

CHALMERS



New Metrics for the Characterization of Stage Acoustics in Concert Halls

for Symphony Orchestras

Master's Thesis in the Master's programme in Sound and Vibration

BEHZAD RANJBARI

Department of Civil and Environmental Engineering

Division of Applied Acoustics

Chalmers Room Acoustics Group

CHALMERS UNIVERSITY OF TECHNOLOGY

Göteborg, Sweden 2013

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Cover: Concert hall stage of the Göteborgs Konserthus (Sweden), during
measurements of the new proposed metrics. (Photo by Maryam Sadeghi)

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ABSTRACT

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 for musicians, appears mainly to be associated with the communication with the audience rather than with the communication between musicians. 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. In this project, a number of laboratory simulations and psychoacoustical experiments as well as measurements on real stages have been studied and a pair of joint metrics, namely G_{Self} and G_{Other} are suggested to assess the balance between the hearing of self and that of hearing others.

Keywords: architectural acoustics, room acoustics, stage acoustics, concert halls, symphony orchestras, acoustical conditions for musicians, masking, early reflections, instrument directivity, stage measurement, musical acoustics, sound strength, ST_{Early} , ST_{Late} , G_{Self} , G_{Other}

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Preface

A few months prior to time for choosing a topic for my Master's thesis within the Chalmers Room Acoustics Research Group (CRAG), I asked Professor Mendel Kleiner to suggest me a research topic and I remember he first encouraged me to think about and choose among an already-existing list of topics in relation to the "acoustics of small rooms". I tried to convince Mendel that a thesis topic relevant to fundamental studies on performance venues and/or the musicians' room acoustical conditions would definitely more fit into my passion. Finally, we agreed on the work possibly be a "new idea", and to benefit from experience of presenting future results at least in one top-ranked international conference, in addition to possibly a journal paper. Mendel therefore encouraged me to do a research throughout the conference papers and journal papers to see which topics would more interest me. I made a comprehensive-long list of conference/journal paper topics in "architectural acoustics" during the past three decades including the Journal of the Acoustical Society of America (JASA), Journal of the Acoustical Society of Japan, International Conference in Acoustics (ICA), etc. I selected a few of them and discussed them with Mendel. A couple of weeks later Mendel and I had a discussion on a musically/acoustically symphony-orchestra-related topic and all of a sudden, Mendel mentioned about an old idea of his own about investigating some modifications into the existing stage acoustics parameters (ISO 3382-1, (2006)) for some particular orchestral instruments. Mendel showed me some papers done by Dr. Anders Gade (Gade, (1989a), (1989b) & (1992)), by himself (Kleiner et al., (1986)), and others and it was at that point of time that I realized an astonishing topic for my thesis work is going to be formed. Eventually in September 2010, this thesis work with its preliminary topic as: *"Improved metrics for the characterization of stage acoustics for some musical instruments in concert halls"* was get started in the framework of a long-term (60 credits) thesis project. This topic later on (after ISRA-2010¹), throughout the progress of the study changed to the current topic as: *"New metrics for the characterization of stage acoustics in concert halls for symphony orchestras"*.

The project started with a comprehensive literature study and then was followed by contacting almost everyone active in the field including: Dr. Anders Gade, Professor Michael Barron, Dr. Eckhard Kahle, Dr. Densil Cabrera, Dr. Jens Jørgen Dammerud and others, primarily to search whether they are aware of any on-going relevant research initiatives across the globe — other than their own publications — but also to receive their advice.

Based on these early correspondences, from the very beginning, the work appeared quite challenging. Professor Michael Barron pointed out that they have convinced themselves that Anders Gade's "Support" metrics — Early Support (ST_{Early}) & Late Support (ST_{Late}) — do not work for the condition of stage acoustics in particular for symphony orchestras, but they also have failed to establish an alternative. (Based on the author's correspondence with Professor Michael Barron (Barron, (2010))).

¹ International Symposium on Room Acoustics (ISRA), 29-31 August 2010, Melbourne, Australia.

Moreover, some interviews in the very early stage of the project were conducted including interviews with Professor Emeritus Asbjørn Krokstad and Jan-Inge Gustafsson. Later on during the mid-time thesis presentation associated with this project done by author in May 2011, entitled as *“Review and criticism of the existing stage acoustics metrics for symphony orchestras”*—held in the lecture room of the Division of Applied Acoustics, Chalmers University of Technology— even more comments/feedbacks including those by Alf Berntson and others were received.

It was a few months since the beginning of the project that I received several papers associated with the International Symposium on Room Acoustics (ISRA) 2010 which indeed influenced this work. The results from ISRA-2010 in general revealed that there are still many unresolved questions regarding the qualitative understanding of how stage acoustics conditions are perceived by musicians. In particular a paper work co-authored by Dr. Jens Jørgen Dammerud, Professor Michael Barron and Dr. Eckhard Kahle (see Dammerud et al., (2010)), put the existing stage acoustics metrics (ISO 3382-1, (2006)) — originally proposed by Dr. Anders Gade (Gade, (1989a), (1989b) & (1992))— under strong criticism. This article, declared that the subjective relevance of the existing stage acoustic metrics (ISO 3382-1, (2006)), appears mainly to be associated with the communication with the audience rather than with the communication between musicians. Moreover, it clarified that 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.

The results from ISRA-2010 Symposium, on the one hand, were very interesting to our study since it clarified the existing status regarding the lack of success for the existing stage acoustics metrics (ISO 3382-1, (2006)), but on the other hand, it made the progress of our study much more complex than before. Based on the criticism introduced by Dammerud et al. (2010) even our initial idea of the work no longer had chance of survival.

Up to this point of time, in May 2011, all the investigations associated with the project were summarized and presented as the first part (half-time) of the thesis work, entitled as: *“Review and criticism of the existing stage acoustics metrics for symphony orchestras”* held in the lecture room of the Division of Applied Acoustics, Chalmers University of Technology.

The second part of the project started even more challenging. The criticism introduced together by Dr. Jens Jørgen Dammerud, Professor Michael Barron and Dr. Eckhard Kahle (see Dammerud et al., (2010)) at the International Symposium on Room Acoustics (ISRA) 2010, entirely influenced the initial idea of the work. This, along with the inherent complexity of the problem made this stage of the study extremely challenging:

Based on the author’s correspondence with Professor Michael Barron (Barron, (2010)), Professor Barron indicated that so far, in their attempts to find a new metric for orchestra stages, they have used several approaches including: scale model testing, objective measurements on actual concert hall stages and questionnaires to musicians and have looked at all the usual measured quantities but “without any luck” and that finding a new metric for

orchestra stages is not likely to be easy, however a possible challenge for the author! (Barron, (2010)).

Hence, looking into failure of three decades of attempts to find a metric in stage acoustics for symphony orchestras, while looking at all the usual measured quantities (see: Gade, (2010) and Barron, (2010)), raised this important question in mind of author that why not focusing on the problem from another perspective?!

The idea started with the question that: isn't it true that ease of communication between players appears to relate to the complex perceptual effects such as: level masking, temporal masking and synchronicity, precedence effect, cocktail-party effect, etc. (see Dammerud et al., (2010))?! However, over the years, this has been totally neglected. In other words none of the above important effects have been taken into account because they had not seemed to be easy to quantify! (see Dammerud et al., (2010))

Therefore, author in this work, in particular looked through the complex perceptual effects and above all, focused on the vital role of the so-called "level masking" as the most dominant one. Accordingly a new approach applied to this study (see Chapter 3), which then was followed by a set of laboratory simulations and psychoacoustical experiments (see Chapter 4). The succeeding chapter (Chapter 5) introduced the new proposed metrics. The results from the stage measurements were discussed in Chapter 6. Chapter 7 is dedicated to the conclusion and discussion concerning the achievements of the study and finally the last chapter (Chapter 8) suggested the future work.

Behzad Ranjbari
Gothenburg, Oct. 2013

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Acknowledgments

Many people have contributed directly and indirectly to this study. On top, I wish to thank my supervisor Professor Mendel Kleiner for his valuable and always-encouraging comments and support during the work and also my wife Maryam Sadeghi for her unfailing assistance throughout the project.

I would like to especially express my gratitude to Dr. Eckhard Kahle, Professor Michael Barron, Dr. Densil Cabrera Professor Emeritus Asbjørn Krokstad, Dr. Anders Gade, Dr. Jens Jørgen Dammerud, Jan-Inge Gustafsson, Alf Berntson and Thomas Wulfrank who have been generous in supplying valuable advice/comments each during a critical stage of the work.

I would like to in particular thank Dr. Densil Cabrera —the papers chair and member of the local organising committee at the International Symposium on Room Acoustics (Melbourne) 2010 for providing me with the full-papers package of the symposium, and Dr. Eckhard Kahle for providing me with valuable documents regarding their research on stage acoustics.

I would like to thank all of my colleagues at the Division of Applied Acoustics, especially Professor Wolfgang Kropp for all his generous support throughout my Master's studies and Börje Wijk for all his technical supports. I am grateful to my friends Lars Hansson and Mihkel Toome for their helpful comments on my presentation-material for the 163rd meeting of the Acoustical Society of America and at last but not least, to Gunilla Skog for all her support in the administrative side.

I would like to thank Christer Nyström for the arrangements at the Göteborgs Konserthus to make the measurements possible.

This thesis project was done as part of the Master's program in Sound and Vibration within the Chalmers Room Acoustics Research Group (CRAG) at the Division of Applied Acoustics at Chalmers University of Technology supervised by Professor Mendel Kleiner during Sep 2010 to Nov. 2012.

Göteborg, Oct. 2013

Behzad Ranjbari

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Abbreviations

CP	Critical Path
HO	Hearing Others
HS	Hearing Self
SC	Stage Conditions
OA	Orchestra Arrangement
VI	2nd Violin
TR	Trumpet
CE	Cello
FL	Flute
TI	Timpani

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“Excellent paper¹! I appreciate especially the great simplifications you introduce, and am convinced that the metrics give a reasonable indication on the influence of stage and room acoustics on the experience of the conditions for performers.”

Professor Emeritus Asbjørn Krokstad²
November 2012

¹ Refer to a manuscript summarized the results of this thesis work, submitted at the 163rd meeting of the Acoustical Society of America (Ranjbari, (2012)).

² See section: “List of Acousticians and Musicians” on page 41.

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1 Background to the Study

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 for musicians (ISO 3382-1, (2006)) —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)). In 2010, Dammerud et al. introduced alternatives to the Gade's metrics (Dammerud et al., (2010)). Table 1.1 summarizes some of the notable previously proposed metrics for assessing the acoustical conditions for the performers.

Table 1.1. Some of the notable previously proposed stage acoustics metrics for assessing the acoustical conditions for the performers. (From Dammerud, (2009))

Metrics	Proposed by	Description	Validity
MTF (Modulation Transfer Function)	Naylor (1988)	Naylor proposed the use of modulation transfer functions (MTF) measured across the stage to evaluate conditions for mutual hearing.	No investigations by others have been found regarding the validity of Naylor's proposed method.
RR160 ("Running Reverberation")	Griesinger (1995)	Griesinger proposed the "Running Reverberation" for assessing the perceived reverberation during the performance.	No investigations have been found regarding the validity of RR160.
ST_{Early} and ST_{Late}	Gade (1992)	Ensemble conditions (Early Support, ST _{Early}) Perceived reverberance (Late Support, ST _{Late})	Already included in the standard (ISO 3382-1, (2006)), however under strong criticism
G₂₀₋₁₀₀ and G_{Late}	Dammerud et al. (2010)	Ensemble conditions (G ₂₀₋₁₀₀) Perceived reverberance (G _{Late})	

Furthermore, the Ph.D. thesis done by Dr. Jens Jørgen Dammerud, describes in details the stage acoustics for symphony orchestras in concert halls (Dammerud, (2009)).

1.1 Review and Criticism of the Existing Stage Acoustics Metrics

Several metrics have been proposed to assess the acoustical conditions on concert hall stages, notably by Dr. Anders Gade. Later on, the work by Dammerud et al. (2010) additionally introduced alternatives to the Gade's metrics. The metrics that are currently included in the International Standard ISO/DIS 3382-1 (ISO 3382-1, (2006)) are those originally proposed by Dr. Anders Gade (Gade, (1989a), (1989b) & (1992)), however, over the years have come under strong criticism. The following section lists some of the most important items in relation to the criticism of the existing stage acoustics metrics.

1.2 Checklist

Table 1.2 gives a summary of some of the most important items in relation to the criticism of the existing stage acoustics metrics associated with the International Standard ISO/DIS 3382-1 (ISO 3382-1, (2006)). This table also reviews the alternatives to Gade's metrics introduced by Dammerud et al. (2010) discussed in the previous section. The table more importantly gives an indication of to what extent these attempts have been successful.

Table 1.2. Some of the most important items in relation to the criticism of the existing stage acoustics metrics and indication of to what degree they have been successful.

	Item	Gade (1992) ST_{early} & ST_{late}	Dammerud et al. (2010) G_{20-100} & G_{late}
1	Possibility to be measured all across the stage	Not for ST_{early}	<u>Yes</u>
2	Taking into account the directional characteristics of instruments	No	No
3	Taking into account the distance from instrument to the ears of musician	No	No
4	Ability of local diagnosing	No	No
5	Taking into account the effects of complex perceptual effects (level masking, etc.)	No	No
6	Avoid averaging of results among different measurement positions	No	No
7	Use of G based metrics	No	<u>Yes</u>
8	Inter-Orchestra Simulation	No	No
9	Validation and reliability	No	No

2 Objective of the Study

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). Additionally, this study 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 orchestra arrangement (OA) were distinguished from those associated with the stage conditions (SC).

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3 Approach

3.1 Focus on the Problematic Situations

Acoustical situation on concert hall stages regarding the mutual communication between orchestral players is indeed complex. The problem of balance between the hearing of others (HO) and the hearing of one's own instrument (HS) which appears paramount to orchestral musicians seems not to be easily quantified, unless focus on the problematic situations along with study the problem in more details.

3.1.1 Critical Paths (CPs)

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. Figure 3.1 shows a sample of an orchestra arrangement.



Figure 3.1. Orchestra arrangement — shown is the Philharmonic Orchestra of Jalisco (Photo by Pedro Sánchez from Wikipedia, used under the Creative Commons Attribution 2.5 Generic license)

3.2 Hypothesis I

3.2.1 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 3.2 shows the combination of sound pressure levels for individual instrument sections including the number of players of each instrument (Meyer, (2009)). As Figure 3.2 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.

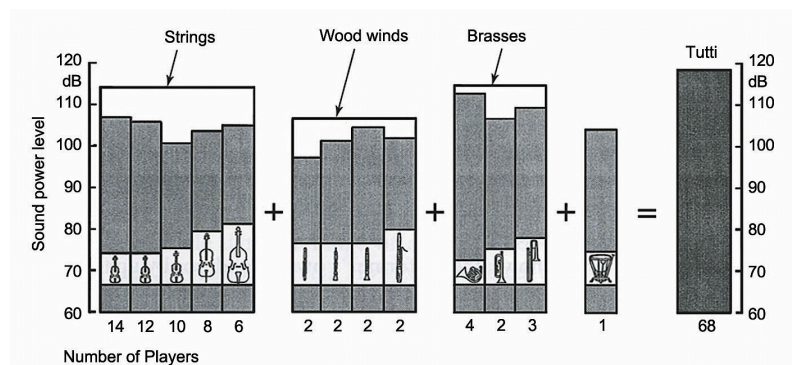


Figure 3.2. Sound power level of an orchestra in fortissimo (from Meyer, (2009)).

3.2.2 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.

3.2.3 Educated Guess and the First Hypothesis

Due to the wide range of differences of inherent sound strengths among the orchestral instruments, as well as the musicians' complaints regarding the loud instruments, an educated guess was involved in the study. It was expected that level masking contributes 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 (to see the full-scale study see Chapter 4). In addition, for simplification purposes the influence of other complex perceptual effects has been neglected.

3.3 Orchestra Arrangement (OA) vs. Stage Conditions (SC)

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 orchestra arrangement (OA) and some to the stage conditions (SC) (See Table 3.1). The followings are some of the most important aspects in relation to the musicians' room acoustical conditions categorized to either orchestra arrangement (OA) or stage conditions (SC).

3.3.1 Directional Characteristics of Instruments

In general, depending on frequency range musical instruments do not radiate sound in all directions with equal intensity, but rather express more or less pronounced directional behaviour. This dependence of the radiated sound pressure on direction is referred to as the directional characteristic. Figure 3.3 and Figure 3.4 summarize the principal radiation directions of violin in horizontal plane and in the plane of the bridge respectively. Furthermore, the directional characteristics vary among different instruments. Figure 3.5 compares the principal radiation directions of violin and trumpet in horizontal plane.

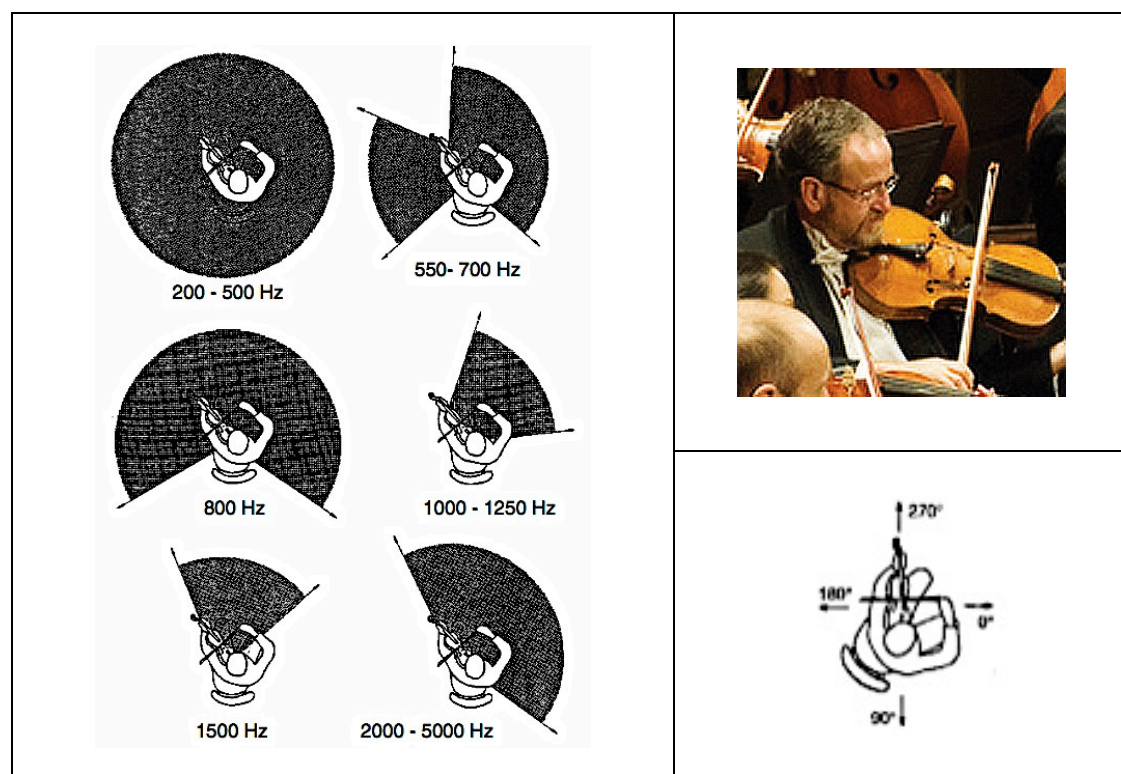


Figure 3.3. Left: Principal radiation directions of violin in horizontal plane given for different frequency ranges (from Meyer, (2009)). Top-right: shown is a Violin player at the Vancouver Symphony Orchestra (Photo by Vancouver 125 - The City of Vancouver from Wikipedia, used under the Creative Commons Attribution 2.0 Generic license)

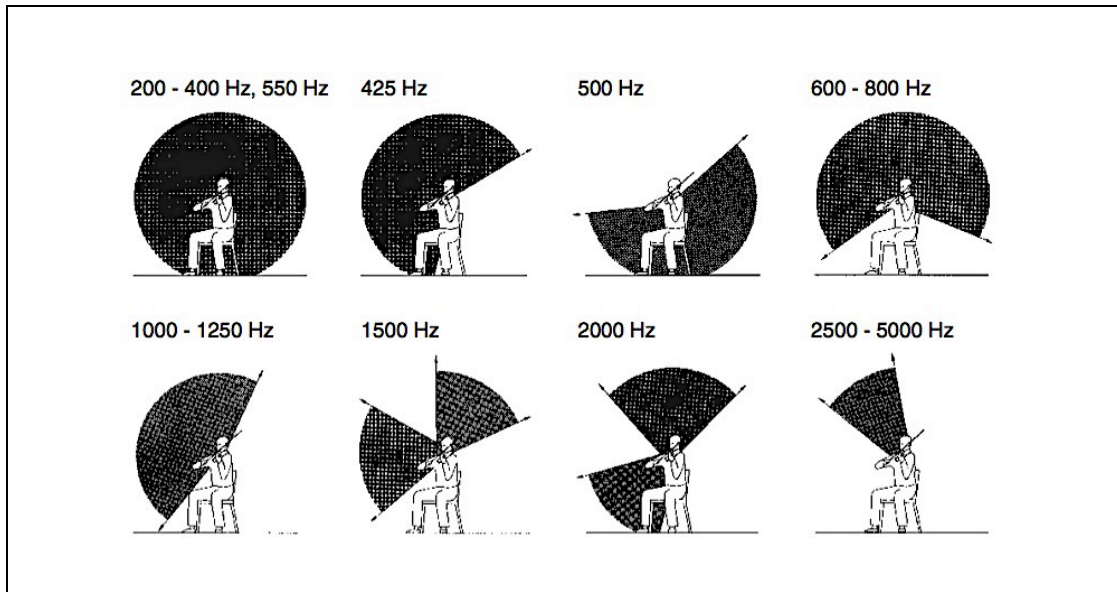


Figure 3.4. Principal radiation directions of violin in the plane of the bridge given for different frequency ranges (from Meyer, (2009)).

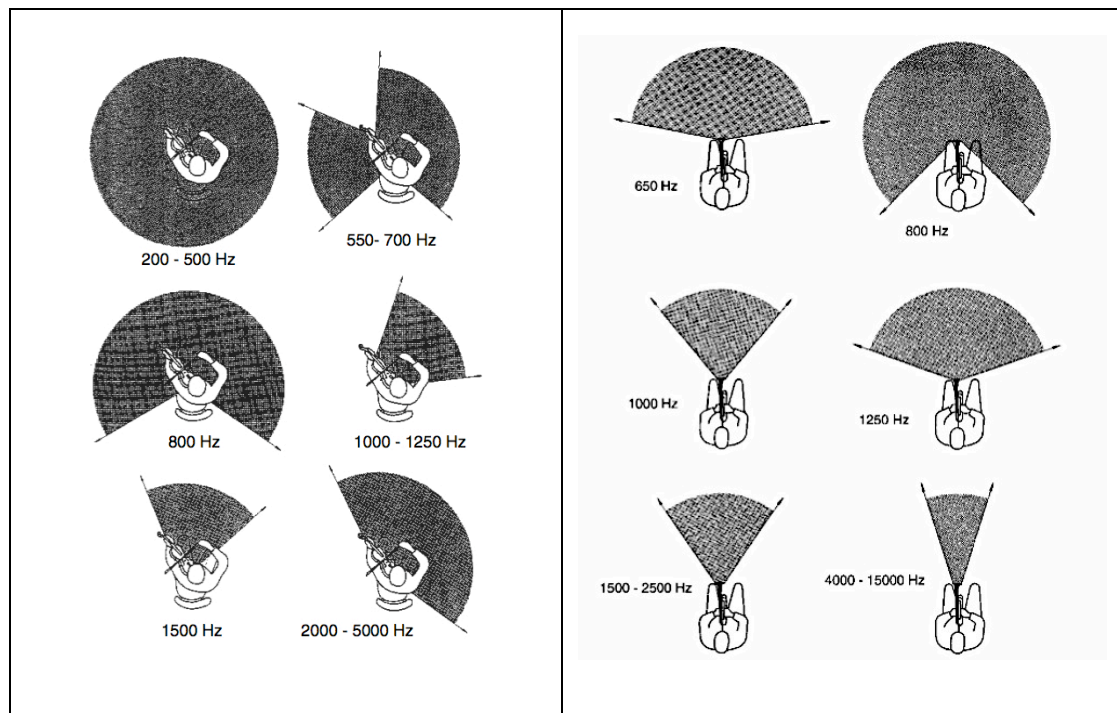


Figure 3.5. Comparison of the principal radiation directions of violin and trumpet in horizontal plane given for different frequency ranges (from Meyer, (2009)).

3.3.2 Distance from Instrument to the Ears of Musician

Looking at the orchestral instruments, depending on type of the instruments, the distance from instrument to the ears of player can largely differ. Figure 3.6 shows some examples of these differences among the orchestral instruments.



Figure 3.6. Large differences of the distance from instrument to the ears of musician among the orchestral instruments: 1) a Trumpet player — Shown is Louis Armstrong (Photo by World-Telegram staff photographer from Wikipedia), 2 & 3) a Double Bass player and a Violin player — shown are at the Vancouver Symphony Orchestra (Photo by Vancouver 125 - The City of Vancouver from Wikipedia, used under the Creative Commons Attribution 2.0 Generic license), 4 & 5) a Timpani player and a Flute player — shown are at the Mérida State Symphony Orchestra (Photo by Lodewijk Vadacchino from Wikipedia, used under the Creative Commons Attribution-Share Alike 3.0 Unported) 6) a Cello player — shown is a Cello player at the Orchestra of the Munich University of Applied Sciences, (Photo by Mark Kamin from Wikipedia, used under the Creative Commons Attribution-Share Alike 2.5 Generic license.)

3.3.3 Seating Arrangement in Orchestra

Although there is no uniform rule for seating arrangements within an orchestra; the placement of individual instrument groups is handled in many different ways. Figure 3.7 shows three major typical layouts that are commonly used in positioning of instrument groups.

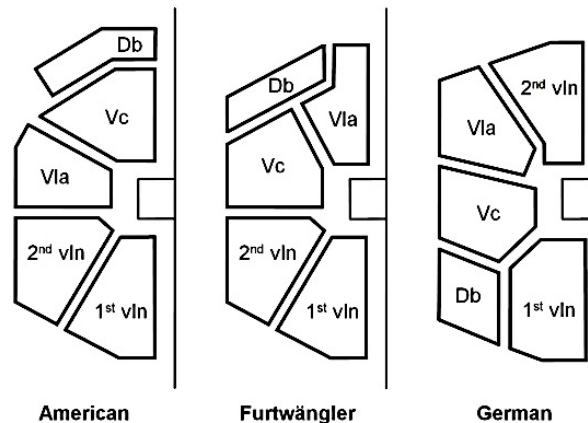


Figure 3.7. Three major typical orchestra layouts that are commonly used in positioning of instrument groups (from Meyer, (1987))

3.3.4 Relative Positions in Orchestra Layout and the Corresponding Distances Between Players

Figure 3.8 shows an example of relative positions in an orchestra layout and the corresponding distances between players:



Figure 3.8. An example of relative positions in an orchestra layout and the corresponding distances between players (Photo: based on internet [15])

3.3.5 Stage Design and Architectural Considerations

Figure 3.9 shows some typical architectural considerations for the benefit of the stage design including canopy, wall reflectors, risers, overhead reflections, side and back shells, stage area and stage dimensions.

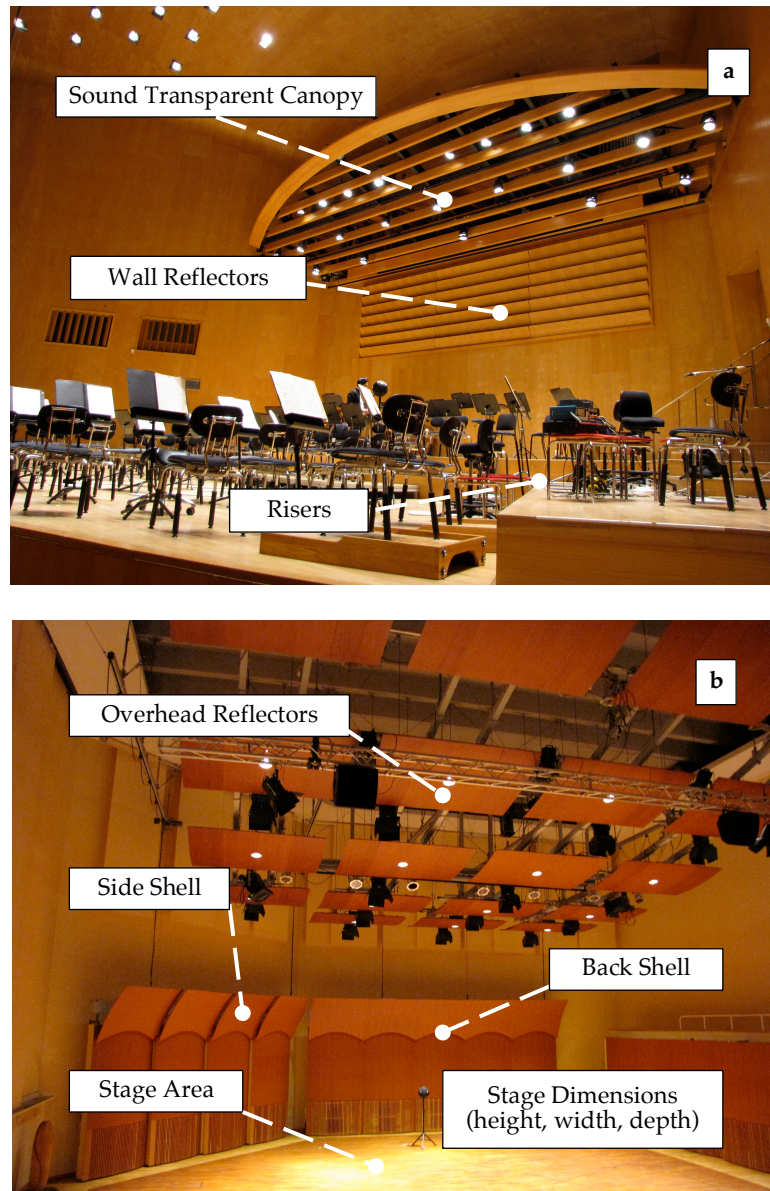


Figure 3.9. Some typical architectural considerations for the benefit of the stage design. a) Concert hall stage of the Göteborgs Konserthus (Sweden), b) Concert hall stage of the Artisten (Sweden). (Photos by Maryam Sadeghi)

3.4 Hypothesis II

As discussed in Section 3.3, a number of physical aspects can influence the musicians' room acoustical conditions on concert hall stages. Among these physical aspects, some can be attributed to the orchestra arrangement (OA) and some other to the stage conditions (SC). Those physical aspects associated with the 'orchestra arrangement', are either the same from one stage to another (items 1, 2 and 3 in Table 3.1) or can be assumed the same for simplification purposes (items 4 and 5 in Table 3.1).

Table 3.1. Some physical aspects in relation to the musicians' room acoustical conditions categorized to either orchestra arrangement (OA) or stage conditions (SC).

<i>Some physical aspects in relation to the musicians' room acoustical conditions</i>		<i>OA</i>	<i>SC</i>
1	Directional characteristics of instruments (See Section 3.3.1.)	OA	—
2	Distances from instruments to the musicians' ears (See Section 3.3.2.)	OA	—
3	Inherent sound strengths of individual instrument types (See Section 3.2.1.)	OA	—
4	Arrangement of players, chairs, stands and screens	OA	—
5	Relative positions in orchestra layout and the corresponding distances between players (See Section 3.3.4.)	OA	—
6	Stage design, stage area, risers, overhead reflectors, shells, canopies, etc. (See Section 3.3.5.)	—	SC

3.4.1 The Second Hypothesis

As the second hypothesis involved in this study, those physical aspects associated with the orchestra arrangement (items 1-5 in Table 3.1) are assumed to be the same among different stages.

3.5 Variables vs. Constants

In section 3.4, the physical aspects associated with the orchestra arrangement (OA), 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 3.1 are invariable. The metrics we look for in this study are expected to measure the influences of the stage conditions—which are variable—rather than those of the orchestra arrangement—which are constant. The problems associated with the orchestra arrangement although may contribute significantly to the problem of balance between the HO and the HS, are considered as typical problems.



Figure 3.10. Orchestra arrangement (OA) — shown is the Vancouver Symphony Orchestra with Bramwell Tovey (Photo by Vancouver 125 - The City of Vancouver from Wikipedia, used under the Creative Commons Attribution 2.0 Generic license)

4 Laboratory Simulations and Psychoacoustical Experiments

4.1 Masking

It quite often happens during a symphony orchestra performance, that one instrument becomes masked by another. Meaning due to the loudness level of one, the other is no longer audible. This occurs when one instrument produces high levels while the other remains faint. In this example the faint sound and the dominant sound are called 'masked tone' and 'masking tone' (the expression "masker tone" is also used) respectively. If the loud instrument pauses, the faint one becomes audible again. Figure 4.1 shows an example of masking effect of a masking tone of 1000 Hz, 80 dB, and the corresponding so-called 'masking threshold' (from Zwicker, 1999)).

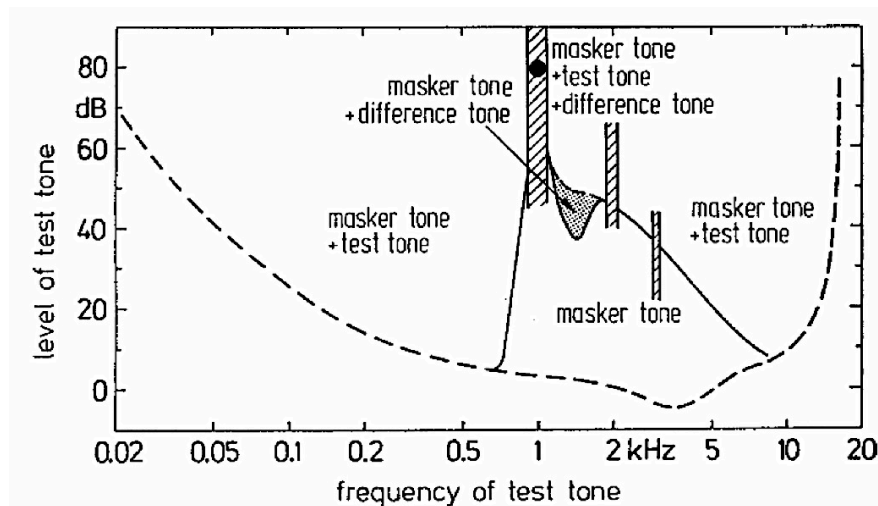


Figure 4.1. Pure tone masked by pure tone. Masking threshold of a test-tone, masked by a masking-tone of 1,000 Hz, 80 dB as a function of the test-tone frequency (from Zwicker, (1999)).

'Masking thresholds' (the solid curve in Figure 4.1), must be exceeded by the softer test-tone to become audible. The reason that the curve in Figure 4.1 is interrupted at 1000 Hz, as well as partially in 2000 Hz and 3000 Hz is that the masking phenomenon is most strongly pronounced in the neighbourhood of the frequency of the masking tone and the corresponding harmonics making the measurement at these points impossible.

4.2 Simulation Outline (Laboratory Experiments of Masking Thresholds Including the Directivity Characteristics)

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. 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 4.2 shows a schematic view of the laboratory experiments of masking thresholds, including the directivity characteristics. In Figure 4.2 the path (VI-TR), is marked by a red dashed line.

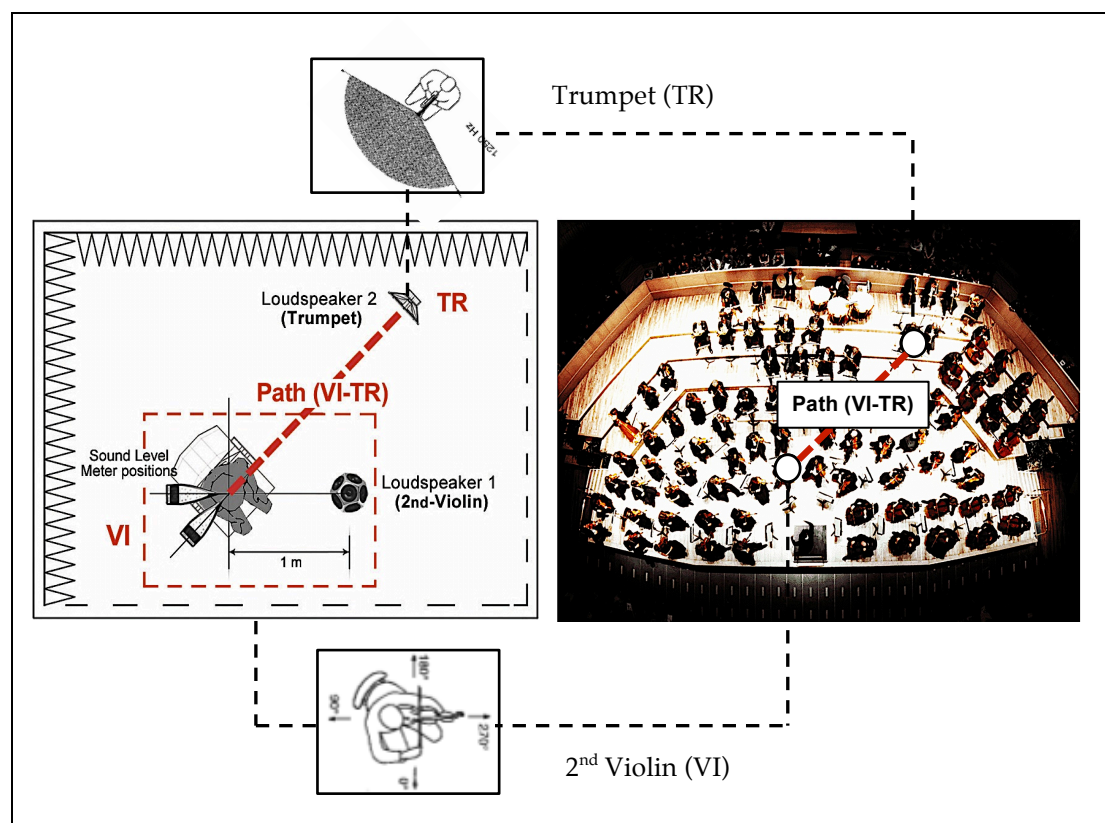


Figure 4.2. Schematic view of the laboratory experiments of masking thresholds, including the directivity characteristics. The path (VI-TR), is marked by the red dashed line. The experiments were carried out in the anechoic chamber of the Division of Applied Acoustics of Chalmers University of Technology. (Figure-left by Behzad Ranjbari, Photo-right: based on internet [15])

To simulate the directivity of ears of the violin player in the anechoic chamber, as is shown in Figure 4.2 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 (1m) and long distances respectively, from two different directions resembling the situation in the orchestra layout were used (see Figures 4.2 and 4.3). 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.



Figure 4.3. Laboratory experiments of masking thresholds, including the directivity characteristics— view from position of the loudspeaker 2 (Trumpet). The experiments were carried out in the anechoic chamber of the Division of Applied Acoustics of Chalmers University of Technology. (Photo by Behzad Ranjbari)

4.3 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 4.4 shows a sample averaged masking thresholds of two sinusoidal tones representing a trumpet, masked by a sinusoidal masking tone of 392 Hz with $L_s=80\text{dB}$, representing note G4 of a 2nd-violin, including the directivity characteristics of the corresponding path (VI–TR). The red dashed curve in Figure 4.4, is the threshold that must be exceeded by the softer masked-tone to become audible. Accordingly, below the masking threshold, the sound of trumpet (OTHER) was completely inaudible due to the sound of 2nd-violin (SELF).

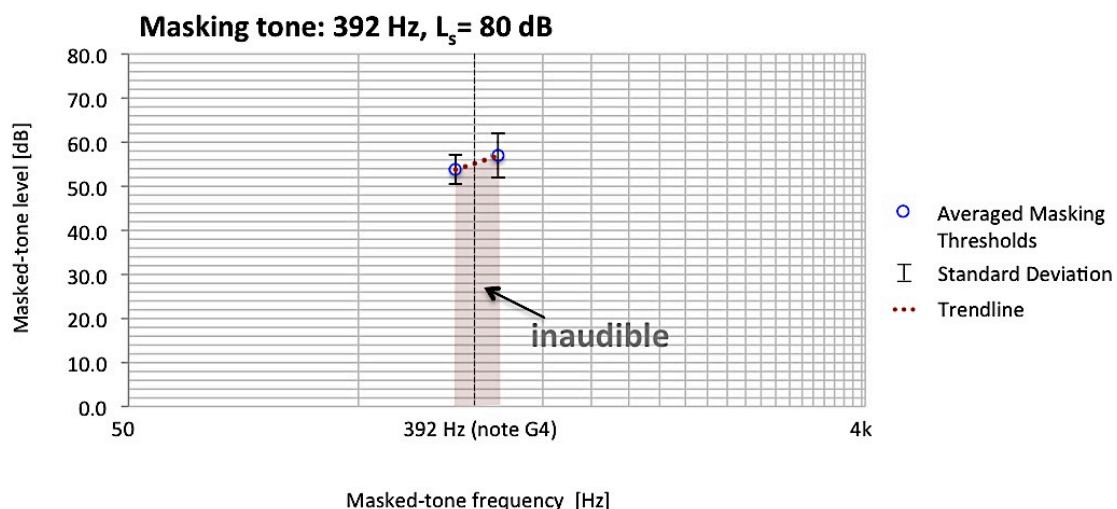


Figure 4.4. Sample averaged masking thresholds of two sinusoidal tones representing a trumpet, masked by a sinusoidal masking tone of 392 Hz with $L_s=80\text{dB}$, representing note G4 of a 2nd-violin, including the directivity characteristics of the corresponding path (VI–TR).

Accordingly, Figures 4.5 and 4.6 show the averaged masking thresholds of several sinusoidal tones representing the trumpet, masked by two sinusoidal masking tones of 392 Hz with different levels of $L_s=80\text{ dB}$ and $L_s=70\text{ dB}$ respectively, representing the note G4 (G-middle) of the 2nd-violin. The blue circles in Figure 4.5 and 4.6, 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.

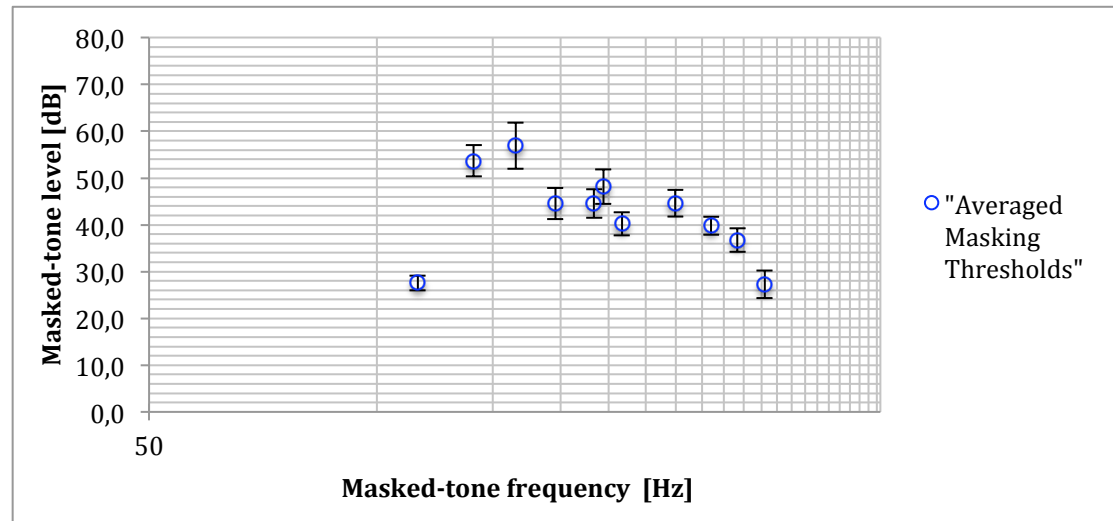


Figure 4.5. Averaged masking thresholds of several sinusoidal tones representing a trumpet, masked by a sinusoidal masking tone of 392 Hz $L_s=80$ dB, representing note G4 of a 2nd-violin, including the directivity characteristics of the corresponding path (VI–TR).

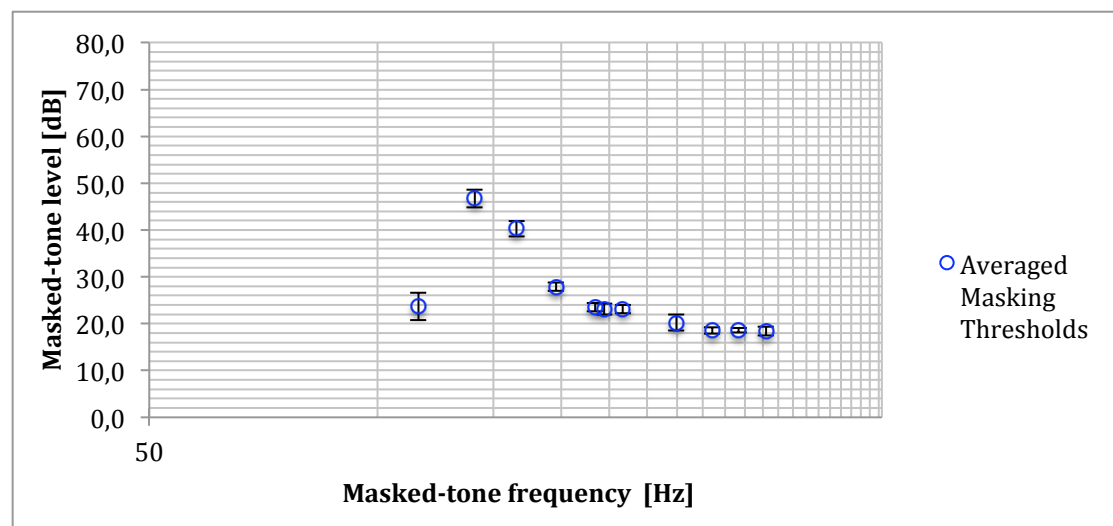


Figure 4.6. Averaged masking thresholds of several sinusoidal tones representing a trumpet, masked by a sinusoidal masking tone of 392 Hz $L_s=70$ dB, representing note G4 of a 2nd-violin, including the directivity characteristics of the corresponding path (VI–TR).

Figure 4.7 illustrates a summary of the averaged masking thresholds of several sinusoidal tones representing the trumpet, masked by two sinusoidal masking tones of 392 Hz with different levels, representing the note G4 (G-middle) of the 2nd-violin. The two solid curves in Figure 4.7 are the thresholds that must be exceeded by the softer masked-tone to become audible. 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 4.7 represents the schematically simplified threshold of hearing curve. Solid masking curves drawn similar to those by Zwicker (1999).

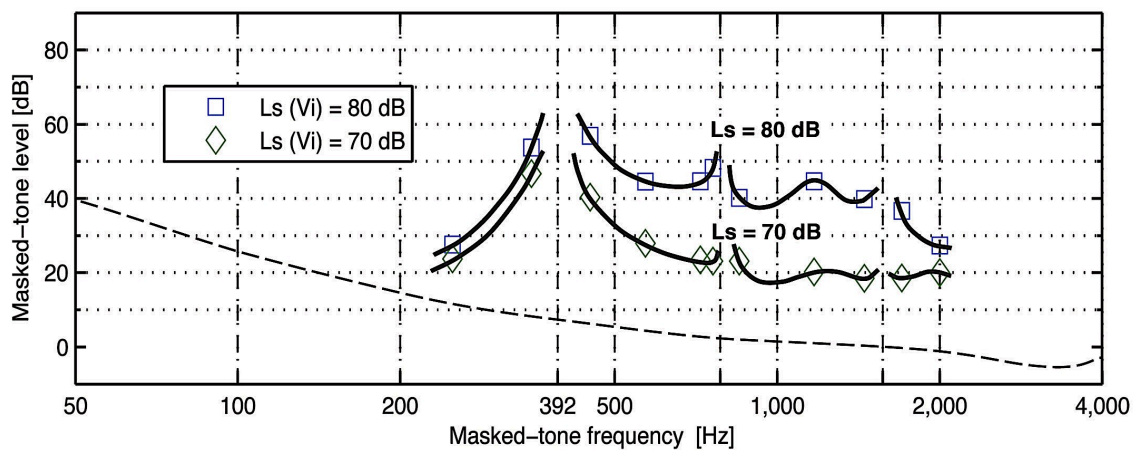


Figure 4.7. Averaged masking thresholds of several sinusoidal tones representing a trumpet, masked by two sinusoidal masking tones of 392 Hz with different levels of L_s , representing note G4 of a 2nd-violin, including the directivity characteristics of the corresponding path (VI-TR). Solid masking curves drawn similar to those by Zwicker (1999).

4.4 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 Figures 4.8, 4.9 and 4.10).

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 2nd-violin signals (representing the SELF instrument) masked by different masking signals of the trumpet (representing the OTHER instrument) were studied. Figures 4.8 and 4.9, show the averaged masking thresholds of several sinusoidal tones representing the 2nd-violin, masked by two sinusoidal masking tones of 392 Hz with different levels of $L_s=80$ dB and $L_s=70$ dB respectively, representing the note G4 (G-middle) of the trumpet. The blue circles in Figures 4.8 and 4.9, are the thresholds that must be exceeded by the softer masked-tone to become audible. Accordingly, below the masking thresholds, the sound of 2nd-violin (SELF) was completely masked by the sound of trumpet (OTHER).

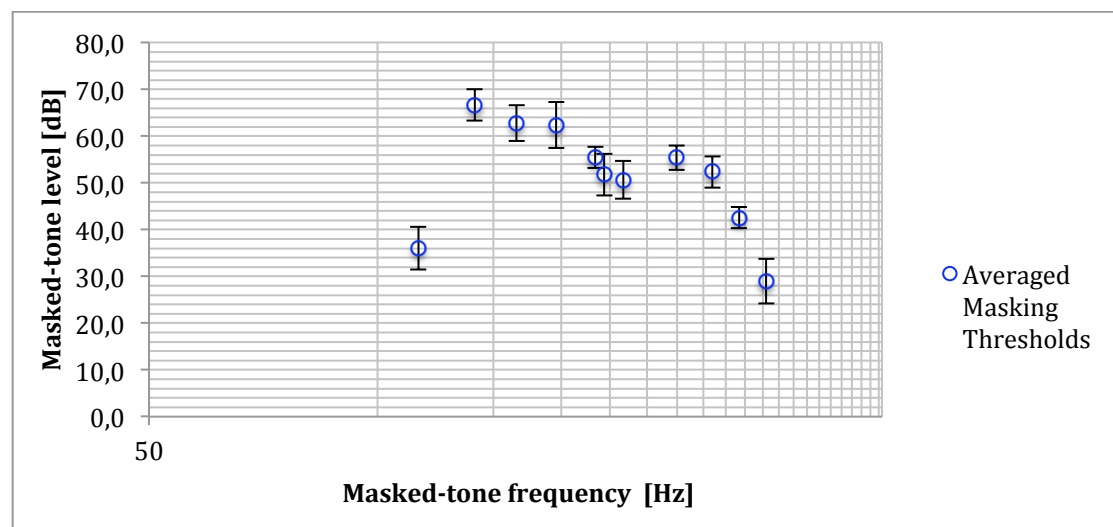


Figure 4.8. Averaged masking thresholds of several sinusoidal tones representing a 2nd-violin, masked by a sinusoidal masking tone of 392 Hz $L_s=80$ dB, representing note G4 of a trumpet, including the directivity characteristics of the corresponding path (VI–TR).

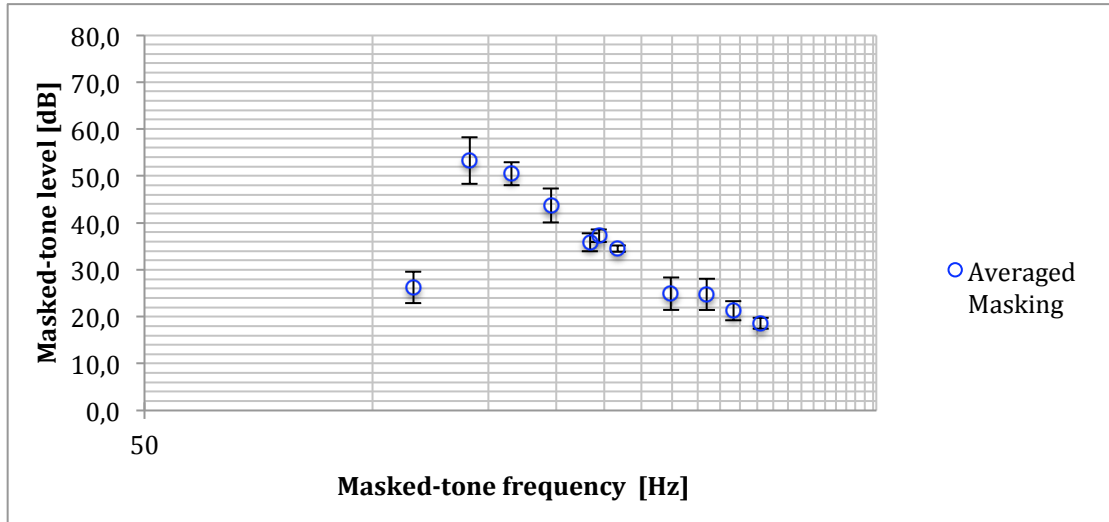


Figure 4.9. Averaged masking thresholds of several sinusoidal tones representing a 2nd-violin, masked by a sinusoidal masking tone of 392 Hz $L_s=70$ dB, representing note G4 of a trumpet, including the directivity characteristics of the corresponding path (VI-TR).

Figures 4.10, illustrates a summary of the averaged masking thresholds of several sinusoidal tones representing the trumpet, masked by two sinusoidal masking tones of 392 Hz with different levels, representing the note G4 (G-middle) of the trumpet. The two solid curves in Figure 4.10 are the thresholds that must be exceeded by the softer masked-tone to become audible. Below the masking thresholds, the sound of 2nd-violin (SELF) was completely masked by the sound of trumpet (OTHER). Furthermore, as is seen from the curves, the masking thresholds increase with increasing loudness. The dashed curve in Figure 4.10 represents the schematically simplified threshold of hearing curve. Solid masking curves drawn similar to those by Zwicker (1999).

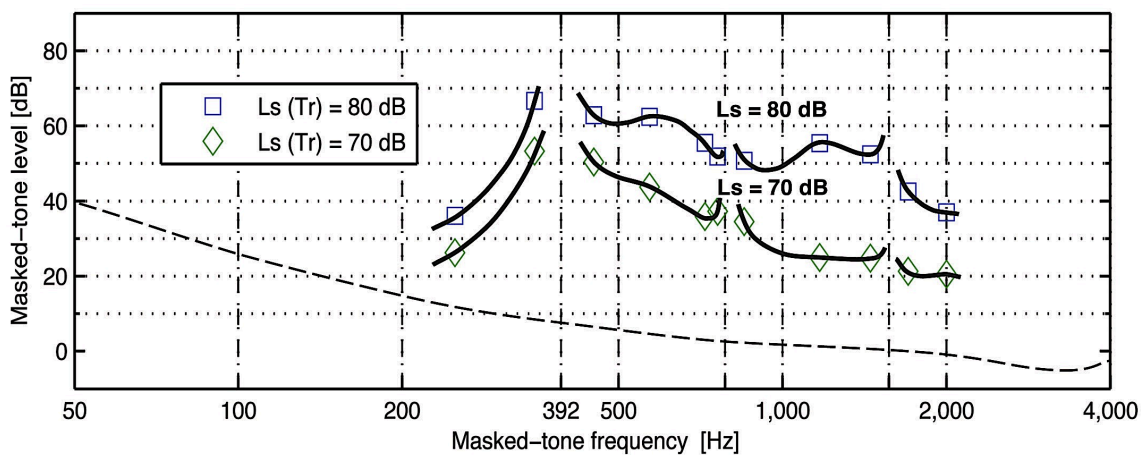


Figure 4.10. Averaged masking thresholds of several sinusoidal tones representing a 2nd-violin, masked by two sinusoidal masking tones of 392 Hz with different levels of L_s , representing note G4 of a trumpet, including the directivity characteristics of the corresponding path (VI-TR). Solid masking curves drawn similar to those by Zwicker (1999).

4.5 Summary of Results

1. 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.
2. As it is seen from the curves (see Figures 4.7 and 4.10), 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.
3. 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.

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5 Proposed 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 Section 4.5) is desirable. Furthermore, a comparative approach is desirable to possibly remove the influence of typical problems associated with the orchestra arrangement as discussed in Section 3.5. 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— as also discussed in section 3.5. 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. The accuracy of a G measurement depending on different calibration methods has been discussed in Hak et al. (2010).

5.1 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 halls stages that are defined as follows:

5.1.1 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 equation (5.1). 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.

$$G_{\text{Self}} = 10 \times \log_{10} \frac{\int_0^{\infty} p_1^2(t) dt}{\int_0^{\infty} p_{10}^2(t) dt} \quad dB \quad (5.1)$$

5.1.2 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 equation (5.2). Where $p(t)$ is the instantaneous sound pressure of the impulse response measured at the SELF musician.

$$G_{\text{Other}} = 10 \times \log_{10} \frac{\int_0^{\infty} p^2(t) dt}{\int_0^{\infty} p_{10}^2(t) dt} \quad dB \quad (5.2)$$

5.1.3 Pair of G_{Self} and G_{Other}

G_{Self} and G_{Other} to be written as $(G_{\text{Self}}, G_{\text{Other}})$ 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 Section 6.2). 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 $(G_{\text{Self}}, G_{\text{Other}})$. 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.

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)) and (Bradley, (2005)))— is 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)) and (Beranek, (2003))).

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6 Stage Measurements

6.1 Measurements

Measurements of the pair of (G_{Self} and G_{Other}) carried out using a calibrated omnidirectional sound source according to Section 5.1 of this report 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) (see Appendix-B, for measurement apparatus & calibration) for three different stage conditions including:

1. The concert hall of the Göteborgs Konserthus (Sweden) with variable acoustic conditions (1) (see Figure 6.1)
2. The concert hall of the Göteborgs Konserthus (Sweden) with variable acoustic conditions (2) (see Figure 6.2)
3. The concert hall of the Academy of Music & Drama— Artisten (Sweden). In this case no variable acoustic condition were used. (See Figure 6.3)

See Appendix-A for the concert halls specifications.

6.1.1 Variable Acoustics Used

Two different variable acoustic conditions were used in the case of the measurements at Göteborgs Konserthus (Sweden). Figure 6.1 and Figure 6.2 show the concert hall of the Göteborgs Konserthus (Sweden) with variable acoustic conditions-1 (wall reflectors open) and variable acoustic conditions-2 (wall reflectors closed) respectively.



Figure 6.1. The concert hall of the Göteborgs Konserthus (Sweden) with variable acoustic conditions 1 (wall reflectors were open) (Photo by Maryam Sadeghi)

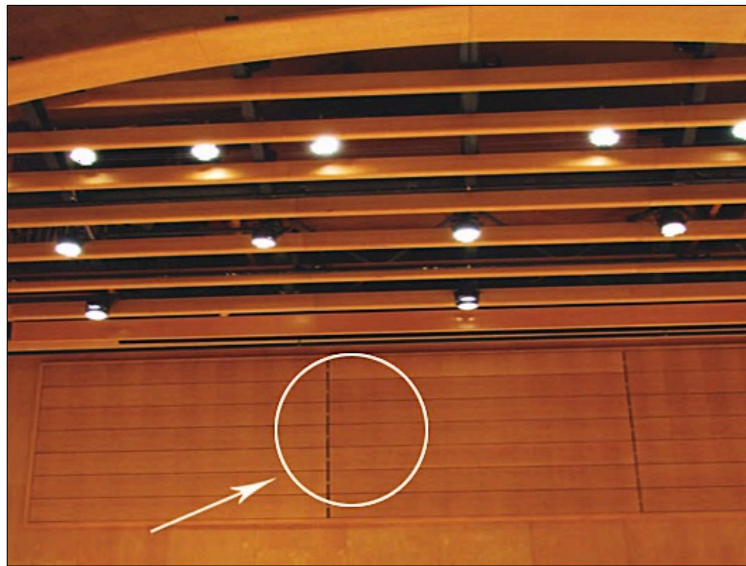


Figure 6.2. The concert hall of the Göteborgs Konserthus (Sweden) with variable acoustic conditions 2 (wall reflectors were closed) (Photo by Maryam Sadeghi)

No variable acoustic conditions were used in the case of measurements at the concert hall of the Academy of Music & Drama— Artisten (Sweden). (See Figure 6.3)

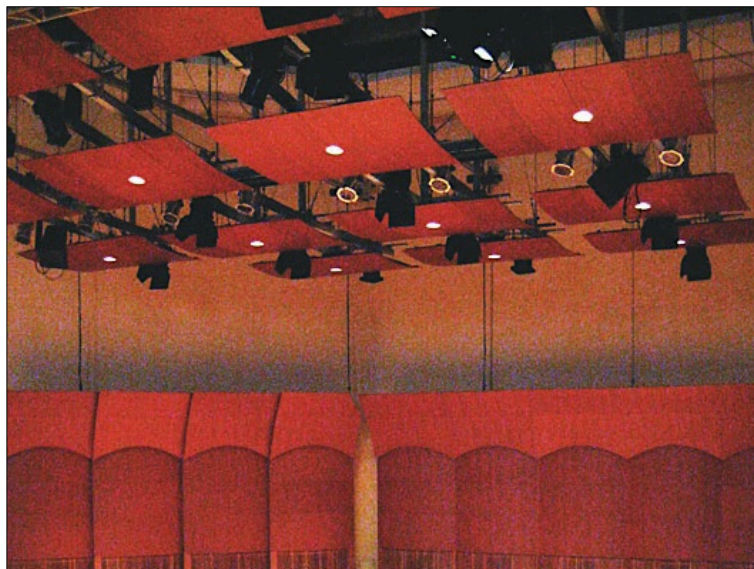

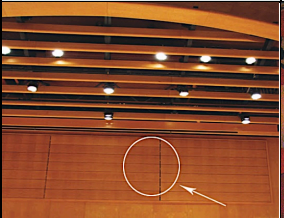
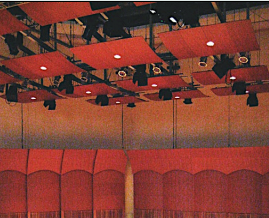


Figure 6.3. The concert hall of the Academy of Music & Drama— Artisten (Sweden). In this case no variable acoustic condition were used. (Photo by Maryam Sadeghi)

6.1.2 Summary of the Measurement Results

Table 6.1 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 Appendix-A for the concert halls specifications)

Table 6.1. Stage measurement results for three different stage conditions

Hall	Göteborgs Konserthus (Sweden)		Artisten (Sweden)
Variable acoustic	Wall reflectors: open	Wall reflectors: closed	No variable acoustic used
			
Sample critical paths ▼	$(G_{Self}, G_{Others})_{m^*}$ [dB]	$(G_{Self}, G_{Others})_m$ [dB]	$(G_{Self}, G_{Others})_m$ [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).

6.2 Interpretation of Results

From the measurement results in table 6.1, 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_{Others} 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 4.7).

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7 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 Section 6.2), 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 $(G_{\text{Self}}, G_{\text{Other}})$. 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 stage acoustic metric ST_{early} (ISO 3382-1, (2006)) proposed by Dr. Anders Gade (Gade, (1989a), (1989b) & (1992)), the newly suggested pair of metrics can be measured all across the stage. For 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))

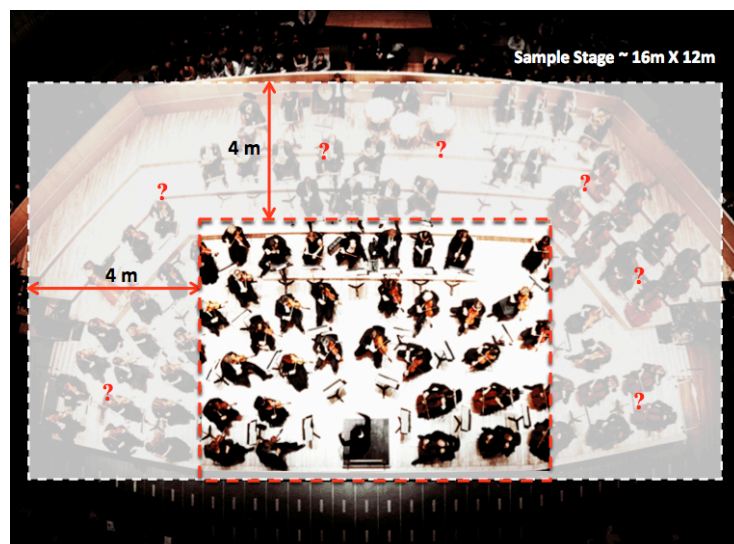


Figure 7.1. For the existing metric ST_{early} (ISO 3382-1, (2006)), the lower time limit of 20 ms implies that the source and receiver should be at least 4 meters away from any reflecting stage surfaces except from the floor, to avoid any of early reflections arriving before 20 ms. As the figure illustrates, ST_{early} cannot be measured all across the stage.

- 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 (Barron, (2005)).
- No averaging of results among different measurement positions 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.

Note:

Please note that 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 Section 6.2), 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 $(G_{\text{Self}}, G_{\text{Other}})$. 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.

Checklist of the Results

Table 7.1. Table below summarizes the achievements of the newly proposed metrics proposed by author in this work, in comparison to the existing stage acoustic metrics (ISO 3382-1, (2006)) proposed by Dr. Anders Gade, in addition to the alternative to the Gade's metrics proposed by Dammerud et al. (2010).

No.	Item	A. Gade (1992) ST_{Early} & ST_{Late}	Barron et al. (2010) G_{20-100} & G_{Late}	B. Ranjbari (2012) (G_{Self} & G_{Other})
1	Possibility to be measured all across the stage	Not for ST_{early}	<u>Yes</u>	<u>Yes</u>
2	Taking into account the directional characteristics of instruments	No	No	<u>Yes</u> (Due to the comparative approach used)
3	Taking into account the distance from instrument to the ears of musician	No	No	<u>Yes</u> (Due to the comparative approach used)
4	Ability of local diagnosing	No	No	<u>Yes</u>
5	Taking into account the effects of complex perceptual effects (level masking, etc.)	No	No	<u>Yes</u> (In this study, it has been assumed as the first hypothesis that in the most problematic situations the problem associated with balance between HO and HS is mainly due to the level masking)
6	Avoid averaging of results among different measurement positions	No	No	<u>Yes</u> Additionally the newly proposed pair of metrics were used as function of source-receiver distance which gives more accurate results
7	Use of G-based metrics	No	<u>Yes</u>	<u>Yes</u> 'G' is a common and convenient room acoustical metric that has been used for many years
8	Inter-Orchestra simulation	No	No	No
9	Validation and reliability	No	No	Further investigations are needed. However since the newly proposed metrics (G_{Self} & G_{Other}) are based on the conventional 'G' factor (but used in a new setup) their validation and reliability partly relies on validation and reliability of the conventional 'G' factor.

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8 Future Work

In this study, focus on individual paths between individual orchestral players was applied and for the purpose of focusing on the problematic situations, some paths assumed to be crucial to the study (named “critical paths”). However, the study of which paths are critical and to what degree they are problematic was not be investigated in this work and a comprehensive study in this area is required and is suggested as future work.

Furthermore, to supplement the achievement of this study and for the benefit of the validation and reliability of this newly proposed pair of joint metrics (G_{Self} , G_{Other}), further investigations including more stage measurements and more comparisons between different stages are needed that are suggested as future work.

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List of Acousticians and Musicians

(Sorted by alphabetical order)

Prof. Michael, Barron: Partner in 'Fleming & Barron' acoustic consultants, and a lecturer in the school of Architecture and Building Engineering, University of Bath (Barron, (1993)), UK.

Alf Berntson: Acoustic consultant since 1988. Acoustic consultant at 'Artifon AB', also has been active as choir conductor and is presently section leader in the Pro Musica chamber choir, Sweden.

Dr. Densil Cabrera: Senior lecturer in Audio and Acoustics in the Faculty of Architecture, Design and Planning, University of Sydney, Australia.

Dr. Jens Jørgen Dammerud: Author of 'Stage Acoustics for Symphony Orchestras in Concert Halls', PhD thesis, University of Bath, UK. (Dammerud, (2009))

Dr. Anders Christian Gade: Partner in 'Gade & Mortensen Akustik A/S' acoustic consultants, and former lecturer in the Department of Acoustic Technology, the Technical University of Denmark (DTU), Denmark.

Jan-Inge Gustafsson: Acoustic consultant and one of the Akustikon's founders and part owner, 'Akustikon - Consulting company specializing in acoustics, vibration and AV engineering', Sweden.

Dr. Eckhard Kahle: Founder of and director of 'Kahle Acoustics': Acoustic Consulting for the Performing Arts, Belgium.

Prof. Mendel Kleiner: Professor of Architectural Acoustics, Chalmers University of Technology, Göteborg, Sweden, in charge of the Chalmers Room Acoustics Group since 1989.

Prof. Emeritus Asbjørn Krokstad: Former president of the Acoustical Society of Norway 1994-98, chairman of the Scientific Committee for the 15th International Congress on Acoustics 1995 (ICA'95), member of The International Commission on Acoustics, 1994-1999, Norway, author of several textbooks in Norwegian on acoustics as well as a book on conducting orchestras and choirs. He has produced 11 journal papers, many international conference publications, numerous open and classified reports, and holds 4 patents in the field of electroacoustics. He was awarded an honorary membership in the Acoustical Society of Norway in 2001, as only one of five at the time, and in 2002, he was awarded an ASA Fellowship. He has been a member of national groups, as well as several ad hoc working groups, for standardization in ISO and IEC. In parallel with his academic work, he did many professional consultancy projects and has been a conductor of several professional and amateur orchestras and bands from 1958 and on. Recently an article entitled as: "The hundred years cycle in room acoustic research and design" by Professor Emeritus Asbjørn Krokstad was published as part of the book: "Reflections on Sound; In Honor of Professor Emeritus Asbjørn Krokstad" on occasion of the 75-year birthday of Professor Emeritus Asbjørn Krokstad, co-authored by Jürgen Meyer, Peter Svensson, Gerald Fleischer, Svein Strøm and Johan Sundberg (Krokstad, (2008)).

Prof. Wolfgang Kropp: Professor of Acoustics and in charge of the Master's Program in Sound and Vibration at The Division of Applied Acoustics, Chalmers University of Technology, Sweden.

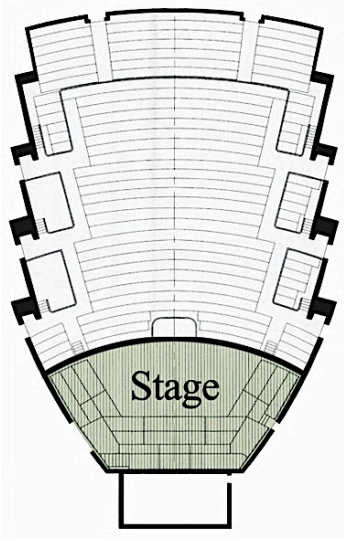
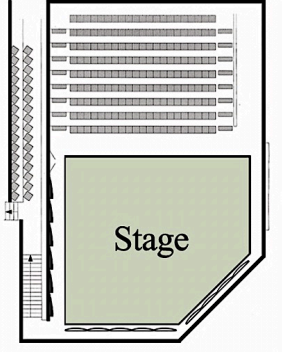
Christer Nyström: Bassoon player in the National Orchestra of Sweden in Goteborg, Sweden.

Thomas Wulfrank: Acoustic consultant and an associate of 'Kahle Acoustics': Acoustic Consulting for the Performing Arts, Belgium.

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Appendix A: Concert Halls' Specifications

Table. Appendix.1. Concert halls specifications. Figure-left: concert hall of Göteborgs Konserthus's floor plan (from 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

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Appendix B: Measurement Apparatus & Calibration

1. Apparatus

Measurements carried out using the following apparatus:

- Sound source: omnidirectional (B&K Type 4292);
- Microphone: omnidirectional dynamic microphone; Beyer Dynamic Type: M101 N(C);
- Input/output: USB audio device (Edirol UA-101: 10 in/10 out);
- Power amplifier: Yamaha Natural Sound 2/4 channel power amplifier (Model No. M35);
- Signals: exponential sine sweeps;
- Turntable: (B&K Type 3921);
- Software: Fuzzmeasure Pro3 and Matlab R2009-b.

2. Calibration

Sound strength calibration carried out according to ISO 3382-1 (2006), using the “free-field calibration method” discussed in Hak et al., (2010). Calibration measurements were performed in the anechoic chamber of the Division of Applied Acoustics of the Chalmers University of Technology (Sweden).

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Paper Submissions

Conference Paper Submission

Journal Paper Submission

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B. Ranjbari.

Investigation of Improved Metrics for the Characterization of Musicians' Room Acoustical Conditions in Concert Halls.

Journal of the Acoustical Society of America, Volume 131, Issue 4, pp. 3358-3358 (abstract).

(Accepted and submitted at the 163rd meeting of the Acoustical Society of America - Acoustics 2012, Hong Kong, May 13-18, 2012.)

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ACOUSTICS 2012 HONG KONG

THE ACOUSTICS 2012 HONG KONG conference (May 13-18, 2012), consists a joint meeting of the 163rd meeting of the Acoustical Society of America (ASA), the 8th meeting of the Acoustical Society of China (ASC), the 11th Western Pacific Acoustics Conference (WESPAC) and the Hong Kong Institute of Acoustics (HKIOA).



The Acoustical Society
of America



The Acoustical
Society of
China



The Hong Kong
Institute of Acoustics
(HKIOA)



The Western Pacific
Commission for
Acoustics

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

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http://asadl.org/jasa/resource/1/jasman/v131/i4/p3358_s6?bypassSSO=1

Behzad Ranjbari

Division of Applied Acoustics, Chalmers University of Technology,
SE-41296, Gothenburg, Sweden

ABSTRACT:

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 for musicians, appears mainly to be associated with the communication 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. Problems regarding presence of orchestra, directional characteristics of instruments, distances from instruments to ears of musicians, etc., also have been an issue for researchers, making the work difficult, expensive and imprecise. However, in this paper, due to the comparative approach used, some of these problems were removed, since they are basically the result of properties of orchestral arrangement rather than stage conditions and can be assumed similar from one stage to another. In this paper, a number of laboratory experiments as well as measurements on real stages have been studied and a pair of metrics, namely G_{Self} and G_{Other} are suggested to assess the balance between the hearing of self and that of hearing others.

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B. Ranjbari.

New Metrics for the Characterization of Musicians' Room Acoustical Conditions in Concert Halls

Forthcoming, submitted and recently peer reviewed for publication in the Journal of the Building Acoustics, 2013.

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

Behzad Ranjbari

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