on stage in the existing hall without stage reflector show a gap between these early stage wall reflections and the reflections from walls and ceiling, see figure 2.

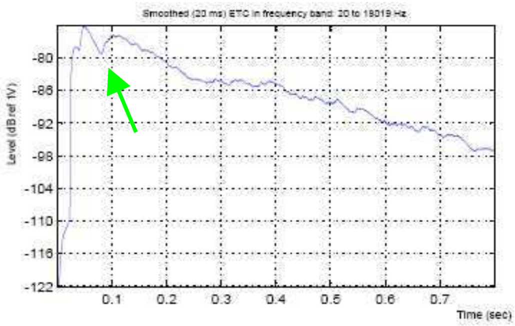


Figure 2. Smoothed energy time curve from IR measured on stage.

4 COMPARISON MEASUREMENT RESULTS AND MUSICIANS OPINION

The loudness and intelligibility of the musical instrument depends above all things on the instrument itself, its loudness, its frequency range and its directivity. The stage and its surroundings won't change the individual character of the different instruments. But depending on the size and form of reflecting surfaces, the stage surroundings can add early first order reflections, which enhance the "natural" sound of the instruments.
It is noted that there is a significant individual variation in the response on the questionnaires. For that reason the responses are averaged. Nevertheless this average judgement will also have a limited accuracy. The number of measured situations (Doelen, Singel) is limited and therefore the spread in acoustical quality is rather low. These factors make that is difficult to find a significant relation between measured parameters and subjective quality.

4.1 Loudness and intelligibility of the musicians' own instruments

The opinion of the musicians on loudness and the intelligibility of their own instruments is compared to the measured values of these support values ST1 and ST2[5], but also to speech intelligibility, direct-to-reverb, clarity (C_{80}) and definition (D_{50}). All these parameters are derived from the measured impulse response. Except for the support, no clear correlation was found between the parameters mentioned above and the musicians' judgement.
Generally it is considered that the support ST1 should be –12 to -15 dB and the ST2 –9 to –14 dB. (Which is not a statement that this is a sufficient condition, since influence of coloration or typical reflection patterns are not included).
It is noted that in the calculation of the ST1 only reflections after 20 ms are taken into account. This makes it a difficult parameter for musicians positioned at a distance less than 3,5 m to a wall. In De Doelen this is the case for percussion, brass and double bass.

For De Doelen, the musicians who judged the loudness of their own instrument as on the quiet side are the violins, the violas and the cellos (and the double bass). This correlates well to the measured ST values of –16 to –17 dB. The natural less loud instruments at the front of the stage receive the least early enhancing reflections from the stage surroundings.
In De Singel only a few musicians were not completely happy with the loudness or intelligibility of their instrument. This also corresponds quite well with the fact that all ST values are within the mentioned proposed range.
When the measured ST1's of the two stages are compared to the musicians opinions in one graph, a clear trend can be observed: a higher value for ST1 gives in general a higher score for loudness and intelligibility, See figure 3.

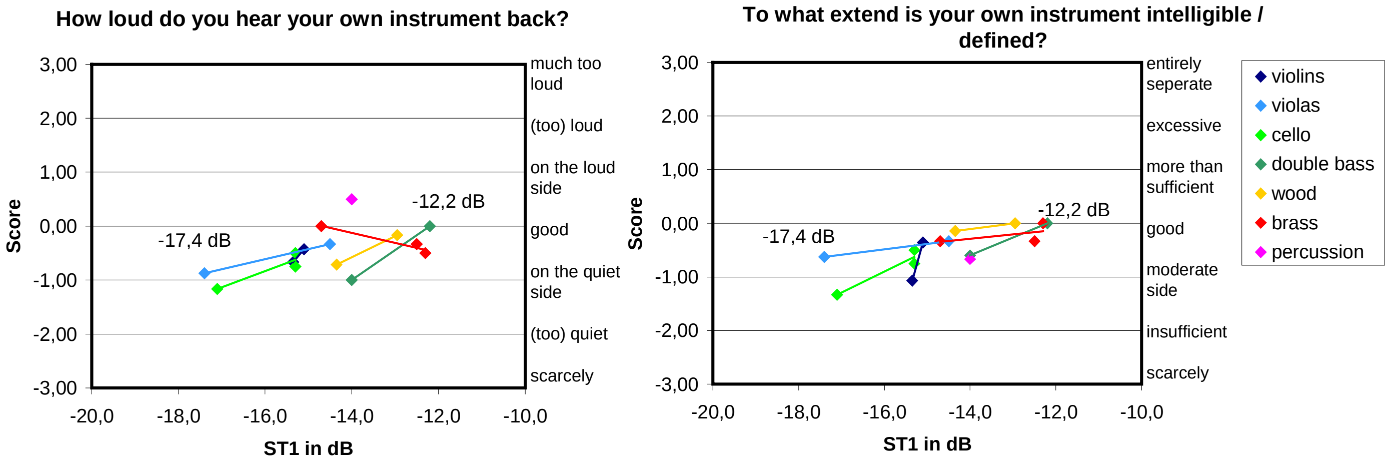


Figure 3. Relation between ST1 and musicians' own playing conditions

4.2 Ensemble conditions on loudness and intelligibility

To evaluate ensemble conditions, the acoustic parameters AL_{cons}, Dir/Rev, C_{80}, D_{50} and ST2 are derived from the measured impulse responses and compared with the musicians opinions on loudness and intelligibility. The ST2 is in this case not compared to the proposed value, but because of its time window, it might be a good parameter to evaluate the influence of the stage environment, especially when looking at possible improvements. Although one would expect a higher score on loudness or definition with a lower AL_{cons} or higher Dir/Rev, C_{80}, D_{50} and ST2, no clear relation was found. The main difference for ensemble conditions between De Doelen and De Singel is that almost 70% of the musicians judged the loudness and intelligibility of the violins as moderate (or worse) in De Doelen, to about 45% in De Singel. No clear correlation between the mentioned parameters and this judgement has been found though.

To describe the influence of the stage environment on the perceived loudness and intelligibility on stage, a parameter is required that is related to loudness, but not dependent on the distance between microphone and source. Otherwise the differences in distance at stage will dominate the resulting values which makes them incomparable. To describe the influence of the stage surroundings on intelligibility, only the early reflections are important (with no echoes or flutters present). Therefore the "strength" parameter G is used, but with a time window from 5 to 80 ms after direct sound, which excludes direct sound and takes into account reflections from surfaces up to a distance of roughly 14 m (from middle stage), which is of course arbitrary. It is referred to as Early Reflections Strength, $G_{5\text{-}80}$ in dB.

$$G_{5-80} = 10\log\frac{\int_{5}^{80} p^2(t)dt}{\int p_{10}^2(t)dt}[dB] \qquad (1)$$

When the loudness of De Doelen stage was compared to De Singel, it appeared that the average $G_{5\text{-}80}$ measured (at a source to microphone distance larger than 5m) in De Singel is 1,3 dB higher than in De Doelen, even with larger distances between the musicians. It also related quite well to the musicians opinions. From the fact that at a certain value of Early Reflections Strength the judgement differs for different instrument groups, it seems that it will be hardly possible to define an optimum value for all instruments. It may be done for individual instrument groups. But when asked "how loud do you hear a particular instrument group", a higher value relates quite well to a higher $G_{5\text{-}80}$, see figure 4.

The measured impulse responses and survey from research on speech intelligibility on stages of 20 concert halls[6,7] is also used to evaluate the $G_{5\text{-}80}$, see figure 5. The amount of data is far too little and the spread too large to draw conclusions on an optimum value, but nevertheless, it is quite consistent that a higher value for $G_{5\text{-}80}$ results in a higher subjective value on ensemble conditions.

The $G_{5\text{-}80}$ is therefore used to evaluate the influence of the proposed alterations in De Doelen on the ensemble conditions, with the aspiration to enhance the $G_{5\text{-}80}$ across stage.

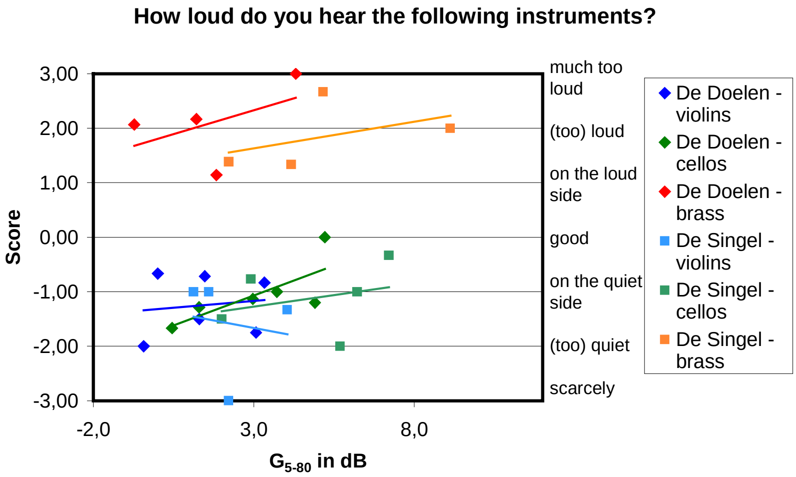


Figure 4. Comparison of $G_{5\text{-}80}$ to the musician's opinion

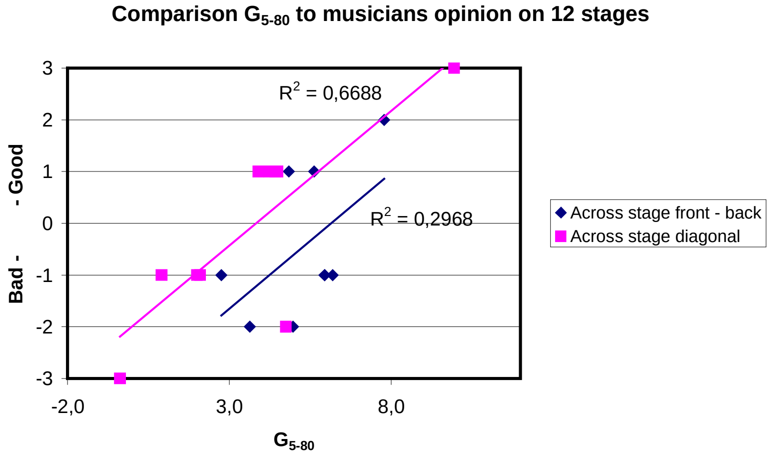


Figure 5. Comparison G5-80 to musician's opinion of 12 stages

4.3 Timbre

The musicians judgement on the timbre of the different instruments in De Doelen is that the loud and high-frequency-instruments are shrill, and the low-frequency instruments are judged as dead/woolly. This can be related to the measured reverberation time in the hall. The low frequencies have a shorter reverberation time (2.1 s) then the mid frequencies (2.3 s). Because of this, the hall lacks some "warmth", which is also noticeable for the musicians on stage. It is proposed to lengthen the reverberation time of the hall at low frequencies, mainly by adding weight to the surface materials of the hall.

Besides that, a few tests were done with the marble blocks which form the stage and parterre surroundings. One of the tests involved the high frequency reflections from the marble due to its flat and smooth (hard) surface. A small test set-up was made in an anechoic room with impulse sound incident on a marble plate. The microphone was placed 1 m in front of the plate. The frequency response of the smooth plate (as it is now) is compared to a plate with 3 mm deep, 2 cm wide slits. The frequency response with the irregular structure is lower and smoother, especially at the high frequencies (>8 kHz). Listening to the impulses it was concluded that the sharpness of tone was less with the slits.

5 INVESTIGATION RESULTS OF PROPOSED REFLECTOR

5.1 Stage Reflector

A stage reflector is proposed to improve the support at the front of the stage and the ensemble conditions. The stage reflector is positioned at a height of 10.5 m above the front of the stage and has slightly curved panels for diffusive reflections back to the stage. The reflector will be part of a suspended technical ceiling, the other parts of this technical ceiling will be acoustically transparent.
By means of a 1:10 scale model and a computer model (CATT-Acoustic) the influence of the proposed reflector as well as the influence of the original (1966) reflector is investigated. The original stage reflector consisted of six canopies and the front three were (according to pictures and drawings from then) quite tilted, and therefore primarily reflecting to the audience and as such not back to the stage (see also figure 1).

Figure 6. Proposed reflector in scale model

It is noted that besides the proposed reflector other reflectors have also been investigated. A smaller reflector gave to little improvement, especially at the edges of the stage. A larger reflector gave too much influence in the audience area and reduction of the reverberation time.

5.2 Scale model

Figure 6 gives a photo of the scale model from behind the investigated stage reflector. Figure 7 gives the measured impulse responses from B1 to M2 and from B2 to M1.

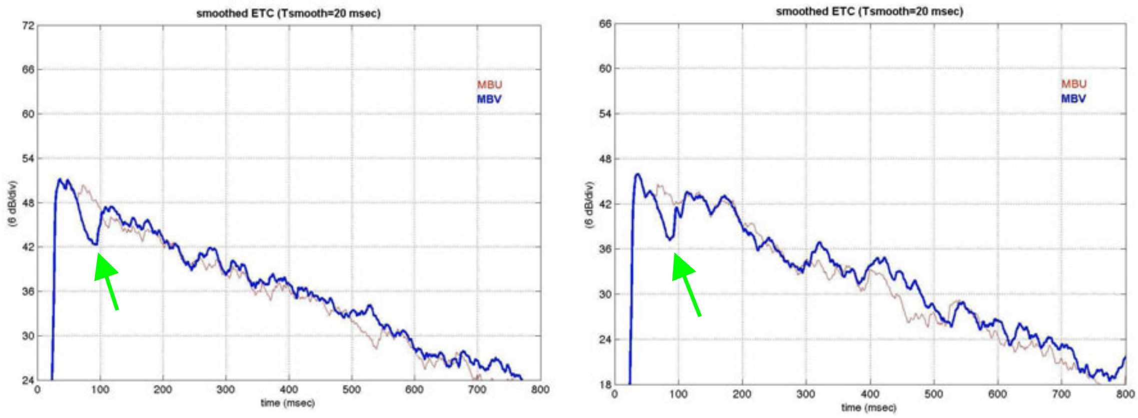


Figure 7. Scale model impulse responses with (red) and without (blue) stage reflector. Left is from B1 (cellos) to M2 (trumpets), right from B2 (trumpets) to M1 (cellos).

The stage reflector clearly fills the gap between the early reflections from the existing stage enclosure and the ceiling, which is marked by the green arrow. Within the own instrument groups (B1-M1 and B2-M2) the ST1 increases with 0.4 and 0.7 dB respectively at positions at the front of the stage. For a position more in the middle an increase was found of 1.7 dB.

Between the instrument groups, it can be concluded that for all positions the early reflections strength (G_{5-80}) increases with about 1.5 dB (averaged), see also figure 8, that also incorporates the measured influence of the original reflector.

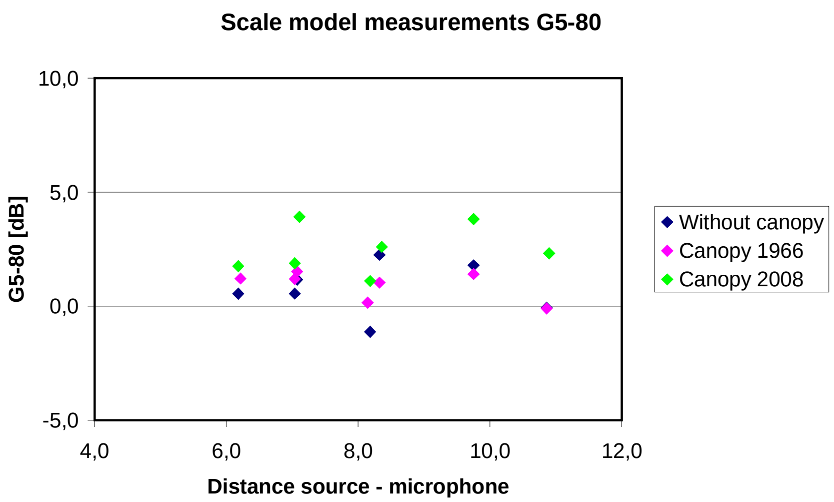


Figure 8. Measured G_{5-80} on stage of the scale model, with and without canopy

5.3 Computer model

Most important objective of the computer model investigation was to determine the impact of the stage reflector on the reverberation time of the hall. With the proposed reflector the impact on the RT due to the reflector is minus 0.1 s, which will be compensated by other means (reduction of absorption of walls, ceiling, chairs). Just like in the scale model, the computer model calculations show that adding the stage reflector fills the gap between early reflections from the enclosure and the relative late reflections from the existing ceiling, resulting in an increase in ST1 and $G_{5\text{-}80}$ of about 1 dB.

5.4 Conclusion

The main alteration investigated in respect to stage acoustics of the main hall of De Doelen is the introduction of a stage reflector. From comparison between subjective research and measurements it was concluded that increasing support (ST1) and Early Reflections Strength ($G_{5\text{-}80}$) would be required to improve stage conditions. The Early Reflections Strength ($G_{5\text{-}80}$) is not a standardized parameter but is proposed for this purpose.
From scale model measurements and computer calculations it was found that the stage reflector as proposed increases the ST1 values (for own instrument) with 0.4 to 1.7 dB and increases the audibility of other instruments expressed in the Early Reflections Strength ($G_{5\text{-}80}$) with approximately 1 to 2 dB. The most significant influence of the stage reflector lies in filling the gap between very early reflections from the side walls and later reflections from walls and ceiling. The improvement is therefore expected to be modest but consistent.
Proposed improvements in respect to timbre are: reduction of low frequency absorption and rougher surface finishing around the orchestra.

6 REFERENCES

1. M. Barron, Auditorium Acoustics and Architectural Design, 1993
2. L. Beranek, Concert halls and opera houses, Springer, 2004
3. C.W. Kosten, De Nagalmtijden van De Doelenzalen te Rotterdam, NAG publicatie nr. 9 (1967, in Dutch)
4. P.A. de Lange, Aspecten van het akoestisch advies, NAG publicatie nr. 9 (1967, in Dutch).
5. A.C. Gade, Investigations of Musicians’ Room Acoustic Conditions in Concert Halls. Part I and part II. Acustica volume 69 (1989).
6. K.-H. Lorenz-Kierakiewitz, M. Vercammen, Podienakustik und Sprachverständlichkeit in Konzertsälen, DAGA (2008 in German).
7. K.H. Lorenz, R.A. Metkemeijer, S. Mercier, Objektive Erforschung der Podiumsakustik Europäischer Konzertsäle, DAGA (2005 in German).

7 ANNEX, OVERVIEW OF THE QUESTIONNAIRE

Questionnaire experience acoustics on stage (English version)

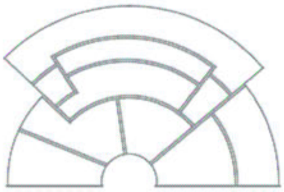
PEUTZ

Dear musician,

Plans for renovation of the main hall of de Doelen are currently worked out. Bureau Peutz advises about the acoustical aspects regarding the renovation. Part of the research is the investigation into the present quality of the stage environment. We would gladly invite you to answer following questions individually, so we can form a right notion of your subjective experience of the acoustics on stage. Later on we will relate this subjective experience to the results of objective acoustical measurements.

We would like to thank you for your assistance!

Instrument: Age: Position in orchestra and instrument group: *(please indicate in the figure)*



1. How **loud** do you hear your own instrument back?	*scarcely*	*(too) quiet*	*on the quiet side*	*good*	*on the loud side*	*(very) loud*	*much too loud*
2. To what extent is your own instrument **intelligible** ('defined')?	*scarcely*	*insufficient*	*on the moderate side*	*good*	*more than sufficient*	*excessive*	*sounds entirely separate*
3. How do you experience the **timbre** of your own instrument on stage?	*too boxy / sharply*	*shrill*	*on the shrill side*	*well-balanced*	*a bit dead / woolly*	*dead / woolly*	*much too dead / woolly*

4. How **loud** do you hear back the following instruments?

	violins	violas	celli	double basses	harps	grand piano	reeds	brass	percussion
scarcely	❑	❑	❑	❑	❑	❑	❑	❑	❑
(too) quiet	❑	❑	❑	❑	❑	❑	❑	❑	❑
on the quiet side	❑	❑	❑	❑	❑	❑	❑	❑	❑
good	❑	❑	❑	❑	❑	❑	❑	❑	❑
on the loud side	❑	❑	❑	❑	❑	❑	❑	❑	❑
(very) loud	❑	❑	❑	❑	❑	❑	❑	❑	❑
much too loud	❑	❑	❑	❑	❑	❑	❑	❑	❑

5. To what extent are the following instruments **intelligible** ('defined')?

	violins	violas	celli	double basses	harps	grand piano	reeds	brass	percussion
scarcely	❑	❑	❑	❑	❑	❑	❑	❑	❑
insufficient	❑	❑	❑	❑	❑	❑	❑	❑	❑
on the moderate side	❑	❑	❑	❑	❑	❑	❑	❑	❑
good	❑	❑	❑	❑	❑	❑	❑	❑	❑
more than sufficient	❑	❑	❑	❑	❑	❑	❑	❑	❑
excessive	❑	❑	❑	❑	❑	❑	❑	❑	❑
sounds entirely separate	❑	❑	❑	❑	❑	❑	❑	❑	❑

6. How do you experience the **timbre** of following instruments on stage?

	violins	violas	celli	double basses	harps	grand piano	reeds	brass	percussion
too boxy / sharply	❑	❑	❑	❑	❑	❑	❑	❑	❑
shrill	❑	❑	❑	❑	❑	❑	❑	❑	❑
on the shrill side	❑	❑	❑	❑	❑	❑	❑	❑	❑
well-balanced	❑	❑	❑	❑	❑	❑	❑	❑	❑
a bit dead / woolly	❑	❑	❑	❑	❑	❑	❑	❑	❑
dead / woolly	❑	❑	❑	❑	❑	❑	❑	❑	❑
much too dead / woolly	❑	❑	❑	❑	❑	❑	❑	❑	❑

7. To what extent do you experience a **balanced general impression** of the whole orchestra?	*very bad*	*bad*	*moderate*	*quiet good*	*(very) good*	*excellent*	
8. How do you experience the **melting of sounds** of the different instruments?	*very bad*	*bad*	*moderate*	*quiet good*	*(very) good*	*excellent*	
9. To what extent are the stage acoustics **supporting your play**?	*very bad*	*bad*	*moderate*	*quiet good*	*(very) good*	*excellent*	
10. What is your **overall opinion** of the acoustics on stage?	*very bad*	*bad*	*moderate*	*quiet good*	*(very) good*	*excellent*	
11. How good are the stage acoustics of this hall **compared to** an other hall you are familiar with?	*much worse than....*	*worse than....*	*a little worse than....*	*a little better than....*	*better than....*	*much better than....*	***in comparison with:***
12. How do you experience the **reflections** of the sound **from the hall**?	*very bad*	*bad*	*moderate*	*quiet good*	*(very) good*	*excellent*	
13. What is your overall opinion of the **acoustics of the hall**?	*very bad*	*bad*	*moderate*	*quiet good*	*(very) good*	*excellent*	

14. Do you have further comments towards the acoustics on stage?