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New (stage) parameter for conductor's acoustics? - part 2: further investigation on $LQ_{7\text{-}40}$

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ABSTRACT

In the previous paper 'New (stage) parameter for conductor's acoustics?' a new parameter ($LQ_{7\text{-}40}$) has been defined. The research with respect to this parameter was presented at ICA2007 in Madrid and at Acoustics'08 in Paris. As elucidated, the objective measurement results for $LQ_{7\text{-}40}$ seem to correspond with the subjective perception of the musicians and the conductor, for the two measured stages, and provide information about the 'transversely support over the stage' as well. However, the amount of measured situations was limited. As the parameter $LQ_{7\text{-}40}$ seems to be very promising, the validity and applicability of this parameter have been further investigated. Therefore measurements have been carried out on stages of several Dutch concert halls. Additionally the experiences of the orchestra and the conductor have been determined through a questionnaire. In this paper the results of this investigation are presented and the usefulness of $LQ_{7\text{-}40}$ for the design and control of stage acoustics in concert halls is elucidated.

1. INTRODUCTION

In the previous paper[1] the $LQ_{7\text{-}40}$ is defined to fine-tune the stage acoustics and to describe the acoustics at the conductor's position. Consulting experience[2] indicated a need for such a parameter: the conductor experienced noticeable changes in the 'stage' acoustics for four different canopy configurations. However, the 'commonly' used stage parameters did not indicate a (noticeable) difference. This lead to the idea of taking a close look on the existing stage parameters as well as trying to find a 'new' parameter that would correspond with the experience of the conductor and that would provide information about the sensitivity of the

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musician's position on the stage in order to fine-tune the stage acoustics. Meyer also investigates the conductor's acoustics and states in his paper[3] that some requirements put special demand on the room-acoustical conditions at the conductor's location.

This study is aimed at determining the validity and applicability of $LQ_{7\text{-}40}$. In order to further investigate the usefulness of this parameter for the design and control of stage acoustics, measurements have been carried out in seven different Dutch concert halls[4]. Furthermore the experiences of the Dutch Students' Orchestra (NSO, musicians and conductor), performing in these concert halls within two weeks, have been determined through a questionnaire[4] as well.

2. CONCERT HALLS AND STAGES

For the earlier paper measurements have been carried out on the stages of Casa da Musica (Porto, Portugal)[1,2] and Muziekgebouw aan de A2 (Leidsche Rijn, the Netherlands)[1]. For this paper extra measurements have been carried out on the stages of seven Dutch concert halls. Figure 1 shows an overview of the measured stages (without orchestra). As can be seen, the concert stages differ in shape, size, materials and reflecting surfaces.

Casa da Musica[d,e]

stage area	200 m^2
stage conditions	empty

Muziekgebouw aan de A2[d,e]

stage area	± 200 m^2 (total 370 m^2)
stage conditions	stage risers

Concertgebouw Amsterdam

stage area	150 m^2
stage conditions	risers, chairs & stands

De Doelen Rotterdam

stage area	210 m^2
stage conditions	empty

Dr. Anton Philipszaal Den Haag[e]

stage area	260 m^2
stage conditions	stage risers

De Vereeniging Nijmegen[e]

stage area	240 m^2
stage conditions	empty

Muziekcentrum Eindhoven[e]

stage area	200 m^2
stage conditions	empty

Muziekcentrum Enschede

stage area	220 m^2
stage conditions	risers & some instruments

Theater aan het Vrijthof Maastricht[e]

stage area	390 m^2
stage conditions	boxes in back of stage

Figure 1: Overview of measured stages (main auditorium)[4].

[d] The results for $LQ_{7\text{-}40}$ of these halls were presented in the earlier paper[1].
[e] With canopy/reflectors above stage.

3. STAGE PARAMETERS AND ACOUSTICS

Objective (measurable) stage parameters can be correlated to subjective categories. The objective parameters can be derived from the measured impulse response p(t). The sound on the stage can be divided into the direct sound, the 'early sound' as well as the 'late sound'. The 'early sound' consists of sound being reflected (e.g. by wall, ceiling) and arriving within 40 ms after the direct sound[5]. The early sound provides information of the sound, produced by the other instruments, not being part of the direct sound (due to directional characteristics of the instruments as well as objects between source and receiver). This part of the sound is important for the musicians and conductor for the playing ensemble (and to find balance within the orchestra)[6]. The 'commonly' used stage parameters focus on the relation between the (early) reflections and the direct sound, for example the objective parameter *STearly* (Support)[7,8].

Especially for fine-tuning the stage acoustics the influence of the (very) early sound is interesting, because these (small) changes in the stage environment will most likely influence the sound in range of 40 ms. By comparing the very early sound to the 'late' early (40 - 80 ms) and late reverberant (80 - ∞) sound, an impression of the (relative) amount of early energy can be obtained. The $LQ_{7\text{-}40}$ (eq. 1) focuses on the amount of very early sound compared to late early and late reverberant sound.

$$LQ_{7-40} = 10\log\left(\frac{\int_{7}^{40} p^2(t)dt}{\int_{40}^{\infty} p^2(t)dt}\right) \quad [\text{dB}] \tag{1}$$

4. RESEARCH METHOD

For this paper we had the opportunity to use the data (impulse responses and questionnaires) from a research of Eindhoven University of Technology[4]. The results of that research are elucidated in another paper[9].

A. Measurements

The measurements have been carried out on the stages of seven unoccupied Dutch concert halls by two students of Eindhoven University of Technology[4]. Two different types of measurements have been carried out:

1. measurements without orchestra (figure 1) with four source and eleven receiver positions;
2. measurements with orchestra on stage, with one source position and two receiver positions.

Gade suggests in his paper[10] to carry out measurements with at least chairs and music stands on stage in order to provide some absorption and scattering as a rough substitute for the absent musicians, as well as avoiding too large and unrealistic reflections from eventual risers. In this research it was possible to carry out measurements with a complete orchestra on stage.

The measurements have been carried out with an omnidirectional sound source and omni-directional receivers. Impulse responses were measured by Dirac 4.1. The impulse response to noise ratio (INR[11]), providing information about the measured decay range, is at least 45 dB, which means the used impulse responses are of good quality.

The measurement positions and equipment are slightly different from those used for the measurements in Casa da Musica[1,2] and Muziekgebouw aan de A2[1]. The impulse responses have been measured at four source positions (representing the percussion, woodwinds, brass and string

section) and eleven receiver positions (height 1.3 m). All positions can be mirrored (in case of symmetrical stage environment).

Two receivers were placed at one meter from the source (e.g. R1f and R1r), one receiver at the conductor's position (R10) and the other receivers were distributed over the stage, based on a grid. Figure 2 shows the source and receiver positions. For measurement type 2, source position S1 and receiver positions R4 and R10 are used. They are placed in between the orchestra members and their equipment.

The source (height 1.3 m) is rotated four times in order to omit the influence of the source, not being fully omnidirectional. For all these source and receiver positions the *STearly* as well as $LQ_{7\text{-}40}$ are determined (software Dirac 4.1).

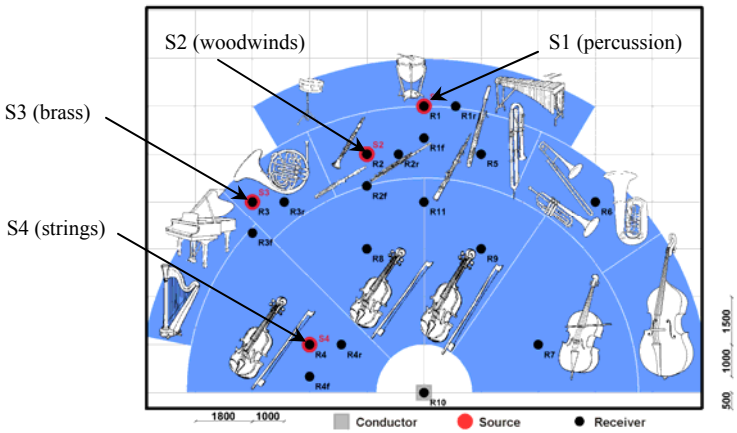


Figure 2: Measurement positions (red: source position; grey: conductor's position; black: other receiver positions), shown on example of stage plan.

B. Questionnaires

In order to determine the usefulness of the $LQ_{7\text{-}40}$, the measurement results for $LQ_{7\text{-}40}$ and the *STearly* are compared with the experiences of the musicians and conductor. As said we had the opportunity to use data from the research by Eindhoven University of Technology[4]: the conductor and musicians filled in questionnaires after each concert.

RESULTS

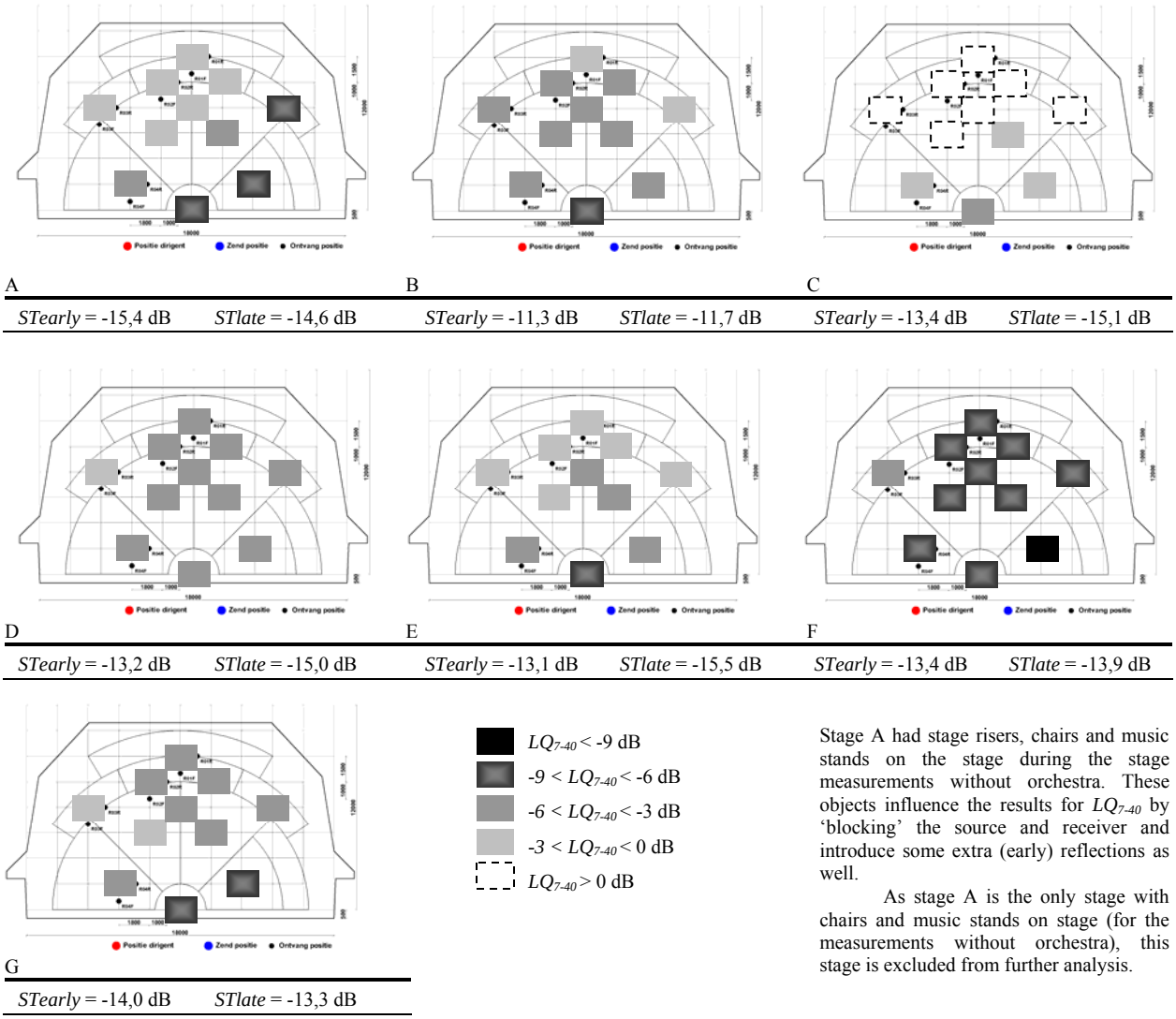
A. Measurements

This paper focuses on the validity and applicability of $LQ_{7\text{-}40}$. Therefore one of the aspects that has been investigated is the relation between the conductor's experience and an absolute value for $LQ_{7\text{-}40}$. The results for $LQ_{7\text{-}40}$, averaged over all source position for each receiver position (500-2000 Hz), for all stages of the seven Dutch concert halls is shown in figure 3. Due to privacy the halls are marked from A to G and the results are shown on an example of a stage plan.

The $LQ_{7\text{-}40}$ is on almost all measured stages lower at the conductor's position compared to the rest of the orchestra. This can be explained by the fact that on those stages the conductor is positioned further away from the (early) sound reflecting elements (stage walls etcetera) than the musicians are.

As can be seen in figure 3 the amount of very early reflections compared to the early and late reflections ($LQ_{7\text{-}40}$) on stage C is relatively high (compared to the other stages). This can be

explained by the amount of diffusing elements on the stage walls. Stage F shows a relatively low value for the $LQ_{7\text{-}40}$. This can be explained by the large stage with few diffusing elements.



Stage A had stage risers, chairs and music stands on the stage during the stage measurements without orchestra. These objects influence the results for $LQ_{7\text{-}40}$ by 'blocking' the source and receiver and introduce some extra (early) reflections as well.

As stage A is the only stage with chairs and music stands on stage (for the measurements without orchestra), this stage is excluded from further analysis.

Figure 3: Overview of averaged results for $LQ_{7\text{-}40}$, *STearly* and *STlate* for all measured stages without orchestra.

Influence of orchestra on $LQ_{7\text{-}40}$

To understand more of the influence of the orchestra (orchestra members and their 'equipment') on the $LQ_{7\text{-}40}$, measurements have been carried out on the stage with orchestra. On almost all the stages the values for $LQ_{7\text{-}40}$ drop approximately 0-5 decibels, see figure 4 for an example. The ('blocking'/ absorbent) effect of the orchestra on the very early (horizontal) reflections seems to be larger than the very early reflections caused by the music stands etcetera, which results in a lower value for $LQ_{7\text{-}40}$.

However, on stage F with orchestra the values for $LQ_{7\text{-}40}$ increase compared to the stage without orchestra, see figure 5. In this case this probably means that the amount of early reflections by the orchestra equipment is larger than the ('blocking'/ absorbent) effect of the orchestra. This can be explained by the large stage, which causes a relatively low value for $LQ_{7\text{-}40}$ in case of absence of the orchestra.

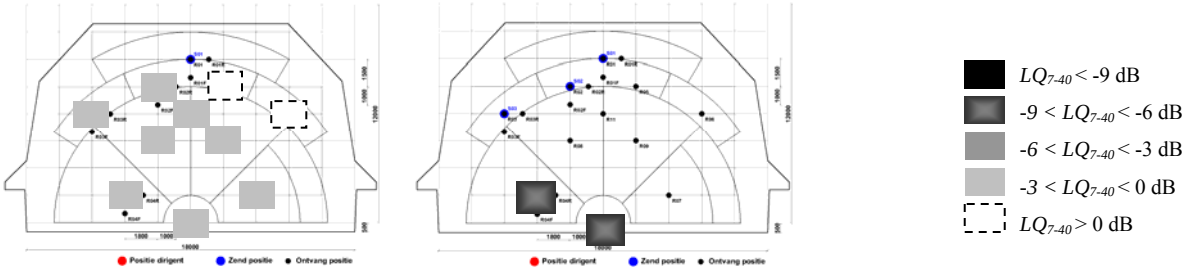


Figure 4: Stage E - overview of results for $LQ_{7\text{-}40}$ for source S1, without orchestra (left) and with orchestra (right); values for this stage differ about 3-5 dB for R10 and R4.

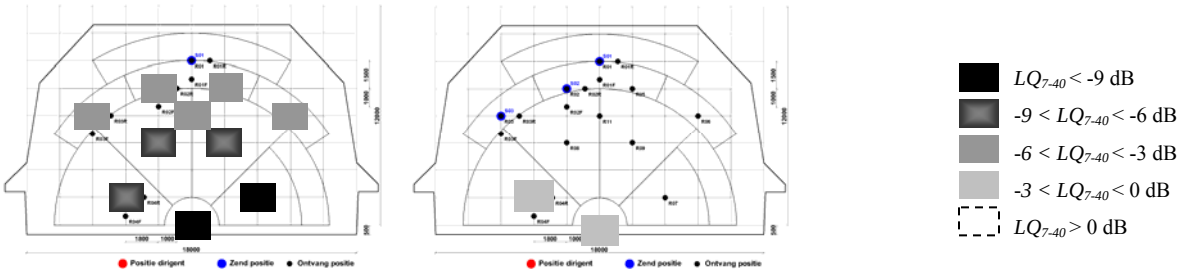


Figure 5: Stage F - overview of results for $LQ_{7\text{-}40}$ for source S1, without orchestra (left) and with orchestra (right); values for this stage differ about 7-8 dB for R4 and R10.

One must not forget that an orchestra influences the horizontal reflections more than the non-horizontal reflections. Meyer[3] states that the horizontal or less declined sound reflections from the side walls of the stage support the conductor's control of the homogeneity of the string groups (if the distance between the walls and the players of the back desk is rather small). Furthermore he concludes that a conductor needs to experience and control the spaciousness of the full sound. In the horizontal plane, he hears predominantly the direct sound of the orchestra. The conductor can perceive a spatial impression only from the space above his location or from higher room sections behind the orchestra.

Transversely support over the stage

Because the parameter seems to provide information about the 'transversely support over the stage', the results without averaging per source or receiver are very interesting. For example the orchestra (mainly string section and conductor) seems to have problems with hearing the (other) string instruments. Figure 6 shows the results for $LQ_{7\text{-}40}$ for source positions S4 (and S1 to compare). The situation with the source on position S4 is the only measured situation for this stage, which shows results of the $LQ_{7\text{-}40}$ below -6 dB.

The use of $LQ_{7\text{-}40}$ to provide more information about transversely support over the stage will be further elucidated in the following paragraph 'Questionnaires'.

Figure 6: Stage E - overview of results for $LQ_{7\text{-}40}$ for source S4 (left) and source S1 (right).

B. Questionnaires

To understand more of the values for $LQ_{7\text{-}40}$, the measurement results on the stage without orchestra have been compared to the conductor's experiences, obtained by questionnaires. For the conductor's experience, his opinion on 'the balance within the orchestra between the different instrument sections' (below referred to as *B*; 1 = bad, 5 = good) as well as on 'the total judgment on the stage acoustics' (below referred to as *T*) is investigated. In this case the conductor's classification of the different halls can be divided into three groups:

1. stage A (*B*:5 – *T*:4), stage B and C (*B*:4 – *T*:5)
2. stage D, E and F (*B*:4 – *T*:4)
3. stage G (*B*:3 – *T*:3)

The difference between the three groups seems to be determined by the amount of very early reflections caused by source positions S1 and S2 (cat. 1 ~ relatively high $LQ_{7\text{-}40}$), as well as by source positions S3 and S4 (cat. 1 ~ relatively low $LQ_{7\text{-}40}$), see figure 7.

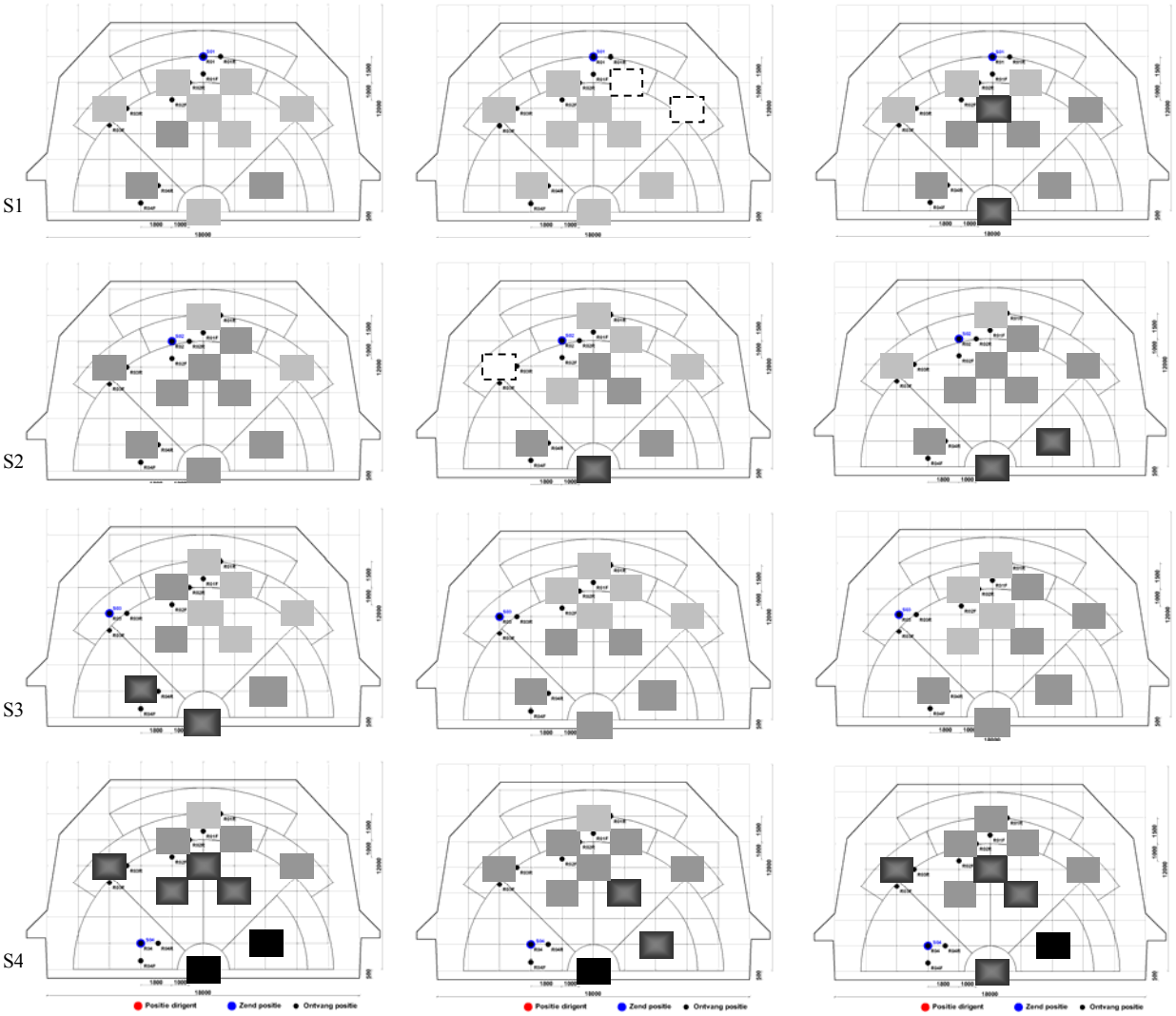


Figure 7: Results for $LQ_{7\text{-}40}$ for three stages (category 1, 2 and 3) for source positions S1 – S4.

DISCUSSION

The total overview of results for $LQ_{7\text{-}40}$ (average for all source positions) provides information about the distribution of early reflections on the stage. However it is not yet clear whether the absolute values for this averaged $LQ_{7\text{-}40}$ can be correlated to the results of the conductor's questionnaires. This unclear correlation is actually also valid for the *STearly* and *STlate* in this research. Furthermore there does not seem to be a correlation between the results for $LQ_{7\text{-}40}$ and *STearly*, *STlate* either.

However by checking the results for $LQ_{7\text{-}40}$ for each sound source and receiver, the distribution of the very early reflections on the stage is more elucidated. These results provide more detailed information about the 'transversely support over the stage'.

Furthermore there seems to be a correlation between the conductor's total judgment on the stage acoustics and the experienced balance within the orchestra at his position on the one hand and the $LQ_{7\text{-}40}$ for different source positions on the other hand. The conductor of NSO seems to prefer a balance between the (early reflected) sound produced by the brass instruments (relatively low $LQ_{7\text{-}40\_brass}$) and the woodwinds (relatively high $LQ_{7\text{-}40\_woodwinds}$).

There are several aspects (acoustical, physical and psychological) that influence the conductor's experience, which are not taken into account in this research. More insight in the relation between the conductor's experience and (stage) acoustical parameters, like $LQ_{7\text{-}40}$, is needed.

The $LQ_{7\text{-}40}$, only measured for one stage configuration (with *or* without orchestra), can not (yet) distinguish between the amount of horizontal and vertical reflections. According to Meyer[3] the direction of the reflections is important for the conductor's acoustics (horizontal reflections: control of the homogeneity of the string groups; vertical reflections: spatial impression). Only comparing the measurement results with and without orchestra might provide information about the amount of horizontal and vertical early reflections.

In case of an orchestra the amount of (horizontal) early reflections by the stage surroundings is reduced by the orchestra, but the amount of (horizontal) early reflections is increased by the music stands on stage. The influence of the orchestra on the distribution of very early reflections on stage (and on $LQ_{7\text{-}40}$) should not be underestimated.

The height of the receiver placed at the conductor's position (1.3 m) is questionable, especially for the measurements with orchestra on stage. However, the measurement results with orchestra on stage still provide information about the influence of the orchestra on the distribution of the early sound.

One must also realize that by omitting the direct sound the $LQ_{7\text{-}40}$ will no longer provide information about the sound (timbre etc.), but instead it provides a more detailed view on the contribution of the very early reflections.

The obtained and discussed values are only valid for the NSO (conductor and musicians) and the measured concert halls.

CONCLUSION

The parameter $LQ_{7\text{-}40}$ seems to be promising, according to the measurement and questionnaire results of this investigation, especially for determining the 'transversely support over the stage'.

With the results of $LQ_{7\text{-}40}$ and the questionnaires, one might conclude that the conductor of NSO seems to prefer a stage, which provides a balanced distribution of the early reflected sound produced by the brass instruments and the woodwinds.

This type of information, concerning the 'transversely support over the stage', helps to fine-tune and control the stage acoustics and stage design.

On most of the measured stages the orchestra causes a decrease of the $LQ_{7\text{-}40}$. This is probably caused by a larger (absorbent) effect by the orchestra than the (early sound) reflecting effect of the music stands etcetera.

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REFERENCES

[1] Elisabeth W.M. van den Braak, Laurentius C.J. van Luxemburg, "New (stage) parameter for conductor's acoustics?" *Acoustics'08 Paris* (2008).

[2] Laurentius C.J. van Luxemburg, Constant C.J.M. Hak, Ben H.M. Kok, Elisabeth W.M. van den Braak, "Transparent concert hall acoustics", *19th ICA Madrid* (2007).

[3] Jürgen Meyer, "Acoustical demands for the Conductor's Location", *Building Acoustics, volume **15**, number **2**,* 79-94 (2008).

[4] Philomena H. Heijnen, Martijn Kivits, "Podium Akoestiek 'Wetenschap vs. Beleving'", *master report, Eindhoven University of Technology* (2009).

[5] A.H. Marshall, D. Gottlob and H. Alrutz, "Acoustical conditions preferred for ensemble", *J. Acoustic. Soc. Am. **64***, 1437-1442 (1978).

[6] Elisabeth W.M. van den Braak, Constant C.J.M. Hak, Laurentius C.J. van Luxemburg, Heiko J. Martin, "Influence of stage risers on stage acoustics", *Forum Acusticum 2005 Budapest*, 2421-2426 (2005).

[7] Anders C. Gade, "Investigations of Musicians' Room Acoustic Conditions in Concert Halls. Part I: Methods and Laboratory Experiments", *Acustica* **69**, 193-203 (1989).

[8] Anders C. Gade, "Investigations of Musicians' Room Acoustic Conditions in Concert Halls. Part II: Field Experiments and Synthesis of Results", *Acustica* **69**, 249-262 (1989).

[9] Laurentius C.J. van Luxemburg, Constant C.J.M Hak, Philomena H. Heijnen, Martijn Kivits, "Stage acoustics: experiments on 7 stages of concert halls in the Netherlands", *Internoise 2009* (2009).

[10] Anders C. Gade, "Practical aspects of room acoustic measurements on orchestra platforms", *14th ICA Beijing F3-5* (1992).

[11] Constant C.J.M. Hak, J.P.M. Hak, R.H.C. Wenmaekers, "INR as an Estimator for the Decay Range of Room Acoustic Impulse Responses", *AES Convention Amsterdam* (2008).