Investigation of new metrics for the characterization of musicians' room acoustical conditions in concert halls

by Behzad Ranjbari

Summary

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with the audience, rather than with the communication between musicians. No acoustic metrics have been identified to assess the balance between the hearing of others vs. the hearing of one's own instrument, which appears paramount to orchestral musicians. In this paper, a number of laboratory experiments as well as measurements on real stages have been studied and a pair of joint metrics, namely GSelf and GOther are suggested to assess the balance between the hearing of self and that of hearing others.

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3aAA10. Investigation of new metrics for the characterization of musicians' room acoustical conditions in concert halls

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1. INTRODUCTION

A number of metrics for assessing the acoustical conditions for performers on concert hall stages have been proposed, notably by Dr. Anders Gade but also others. However, the subjective relevance of existing stage acoustic metrics —originally proposed by Dr. Anders Gade (Gade, (1989a), (1989b) & (1992))— appears mainly to be associated with the communication with the audience rather than with the communication between musicians (Dammerud et al., (2010)). So far, no acoustic metrics have been identified to assess the balance between the hearing of others vs. the hearing of one's own instrument, which appears paramount to orchestral musicians (Dammerud et al., (2010)).

The objective of this study is to search for a set of metrics to be measured on concert hall stages, useful for assessing the balance between the hearing of others (HO) vs. the hearing of one's own instrument (HS). This paper also attempts to provide a better understanding of the problems associated with the balance between the HO and the HS, among the orchestral musicians.

Due to existence of various complex perceptual effects in the problem —ranging from level masking, temporal masking and synchronicity, precedence effect and cocktail party effect, level masking in frequency domain as well as a number of individual physical aspects in relation to the orchestra arrangement— some assumptions and simplifications were used. In addition, problems associated with the stage conditions, were distinguished from those associated with the orchestra arrangement and the instrument's characteristics.

2. APPROACH

2.1 Focus on the problematic situations

Acoustical situation on concert hall stages regarding the mutual communication between orchestral players is indeed complex (Gade, (2010)). In this study to investigate the problem of balance between the hearing of others (HO) and the hearing of one's own instrument (HS) —which appears dominant to orchestral musicians— focus on the problematic situations along with study the problem in more details were considered.

2.1.1 Critical paths (CPs): Therefore in this approach, focus on individual paths between two individual orchestral players was applied. To focus on the problematic situations, some paths assumed to be crucial to the study namely the "critical paths" or "CPs". The study was done on a sample CP that gives an idea for study of other CPs as well. However, the study of which paths are critical and to what degree they are problematic has not been involved in this work since a comprehensive investigation in this area is required and is suggested as future work.

2.2 Hypothesis 1

2.2.1 Large differences of inherent sound strengths among the individual orchestral instruments: looking at the orchestral instruments, ranging from strings, woodwinds, brasses, percussions etc., wide range of inherent sound strengths among the instrument types can be seen. Figure 1 shows the combination of sound power levels for individual instrument sections including the number of players of each instrument (Meyer, (2009)). As Figure 1 shows for such an orchestration, the woodwinds section is weaker than the strings section and the strings section consisting of 50 instruments is still weaker than the brasses. This clearly indicates the large differences of relative sound power levels among the orchestral instruments, which is expected to cause serious problems from the viewpoint of level masking.

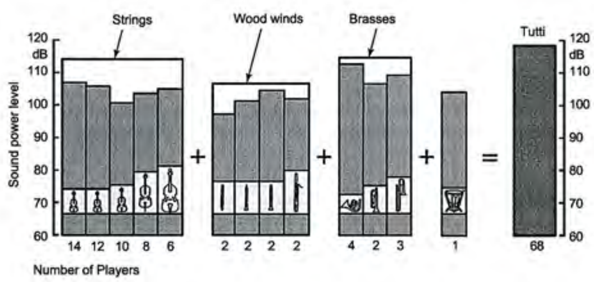


Figure 1. Sound power level of an orchestra in fortissimo (from Meyer, (2009)).

2.2.2 Musicians' complaints regarding the loud instruments: the musicians' complaints indicate that some orchestral instruments are most frequently too loud making the hearing situation problematic. Based on a survey on musicians' impressions of acoustic conditions (Dammerud, (2009)) for the string players, brasses, percussions and woodwinds respectively have been mentioned as to be most frequently too loud. For the woodwind players, brasses and percussions have been mentioned as being too loud and for the brass players, percussions and other brass players including oneself have been mentioned. Also French horns, brasses and other percussions has been said to be too loud for the percussion players.

2.2.3 Educated guess and the first hypothesis: due to the wide range of differences of inherent sound strengths among the orchestral instruments (discussed in 2.2.1), as well as the musicians' complaints regarding the loud instruments (discussed in 2.2.2), an educated guess was involved in the study. It was expected that level masking contribute considerably. After carrying out some pilot studies, it was assumed as the first hypothesis that in the most problematic situations the problem associated with balance between the HO and the HS is mainly due to the level masking (see the full-scale study in section 3). In addition, for simplification purposes the influence of other complex perceptual effects has been neglected.

2.3 Hypothesis 2

2.3.1 Stage conditions (SC) vs. instrument's characteristics (IC) and orchestra arrangement (OA): musicians' room acoustical conditions on concert hall stages can be influenced by a number of physical aspects. Among the physical aspects, some can be attributed to the instrument's characteristics (IC), some to the orchestra arrangement (OA) and some other to the stage conditions (SC). (See Table 1)

Table 1. Some physical aspects in relation to the musicians' room acoustical conditions categorized to either instrument's characteristics (IC) or orchestra arrangement (OA) or stage conditions (SC)

	Some physical aspects in relation to the musicians' room acoustical conditions	*IC*	*OA*	*SC*
1	Directional characteristics of instruments	*IC*	-	-
2	Distances from instruments to the musicians' ears	*IC*	-	-
3	Inherent sound strengths of individual instrument types	*IC*	-	-
4	Arrangement of players, chairs, stands and screens	-	*OA*	-
5	Relative positions in orchestra layout and the corresponding distances between players	-	*OA*	-
6	Stage design, stage area, risers, overhead reflectors, shells, canopies, etc.	-	-	*SC*

Those physical aspects associated with the instrument's characteristics (IC) and orchestra arrangement (OA), are either the same from one stage to another or can be assumed to be the same for simplification purposes.

2.3.2 The second hypothesis: as the second hypothesis involved in this study, those physical aspects associated with the instrument's characteristics and the orchestra arrangement (items 1 to 5 in Table 1) are assumed to be the same among different stages.

2.4 Variables vs. constants

In subsection 2.3, the physical aspects associated with the orchestra arrangement (OA) and the instrument's characteristics (IC), were distinguished from those associated with the stage conditions (SC). The latter including the stage design, stage area, risers, overhead reflectors, shells, canopies, etc., are variable from one stage to another, however the former including items 1-5 in Table 1 are invariable. The metrics we look for in this study are expected to measure the influences of the stage conditions (SC) —which are variable— rather than those of the orchestra arrangement (OA) and instrument's characteristics (IC) —which are constant. The problems associated with the orchestra arrangement (OA) and instrument's characteristics (IC) although may contribute significantly to the problem of balance between the HO and the HS, are considered as typical problems.

3. LABORATORY EXPERIMENTS

For a better understanding of how and to what extent the level masking contributes to the problem of the balance between the HO and the HS, a set of laboratory experiments was carried out (Ranjbari, (2013)). The experiments were performed in the anechoic chamber of the Division of Applied Acoustics of the Chalmers University of Technology. For the purpose of the experiments, a particular path consisting of a particular 2nd-violin (VI) and a particular trumpet (TR) was assumed to be a critical path (VI-TR) in which the violin player was supposed to judge the HO and the HS.

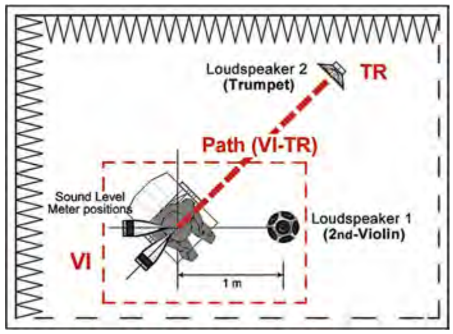


Figure 2. Schematic view of the laboratory experiments of masking thresholds, including the directivity characteristics. The path (VI-TR) is marked by the red dashed line.

To simulate the directivity of ears of the violin player in the anechoic chamber, as is shown in Figure 2 the position of the subject was adjusted to resemble the position of the 2nd-violin player in the orchestra layout. For the sound samples, use of loudspeakers and pure tone signals were preferred since working with a live motif including variable tones with variable loudness makes the judgments of the level masking difficult and imprecise. In order to simulate the 2nd-violin and the trumpet, two loudspeakers of short (1 m) and long (~5 m) distances respectively, from two different directions resembling the situation in the orchestra layout were used (see Figure 2). Loudness of all signal samples was measured at the place of the subject. During the experiments five trained listeners with normal hearing on both ears were subject to the test.

3.1 Laboratory experiments regarding the problem of hearing others —masking thresholds

The objective was to study how the perceived loudness of the OTHER instrument in the corresponding path, contributes to the problem of balance between the HO and the HS. The experiments of masking thresholds were carried out similar to the work discussed in Meyer (2009), but also including the directivity characteristics. The masking thresholds of different trumpet signals (representing the OTHER instrument) masked by different masking signals of the 2nd-violin (representing the SELF instrument) were studied. Figure 3 shows the averaged masking thresholds of several sinusoidal tones representing the trumpet, masked by two sinusoidal masking tones of 392 Hz with different levels of L_S, representing the note G4 of the 2nd-violin. The two solid curves in Figure 3, are the thresholds that must be exceeded by the softer masked-tone to become audible. Accordingly below the masking thresholds, the sound of trumpet (OTHER) was completely masked by the sound of 2nd-violin (SELF). Furthermore as is seen from the curves the masking thresholds increase with increasing loudness. The dashed curve in Figure 3 represents the schematically simplified threshold of hearing curve.

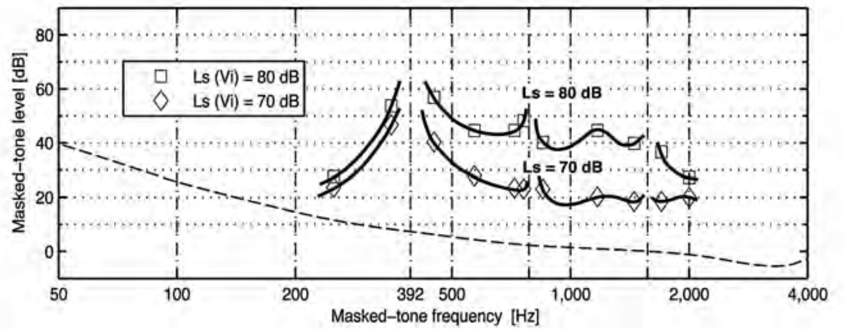


Figure 3. Averaged masking thresholds of several sinusoidal tones representing a trumpet, masked by two sinusoidal masking tones of 392 Hz with different levels of L_S, representing note G4 of a 2nd-violin, including the directivity characteristics of the corresponding path (VI−TR). Solid masking curves drawn similar to those by Zwicker (1999).

3.2 Laboratory experiments regarding the problem of hearing self —masking thresholds

In the very same way, to study how the perceived loudness of one's own instrument contributes to the problem of balance between the HO and the HS, masking thresholds of different 2nd-violin signals, masked by different masking signals of trumpet, were investigated (see Figure 4).

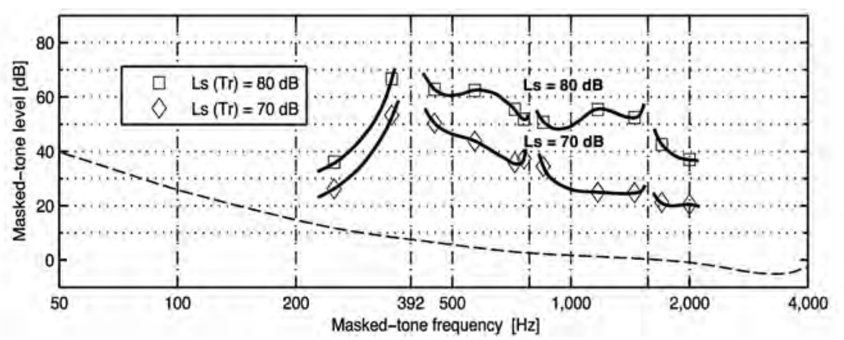


Figure 4. Averaged masking thresholds of several sinusoidal tones representing a 2nd-violin, masked by two sinusoidal masking tones of 392 Hz with different levels of L_S, representing note G4 of a trumpet, including the directivity characteristics of the corresponding path (VI−TR). Solid masking curves drawn similar to those by Zwicker (1999).

3.3 Summary of results

- The experiments of masking thresholds for the sample CP, clearly show that how the perceived loudness of the SELF instrument and the perceived loudness of the OTHER instrument, contribute to the problem of poor balance between the HO and the HS.
- As it is seen from the curves (Figure 3 and 4), the masking thresholds increase with increasing loudness i.e. the perceived loudness of the 'masked signal' and the perceived loudness of the 'masker signal' are joined together.
- The laboratory experiments imply that the balance between the HO and the HS can be influenced in such a way that the perceived loudness of an instrument be placed below or above it's masking threshold curve, becoming completely masked or audible as two extreme cases respectively.

4. PROPOSAL OF METRICS

To assess the balance between the hearing of others vs. the hearing of one's own instrument, a pair of metrics as an objective counterpart to the pair of perceived loudness of each of the instruments —of the corresponding critical path— (see subsection 3.3) is desirable. Furthermore, a comparative approach is desirable to possibly remove the influence of typical problems associated with the orchestra arrangement as discussed in subsection 2.4. In addition, the metrics we search for, are expected to measure the variables —influences of stage conditions— rather than the constants —influences associated with the orchestra arrangement and the instrument's characteristics— as also discussed in 2.4. Hence, the physical sound field parameters we look for, are expected to have the following basic properties: a) well defined to describe the loudness, b) suitable for comparing purposes, c) convenient to measure and d) possessing adequate measurement accuracy.

Therefore, the conventional sound strength factor "G", which is a common room acoustical metric convenient for comparison purposes of loudness, already has all the required properties mentioned above. Moreover, G based metrics can nicely be used for making a pair of joint metrics to well correlate to the pair of perceived loudness of each of the instruments in the corresponding path as discussed in subsection 3.3. The accuracy of a G measurement depending on different calibration methods has been discussed in Hak et al. (2010).

4.1 Definitions and recommendations

G_{Self} and G_{Other} are two joint metrics, suggested to assess the balance between the hearing of others vs. the hearing of one's own instrument, to be measured on concert hall stages that are defined as follows:

4.1.1 G_{Self}: the G_{Self} is defined as the sound strength G at 1 m distance in order to assess the sound strength corresponds to of one's own instrument uniformly for any path as eqn (1). Where $p_1(t)$ is the instantaneous sound pressure of the impulse response measured at 1 m distance and $p_{10}(t)$ is the instantaneous sound pressure of the impulse response measured at a distance of 10 m in a free field. To measure the G_{Self} for a certain path, the centre of the omnidirectional sound source is suggested to be placed at 1 m distance in front of the SELF musician according to the orchestra layout.

$$G_{Self} = 10 \times \log_{10} \frac{\int_0^\infty p_1^2(t)\,dt}{\int_0^\infty p_{10}^2(t)\,dt} \quad dB \tag{1}$$

4.1.2 G_{Other}: the G_{Other} is defined as the sound strength G at a certain distance according to the corresponding path in order to assess the sound strength corresponds to the OTHER instrument as eqn (2). Where $p(t)$ is the instantaneous sound pressure of the impulse response measured at the SELF musician.

$$G_{Other} = 10 \times \log_{10} \frac{\int_0^\infty p^2(t)\,dt}{\int_0^\infty p_{10}^2(t)\,dt} \quad dB \tag{2}$$

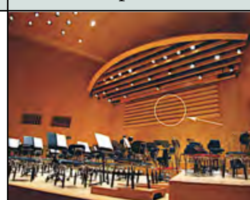
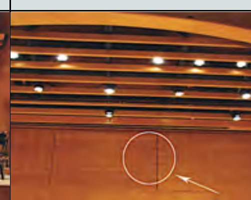
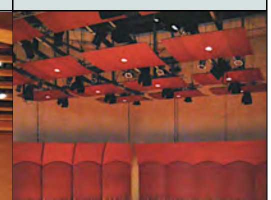
4.1.3 Pair of G_{Self} and G_{Other}: the pair of G_{Self} and G_{Other}, to be written as (G_{Self}, G_{Other}) are defined for an individual path consisting of two individual instruments namely the "SELF instrument" and the "OTHER instrument" respectively. G_{Self} and G_{Other}, are two joint metrics i.e. the G_{Self} and the G_{Other} individually are not supposed to be informative for the purpose of assessing the balance between HS (hearing self) and HO (hearing other), however they are informative when they are joint together (see subsection 4.2). The pair of G_{Self} and G_{Other} assesses the influence of stage conditions on the perceived loudness of each of the instruments of the corresponding path. In other words for any path, stage conditions and consequently the sum of the reflections arriving at the musician results in a sound strength relationship as (G_{Self}, G_{Other}). To interpret how likely a stage is to have problem with HO or HS, comparison of results of pair of G_{Self} and G_{Other} between different stages (the stage under assessment and a reference stage) is required (see subsection 4.2).

For any stage conditions, a minimum of three pairs of measurements for three particular critical paths of certain distances —G as function of source-receiver distance is more accurate (Barron, (2005) & Bradley, (2005))— are suggested. However a consensus on chooses of critical paths of certain distances to be measured among the stages is required. More critical paths and more number of measurements may be required due to the sensitivity of the assessments. No arithmetically averaged results between different critical paths are recommended. Additionally, the Early Decay Time (EDT), or the reverberation time (T) is required to be reported in the statement of results —it is generally accepted that perceived reverberance is better related to the Early Decay Time (EDT) than the reverberation time (T) (Bradley, (2010) & Beranek, (2003)).

4.2 Stage measurements and interpretation of results

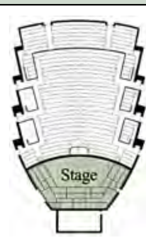
Table 2 shows the measurement results from three different stage conditions including the concert hall of the Göteborgs Konserthus (Sweden) —with two different variable acoustic conditions— and the concert hall of the Academy of Music & Drama —Artisten (Sweden). (See Table 3 for the concert halls specifications). Measurements carried out using a calibrated omnidirectional sound source according to subsection 4.1 of this paper and the measurement procedure of sound strength G in: ISO 3382-1 (2006), using free-field measurement method in anechoic chamber as it has been discussed in Hak et al. (2010).

Table 2. Stage measurement results for three different stage conditions. *Figure-left: Göteborgs Konserthus (open wall reflectors), Figure-middle: Göteborgs Konserthus (closed wall reflectors), Figure-right: Artisten (no variable acoustic used) (All Photos by M. Sadeghi).*

Hall	Göteborgs Konserthus (Sweden)		Artisten (Sweden)
Variable acoustic	Wall reflectors: open	Wall reflectors: closed	No variable acoustic used
			
Sample critical paths ▾	$(G_{Self}, G_{Other})_{m*}$ [dB]	$(G_{Self}, G_{Other})_{m}$ [dB]	$(G_{Self}, G_{Other})_{m}$ [dB]
CP (VI-TR)	*(18.5, 16.1)*	*(20.8, 10.0)*	*(25.1, 22.5)*
CP (CE-TR)	*(16.2, 16.0)*	*(16.3, 10.7)*	*(21.3, 19.4)*
CP (FL-TI)	*(18.2, 18.9)*	*(17.5, 11.9)*	*(27.9, 23.9)*
	EDT_{m*}: 1.8 s *(unoccupied)*	EDT_{m}: 1.8 s *(unoccupied)*	EDT_{m}: 1.7 s *(unoccupied)*

**Single-number values are given for* mid frequency range according to ISO 3382-1, 2006.

Table 3. Concert halls specifications. *Figure-left: concert hall of Göteborgs Konserthus's floor plan (Beranek, (2004)), Figure-right: concert hall of Artisten's floor plan (the plan was provided by the Academy of Music and Drama —Artisten— Sweden).*

Hall	Göteborgs Konserthus	Artisten
Floor plan		
Number of seats	1,247	396
Volume [m^3]	11,900	5,866
Area of stage [m^2]	200	147

To interpret how likely a stage condition is to have problem with HO or HS, comparison of G_{Self} between stage conditions, together with comparison of G_{Other} between stage conditions is required. In other words, when comparing different stage conditions, G_{Self} (from a stage under assessment) must be compared to G'_{Self} (from another stage condition considered as a reference stage) and in a very similar way, G_{Other} must be compared to G'_{Other}. Increase or decrease of G_{Self} in relation to increase or decrease of G_{Other} is expected to provide an indication of how likely a stage is to have problem with HO or HS (see subsection 3.3). Here is an example of how to interpret the measurement results: from the measurement results in table 2, it can be seen that for instance in Göteborgs Konserthus, for the path: (VI-TR), when the wall reflectors are open, it is more likely to be a problem with the hearing of SELF, in comparison to when the wall reflectors are closed. In this case, G_{Other} has been increased and the G_{Self} has been decreased. Meaning, it is more likely that the perceived loudness of the SELF instrument is below it's masking threshold (see Figure 3).

5. CONCLUSION AND DISCUSSION

A pair of joint metrics namely the G_{Self} and the G_{Other} are suggested to assess the balance between the hearing of others vs. the hearing of one's own instrument, to be measured on concert hall stages. The G_{Self} and the G_{Other} individually are not supposed to be informative for the purpose of assessing the balance between the hearing of others (HO) and the hearing of one's own instrument (HS). However as discussed in the case of the concert hall of Göteborgs-Konserthus (see subsection 4.2), the G_{Self} and the G_{Other} are informative when they are joint together. The pair of G_{Self} and G_{Other} assesses the influence of stage conditions on the perceived loudness of the SELF and the OTHER instruments within the corresponding path. In other words for a certain path, stage conditions and consequently the sum of the reflections arriving at the musician results in a sound strength relationship as (G_{Self} , G_{Other}). For interpretation of how likely a stage is to have problem with HO or HS, comparison of results of pair of G_{Self} and G_{Other} between different stages —the stage under assessment and a reference stage— is required. The pair of proposed metrics has both some advantages and disadvantage in comparison to the existing acoustic metrics: ISO 3382-1 (2006) as follows:

Advantages:

- *Can be measured all across the stage:* in contrast to the existing acoustic metric ST_{early} (ISO 3382-1 (2006)) proposed by Gade (Gade, (1989a), (1989b) & (1992)), the newly suggested pair of metrics can be measured all across the stage. In the existing metric ST_{early}, the lower time limit of 20 ms implies that the source and receiver should be at least 4 meters away from any reflecting stage surfaces except from the floor, to avoid any of early reflections arriving before 20 ms (Dammerud, (2009)).
- *Directional characteristics of instruments:* due to the comparative approach used, problems associated with the directional characteristics of instruments, to some extents were removed. Since only the same instruments with the same directivity characteristics are being compared, the same amount of shifts in results can be assumed.
- *Distance from instrument to the ears of musician:* due to the comparative approach used, problems associated with the simulation of distance between instrument to the ears of musician to some extents were removed. Since only the same instruments with the same distances are being compared, the same amount of shifts in results can be assumed.
- *Local diagnosing:* the newly proposed pair of metrics can be used as a local diagnostic tool to detect the local deficiencies based on the chosen path.
- *Use of G as function of source-receiver distance:* the newly proposed pair of metrics used as function of source-receiver distance which gives more accurate results.
- *No arithmetically averaged results used:* for better correlation of results and to enable locally diagnose, no arithmetically averaged results over different paths were used.
- *Use of G based metrics:* another advantage of use of G based metrics is that G is a common and convenient room acoustical metric that has been used for many years (Dammerud et al., (2010)).

Disadvantage:

- Interpretation of results regarding the increase or decrease of both the G_{Self} and G_{Other} is sometimes difficult. This is natural in view of the limited range of data available in these investigations. However measurement results covering many more situations and geometries coupled to musician interviews will lead to trusted design criteria.

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REFERENCES

1 Barron, M. 2005. Using the Standard on Objective Measures for Concert Auditoria, ISO 3382, to Give Reliable Results, in: *Acoust. Sci. & Tech.* 26, 2, 162-169.

2 Beranek, L.L. 2003. Subjective Rank-Ordering and Acoustical Measurements for Fifty-eight Concert Halls, in: *Acta Acoustica united with Acoustica,* 89 (3) 494-508.

3 Beranek, L.L. 2004. *Concert halls and opera houses: music, acoustics, and architecture,* 2nd edn., Springer, New York; Berlin; Heidelberg; Hong Kong; London; Milan; Paris; Tokyo, 459.

4 Bradley, J.S. 2005. Using ISO 3382 Measures, and Their Extensions, to Evaluate Acoustical Conditions in Concert Halls, in: *Acoust. Sci. & Tech.* 26, 2, 170–178.

5 Bradley, J.S. 2010. Review of Objective Room Acoustics Measures and Future Needs, in: *Proc. Int. Symp. Room Acoustics (ISRA).*

6 Dammerud, J.J. 2009. *Stage Acoustics for Symphony Orchestras in Concert Halls*, PhD thesis, University of Bath, 45 and 143.

7 Dammerud, J.J., Barron, M. and Kahle, E. 2010. Objective Assessment of Acoustic Conditions on Concert Hall Stages – Limitations and New Strategies, in: *Proc. Int. Symp. Room Acoustics (ISRA).*

8 Gade, A.C. 1989a. Investigations of Musicians' Room Acoustic Conditions in Concert Halls. Part I: Methods and Laboratory Experiments, in: *Acustica,* 65, 193– 203.

9 Gade, A.C. 1989b. Investigations of Musicians' Room Acoustic Conditions in Concert Halls. Part II: Field Experiments and Synthesis of Results. *Acustica*, 69, 249–262.

10 Gade, A.C. 1992. Practical Aspects of Room Acoustic Measurements on Orchestra Platforms, in: *Proc.14th ICA,* Beijing. Paper F3-5.

11 Gade, A.C. 2010. Acoustics for Symphony Orchestras; status after three decades of experimental research, in: *Proc. Int. Symp. Room Acoustics (ISRA).*

12 Hak, C.C.J.M., Wenmaekers, R.H.C., Hak, J.P.M., Luxemburg, L.C.J.van and Gade, A.C. 2010. Sound Strength Calibration Methods, in: *Proc. 20th Int. Cong. Acoust. (ICA).*

13 ISO 3382-1. 2006. *ISO 3382-1 Acoustics-Measurement of Room Acoustic Parameters- Part1: Performance Rooms, Draft International Standard ISO/DIS 3382-1,* International Organization for Standardization.

14 Meyer, J. 2009. *Acoustics and the Performance of Music,* 5th edn., Springer, New York, 10-13, 359-370.

15 Ranjbari, B. 2013. *New Metrics for the Characterization of Stage Acoustics in Concert Halls for Symphony Orchestras,* Master's thesis, Chalmers University of Technology, 15-23.

16 Zwicker, E. and Fastl, H. 1999. *Psychoacoustics-Facts and Models,* 2nd edn., Springer, Berlin; Heidelberg; New York, , 67-70.

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