AN INVESTIGATION OF PERFORMANCE INDICATORS FOR STAGE ACOUSTICS IN MUSIC HALLS

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ABSTRACT

AN INVESTIGATION OF PERFORMANCE INDICATORS FOR STAGE ACOUSTICS IN MUSIC HALLS

It is vital for concert halls to provide suitable acoustic conditions, as they provide the physical environment in which the communication between musicians and the audience is established. Although the acoustic conditions in these halls have been studied in detail for audiences, relatively little is known about the conditions under which musicians perform on stage and how they perceive acoustics.

This thesis research investigates how the acoustics of the hall in which they perform are perceived by the musicians and how the objective data obtained through measurements carried out on stage matches the evaluations of the musicians through quantitative methods. Acoustic measurements were carried out in the Main Hall of the Ahmed Adnan Saygun Arts Center Izmir. Evaluations by the orchestra musicians about their own home stage were collected through questionnaires using a 10-point semantic differential scale for subjective acoustic parameters. A total of 33 musicians who regularly perform on this stage participated in the study as respondents. Compatibility between subjective data obtained from opinions and objective data obtained from measurements were compared.

The main objective of this investigation was to scrutinize the tools and parameters that are recommended for acoustic design of concert hall stages, and provide further data for studies into understanding musicians' preferences and objective parameters that are being developed to reflect them. The correlations among subjective parameters on stage acoustics, were examined. Overall Acoustic Impression was found to be highly correlated with Hearing Others (0.833) and Support (0.753). This was supported by the objective measurements where ST_{early} values were in a highly favorable range with a mean of -13.7 dB for this stage that is generally deemed to have good acoustics by musicians. The objective and subjective support parameters were found to be useful indicators within the limited context of Ahmet Adnan Saygun Arts Center Main Hall.

Keywords: Stage Acoustics, Music Halls, Questionnaire, Symphony Orchestra, Musicians, Measurements, Correlation,

ÖZET

MÜZİK SALONLARINDA SAHNE AKUSTİĞİ BAŞARIM GÖSTERGELERİ ÜZERİNE BİR İNCELEME

Konser salonlarının, müzisyenler ve seyirciler arasındaki iletişimin kurulduğu fiziksel ortamı sağlaması nedeniyle uygun akustik koşullara sahip olması büyük önem taşımaktadır. Bu salonlarda akustik koşullar seyirciler için ayrıntılı bir şekilde incelenmiş olsa da müzisyenlerin sahnedeki tercihleri ve akustiği nasıl algıladıkları hakkında çok az şey bilinmektedir.

Bu tez araştırması, performans gösterdiği salonun akustiğinin müzisyenler tarafından nasıl algılandığını ve sahnede yapılan ölçümler yoluyla elde edilen nesnel verilerin, müzisyenlerin değerlendirmeleriyle ne kadar uyumlu olduğunu nicel yöntemlerle araştırmaktadır. İzmir'de bulunan Ahmed Adnan Saygun Sanat Merkezi Ana Salon'da akustik ölçümler yapıldı. Orkestra müzisyenlerinin kendi ev sahneleri hakkındaki değerlendirmeleri, subjektif akustik parametreler için 10 puanlık bir semantik diferansiyel ölçeği kullanan anketler aracılığıyla toplandı. Bu sahnede düzenli olarak performans sergileyen toplam 33 müzisyen araştırmaya gönüllü olarak katılım sağladı. Müzisyenlerin görüşlerinden elde edilen subjektif veriler ile ölçümlerden elde edilen objektif veriler arasındaki uyum karşılaştırıldı.

Bu araştırmanın temel amacı, konser salonu sahnelerinin akustik tasarımı için önerilen yöntem ve parametrelerin irdelenmesi; müzisyenlerin tercihlerinin anlaşılmasına yönelik çalışmalara ve bunları yansıtmak için geliştirilmekte olan nesnel parametrelere daha fazla veri sağlayabilmekti. Sahne akustiğine ilişkin subjektif parametreler arasındaki korelasyonlar incelendi. Genel Akustik İzlenimin, Diğer Müzisyenleri Duyabilme (0,833) ve Destek (0,753) ile yüksek oranda ilişkili olduğu bulundu. Müzisyenler tarafından genel olarak iyi bir akustiğe sahip olduğu kabul edilen bu sahne için STearly değerlerinin ortalama-13.7 dB ile oldukça uygun bir aralıkta olduğu objektif ölçüm sonuçlarıyla desteklenmiştir. Nesnel ve öznel destek parametreleri, Ahmed Adnan Saygun Sanat Merkezi Ana Salonu'nun sınırlı bağlamında yararlı göstergeler olarak bulunmuştur.

Anahtar Kelimeler: Sahne Akustiği, Konser Salonları, Senfoni Orkestrası, Korelasyon, Anket, Müzisyenler, Ölçüler, Mimari

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CHAPTER 1

INTRODUCTION

1.1. Motivation

While investigating the acoustic conditions in concert halls, the focus is mostly on the perception of the audience and the practices in the design of auditoriums. Optimal conditions for musicians have been much less explored, and many issues about acoustic conditions on the stage remain unexplained (Barron & Dammerud 2006). For the musical performance to be the best it can be for the audience, it is necessary that the stage design provides the best acoustic conditions for the musicians.

Since the beginning of the 70s, studies on the acoustic properties of the stage has been increasing. For stage design, it is important to investigate how space can be analyzed to represent the sound elements of the stage and then to define the relationship between the objective parameters defined by previous studies and the preferences of musicians (Wenmaekers 2017). It is often difficult for acoustic consultants to consider the musicians' opinions on the design of the hall because they are often based on the expression of emotions. Communication can be established more easily if the researcher conducting the acoustic study has a musical background and the musician has a technical interest in this subject (Gade 2015).

Another important issue is to increase the fidelity of communication between the acoustic expert who is trying to provide optimum conditions for the hall and the artist performing on stage. The measurements made by the acoustic expert and the methods used to evaluate the data can be expressed with numerical data. However, the artist tends to express his/her thoughts about the performance on stage more subjectively and sometimes allegorically. A common language should be established to increase the effectiveness of the communication between these two groups which have an active role in the development of stage acoustic conditions. For this purpose, studies should be conducted where artists share their opinions about the stages they perform on, and inferences made from these are compared with numerical data measured on these stages.

In studies exploring stage acoustics, research has followed various strategies: Questionnaire studies for understanding musicians' perspective, experiments in laboratories, measurements made in existing halls, and modeling and simulation of halls using computational tools. Preferably, these methods should be combined in order to reach more accurate results.

One of the ways to learn the acoustic conditions in the halls is to measure the acoustic properties through measuring devices. There are many parameters determined for both the hall and the stage. The requirements for stage measurements are contained in 3382-1, the ISO standard for the acoustics of performance halls. The microphone and speaker distances and heights required for measuring the Support Parameters originally recommended by Gade for stage acoustics are included in this standard. Measurements are sometimes made on an empty stage, sometimes with a chair, and sometimes with a fully loaded one. Since it is difficult to carry out lengthy measurements with the musicians on stage, it is recommended to carry out the measurements with only chairs present on stage (Gade 1992).

Laboratory experiments are usually made in an anechoic room, usually in the form of solo playing or simulating two-person ensembles. Naylor&Craik (1988) and Gade (1989b) conducted studies with this method.

Simulations allow us to test the effects of changes to the stage conditions. Although it is not yet known whether it gives as accurate results as on-site measurements, different scenarios can be quickly tested using simulations. It is important to examine the impact of architectural elements and the changes to be made. However, it can be difficult and costly to make these changes on the actual stage. Simulation software can be used to facilitate these studies after the model is calibrated based on measurements made on-site.

Another research method employed in stage acoustics is to conduct questionnaire studies to understand the perceptions of musicians. Many different researchers have used this method in their studies. One of the first and most important is Gade's work on 11 halls (Gade 1989a). Another is Leo Beranek's study for the design of the New York Philharmonic Hall that collected responses from 67 conductors from 21 opera houses. Halls were ranked according to the results. For his Ph.D the dissertation, Lorenz-Kierakiewitz & Vercammen (2009) made comparative acoustic measurements of 25 European concert halls, following the example of Gade (1989a). Among the measured halls there are also halls known to have good acoustics, such as the Vienna Musikverein. In addition to these,

Questionnaire studies have been included in recent academic thesis research. Dammerud (2009) included an extensive questionnaire study in his research. It was conducted with eight different orchestras in England and Norway. Which objective parameters corresponded to which subjective stage acoustic conditions were examined.

Researchers working on stage acoustics have made both physical measurements and perceptual studies. Gade (2011), in his study summarizing these studies, concluded that the concert halls studied to reach the stage acoustic indicators were insufficient in number.

Gade (2013) states that more research needs to be done that includes a full symphony orchestra and more realistic conditions are provided, and that acoustic researchers should take a unified approach when collecting data in their work.

1.2. Objective and Aim of Research

The main goal of this thesis is to investigate the correlations between the preferences of the musicians and the objective acoustic parameters obtained from previous studies on the subject. The objective and subjective data collected from a stage where a symphony orchestra plays, will add to the available data for improving our understanding of the usefulness of Support Parameters for stage acoustics. Establishing the soundness of these parameters is important in improving the design of stages using simulation tools.

1.3. Research Questions

The research seeks to answers the following questions:

• How do musicians perceive the acoustics in the spaces they play and how do they express their opinions?

•When evaluating the acoustic conditions of the space, can the acoustic researcher and the musician performing in the hall speak a common language? Does the objective data obtained through measurements support subjective evaluations?

• How are the results when the Ahmed Adnan Saygun concert hall is evaluated in terms of the findings obtained in the stage acoustics research carried out until today? How are the results compared to the numerical data obtained from the examined volume with the halls known to have high acoustic values in the world?

• Which subjective parameters are more important in shaping the overall opinions of the musicians?

• What are the issues that musicians or groups of musicians’ care about and attach importance to in the acoustic conditions of the space they perform?

1.4. Structure of the Thesis

The thesis is divided into five chapters. Information included in these chapters is summarized below:

Chapter 1 provides a general introduction to the study. Aim and scope are defined and research questions are stated in this chapter.

Chapter 2 provides required background information about the parameters of room acoustics that are examined in the study and which are important in concert hall acoustics.

Chapter 3 contains the literature review that will provide a basis for the study. Methods such as questionnaires, laboratory experiments or current stage measurements, previously made by researchers, are shared under different headings.

Chapter 4 describes the methodology followed in this study. Two different methods are employed. Questionnaire study and measurement of stage acoustics.

Chapter 5 reports the results obtained in the study. The objective parameters obtained from the measurements and the values obtained from the 1-10 ratings in the questionnaire are compared statistically. The open questions and ratings obtained from the questionnaire are shared under different headings.

CHAPTER 2

BACKGROUND ON STAGE ACOUSTICS

In this part of the thesis, parameters related to the research are introduced to form a basis for the discussions. Some of the parameters are only related to the stage conditions, and some are for determining the general acoustic characteristics of the concert hall.

2.1. ST (Support)

In 1989, Danish researcher Anders C. Gade's experiments with musicians in two electronically connected anechoic chambers formed the basis of this parameter. A virtual sound field was created with delays delivered via speakers. As a result of these studies, Gade proposed two parameters named ST and EEL. Support (ST) is a measure of how well a musician can hear himself or other nearby instruments. ST is defined as the ratio of the energy of the early reflections to the energy of the direct sound (ISO 2009).

Gade (1989) originally suggested two parameters for support, namely ST1 and ST2. However, Gade (1992) later revised these parameters to ST_{early}, $ST_{late,}$ and ST_{total} (for energies in 20-100-1000 ms ranges). ST_{early}:(0-20 ms) is used to evaluate ensemble conditions, ST_{late}:(100-1000 ms) is used to evaluate RT impression, STtotal (20-1000 ms) is used to evaluate the effect of room support on the sound coming from the performer's own instrument.

In the original version, the lower limit was 10 ms instead of 20 ms. However, 10 ms range was not easily calculated with the measurement techniques of the time. It was done with sinus bursts at 20 ms intervals emitted from the sound source (Wenmaekers 2017). The receiver positions are placed at a minimum distance of 4 meters from reflecting surfaces (except the floor) and there should not be any obstacles on the stage that will reflect the sound within 0-20 milliseconds. It means removing all obstacles within a 2 m radius of the loudspeaker.

The distance between the sound source and the microphone should be 1 m. Both the speaker and the microphone should be 1.5 m or 1 m high. Calibration is required for frequencies where the sound source is not sufficiently omni-characteristic. When calculating the overall ST parameter, the arithmetic average is taken for 250 Hz – 2000 Hz octave bands.

Gade and other researchers recommend that the stage has chairs and music stands during the measurements. Measurement on an empty stage may be appropriate and accurate for a chamber orchestra with a small number of musicians, but for a full symphony orchestra it is better to have objects on the stage. Dammerud (2009) references O'Keefe (1995) for his study where the measurement results of ST were compared in full and empty stages and it was found that the results changed 0.5 dB at low frequencies and 1 dB at high frequencies.

ST parameters are added to Annex C of the standard 3382-1: Measurement of room acoustic parameters published in 2009. Only the parameters specific to stage acoustics are included in the standard. These are ST_{early} , ST_{late}, and ST_{total} parameters and they are defined as:

$$\mathrm{ST_{early}} = 10\log\frac{\mathrm{E_e(20-100ms)}}{\mathrm{E_e(0-10ms)}} = 10\log\frac{\int_{20}^{100}\mathrm{p^2(t)dt}}{\int_{0}^{10}\mathrm{p^2(t)dt}} \qquad (2.1)$$

$$\mathrm{ST_{late}} = 10\log\frac{\mathrm{E_e(100-1000ms)}}{\mathrm{E_e(0-10ms)}} = 10\log\frac{\int_{100}^{1000}\mathrm{p^2(t)dt}}{\int_{0}^{10}\mathrm{p^2(t)dt}} \qquad (2.2)$$

$$\mathrm{ST_{total}} = 10\log\frac{\mathrm{E_e(20-1000ms)}}{\mathrm{E_e(0-10ms)}} = 10\log\frac{\int_{20}^{1000}\mathrm{p^2(t)dt}}{\int_{0}^{10}\mathrm{p^2(t)dt}} \qquad (2.3)$$

The validity and reliability of ST have been the subject of studies, but discussions about useful early reflections have made it challenging to reach a definitive conclusion. Some studies, such as Halmrast (2000), have found that reflections between 5-20 milliseconds can cause unwanted coloration effects, which may not accurately represent real-world situations.

Various studies have used different time intervals to evaluate the sum of early sound energy, and these have been correlated with ST. According to ISO 3382-1, the typical range of ST_{early} is between -24 dB to -8 dB, averaged over octave bands between 250 to 2000 Hz (ISO 2009).

Wenmaekers (2017) have proposed an alternative calculation method $ST_{early;d}$ for evaluating the early reflections. $ST_{early;d}$ takes into account the attenuation of sound over larger distances than ST_{early}. The difference is in the integration of the numerator, which starts from 10 ms (instead of 20 ms in ST_{early}) until a variable time limit called "103-delay" calculated based on the distance between source and receiver. The definition of 103-delay is the distance between the source and receiver divided by the speed of sound. This results in 100 ms when S-R distance is 1 m, and 30 ms when S-R distance is 25 m (max distance the method is applicable for). According to Wenmaekers, $ST_{early;d}$ seems to better correlate with musicians' preferences for halls with high early reflections compared to ST_{early}, but he notes that further investigations are needed. Wenmaekers et al. also propose a similar change to ST_{late} as $ST_{late;d}$, using a variable time limit 103-delay.

These proposed measures offer a new approach to evaluating early reflections and decay of sound within an orchestra, and further research and investigation are needed to fully understand their subjective correlations and potential applications in the field of acoustics.

Gade (1989a) conducted questionnaire studies for musicians to judge the acoustic conditions of the stages in various halls. In his studies, it was found that there was a relationship between the "ease of ensemble" judgement and ST_{early} measurements. Based on all the data obtained, it was determined that the optimum range for ST_{early} could be between -11 and -13 dB. This range has not been verified by Dammerud (2009). In Beranek's book, he stated that the most appropriate range in the results he reached in his studies with concert halls was between -12 and -15 dB (Beranek 2004). Although different studies have been carried out to date, there is no established guideline for the optimum values for ST parameters.

2.2. EEL

EEL (Early Ensemble Level) is another parameter that A.C. Gade (1989b) proposed as a result of his laboratory studies. When the EEL was first defined, it was thought to be a parameter that could explain the ease of hearing others (Gade, 1989b).

This parameter is calculated using the difference between the sound level of direct sound and the sound level of reflections (reflected sounds within 80 ms), and the difference between the sound level of the collection of direct sound and reflections from the ground (the emitted direct sound), after the sound is propagated at a distance of 1 meter, in a time interval of 0-80 ms (Gade 1989).

$$EEL = 10\,.\,log\ 10\left(\frac{E_r(0-80ms)_e}{E_e(DIR)}\right) \qquad (2.4)$$

For overall EEL, arithmetic mean is taken for 500 Hz – 2000 Hz octave bands. A higher EEL value corresponds to better hearing of others (Gade 1989).

Comparing the parameters with the subjective parameters measured by questionnaires, it was revealed that ST_{early} was a better predictor for the ease of hearing other musicians than the EEL parameter (Gade 1989). The 3382-1 standard recommends using the ST_{early} parameter to examine ensemble conditions (ISO 2009). There is no further study to improve the EEL parameter and this parameter was not included in ISO 3382-1 standard.

The major difference between ST and EEL is that the ST parameter does not require measuring direct sound (Barron & Dammerud 2006). It is difficult to measure direct sound on stage because of the variation in musical instruments and the presence of objects on stage that act as obstacles. When measuring in the absence of musicians, the reliability of EEL will be less compared to ST (Barron & Dammerud 2006).

2.3. RR160(Running Reverberation)

A measure called "running reverberation" has been proposed to examine how reverberation is perceived during musical performance Griesinger (1995). For this parameter, sound energies are calculated at 0-160 ms, and 160-320 ms time intervals. After Griesinger’s work, further studies investigating RR160 are limited and the parameter is not included in 3382-1.

$$RR160 = 10\,.\log 10\left(\frac{E(160-320\ ms)}{E(0-160\ ms)}\right) \qquad (2.5)$$

2.4. $LQ_{7\text{-}40}$

In a conference paper, Braak & Van Luxemburg proposed (2009) a parameter called LQ7-40, which aims to measure the state of the conductor on stage. The parameter is similar to EEL.

The assumption was that ST alone is not enough to evaluate the relationship between the conductor and the musicians (Dammerud 2009). LQ7-40 is determined by calculating the difference in sound level between early reflections in the time range of 7-40 milliseconds and late reflections in the range of 40 milliseconds to infinity. It is similar to the EEL parameter, but this parameter does not require calculating direct sound energy.

$$LQ_{7-40} = 10\,.\log 10\left(\frac{E(7-40\ ms)}{E(40-\infty\ ms)}\right) dB \qquad (2.6)$$

2.5. RT

Reverberation Time (RT or T_{60}), in its simplest definition, is the time required for the sound pressure level to drop by 60 decibels. 60 dB drop describes the reduction of sound energy by one million and in practice background noise often limits this measuring range. Therefore, measurements are commonly conducted using a 30 dB or 20 dB drop. The drop from 5 dB to 35 dB is specified as T_{30}, a drop from 5 dB to 25 dB is specified as T_{20}.

Measuring reverberation times is difficult when a hall is occupied with audience. Most halls do not allow measurements during concerts. Reverberation time is not the same in all parts of the hall. For this reason, the reverberation time is calculated by averaging the measurements taken from several different positions in the hall. As most halls are symmetrical, measurement points are determined in one half of the hall. In most cases 8 positions are enough (Beranek 2004).

In his measurements across 36 concert halls, Beranek has obtained the result that the best halls for symphonic music have a reverberation time of around 2.0 seconds, and the lowest-grade ones have a reverberation time of around 1.5 seconds, at 500 Hz - 1000 Hz frequencies (Beranek 2004).

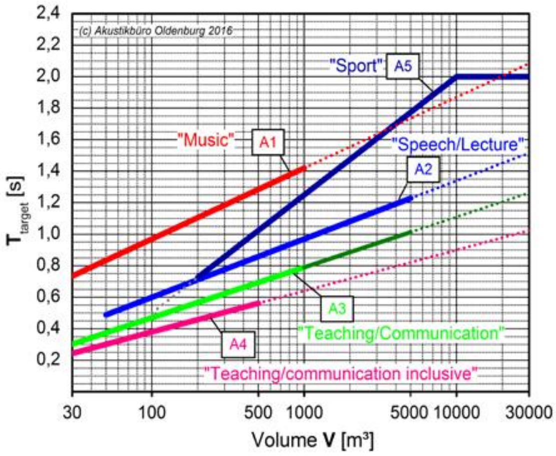

Figure 1. The target value of the reverberation times according to the DIN 18041

Barron (1993) states that the optimum reverberation time for the mid-frequency range in symphony concert halls is generally accepted as 1.8–2.2 seconds. One of the important guides used to determine the optimum reverberation time value in room acoustic studies is the DIN 18041 Standard. As in the image shared in Figure 1, target values can be determined according to the size and function of the volume.

Variable acoustics can be achieved with some acoustic design elements with variability. This variability gives the conductor the advantage of adjusting a longer reverberation when performing Romantic music and a shorter reverberation when performing Baroque music (Beranek 2004).

1.5. EDT

When an ensemble of musicians plays a piece quickly, notes follow one another, and in this case only the first part of the sound reduction is audible. EDT can be expressed as the initial portion of this sound reduction. In more numerical terms, it is the time required for the sound pressure level to diminish by 10 decibels (Drop from -0 to -10 dB). Beranek also performed EDT measurements in 36 concert halls he examined. And the results reveal that EDT shows acoustic quality better than RT, as notes often follow each other very quickly when playing music.

The standard states that both EDT and RT must be calculated. EDT is accepted as a better predictor of subjective perceived reverberance, while RT describes the actual physical conditions of the auditorium.

1.6. G (Strength)

The strength (G) parameter is a parameter that has emerged to measure how much the volume increases the sound pressure level of the sound source. It is based on the comparison of the integrated impulse responses measured at a point in a volume with the impulse responses measured in decibels at a distance of 10 meters in free field (ISO 2009). Loudness G is often associated with loudness, which is a subjective measure of the physical sound level in a concert hall. In recent years, it has been considered as a candidate for a stage acoustic parameter (Dammerud 2009). Standard specifies and explains how G should be measured (ISO 2009).

Dammerud (2009) considered the parameter G for two different time intervals and named them as G_e G_l. If the values of G and C80 parameters are known, these parameters can be calculated according to the formulas. The time intervals are 0 to 80 ms for G_e and 80 to infinite for G_l. 50 ms cutoff time can also be used for early energy, but in order to make this calculation, it is necessary to know the D50 parameter.

For reference sound level measurement, the distance is always 10 meters, but for on-site measurement this distance may be different. Wherever it is measured, source-receiver distance and location combinations must be taken into account when making evaluations (Gade 2013).

In order to calculate the parameter, the presence of an anechoic chamber is required for the measurements of the reference values. In addition, the equipment conditions and settings must be the same for the reference measurements made in the anechoic chamber and the in-situ measurements so that comparison can be made. In order to facilitate this staged measurement, research has been carried out in recent years that may allow for on-site reference measurement (Lindfors et al. 2013).

1.7. Lateral Fraction (LF)

The parameter first gained importance when Marshall stated that reflections from lateral surfaces in the concert hall have an important role in determining acoustics (Marshall 1968).

Barron and Marshall expressed this property in 1981 as the LF (Lateral Fraction) parameter that proportions the energy emerging from the lateral reflections and the total energy for a listener position (Beranek 2004).

Lateral Fraction is mathematically expressed as the ratio of the sound pressure measured between 5 and 80 ms with a figure-8 microphone and the sound pressure values measured between 0 and 80 ms with an omni microphone for the same receiver location. The direction of the microphone in figure-8 should be horizontal and exactly orthogonal to the line drawn between the source and the receiver (Jaruszewska et al. 2015).

$$LF = \frac{\int_{5}^{80} P_8^2\ (t)dt}{\int_{0}^{80} P^2(t)dt} \qquad (2.7)$$

The widely published version of Lateral Fraction is LFE4. Here, ‘’E’’ stands for early sound and ‘’4’’ stands for the average value of the parameter in the 125, 250, 500 and 1000 Hz frequency bands (Beranek 2004).

1.8. Bass Ratio & Treble Ratio

BR (Bass Ratio) is the ratio between the arithmetic average of the reverberation times for the bass frequencies (125 and 250 Hz octave bands) and the arithmetic mean of the reverberation times for the mid frequencies (500 Hz and 1Khz octave bands) (Jaruszewska et al. 2015). Beranek (2004) stated that while a value between 1-1.25 is preferred in halls with a long reverberation time, the appropriate range for halls with a reverberation time below 1.8 seconds is between 1.10 and 1.45

$$BR = \frac{RT_{125Hz} + RT_{250\ Hz}}{RT_{500Hz} + RT_{1000\ Hz}} \tag{2.8}$$

TR (Treble Ratio) is the ratio between the arithmetic average of the reverberation times for the high frequencies (2Khz or 4Khz) and the arithmetic mean of the reverberation times for the mid frequencies (500 Hz and 1Khz octave bands).

$$TR = \frac{RT_{2000Hz} + RT_{4000\ Hz}}{RT_{500Hz} + RT_{1000\ Hz}} \tag{2.9}$$

1.9. Initial Time Delay Gap

Beranek (1962) first defined ITDG in 1962 as the feature he called intimacy. Barron (1993) differentiated it and defined it as the ‘’sense of playing music in a small room’’. Beranek changed the definition by saying that sound has the feeling of being played in a suitably sized room (Marshall 2005).

If the sound of the music is coming from close surfaces and the space feels like small place, it can be said to have "acoustic intimacy" for a concert hall. Acoustic researchers will say there is 'presence' in the hall.

This feature is important to the acoustic consultant because it corresponds to when the first reflection will reach the listener's ear, depending on the volume of the hall. The listener first perceives the direct sound and then hears the first reflections. The time difference between direct sound and these reflections can be expressed as ITDG. If this period is short, the hall feels warm and sincere. Studies show that ITDG is 25 milliseconds or less in the most popular concert halls. ITDG is 35 ms in halls that are thought to have low acoustic performance, and 60 ms in halls with poor acoustics (Beranek 2004). ITDG has not been investigated for evaluating stage acoustics since source-receiver distances on stage are too short (Gjers 2014).

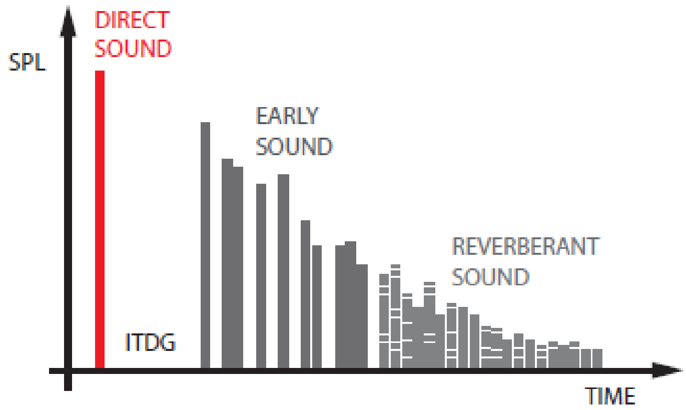

Figure 2. Graph displaying Direct Sound, Early Sound, Reverberant Sound and ITDG Times. (Source: Gjers 2014)

1.10.C80

Clarity (C80) is one of the parameters used to measure the perceived clarity or balance between early and late energy. It has a high inverse correlation with reverberation time. As reverberation increases clarity decreases. C80 is calculated in dB for 80 ms early time limit. If the reverberation is long the music will not be clear and the C80 will drop to low negative dB values. This is not a preferable situation (Beranek 2004).

The calculated C80s are usually averaged over the C80 values in the 500 Hz, 1,000 Hz and 2,000·Hz octave bands and several seats in a hall, and this average value is shown as C80(3).

ISO 3382-1 standard says that the parameter should be calculated by averaging the middle frequencies (500 Hz and 1000 Hz). Recommended range for the parameter is between -5 and +5 dB (ISO 2009).

Another important feature of Clarity is that different values are desired depending on the conditions. While rehearsing, the optimum C80(3) range is between +1 and +5 dB where the details of the music can be perceived clearly. However, a range of -1 to -4 dB may be considered appropriate during performances. A high clarity is especially desired for fast-playing instruments (for example, violins) (Beranek 2004).

C80 is actually a recommended parameter for measuring in the audience area in the 3382-1standard (ISO 2009), but the method used for the audience area can also be applied for investigations of stage acoustics (Gade 2013).

In the interviews conducted for the Beranek research, people were asked to evaluate the halls as if they were a spectator. As expected, halls with clarity between -1 and -5 dB were rated the best. A few very successful halls: Boston, Amsterdam and Vienna have C80 (3) values between -2.7 and -3.7 dB (Beranek 1996).

CHAPTER 2

LITERATURE REVIEW

The literature review for this research have collected the studies in the field of stage acoustics under three headings: 1) Studies Focused on Musician Perceptions, 2) Measurement Based Studies on Specific Stages, and 3) Laboratory Experiments. These will be discussed next followed by a fourth heading where findings on stage design and geometry is summarized.

One of the pioneering studies on stage acoustics was conducted by Barron in 1978, followed by Marshall in the same year and this review will start summarizing these studies.

2.1. Studies Focused on Musician Perceptions

Barron (1978) carried out one of the first studies in this field in 1978. In this research, objective measurements on the stage and studies on subjective opinions of musicians were carried out with a small orchestra of 13 musician in the Calouste Gulbekian Foundation Center Great Hall in Lisbon. For subjective evaluation, a questionnaire was conducted with 13 musicians and listeners in different stage conditions where the same musical motif was repeated.

For the answers to the questions in the questionnaire, 10-point scale was used. The results of the 20 conditions examined were statistically analyzed. The capacity to discern musical intricacies was regarded as clarity. According to the overall acoustic impression, the highest preference was found for the situation with the maximum number of stage reflections.

In the study, there were three main categories in the surveys of the musicians: the general perception of the acoustic situation, the ability to hear themselves/other musicians and the ease of playing. Except for string and wind musicians, all the musicians said that they prefer to have a low reflector above them. Wind musicians stated that they did not like the open stage and diffuse stage conditions. In the study, some results were obtained in terms of parameters. Clarity, calculated by the ratio of early energy to late energy, was inversely correlated with perceived reverberance (Barron et al. 1978).

After Gulbekian, Barron investigated subjective assessments of conditions in 11 British concert halls. Correlations between the subjects' responses showed that the subjective criteria presented in the questionnaires were interrelated (Barron 1988).

During the design process of the New York Philharmonic Hall, Leo Beranek (2004) sent a questionnaire to 67 conductors and collected their opinions on 21 opera houses. Halls were rated on a scale ranging from 1 to 5. Conductors were also included in the evaluation of the orchestra pit. The results obtained in the study are given in Figure 3 (Beranek 2004).

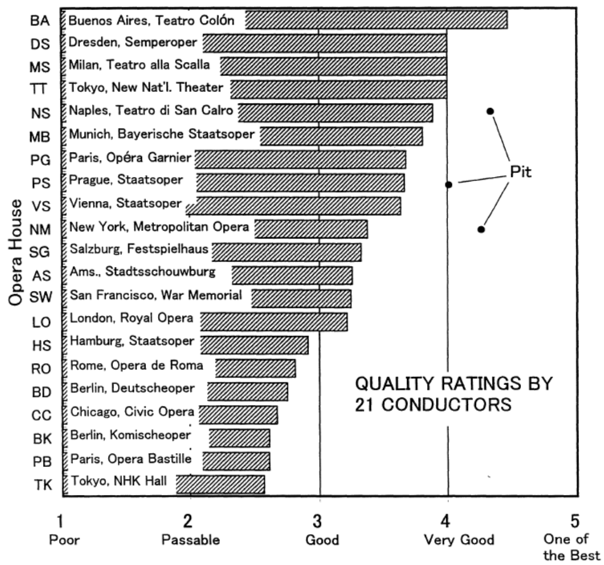

Figure 3. Acoustical quality ratings in the audience areas of 21 opera houses by 21 Opera Conductors (Source: Beranek 2004)

Gade (1981) carried out a study to investigate 32 musicians’ perceptions of acoustic conditions on stage. A key finding of the study was that musicians and acousticians communicate little with each other regarding acoustic conditions. The musicians' thoughts on stage acoustics were examined through parameters such as 'Echo', 'Support', 'Timbre, 'Dynamics', 'Hearing Others', 'Hearing Yourself'. Gade identified three crucial acoustic factors for musicians performing: support, which refers to the ability to hear oneself without exerting excessive effort on the instrument; community ease, which pertains to the ability to hear other musicians clearly; and reverberation, which concerns the ability to perceive the hall's acoustic properties (Gade 1981).

Gade conducted a study in 1985 examining the views of three different Danish symphony orchestras on 9 different performance venues. Performance venues also included the musicians' own home venue. The evaluations of the halls were summoned through questionnaires containing seven continuous semantic differential scales. The subjective aspects were (Gade 1989a): Reverberance, Support, Timbre, Dynamics, Ensemble Generally, Ensemble Others, Ensemble Hear Oneself and Time Delay. The questionnaires were filled within one to two hours after the rehearsal by 20 musicians. The simultaneous evaluation of so many variables made it difficult to draw conclusions. In addition, the fact that the orchestras were used to their own halls and have played less in other halls makes it difficult to compare.

Chiang et al. (2003) worked with 9 musicians in 5 concert halls. Solo artists rated music halls for overall impression, while chamber groups rated halls for self-hearing, hearing others, ease of ensemble, and overall impression. Hearing others, ease of ensemble, and overall impression were correlated higher, indicating that overall impression was judged by the ability to communicate among musicians. Chiang et al. suggested extending the ST_{early} time interval from 20-100 ms to 7-100 ms. In this way, ST_{early} can be used to take measurements closer to the stage boundaries. This proposed parameter was expressed as ED100.

However, Dammerud (2009) points to the fact that results of studies with small chamber ensembles cannot be directly valid for evaluating the acoustic conditions of symphony orchestras. Compared to larger ensembles, smaller groups encounter fewer issues with time delay and obstruction of direct sound (Dammerud 2009).

Cederlöf (2006) conducted a study investigating the impressions of five different orchestras on stage acoustics in their main stages. All 5 halls were built for the purpose. The spaces Gade examined in his studies included both purpose-built concert halls and small spaces with low resonance. The fact that the type of venue and stage design differed so much between the examples made it difficult to make conclusions. Cederlöf therefore only worked in purpose-built concert halls. In the questionnaires, the parameter showing the most correlation with the overall impression was obtained as support. Halls with high clarity and short reverberation time scored highest. Although the highest support value (-12dB) obtained from the measurements was obtained from the hall with the highest score by the musicians, this finding was not very compatible with other halls. It has been concluded that for the good performance of the hall, it is necessary to consider all its parameters.

Dammerud (2009) conducted questionnaires in eight different professional orchestras in England and Norway. Which objective parameters correspond to which subjective stage acoustic conditions were investigated. Although significant correlations could not be established between subjective results and objective parameters, important findings were obtained regarding the stage area and its geometry.

In their study, Ueno and Tachibana (2003) conducted an experiment in an anechoic chamber simulating various sound fields using directional impulse responses from real halls. Musicians are asked for their auditory impressions as they adapt to test conditions in different variations. While almost all musicians agreed that they have a natural impression and feel they are playing on stage, a few noted that the tonal quality of the sound field was unnatural, especially at high tones. In addition, the musicians evaluated the rooms through a questionnaire, and three conditions (early reflection, reverberation and late reflection) were compared for each factor separately.

2.2. Measurement Based Studies on Specific Stages

In the Barron study (1978), objective measurements and subjective tests were carried out with a small orchestra of 13 musicians at the Calouste Gulbekian Foundation Center Great Hall in Lisbon. The effects of the variable stage enclosure of the hall were examined, and when it was noticed that the audience was less sensitive to these changes, other changes in the configuration were tested. The results revealed that reflective surfaces around the orchestra are important and preferable for musicians.

Marshall (1978) through his work has inspired acousticians to develop guidelines for stage design. The works were done with one person or small musical ensembles. Measurements made in the Maidmen Theater were compared and consistent with experiments performed with 23 musicians in the anechoic room. Marshall and his team determined that early reflections 17-35 ms after the direct sound are important in the reflection experiments with a delay of 10,20,40,80 ms. It was also revealed that reflections at high frequency were more important than those below 500 Hz.

In Danish halls studied by Gade (1989c), ST_{early} was significantly associated with ensemble conditions, while ST_{late} was significantly associated with perceived reverberation.

Gade (1989c) found significant correlations between measures of support and subjective parameters in his study. Nevertheless, in his study involving one of the Danish orchestras performing in eight UK concert halls, ST_{early} did not exhibit any correlation with subjective parameters. Therefore, the reliability and validity of the Support parameter were examined in subsequent studies.

Halmrast (2000) performed several measurements on two different stages in the presence of a full orchestra. Halmrast's findings revealed that the presence of comb filtering in the frequency domain of the measured responses signifies negative coloration effects that are perceptible to the performers on stage. The observed comb filtering was caused by an early reflection that created interference with the direct sound. The negative effects were perceived to be most significant when the delay between the direct sound and the reflection was within the range of 5-25 milliseconds. The study also found that players reported negative timbre effects in cases where comb filtering was observed. Additionally, the study revealed that the placement of an overhead reflector above the orchestra resulted in negative timbre coloring effects. Similar adverse effects were not observed when vertical reflectors were installed on the sides.

O'Keefe (1995) conducted studies on the reliability of the ST parameter. The results indicate that the differences between performances with and without chairs are considerably smaller than those between performances with and without a full orchestra. This suggests that the use of chairs may not be a viable alternative to a full orchestra and points to a possible shortcoming of typical measurements of stage parameters on an unoccupied stage without musicians but with empty chairs and stands.

2.3. Laboratory Experiments

Naylor (1988) studied the balance between one's own instrument (SELF) and the levels of other instruments (OTHERS). An experiment was set up where musicians played along with previously recorded music in an anechoic chamber. Various versions of pre-recorded music were utilized to simulate different acoustic conditions. The results suggest that both SELF and OTHERS can be heard more effectively when the level of OTHERS is between -15 and -8 dB relative to SELF. In conclusion, Naylor's studies showed that increasing the temporal and pitch differences between the sound of one's own instrument and that of other players can have a significant impact on the perception of both self and others during a musical performance.

Marshall & Meyer (1985) conducted experiments with one male (a baritone) and two female (one soprano and one alto) singers and studied directivity and auditory impressions. The results showed that ease of ensemble for singers is more influenced by reverberation compared to early reflections. Early reflections contribute only if they have delays of less than 40 ms. These results were found to be in contrast with preferences for instrumental ensembles.

According to Naylor (1988), the level of an individual's instrument is relatively unaffected by the acoustics of the room, whereas the room's acoustics have a significant influence on the levels of other instruments in the ensemble.

Naylor proposed MTF parameter to measure the clarity of sounds. Naylor (1988) created the numerical formulation of the modulation transfer function based on research conducted by Houtgast and Steeneken in 1973. However, he found that this parameter was more related to level ratio rather than clarity.

Naylor and Craik (1988) used interfering sounds for mutual hearing studies to approximate real-life conditions. The study simulated real-life conditions by introducing background noise and accounting for masking effects that may arise due to interference from sounds of other instruments. The study evaluated the communication between two players by taking into account the impact of disruptive sounds.

Gade (1989b) studied how sound level and sound delay affect the experience of two musicians playing together in his experiments in two electronically connected anechoic chambers. Three violinists, three cellists and three flutists participated in the work. The sound from the second musician has been delayed, leveled down, and low-pass filtered. The modifications aim to replicate the blocking effect caused by the orchestra, creating a sense of distance between the players and attenuating high frequencies. According to the results, delays of more than 20 ms in the direct sound and high-frequency loss were found to be disruptive to the musicians. The fact that there was no eye contact between the musicians in the experiments and the orchestra effect was created under laboratory conditions were the limitations of the study.

Gade (1989b) found the 500-2000 Hz octave bands to be the most appropriate frequency range for examining ensemble conditions on stage. It was concluded that musicians can benefit from reflections occurring about 100 ms after the orchestral start during ensemble playing and that direct sound from one's own instrument can effectively mask early reflections up to 50 ms. Based on these studies, Gade proposed two parameters: ST and EEL.

Ueno & Tachibana (2003) installed a system of six six-channel microphones and six speakers placed in the same directions to reproduce the room impulse responses from real halls in an anechoic room. The study involved two musicians playing without visual communication. This allowed players to quickly switch between different playing conditions based on actual room responses. Similar to Naylor and Craik's findings, the results indicated that it is crucial for players to hear each other with clarity and have a balanced sound of their own voices for optimal performance. It was concluded that musicians do not prefer high amount of early reflections since these mask reverberation and cause rooms to be perceived as "smaller".

Using a directional loudspeaker as the sound source and a full symphony orchestra in the Oslo Concert Hall, Skålevik (2007) studied the sound levels at various source heights within 0-50 ms, which depended on the arrival of the direct sound, at a distance of 12 m between the source and receiver. The study investigated the impact of physical criteria such as seating arrangement, canopy, and source orientation.

Based on the findings, it was determined that the orchestra's obstruction effect is highly significant in the frequency range above 500 Hz. The source and receiver heights predominantly govern the frequency regions below 500 Hz. Unobstructed sight-lines were found to have a considerable influence on sound levels at 8 and 16 kHz throughout the orchestra. Sound levels at 1 and 2 kHz were relatively unaffected by the presence or absence of clear sight-lines, possibly because of increased diffraction at lower frequencies.

Dammerud and Barron (2010) found in their study that for 1000 Hz and 2000 Hz octave bands, a significant sound attenuation occurs in the 0-50, increasing with the distance between the source and receiver. These results support Skålevik's findings (Remy 2017).

Kalkandjiev and Weinzierl (2013) analyzed the characteristics of performances from real recordings in an anechoic chamber. Musicians played under different virtual conditions. 10 acoustic parameters (C80, EDT, T30, G, ST_{early}, ST_{late}, G_e, G_l, BR, G_{125}) were calculated and the performances of musicians were analyzed using software and the two sets of data were statistically compared. The results show that the musicians' performances are not strongly correlated with the physical parameters.

2.4. Findings on Stage Area and Geometry

The most important elements in the examination of the acoustic properties on the stage are the spatial and architectural features of the volume in which the stage is located. For this reason, it is of great importance to explore the relationship between properties such as the size and proportion of the performed volume and its effect on acoustics, and to obtain important information for acoustic design. In this part, one of the studies on this subject is shared.

Dammerud (2009) proposed geometric parameters to relate to the subjective judgments of musicians. Figure 4 illustrates these parameters and their corresponding dimensions of the stage. Wrs is the average width of the surfaces of the part where the string instruments are placed on the stage that are likely to reflect the sound. Hrb is the average height from the ground between the brass and string instruments to a reflective surface that is likely to reflect the sound from the brass instruments towards the string instruments. D is the distance between the rear end of the stage and the front of the stage according to the placement of the orchestra. Ratios such as Hrb/Wrs and D/Wrs were also examined using these parameters.

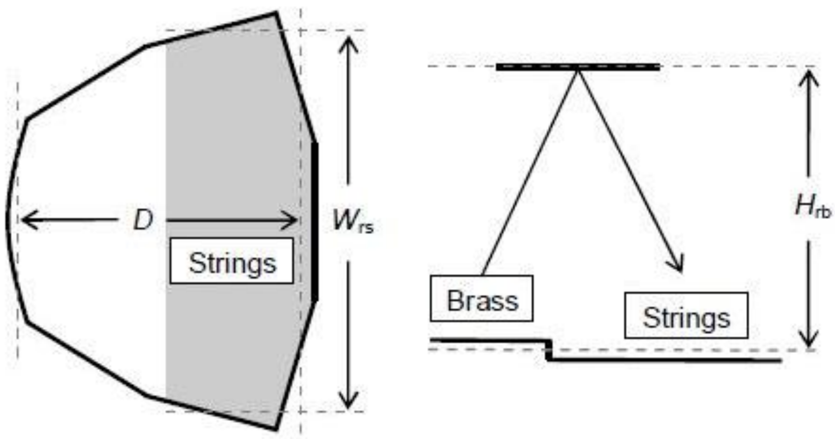

Figure 4. Schematic drawing showing geometric dimensions proposed by Dammerud (2009)

Dammerud found high correlations between these parameters and Overall Acoustic Impression (OAI). Geometric parameters are not examined in this thesis.

CHAPTER 3

METHOD

This study combines subjective evaluations with objective measurements in its research methods to provide a comprehensive analysis. The methods that are used in the study are described under two headings: "Measurements" and "Questionnaire".

Under the "Measurements" section, various quantitative techniques were utilized to collect data. These measurements were conducted using appropriate equipment and tools to capture objective data on acoustic conditions on stage. The specific measurements made were determined by the nature of the study and the parameters investigated. The methodology of the measurements is explained, including details on the technical equipment used, measurement procedures, and data recording protocols.

The "questionnaire" section of the research involved a careful process of designing and implementing questionnaires to collect subjective evaluations from the participants. To ensure the validity and accuracy of the results, expert consultation was sought, and multiple revisions were made until the final version of the questionnaire was established. This section provides details on various aspects of the questionnaire, including the order of the questions, response options, and application procedures. The variables for statistical analyses are described in this section.

The combination of both subjective and objective data in this thesis allows for a comprehensive and multidimensional analysis. By using different data collection approaches, it is aimed to increase the reliability and validity of the findings in order to provide a more holistic understanding of the research problem from multiple perspectives.

3.1. Measurements

The literature review section of the thesis provides a comprehensive overview of the existing research on stage acoustics, encompassing a wide range of parameters that have been previously examined. However, for the purpose of this study, specific parameters including ST_{early}, ST_{late}, EDT, T30, C80, D50, BR, and TR are investigated in detail.

These parameters were selected based on their significance in the context of stage acoustics and their potential comparability with subjective parameters. By focusing on these specific parameters, the study aims to contribute to the existing body of knowledge in the field of stage acoustics, while ensuring methodological consistency with previous research.

Acoustic measurements were carried out at the Ahmed Adnan Saygun Arts Center’s Main Hall where the Izmir Symphony Orchestra performs.

3.1.1. Description of the Hall

Ahmed Adnan Saygun Arts Center, which was opened in Izmir in 2008, takes its name from the Turkish composer and music scientist Ahmed Adnan Saygun, who passed away in 1991. The building has a total area of approximately 30000 m^2. The center consists of a concert hall with 1,153 seats, a recital hall with 243 seats and a visual arts gallery. The registered historical buildings that existed on the site were restored and put into use as a cafe, and a music library.

The concert hall hosts musicians from all over the world, along with the regular concerts of the Izmir Symphony Orchestra. British construction and consultancy firm Arup provided acoustic consultancy for the main hall that has a shoe-box form.

To increase the hall's versatility, there is a retractable curtain system that allows adjusting the reverberation time for different types of performance, such as classical music or jazz. Additionally, the panels located behind the stage are designed to be rotatable, allowing them to exhibit reflective or absorbent properties depending on the specific performance requirements. The concert hall features a platform lift to expand the performance space or increase the seating capacity of the stands. The lifter can also be lowered to create an orchestra pit.

In general, the Ahmed Adnan Saygun Arts Center has become a popular venue for important performances, which preserves the historical heritage of the area where it is located and whose acoustic characteristics are preferred. The Center has become a major cultural focal point in Izmir and a popular destination for music lovers, artists and audiences. Figures 5 and 6 are views of the interiors of the Main Hall and the Recital Hall, respectively.

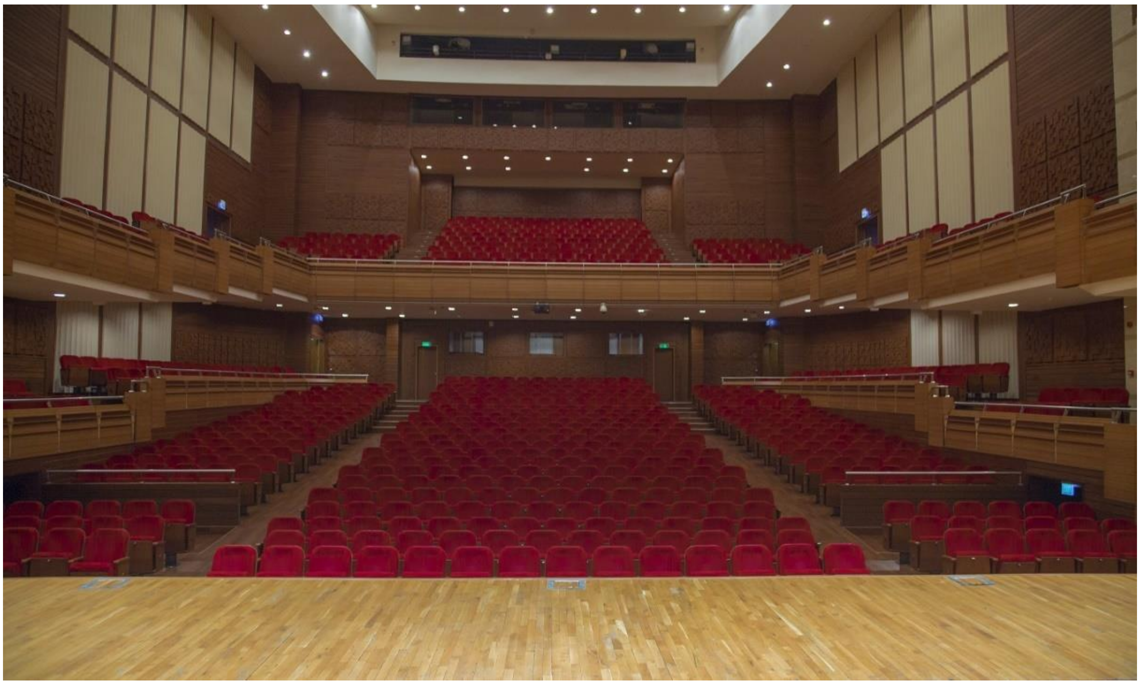

Figure 5. Picture of the Main Hall of AASAC

Figure 6. Picture of the Recital Hall of AASAC

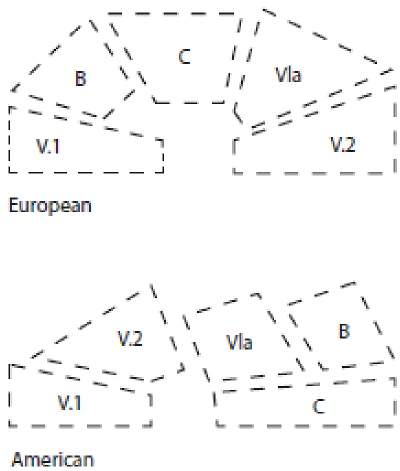

Figure 7. Picture of Orchestra Arrangements (Source: Gjers 2014)

Although the arrangement of the orchestra changes according to the performance and instruments to be played, two common seating arrangements are American and European (Figure 7). In the Ahmed Adnan Saygun Arts Center's Main Hall, the musicians are seated in the American layout, an example of which is shown in Figure 8.

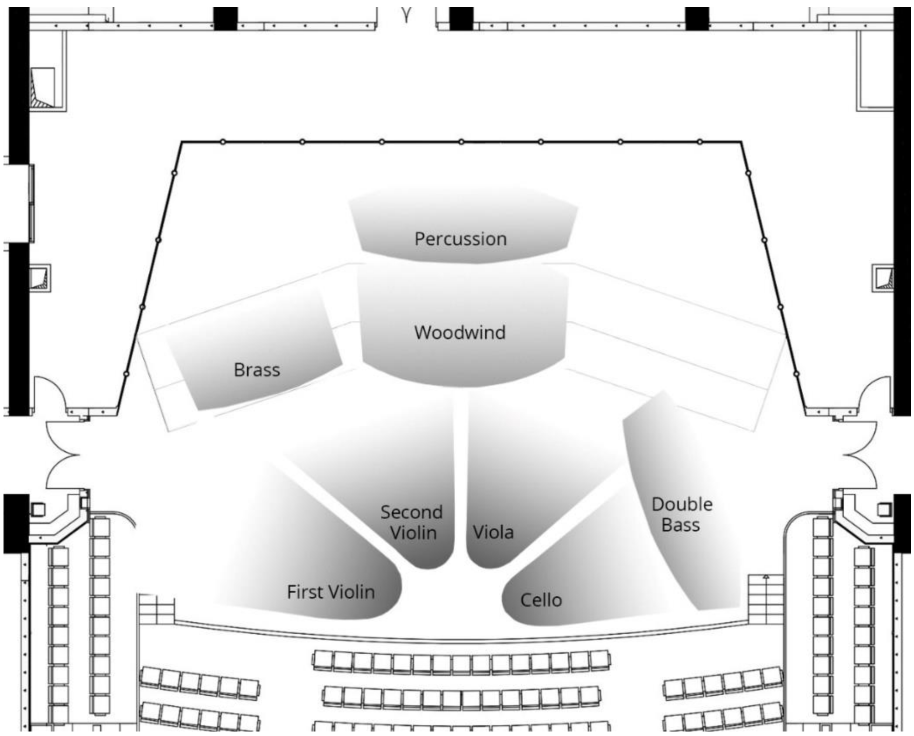

Figure 8. Seating of Instrument Groups on the Stage

3.1.2. Preparation for Measurement

In order to obtain basic information about the measurements, the preparations in the previous studies were examined and procedures in the 3382-1 standard were followed.

Gade recommends measurement with chairs and other objects on the stage, but during the measurements made within the scope of the thesis the stage was empty, but the raised platforms on which the musicians play during performances were on the stage.

As mentioned by Gade (2013), having a full symphony orchestra present during measurements is uncommon or expensive. His recommendation is to use a height of 1.0 m to enhance the sensitivity of the measurement and detect the decrease in propagation attenuation caused by furniture and musicians, given a reasonable riser arrangement.

While ISO 3382-1 suggests taking measurements in a minimum of three locations, Gade (2013) suggests expanding this to at least five positions because it is faster to measure with modern equipment. For this reason, a total of 7 points were determined for resources and recipients. The SUPPORT parameters were measured in 6 of these points.

3.1.3. Measurement Positions

Measurements were conducted according to the requirements set forth in Annex C of ISO 3382-1 “Measurement of Room Acoustic Parameters - Part 1: Performance Spaces”. During the measurement process, measurement points were selected to match the placement of instrument groups to be able to make comparisons with subjective evaluations.

ISO 3382-1 suggests taking measurements in a minimum of three locations for each Support parameter. However, based on the recommendations of Gade (2013), it is suggested to expand the number of measurement positions to at least 5, considering the advancements in modern equipment. For the present study, a total of 7 measurement points are determined for both the sound source and the microphones, and the support parameter was measured at all points except X1.

Taking into consideration the symmetrical nature of the stage, as suggested by Wenmaekers (2017) measurements are made in half of the stage. Similar to the measurement point locations used by Wenmaekers (ref) and Gade (2013), the conductor's position was set as X1, and then the other positions were selected. (Figure 9) The points are selected to reflect the instrument groups in the seating arrangement of the orchestra.

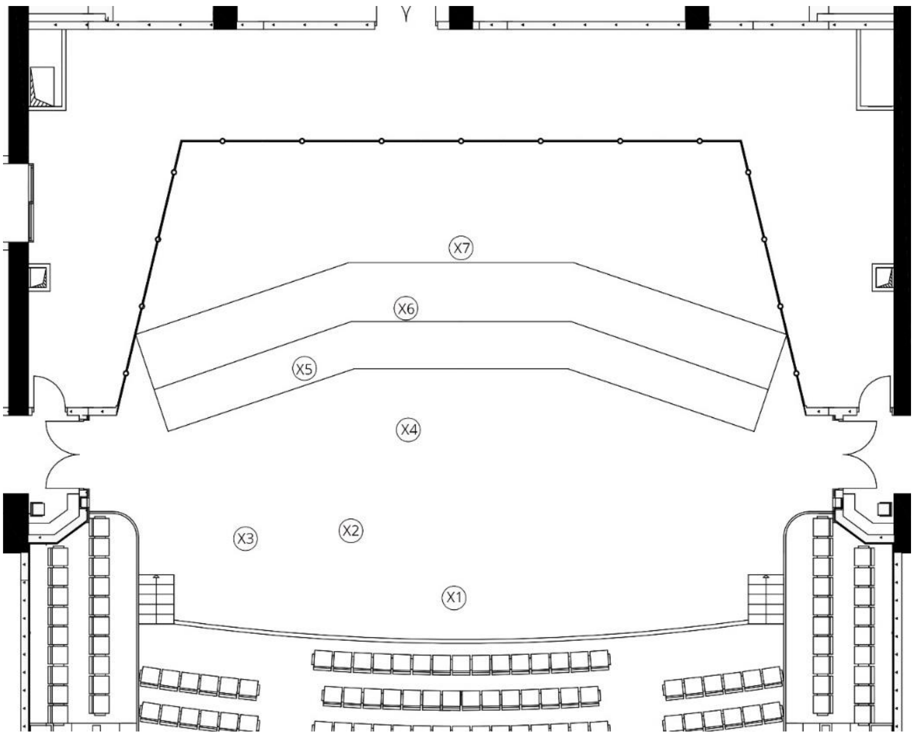

Figure 9. Measurement positions

Placement of the sound source and microphone is also important. According to the standard, the sound source and the microphone are placed at a distance of 1 m from each other and both are kept at a height of 1 m or 1.5 m from the ground. In this study the source and receiver points were kept at a height of 1 m for support parameter measurements.

It is recommended that all objects within a 2-meter radius of the microphone are removed during the measurements, and in cases where the stage area is small, all objects should be removed. During the measurements conducted for the present study, the stage was empty and did not have any chairs or stands. The orchestra tiers were present on the stage.

In addition to ST_{early}. and ST_{late} parameters, other acoustic parameters were also measured on stage using the same measurement points. For these measurements, the microphone and speaker were positioned at a height of 1.2 meters.

3.1.4. Measurement Equipment

For the measurements, a Brüel&Kjaer Omnipower Sound Source / Type 4292-L loudspeaker was used as the source. It was powered with a Brüel&Kjaer 2718 power amplifier connected to a Focusrite Scarlett 2i2 Gen 3 USB sound card on an HP ProBook laptop with an i5 processor. The microphone connected to the sound card was a G.R.A.S. 40AE. The room impulse responses were recorded using ODEON Room Acoustic Software v.14.05.

3.1.5. Measurement Process

The omnidirectional microphone and the omnidirectional sound source were used for all measurements. When measuring for parameters such as T30, EDT, G and C80, the speaker and microphone are set to 1.2 meters high. Measurements were done with the source at three points (X2, X5 and X6) and receivers at four points (X1, X2, X5 and X7). Each measurement was repeated three times.

While measuring the support parameters in 3382-1, for each measurement point (X2-X7) sound source and microphone were placed 1 m apart on a line extended from the conductor position (X1). Impulse responses were captured three times at each of the 6 different locations. The omnidirectional sound source was rotated by 30 degrees between repetitions.

Impulse responses were captured using the Odeon v14.05 Combined software. The sine sweep method was used. (Figure 10)

In accordance with the Odeon manual's recommendations, a measurement was taken using the default settings, and the resulting impulse response was evaluated for its quality. Adjustments were made with the results obtained from here, such as the length of the impulse response and the time remaining after the sweep.

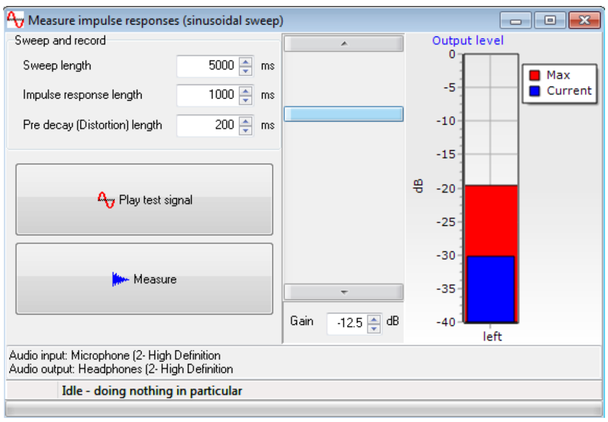

Figure 10. Measure Impulse Responses Controls in ODEON

3.2. Subjective Evaluations

There is a lack of a common language for communication between acoustic consultants and musicians. This negatively affects the acoustic evaluations. Furthermore, different researchers study evaluations based on different parameters. To avoid this problem, in this study subjective evaluations are surveyed using a questionnaire that is based on previous studies.

32 musicians from the Izmir State Symphony Orchestra, which regularly perform in the Ahmet Adnan Saygun Arts Center’s Main Hall, participated in the questionnaire survey.

While preparing the questionnaire, the questions used in previous studies (Dammerud 2009) (Cederlöf 2006) (Gjers 2014)were examined. The questionnaire was designed with two parts. In the first part, there are questions to obtain general information about the participating musicians, including their instrument of choice and the duration of their professional experience in symphony orchestras. In addition, at the end of this section, non-acoustic issues that are important to them were asked in the hall where they performed.

In the next part, there are questions focusing on subjective evaluations of the various aspects of the acoustics of the hall that will be the basis of comparisons with objective parameters. The questions in this section are divided into categories for when making this comparison. In order to make a statistical comparison, the options of the questions are answered through bipolar scoring ranging from 1 to 10. The following aspects of acoustics were asked to be evaluated by the participants:

1-Overall Acoustic Impression

2-Room's Support

3-Hall Dynamics

4-Ability to Hearing Oneself

5-Hearing Others

6--Loudness

7-Reverberation

The information obtained from this section is also discussed in the conclusion section. The language of the questionnaire was Turkish since the participants were Turkish musicians. The original version in Turkish and its English translation are given in Appendix A and Appendix B.

Apart from the 10-grade scale questions for statistical analysis, open-ended questions were also included to allow for the participants to bring up issues they found relevant. It was aimed to improve the language between the musician and the acoustic researcher and to acquire new information.

When the questionnaire was completed, the musicians were asked if they had anything to add. In this way, it is aimed to develop questionnaire studies that can be done in the future.

The final questionnaire was in the form of 4 pages of A4 paper and were distributed to the musicians during their Friday rehearsals. This survey was conducted over a period of three weeks.

CHAPTER 4

RESULTS AND DISCUSSION

In this part of the thesis, the results for objective measurements and musicians' opinions are discussed under two headings.

A number of abbreviations are used for instrument groups to facilitate review in tables and graphs. These abbreviations are shared in the table below(Table 1). The string group is discussed under three different titles as first violin, second violin and viola/cello since they are more numerous than other groups and to increase the sensitivity in analyses.

Table 1. Abbreviations for Instrument Groups

Instrument Group	**Abbreviation**
First Violin	1st Vl
Second Violin	2nd Vl
Viola/Cello	Vla/Cel
Double Bass	Db
Percussion	Perc
Woodwind	Wwd
Brass	Br

4.1. Measurements Results

In this part of the study, the measurements for each parameter is presented under separate headings. All parameters reported were obtained using ODEON's measurement feature. Specifically, the ST_{early} and ST_{late} parameters were calculated using the custom parameter definition capabilities within the software.

Following the support parameters, EDT, T30, C80 and Bass/Treble Ratio parameters were calculated using the impulse response results obtained from various receiver points. ODEON calculates EDT, T30 and C80 parameters from impulse responses and shares the results in tables as singular values for each parameter on the basis of frequency. Additionally, Bass Ratio and Treble Ratio, which are important indicators of the low-frequency and high-frequency energy distribution in the acoustic environment, were calculated using specific frequency bands as defined in the relevant formula. With these parameters with different formulations, it is aimed to make a detailed examination of the spectral properties of the acoustic field under investigation, and information on the distribution of sound energy in different frequency ranges is obtained.

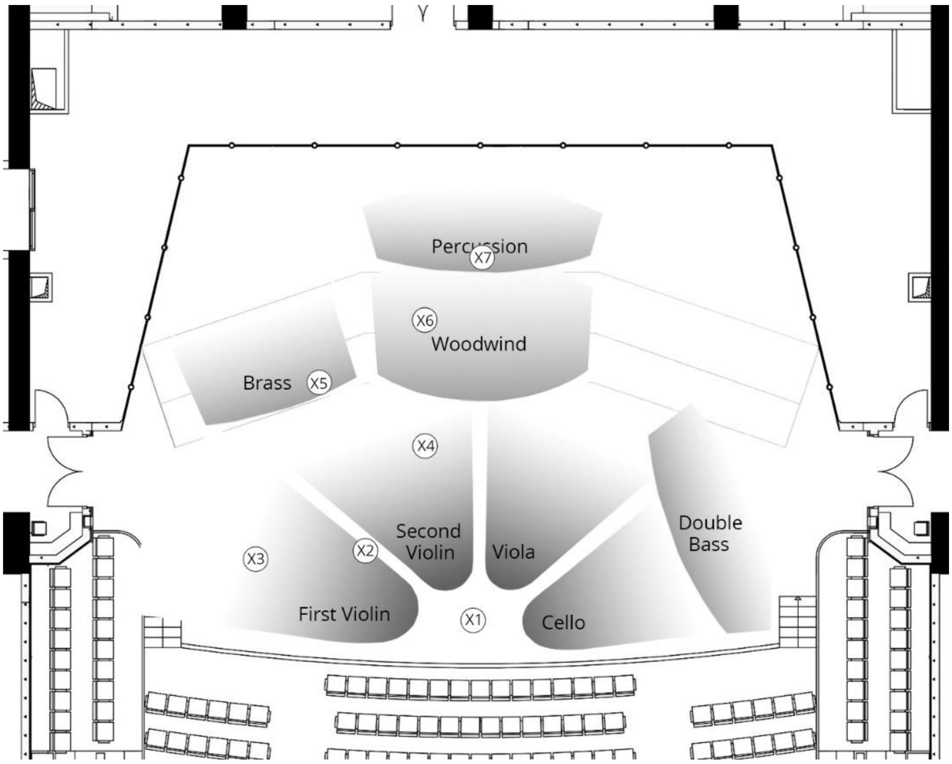

Figure 11. Measurement Positions and Instrument Groups

4.1.1. Support Early

All support measurements were performed at all points except X1, which is considered the conductor location. While measuring at each point, the sound source and microphone were aligned with respect to X1, with a distance of 1 m between them. As explained in the measurement details, both the sound source and the microphone were placed 1 m above the ground. The results include all values between 63-8000 Hz frequency bands. However, as recommended in Annex C of ISO 3382-1 standard, in this study, for Support parameters, the 250-2000 Hz frequency band values were used in analysis. Values obtained for ST_{early} are given in Table 2 below.

Table 2. Average Values of Support Early

ST_{early}	250	500	1000	2000	Average
X2	-13.86	-12.76	-12.68	-10.22	-12.38
X3	-14.57	-11.87	-12.20	-11.33	-12.49
X4	-15.08	-15.48	-14.81	-13.43	-14.70
X5	-12.97	-11.22	-13.55	-13.70	-12.86
X6	-14.42	-15.04	-15.95	-14.40	-14.95
X7	-13.02	-14.02	-15.31	-16.68	-14.76
Average	-13.99	-13.40	-14.08	-13.29	-13.69

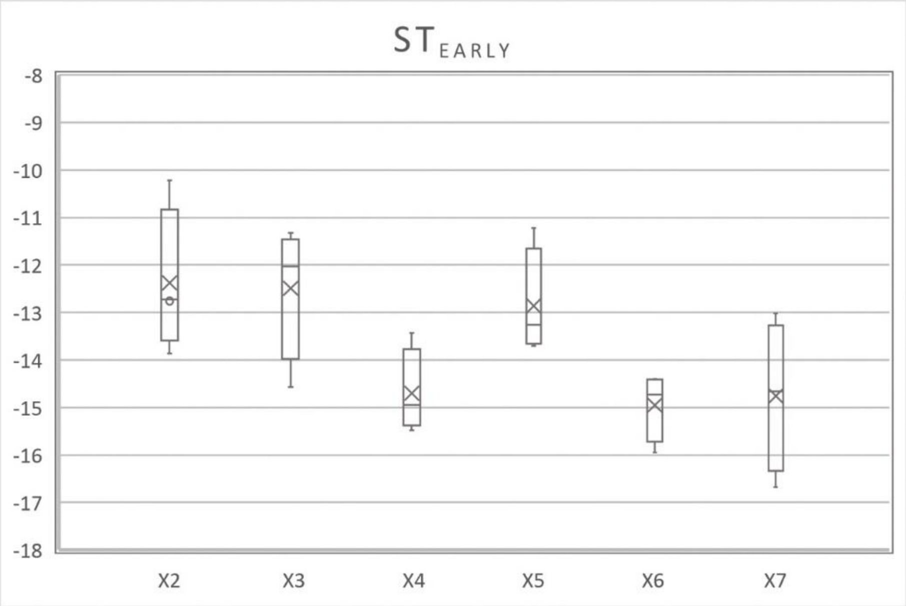

Figure 12. Average Values of Support Early

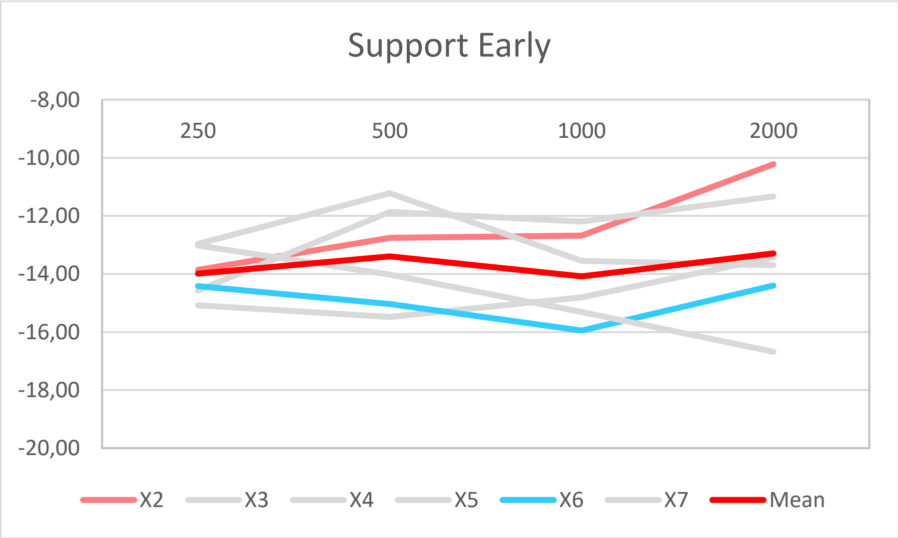

Figure 13. Values of Support Early by Measurement Points

The variance in ST_{early} values obtained is shown in the box-and-whisker plot given in Figure 12. The plot shows the minimum, maximum, mean, median, 1st Quarter and 3rd Quarter values for each measurement point.

Among all the values, the highest value is obtained with -10.22 dB at point X2 and the lowest value is obtained at point X7 with -16.68 dB. The largest difference between the minimum and maximum value is at X7 with 3.66 dB, the smallest difference is at X6 with 1.55 dB. Median value is below the average at X2, X4 and X5, and average is below the median at X3, X6 and X7.

According to the arithmetic average of the frequency values between 250 Hz and 2000 Hz, the lowest value is -14.95 dB in X6 and the highest value is -12.38 dB in X2. The average value of all frequencies and points is -13.69 dB.

Here, the X4, X6 and X7 points in the middle of the stage have smaller values; X2, X3 and X5 values close to the side walls take higher values.

The 3382-1 standard recommends a range of -24 dB and -8 dB for the ST_{early}. parameter. All values are within this range. Research on the optimum values for this parameter is ongoing. Yet, recommendations of previous studies are given here for a more accurate evaluation of the measurement results.

Beranek (2004) stated in his book that the most appropriate range for ST_{early} is between -12 dB and -15 dB according to the results he obtained in his studies with concert halls. The average values below from the measurements at AASAC's main hall are within this range.

Gade (2011) conducted a questionnaire study with musicians to judge the acoustic conditions of the stages in various halls. In the study, it was determined that there is a relationship between "Ease of Ensemble" and ST_{early}. Based on the data obtained in this study, the optimum range for ST_{early} was suggested to be between -11 and -13 dB. In Figure 14, the Average Support Early value obtained from the measurements is added to the figure from Gade's study. Although the value obtained from this hall is close, it is outside the suggested optimal range.

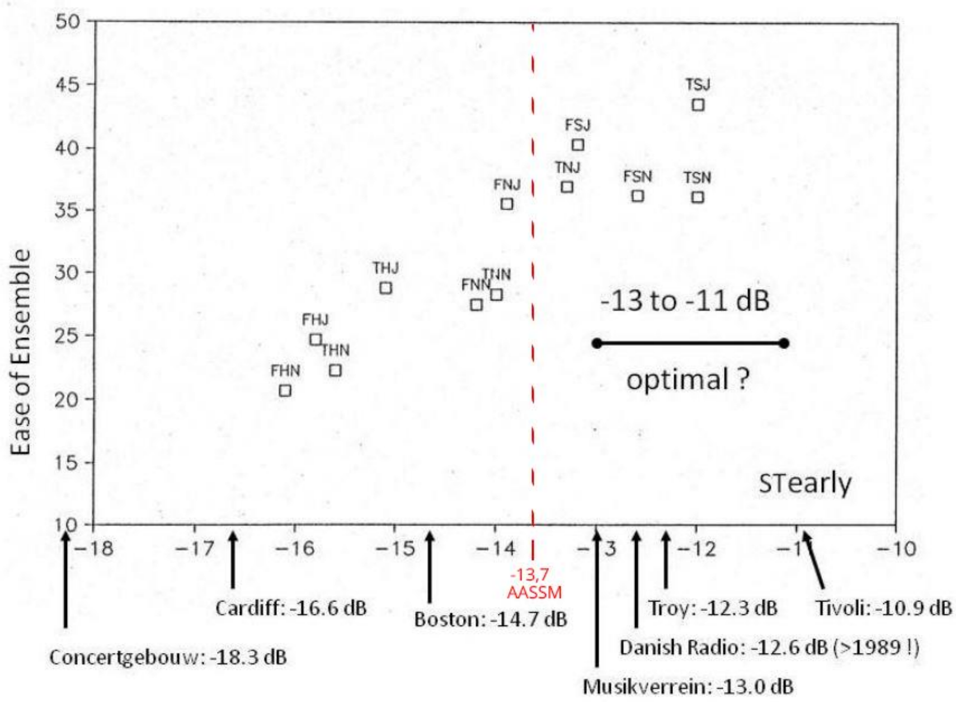

Figure 14. Comparison of this hall with Gade's ST_{early} results

Laird (2017) added the results of Guthrie (2014) to the study by Giovanni and Arianna (2010). The results obtained by Wenmaekers (2017) and within the scope of this study are also added to Table 3 given below.

Table 3. Comparison of the AASAC main hall with previous ST_{early} results. (Source: (Giovannini and Arianna 2010) and (Laird 2017))

Study	Number of Halls	ST_{early} (dB)	ST_{late} (dB)
ISO 3382-1 (2009)	–	-24 to -8	-24 to -10
Gade (1989)	19	-16.6 to -10.9	–
Chiang et al. (2003)	5	-15.9 to -9.0	-17.3 to -10.9
Jeon and Barron (2005)	1	-24.0 to -15.0	–
Dammerud and Baron (2007)	4	-17.1 to -12.5	-17.0 to -14.6
Giovannini and Arianna (2010)	4	-16.5 to -11.2	-17.5 to -11.4
Guthrie (2014)	10	-18.7 to -10.3	-19.3 to -9.7
Wenmaekers (2017)	8	-17.0 to -12	-16.0 to -12
Current Study	1	-14.95 to 12.38	-16.32 to -14.19

It is very useful to present and compare the previous studies as a whole in terms of finding the optimum ranges. When previous studies are examined, it is observed that there are significant differences between the intervals. The width of the gap that emerged for each study may be related to the number of halls measured. The fact that this study was carried out in a hall may cause a difference of approximately 2.5 dB in the range and close values. However, when compared with other studies under similar conditions, it also reveals the reliability of the measurements. The results obtained in the measurements made in this hall are compatible with all studies except the study of Jeon and Barron (2005) and remain within their range. The work of Jeon and Barron (2005) does not seem very close with other halls. From this point of view, the appreciation of the hall by the musicians is also compatible with the optimum conditions obtained from the measurements. The results obtained from all studies should be analyzed in detail in a future study and optimum conditions for this parameter should be further investigated.

4.1.2. Support Late

The 3382-1 standard recommends a range of -24 dB and -10 dB for the ST_{early}. parameter. All values shared in the Table 4 provide this range. Since researches on the optimum values of this parameter are ongoing, comparisons will be made with previous studies for a more precise analysis.

Table 4. Average Values of Support Late

ST_{late}	250	500	1000	2000	Average
X2	-15.92	-15.46	-15.20	-13.38	-14.99
X3	-14.88	-14.95	-15.50	-14.25	-14.90
X4	-14.43	-13.84	-14.90	-13.58	-14.19
X5	-16.81	-15.69	-16.13	-16.64	-16.32
X6	-17.17	-15.24	-15.85	-15.29	-15.89
X7	-15.54	-14.77	-16.07	-17.87	-16.06
Average	-15.79	-14.99	-15.61	-15.17	-15.39

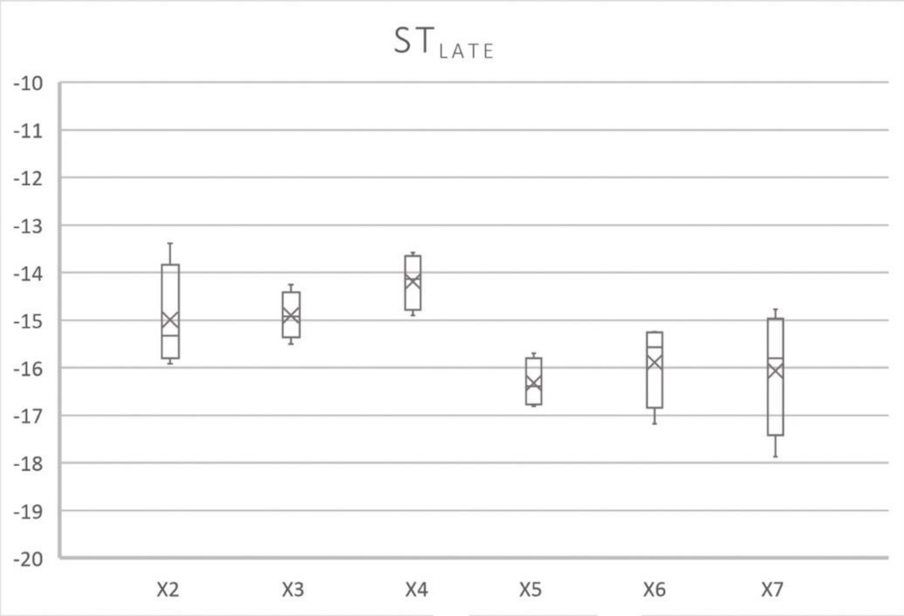

Figure 15. Average Values of ST_{late}

Among all the values, the highest value is obtained with -13.38 dB at point X2, and the lowest value is obtained at point X7 with -17.87 dB. The lowest and highest values were also obtained at these points in the ST_{early} results. The largest difference between the minimum and maximum value is at X7 with 3.1 dB, the smallest difference is at X5 with 1.12 dB.

According to the arithmetic average of the frequency values between 250 Hz and 2000 Hz, the lowest value is -16.32 dB in X6 and the highest value is -14.19 dB in X2. The average value of all frequencies and points is -15.39 dB.

In the graph, the average of the frequencies is taken and the lowest, highest and average values are colored. Accordingly, the lowest value was -16.32 in X2 and the highest value was -14.19 in X6. The average value of all frequencies and points is -13.69.

Table 3 lists the findings of various previous studies along with current measurements in the AASAC Main Hall. When previous studies are examined, it is observed that there are significant differences between the intervals. The width of the gap that emerged for each study may be related to the number of halls measured. Results from this study appear to be in agreement with the range from all studies except Wenmaekers' study. It is important to do a total review with previous studies to understand the parameter. The results obtained from all studies should be analyzed in detail in a future study and optimum conditions for this parameter should be further investigated.

4.1.3. EDT

The optimum ranges for the EDT parameter vary depending on the intended use of the space. Beranek (2004) gives optimum ranges according to different functions in his book. Accordingly, the most suitable EDT interval for symphonic music performances is between 1.5 and 2.0 seconds.

Table 5. Average Values of EDT

Source/Receiver	500 Hz	1000 Hz	2000 Hz	Average
X5/X7	1.84	1.86	1.36	1.69
X5/X2	1.57	1.5	1.57	1.55
X5/X1	1.85	1.71	1.67	1.74
X6/X7	1.3	1.18	1.15	1.21
X6/X2	1.76	1.78	1.56	1.70
X6/X1	1.81	1.69	1.58	1.69
X2/X5	1.55	1.48	1.5	1.51
X2/X7	1.48	1.74	1.69	1.64
X2/X1	1.69	1.82	1.36	1.62
Average	1.65	1.64	1.49	1.59
σ	0.18	0.20	0.16	0.15

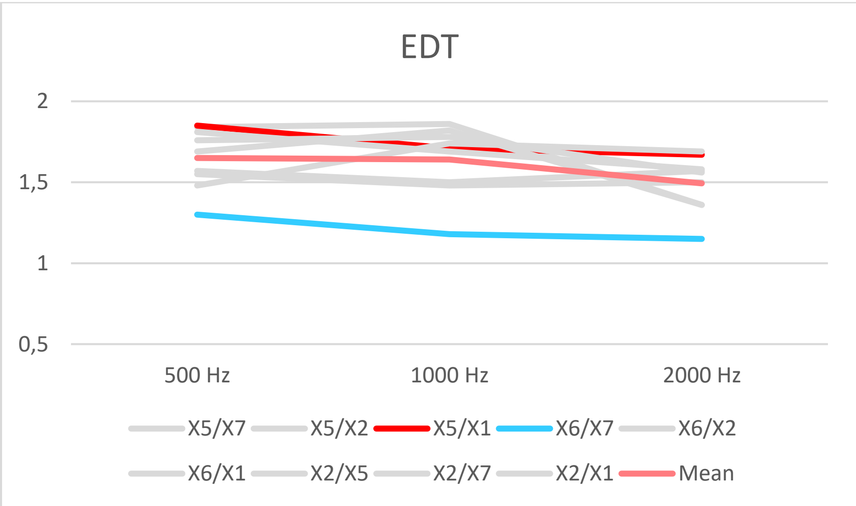

Figure 16. Average Values of EDT

In the graph, the average of the frequencies is taken and the lowest, highest and average values are colored. Accordingly, the lowest value was 1.21 and the highest value was 1.74. The average value of all frequencies and points is 1.59. Among the averages, only the lowest value was outside the optimum range specified by Beranek.

4.1.4. T30

As with the EDT parameter, the optimum target value for T30 varies depending on many factors such as the size of the hall, its shape and the purpose of use of the hall. Within the scope of this study, measurements were taken at 9 different positions for the T30. The values found are very close to each other.

Table 6. Average Values of T30

S/R	500 Hz	1000 Hz	2000 Hz	Average
X5/X7	1.83	1.8	1.74	1.79
X5/X2	1.8	1.79	1.73	1.77
X5/X1	1.82	1.81	1.7	1.78
X6/X7	1.77	1.75	1.68	1.73
X6/X2	1.76	1.79	1.7	1.75
X6/X1	1.78	1.79	1.73	1.77
X2/X5	1.79	1.78	1.68	1.75
X2/X7	1.88	1.79	1.7	1.79
X2/X1	1.77	1.77	1.71	1.75
Average	1.80	1.79	1.71	1.76
σ	0.04	0.02	0.02	0.02

As it was said before in the literature section, Barron (1993) says that the optimum reverberation time for the mid-frequency range in symphony concert halls is generally 1.8–2.2 seconds. The values found are very close to the range and are slightly below. The volume of the hall is smaller compared to other halls that can perform symphonic music. With this approach, it can be said that the measurement results are compatible with this range.

Figure 17. Average Values of T30

In the graph, the average of the frequencies is taken and the lowest, highest and average values are colored. Accordingly, the lowest value was 1.73 and the highest value was 1.79. The average value of all frequencies and points is 1.76. The average values here seem close to this. The results taken at different measurement points are obtained very close to each other.

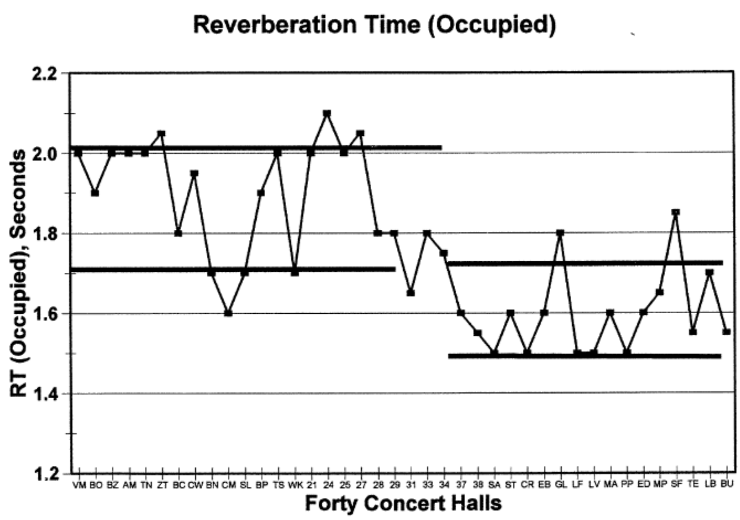

Figure 18. Mid-frequency reverberation times for 40 concert halls, measured with full occupancy (Source: Beranek 2004)

Beranek (2004) discuss the results obtained from the halls where he made measurements. Accordingly, the halls with the highest score by the musicians have a reverberation time of around 2 seconds, and those with the lowest score around 1.5 seconds. The AASAC Main Hall with an average reverberation value of 1.76, is in the center of this range that was observed.

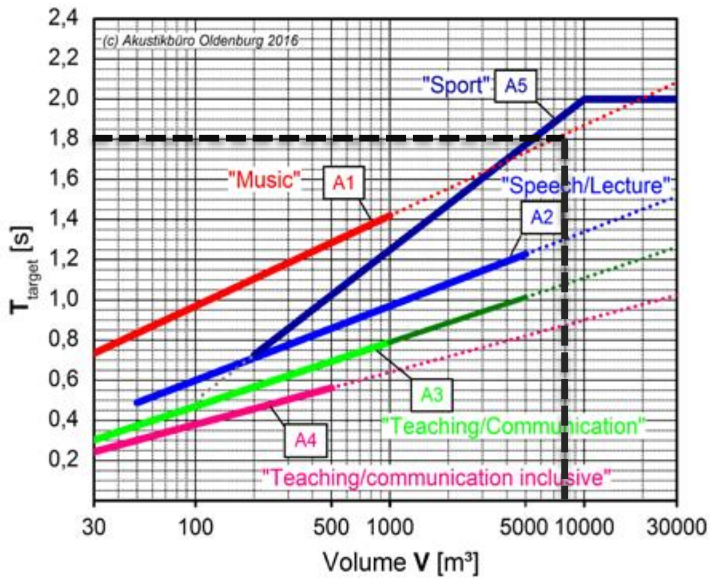

Figure 19. AASAC Main Hall RT according to the DIN 18041

The results obtained from the hall were also examined in terms of the German standard DIN 18041. This hall, which has a volume of approximately 9000 m3, when "A1-Music" is selected as the function, the target value is approximately 1.8 seconds. This value is very close to the average values obtained from the hall (shown in the figure with the black dashed line).

4.1.5. C80

The measured C80s are usually averaged over the 500, 1,000, and 2,000 Hz octave bands, and this average value is shown as C80(3). ISO 3382-1 typically recommends a range of -5 to +5 dB (ISO 2009).

Another important feature of Clarity is that different values are requested depending on the conditions. During rehearsals, the expected C80(3) value should be between +1 and +5 dB so that the details in the music can be heard clearly when the hall is empty. However, a range of -1 to -4 dB can be considered appropriate during performance.

Table 7. C80(3) Values Table

S/R	500	1000	2000	Average
X5/X7	4.30	5.30	7.10	5.57
X5/X2	4.30	4.60	1.90	3.93
X5/X1	2.80	2.60	3.10	2.83
X6/X7	8.83	8.50	7.97	8.43
X6/X2	3.20	3.40	1.60	2.73
X6/X1	2.10	2.50	2.60	2.40
X2/X5	5.10	6.10	5.30	5.50
X2/X7	2.30	1.20	2.40	1.97
X2/X1	7.70	6.90	7.50	7.37
Average	4.63	4.57	4.39	4.53
σ	2.24	2.23	2.44	2.18

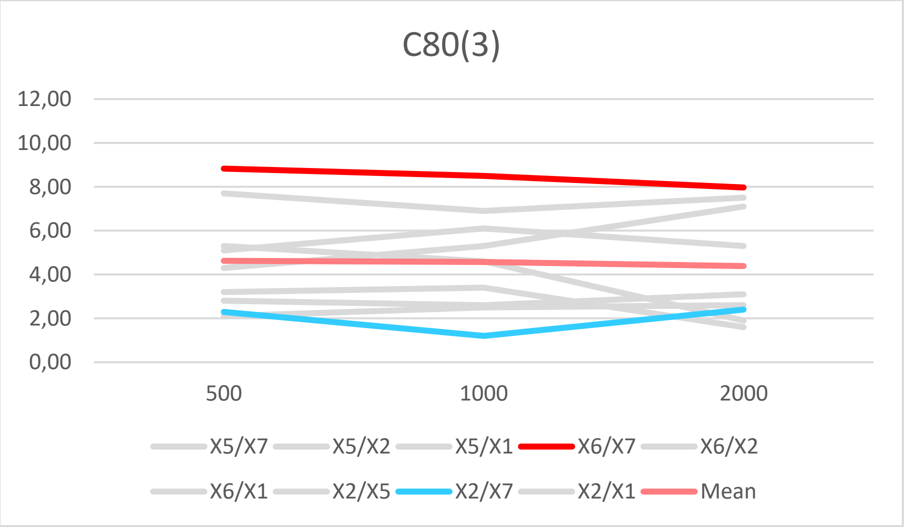

Figure 20. C80 Graph

In the graph, the average of the frequencies is taken and the lowest, highest and average values are colored. Accordingly, the lowest value was 1.97 and the highest value was 8.43. The average value of all frequencies and points is 4.53.

Measurements were made when the hall and the stage was empty. Result values are obtained in the range of +1 and +5 recommended for C80 during rehearsal. It can be said that the average C80 values provide suitable acoustic conditions.

4.1.6. Bass /Treble Ratio

Bass Ratio and Treble Ratio values were also calculated in order to make a further examination from the reverberation values obtained in the measurements.

Beranek (1996) states that while a value between 1-1.25 is preferred in halls with a long reverberation time, the appropriate range for halls with a reverberation time below 1.8 seconds is between 1.10 and 1.45.

Table 8. Bass/Treble Ratio Values Table

BR		TR	
X5/X7	1.13	X5/X7	0.89
X5/X2	1.19	X5/X2	0.89
X5/X1	1.15	X5/X1	0.87
X6/X7	1.19	X6/X7	0.88
X6/X2	1.15	X6/X2	0.89
X6/X1	1.18	X6/X1	0.90
X2/X5	1.16	X2/X5	0.88
X2/X7	1.13	X2/X7	0.87
X2/X1	1.22	X2/X1	0.89
Average	1.17	Average	0.88

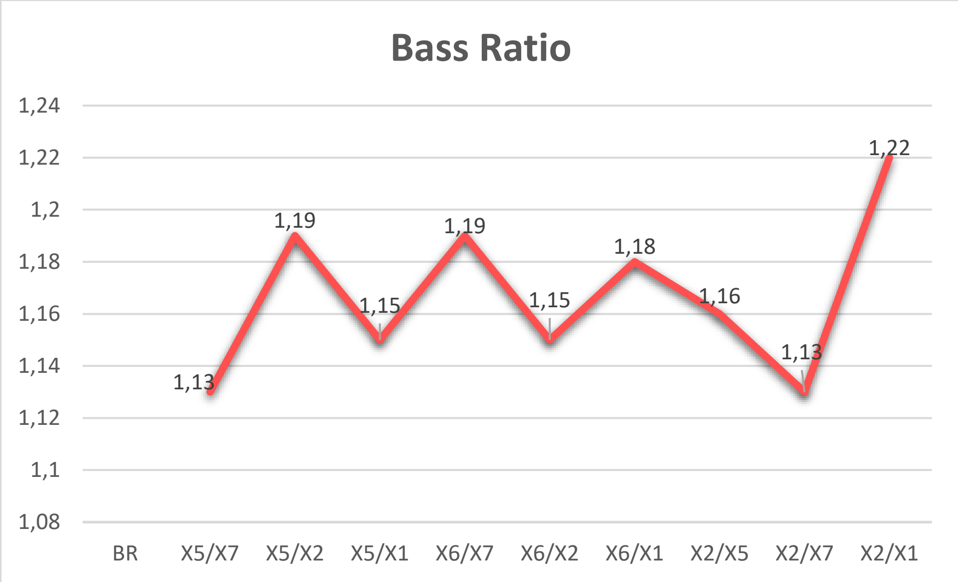

Figure 21. Bass Ratio Results

In the graph, lowest, highest and average values are colored. Accordingly, the lowest value was 1.13 and the highest value was 1.22. The average value of all frequencies and points is 1.17. The result values were obtained very close to each other.

Figure 22. Treble Ratio Results

In the graph, lowest, highest and average values are colored. Accordingly, the lowest value was 1.13 and the highest value was 1.22. The average value of all frequencies and points is 1.17. The result values were obtained very close to each other.

4.2. Subjective Judgement of Musician Impressions

In this part of the thesis, the results obtained from the questionnaire studies are reported. Questions in the questionnaire were organized under different headings. The subjective parameter evaluations were captured using a 10-point semantic differential scale ratings. It was aimed for musicians to answer more easily by having an open-ended answering option as follow-ups to some questions.

In the questionnaires, the evaluations of the musicians were taken on a voluntary basis. 33 people out of approximately 70 musicians participated in the study. The orchestra conductor who was present during the questionnaire due to the weekly schedule and who had a lot of experience was present during the visits and participated in the study. In order to increase the participation rate, as mentioned before, the hall was visited multiple times. These studies were carried out during the short rest periods, between the scheduled practice sessions of the musicians.

4.2.1. General Information on Musicians

A total of 33 players responded – 9 first violins (27.3%), 4 second violins (12.1%), 4 cellos/viola (12.1%), 3 double basses (9.1%), 5 woodwinds (15.2%), 4 brass (12.1%), 2 percussionists (6.1%), 1 piano(3%), and 1 conductor(3%).

In the first part of the questionnaire, there are questions to obtain general information about the participant. To the question of "How many years have you been playing in a professional orchestra?", the participants gave answers ranging from 4 to 32 years. The average of the answers given is 16.1. To the question of "How long have you been playing with this orchestra?", responses ranged from 3 to 22. The average of the answers given was 10.2.

Table 9. Participating Musicians’ Experience Levels

Question	Min	Max	Mean
How many years have you been playing in a professional orchestra?	4	32	16.1
How many years have you been playing with this orchestra?	3	22	10.2

The results obtained from the study are presented in a comprehensive manner, beginning with the findings obtained from the rating questions designed to explore the relationship between the objective data under investigation and the perspectives of the musicians. To facilitate the review an abbreviation has been assigned to each title in the rating questions. Each title was evaluated in a separate section.

In addition to the specific findings, a general evaluation of the results is provided at the end of this chapter. Furthermore, statistical tools are employed to examine the relationships and correlations among the various topics investigated in the study. This approach is intended to help identify any patterns, trends or significant relationships that may emerge from the analysis.

4.2.2. Subjective Parameters

Careful consideration was given to the design and implementation of the questionnaire to ensure accurate and reliable data collection. To streamline the review process, abbreviations were assigned to each subjective parameter investigated in the questionnaire. Furthermore, the range of conditions represented by the minimum and maximum values for each parameter was clearly indicated, providing a comprehensive understanding of the variables under investigation. In order to minimize confusion in participant responses, a numerical scale ranging from 1 to 10 was initially used in the questionnaire. In the first version of the questionnaire, the minimum and maximum values were different for each question. Since it was determined that it could create confusion, "1" was arranged to represent the most negative and "10" to represent the most positive. The list of subjective parameters is given in Table 10, along with the definitions of minimum and maximum values.

Table 10. Subjective parameters, abbreviations, and definitions for min-max values

Subjective Parameter	Abbreviation of Title	Min / 1	Max / 10
Support	SUP	Not Supports	Supports
Dynamics	DYN	Not Sufficient	Sufficient
Overall Acoustic Impression	OAI	Bad	Good
Hearing Others	HO	Bad	Good
Hearing Self	HS	Can't Hear	Hear
RT (Performance)	RT(P)	Too Dry	Too Reverb
RT (Rehearsal)	RT(R)	Too Dry	Too Reverb
Loudness	LOU	Unbalanced	Balanced

The values obtained from the questionnaires were calculated separately for each instrument group. The number of people in the instrument groups is not the same. A total of 33 people participated in the questionnaire and they included 9 first violins (27.3%), 4 second violins (12.1%), 4 cellos/viola (12.1%), 3 double basses (9.1%), 5 woodwinds (15.2%), 4 brass (12.1%), 2 percussionists (6.1%), 1 piano (3%) and 1 orchestra conductor (3%).

4.2.2.1. Support

The question “Do you think this hall supports your performance?” was asked to find out the musicians' evaluations about the support of the hall.

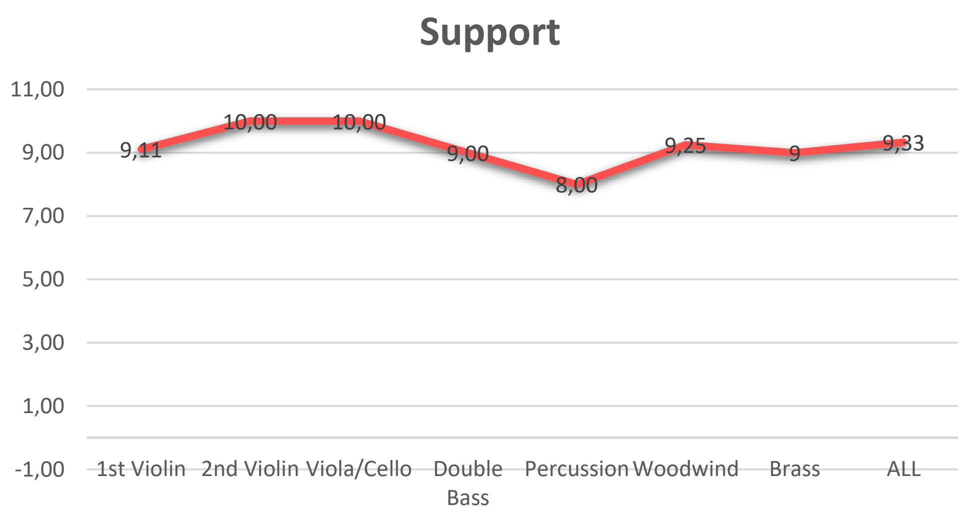

Figure 23. Average Ratings of Support by Instrument Groups

The musician groups that gave the highest scores were second violin, viola and cello. The lowest score 8 was given by the percussion group. The mean of all populations was 9.33. The results show that the musicians are highly satisfied with the support of the hall. The highest average rating was for this parameter.

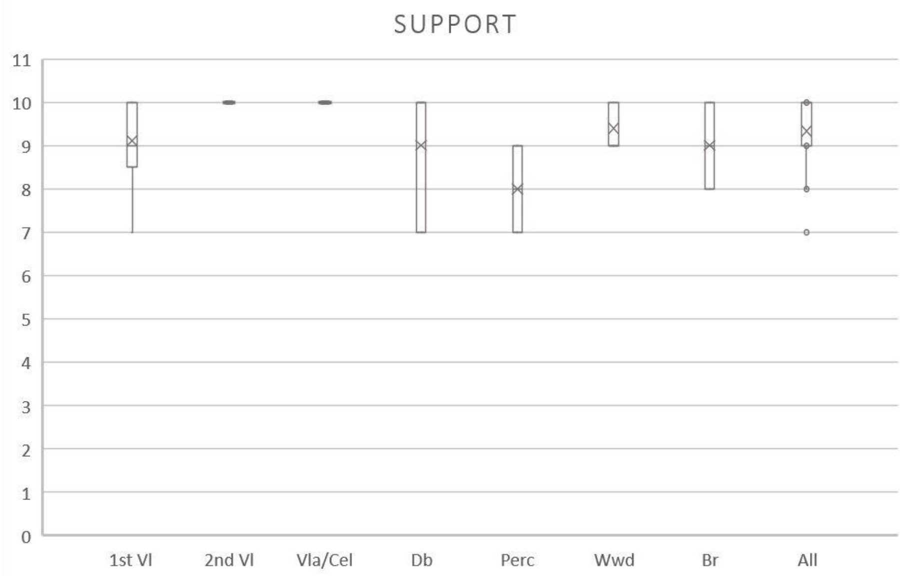

Figure 24. Variance in ratings for Support by Instrument Groups

4.2.2.2. Hearing Self

The question “Can you distinguish the sound of your own instrument from other instruments?” was asked to understand how well musicians could hear themselves.

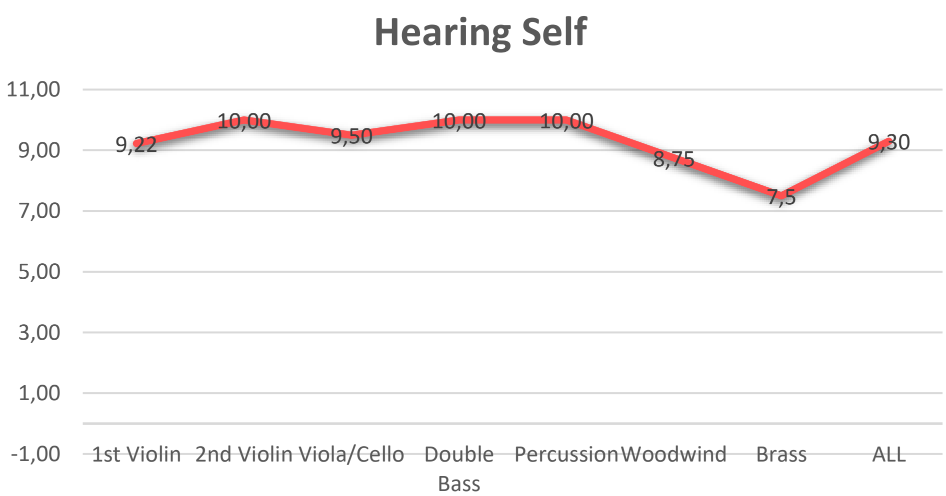

Figure 25. Average Ratings of Hearing Self by Instrument Groups

The musician groups that gave the highest scores were second violin, double bass and percussion. The lowest score, 7.5, was given by the brass group. The mean of all populations was 9.3. The results show that the musicians can hear themselves comfortably while playing.

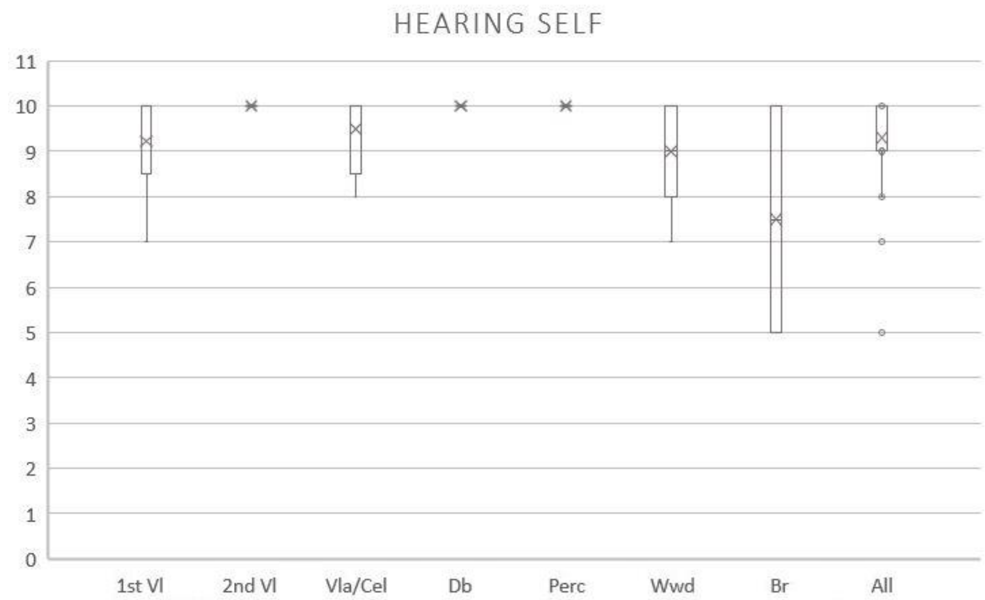

Figure 26. Variance in ratings for Hearing Self by Instrument Groups

4.2.2.3. Hearing Others

To understand how easily musicians can hear other musicians, the question “Do you think it is easy to play with other musicians in this hall?” was asked.

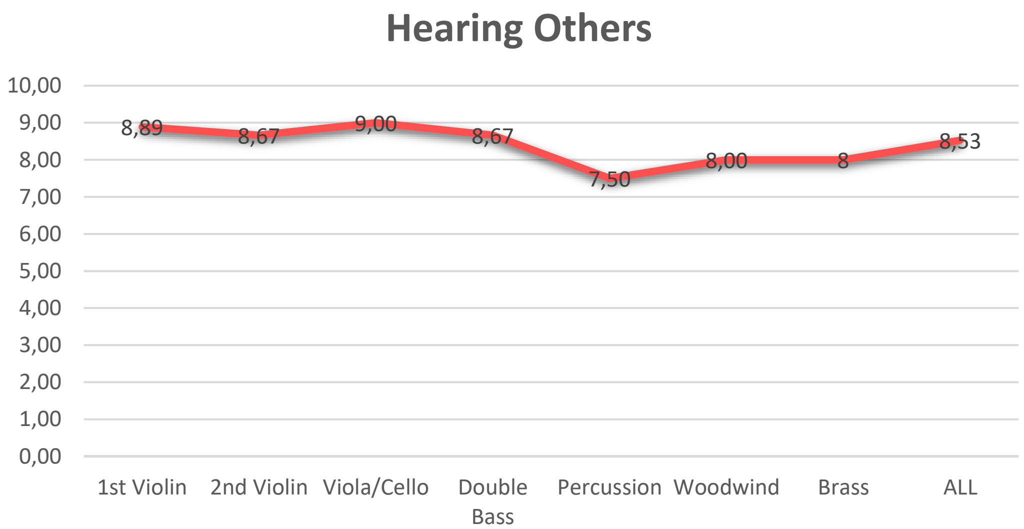

Figure 27. Average Ratings of Hearing Others by Instrument Groups

The viola/cello group gave the highest score with 9. The lowest score, 7.5, was given by the percussion group. The mean of all populations was obtained as 8.53.

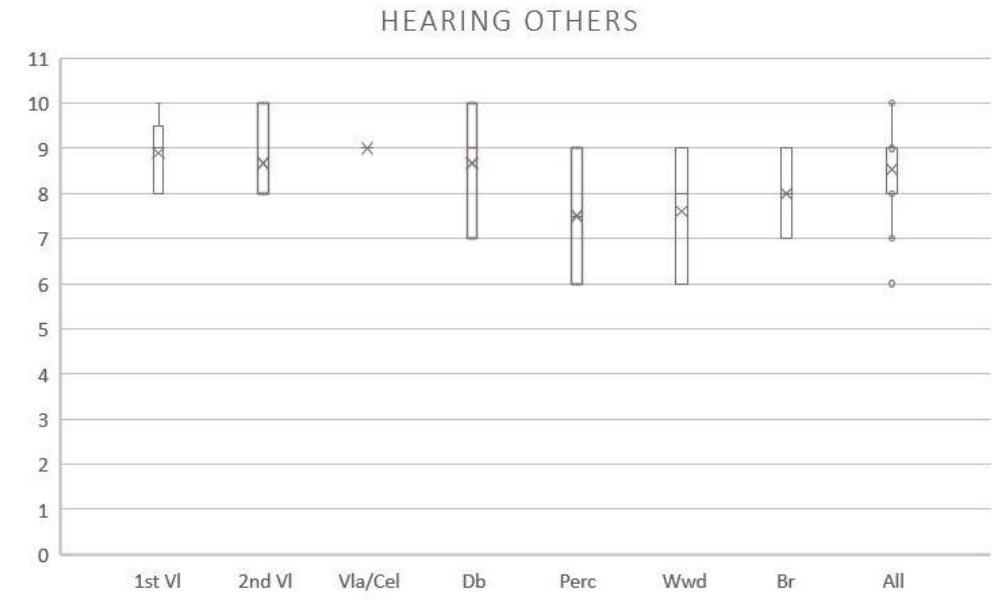

Figure 28. Variance in ratings for Hearing Others by Instrument Groups

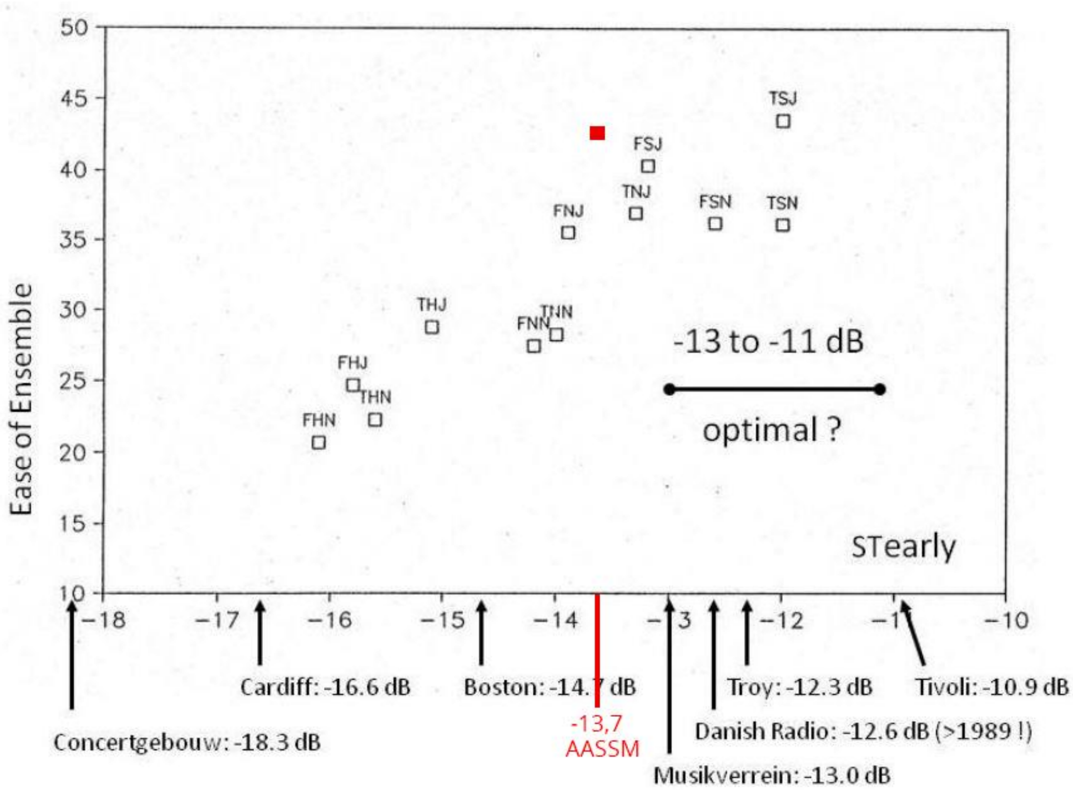

Figure 29. Comparison of this hall with Gade's ST_{early} results

4.2.2.4. RT (During Rehearsal and Performance)

The question “How do you think the acoustic response (reverberance) from the volume is?” was asked to get the musicians' opinions on reverberance.

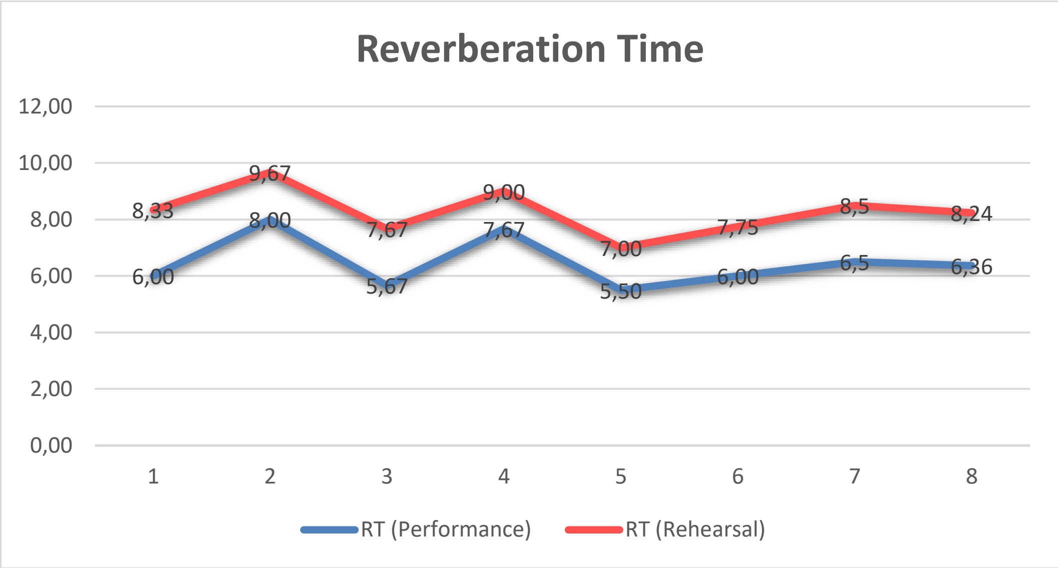

Figure 30. Average Ratings of RT(During Rehearsal and Performance) by Instrument Groups

During rehearsal; The second violin group gave the highest score with 9.67. The lowest score 7 was given by the percussion group. The mean of all populations was obtained as 8.24.

During performance; The 2nd violin group gave the highest score with 8. The lowest score 5.50 was given by the percussion group. The mean of all populations was 6.36. The highest average was also achieved here.

4.2.2.5. Dynamics

The question "Can different performance dynamics such as pianissimo and fortissimo be achieved adequately?" was asked to get the musicians' opinions on dynamics.

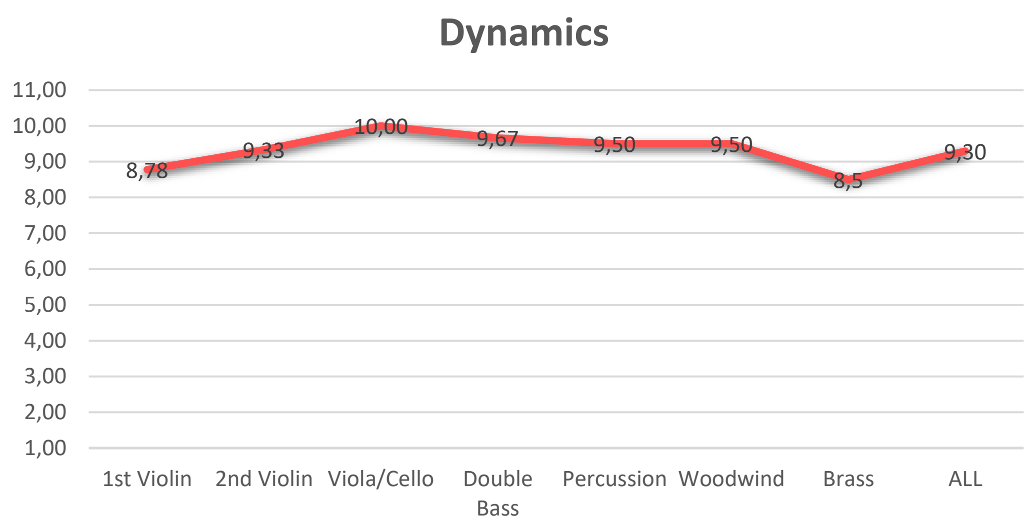

Figure 31. Average ratings for Dynamics by Instrument Groups

The viola/cello group gave the highest score with 10. The lowest score 8.50 was given by the percussion group. The mean of all populations was 9.3.

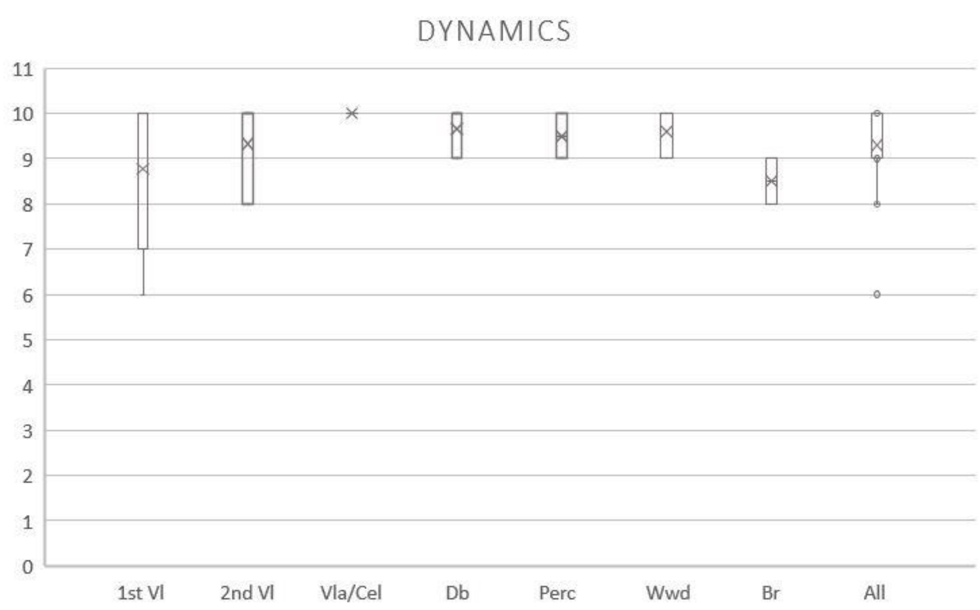

Figure 32. Variance in Ratings of Dynamics by Instrument Groups

4.2.2.6. Loudness

The question “Especially in tutti passages, is there an instrument that makes it difficult for you to hear yourself or other groups and upsets the balance of the music; is the sound perceived as balanced by you?” was asked to get the musicians' opinions on loudness.

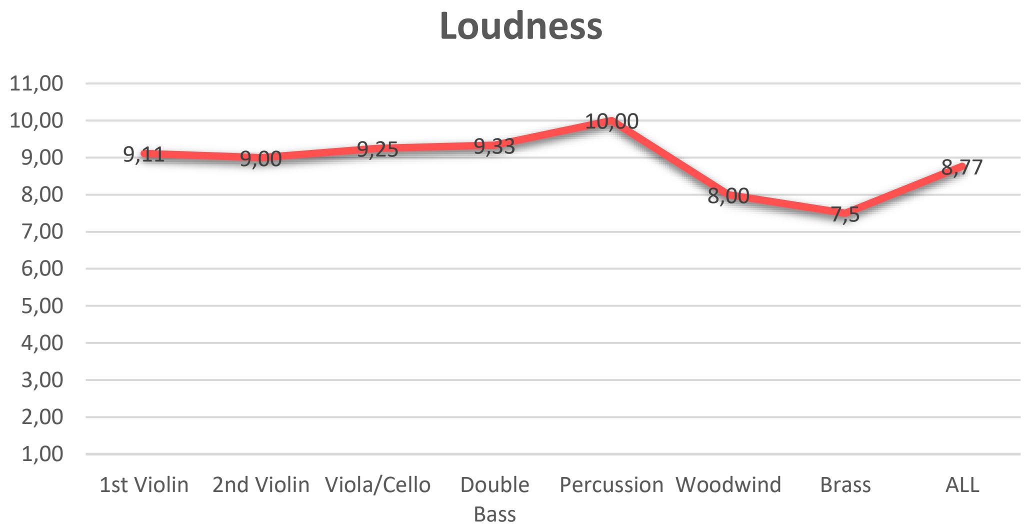

Figure 33. Average Values of Loudness by Instrument Groups

The percussion group gave the highest score with 10. The lowest score 7.50 was given by the percussion group. The mean of all populations was 8.77.

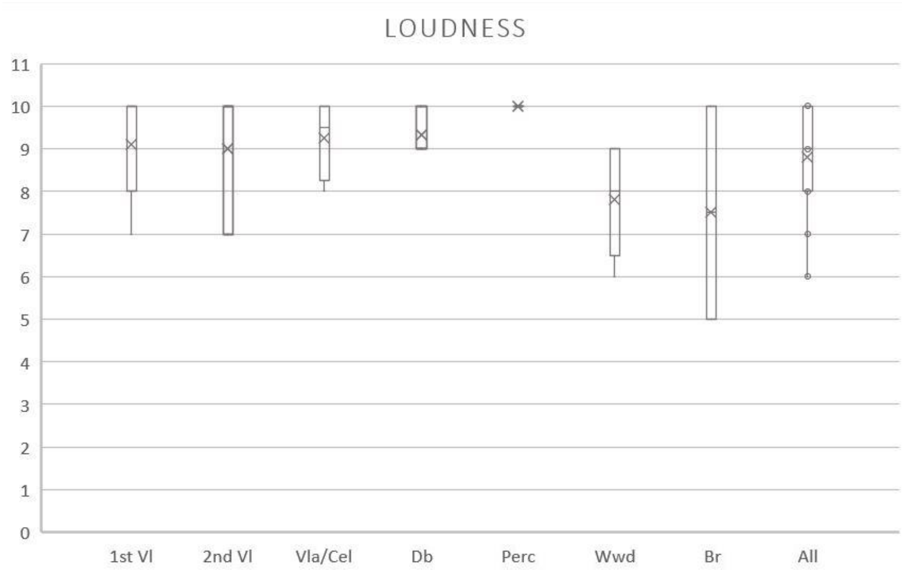

Figure 34. Variance in Ratings of Loudness by Instrument Groups

4.2.2.7. OAI (Overall Acoustic Impression)

To understand musicians' general evaluations of the acoustics, the question, "As a musician performing in this hall, when you consider all the conditions together, what is your overall impression of the acoustic characteristics of this hall?" was asked.

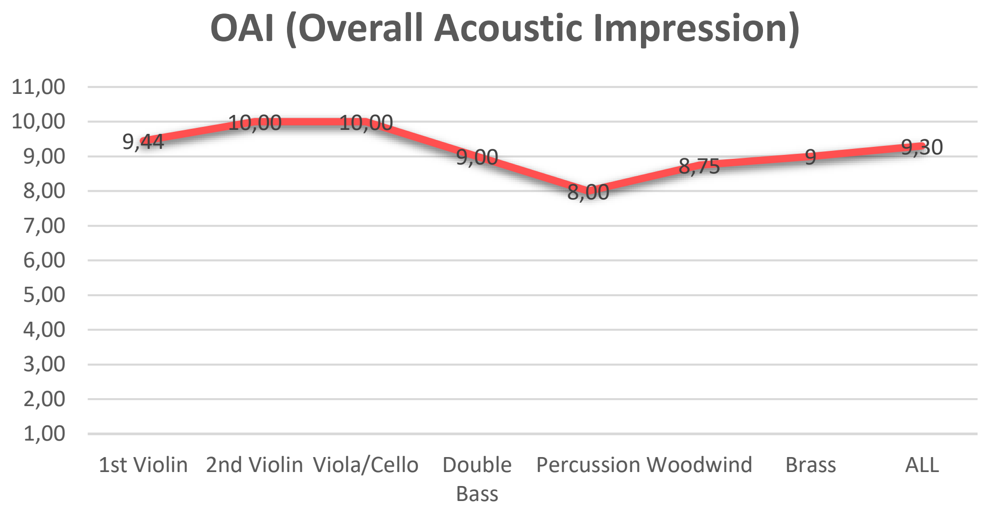

Figure 35. Average Ratings of OAI by Instrument Groups

The musician groups that gave the highest scores were the second violin and viola/cello. The lowest score 8 was given by the percussion group. The mean of all populations was 9.3.

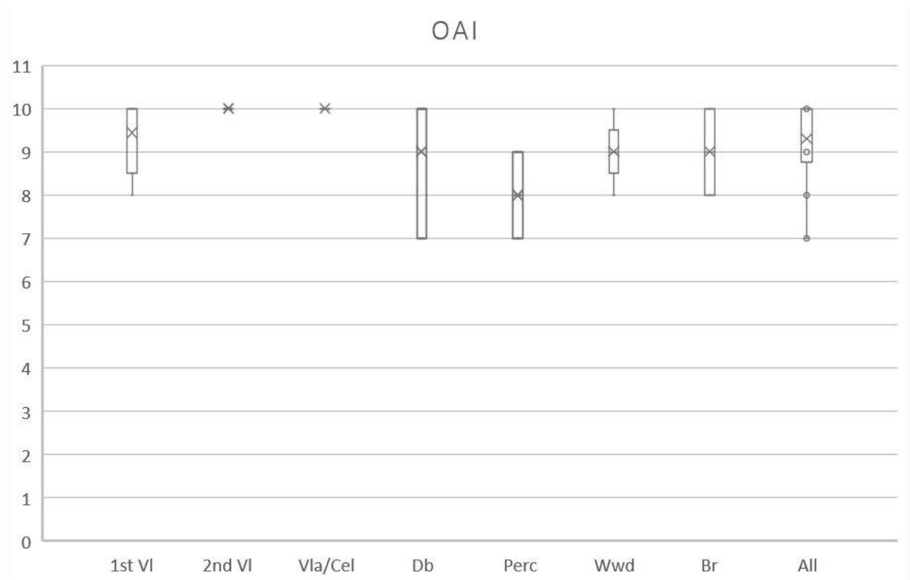

Figure 36. Variance in ratings of Overall Acoustic Impression by Instrument Groups

4.2.2.8. Discussion of Questionnaire results

Overall average ratings of subjective parameters as well as the break down by instrument group is given in Table 11. It is clear that the orchestra musicians have a very positive opinion regarding the acoustics of the Main Hall in AASAC. All subjective parameters have received very high ratings with the exception of Reverberance during rehearsals that is found to be a bit higher than desired. (8.24/10)

Table 11. Average ratings of Subjective Parameters by Instrument Groups

	1st Vl	2nd Vl	Vla/Cel	Db	Perc	Wwd	Br	ALL	σ
SUP	9.11	10.00	10.00	9.00	8.00	9.25	9	9.33	0.59
HS	9.22	10.00	9.50	10.00	10.00	8.75	7.5	9.30	0.80
RT(P)	6.00	8.00	5.67	7.67	5.50	6.00	6.5	6.36	0.85
RT(R)	8.33	9.67	7.67	9.00	7.00	7.75	8.5	8.24	0.77
HO	8.89	8.67	9.00	8.67	7.50	8.00	8	8.53	0.49
DYN	8.78	9.33	10.00	9.67	9.50	9.50	8.5	9.30	0.45
LOU	9.11	9.00	9.25	9.33	10.00	8.00	7.5	8.77	0.74
OAI	9.44	10.00	10.00	9.00	8.00	8.75	9	9.30	0.62

Spearman Rank Coefficient method was used to calculate the correlations between subjective parameters in the study. Spearman's ranks the two variables being compared and determines whether there is a correlation by ranking. Pearson's correlation, which is similar, evaluates linear relationships, while Spearman's correlation evaluates monotonous relationships. In a monotonous relationship, there is no constant increase as in a linear and non-linear relationship, but as one variable increases, the other must also increase. The Spearman correlation between two variables can be thought of as the Pearson correlation between the rank values of these variables.

The values of the data used in this method do not matter, it is useful to use when there is a set of data you want to examine. For example, in a sequence with the numbers 0.4, 0.6, 0.8, it is possible to consider 0.4 as 2, 0.6 as 3 and 0.8 as 4, and consider the sequence as 2, 3, 4.

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \text{ dB} \tag{2.10}$$

where

$d_i = R(X_i) - R(Y_i)$ is the difference between two ranks of each observation,

n is the number of observations

Table 12. Interpretation Table of Spearman Rank-Order Correlation Coefficients (Source: Dancey&Reidy 2004)

Spearman (ρ)	**Correlation**
≥0.70	Very Strong Relationship
0.40-0.69	Strong Relationship
0.30-0.39	Moderate Relationship
0.20-0.29	Weak Relationship
0.01-0.19	No or negligible Relationship

The resulting coefficient takes a value between +1 and -1. The closer the value is to 1 and -1, the greater the association of ranks. If the two data sets being compared take a "+" value, it indicates that both values increase together, and if it takes a "-" value, it indicates that as one increases the other decreases.

Correlations between subjective parameters were analyzed and values ranging between +1 and -1 were obtained. When the parameter is analyzed with itself, the value becomes 1, as expected, and is also shared in Table 13.

Table 13. Correlation Coefficients between Subjective Parameters

	SUP	**HS**	**HO**	**DYN**	**LOU**	**OAI**
SUP	1.000					
HS	-0.038	1,000				
HO	0.586	**0.025**	1.000			
DYN	0.221	0.572	0.141	1.000		
LOU	-0.341	0.753	0.122	0.618	1.000	
OAI	0.753	0.138	**0.833**	-0.143	-0.122	1.000

A positive correlation was obtained in most of the comparisons. 4 of the 15 coefficient values obtained were negative. Parameters that are negatively correlated with each other are Support - Hearing Self, Support - Loudness, OAI - Dynamics and OAI - Loudness.

The strongest correlation was found between Hearing Others and Overall Acoustic Impression (0.833). The other very strong relationships were between Support and Overall Acoustic Impression (0.753) and between Hearing Self and Loudness (0.753) The lowest correlation was obtained between Hearing Others and Hearing Self (0.025). The Overall Acoustic Impression was found to be most correlated with Hearing Others (0.833) followed by Support (0.753), both strong correlations. Overall Acoustic Impression was found not to correlate with the other parameters (all < 0.19).

4.2.3. Non-Acoustic Issues

The question, "What are the non-acoustic subjects that are important to you in the space you perform in?" was included in the questionnaire. Response options were, "Ability to See Other Musicians", "Lighting", "Thermal Comfort", "The Conductor's Line of Sight", and "Others?". The last option was open ended. When the rates are examined, it is revealed that the most important issues for musicians are lighting and thermal comfort.

Musicians made significant contributions to the "Others" option. A musician from the contrabass group stated that it is important to 'see the lead violinist'. A musician said that interaction with the audience is of great importance. It was said that the musicians do not sit close as in other halls or countries, which negatively affects the music. The conductor who participated in the questionnaire said 'to be able to change the stage arrangement'. It has been added to the thermal comfort option that it is of great importance because the ambient temperature has an effect on the musician, as well as it can change the tuning of the instrument and cause distortions. Another musician added that it is very important to be positioned so that he can play in a comfortable position.

4.2.4. Favorite Hall

The last question was, "Which Hall do you think provides the best acoustic environment among the ones you have played so far?" This question was originally asked to the musicians in order to learn about their favorite halls in Turkey, but since some musicians also mentioned the halls abroad, the scope was expanded and considered as all halls. As a result, 15 halls were given as an answer (Table 14). The hall that most musicians like to perform in, turned out to be the Ahmet Adnan Saygun Arts Center Main Hall. The possibility of bias is clear since the study was carried out with the orchestra musicians whose home base is this hall. Further investigations with especially visiting musicians are required. Other than Ahmet Adnan Saygun Arts Center, the halls that participating musicians have performed in more than once are: Vienna Musikverein, Berlin Philharmonic, İzmir Alhambra. The reasons why they found these halls good were that the sound could be heard the same all over the stage, it gave a warmer feeling when playing and the sounds could be mixed better.

In addition to this question, asking the musicians in which other halls they played was necessary for a more accurate assessment. There is no such part in the question, but the musicians were talked about during the survey. Although they all had different experiences, most had performed in more than one hall. A conductor who was only present during the week of the questionnaire and who did not play on a weekly basis like the orchestra musicians also participated in the study. He had experience in many halls. Consistent with the musicians, he stated that this is the best hall he has played in Turkey. From this point of view, it can be said that the acoustics of this hall were found successful by both its own orchestra and the musicians who performed at certain times.

Table 14. Distribution of the Halls Obtained in the Questionnaires According to the Number of People

Favourite Hall	**Country**	**People**
Ahmed Adnan Saygun Arts Center	Turkey	22
Vienna Musikverein	Vienna	2
Berliner Philharmoniker	Germany	2
Elhambra Theater	Turkey	2
Bilkent Concert Hall	Turkey	1
CSO Blue Hall	Turkey	1
Merinos Atatürk Congress and Culture Center	Turkey	1
Saint Voukolos Church	Turkey	1
Royal Albert Hall	United Kingdom	1
Turku Concert Hall	Finland	1

4.2.5. Other Issues Raised by Respondents

Respondents, after filling out the questionnaire offered many opinions related to the acoustics and musical performances in the hall. Many were noteworthy. Some are of the opinion that the members of the orchestra sit too far apart from each other. They said that people prefer to sit a little more apart for comfort, but this negatively affects the quality of the music. Some mentioned the heights of the elevating platforms used on the stage that were either 30 or 40 cm. They stated that this was too high and affected coordination. One person said that because there was no audience in the rehearsals, the reverberation time increased, so the deployable curtains on the sides of the hall had to be lowered. But he said that these curtains were not lowered at every rehearsal.

CHAPTER 5

CONCLUSIONS

While there has been significant research on the perception of music by audiences in concert halls, studies specifically focused on the acoustic perceptions of musicians have been relatively scarce, despite the fact that musicians often express dissatisfaction with the acoustic responses of the venues where they perform. Dammerud (2009) points to the fact that while exploring the on-stage conditions of performances, previous studies primarily focused on smaller ensembles, such as chamber groups. Few studies have included full symphony orchestras, indicating a potential research gap in this area. This has been a major motivation of this study focused on the Izmir Symphony Orchestra and its home stage.

Understanding the acoustic perceptions of musicians is crucial as they are the ones who directly interact with the sound environment of the concert hall. Their perception of the acoustics can significantly impact their performance, interpretation, and overall experience on stage. Factors such as room support, balance, reverberation, and spatial characteristics can greatly affect how musicians perceive and respond to the music they are creating in unison in a concert hall setting.

The main goal of the study has been to investigate the existing acoustic conditions on stage at the Ahmet Adnan Saygun Arts Center Main Hall through both objective measurements and subjective evaluations. Six research questions stated in section 1.3 has guided the study.

With regard to how musicians perceive the acoustics on the stage which they perform, the questionnaire survey findings indicate that the musicians have a strong positive view of the stage conditions.

The objective measurements carried out on stage are in strong alignment with the subjective evaluations. This indicates that the objective parameters that have been developed so far are effective in predicting acoustic performance and are useful for acoustic researchers in communicating with musicians.

Measurements on stage gave an overall average STearly value of -13.7 dB. This is very close to the optimal range of -11 to -13 dB suggested by Gade (2011) and well within the range found in other studies that measure values lower then -15dB in halls that have been studied (Table 3). Reverberation time measurements similarly point to the favorable acoustics on stage with an average T30 of 1.76 s which is very close to the optimal. The subjective evaluations are similarly very positive. Overall Acoustic Impression rating of the stage by the musicians was 9.30/10. Support rating was 9.33/10. Hearing Self was 9.30/10 and Hearing Other was 8.53/10.

When rank correlations among subjective parameters are examined, it can be seen that Overall Acoustic Impression parameter is very strongly correlated with Hearing Others (0.833) and Support (0.753) parameters. Another very strong correlation exists between Hearing Self and Loudness/Balance parameters (0.753). Other strong relationships exists between Loudness/Balance and Dynamics (0.618), Hearing Others and Support (0.586), and Dynamics and Hearing Self (0.572). These correlations suggest the appropriateness of ST_{early} objective parameter for stage design.

Besides acoustic characteristics, musicians were asked which non-acoustic issues affect their performances. Especially the thermal comfort on stage was found to be important for the musicians. The ambient temperature has an effect on the musician, as well as the tuning of the instruments. Musicians have noted that adverse thermal conditions cause distortions.

The majority of the musicians' answer was Ahmed Adnan Saygun Arts Center Main Hall, for the question, "Which Hall do you think provides the best acoustic environment among the ones you have played so far?" While this may due to the biases involved with the fact that it is their own home venue where they play regularly, it should be noted that many of musicians are highly experienced and have stated that they have played many times in other venues as well.

It is also noteworthy that some respondents have mentioned that the members of the orchestra sit far apart from each other. They said that people prefer to sit a little more apart for comfort, but this negatively affects the quality of the music. The heights of each of the elevating platforms used in the stage were 30 or 40 cm. They stated that it was too high and affected coordination.

Another point that was raised by one respondent was that because there was no audience in the rehearsals, the reverberation time increased, so the curtains on the sides of the hall had to be lowered. But he said that these curtains were not lowered at every rehearsal.

In the results obtained in the questionnaires, it is seen that the musicians found the hall very good in terms of acoustics and were satisfied with the conditions. The results of the parameters obtained in the measurements also seem appropriate in terms of acoustics. We can say that the acoustic parameters coincide with the opinions of the musicians.

An important limitation of this study was the fact that it focused on a single orchestra stage and its musicians. However, Izmir Symphony orchestra did not have any other regular venues, and other symphony orchestra stage was available in the time frame of the study. Future studies should extend the data set including other orchestras and venues providing a comparative evaluation of the objective and subjective parameters.
Further research in this area can provide valuable insights into the unique needs and preferences of musicians in different performance contexts, and can potentially inform the design and optimization of concert hall acoustics to better cater to their requirements. By considering the perspectives of musicians alongside those of audiences, concert hall designers and acousticians can work towards creating performance spaces that offer optimal acoustic experiences for all stakeholders, enhancing the overall quality of live music performances. Continued research in the field of musician-centric hall acoustics can contribute to advancing the understanding and practice of concert hall design and acoustics, benefiting both musicians and audiences alike.

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APPENDIX A

QUESTIONNAIRE QUESTIONS

SAHNE AKUSTİĞİNDE MÜZİSYEN ALGISI İLE
NESNEL GÖSTERGELERİN KARŞILAŞTIRILMASI

Salonun İsmi:………………………………………………………………….

1- Hangi enstrümanı çalıyorsunuz?

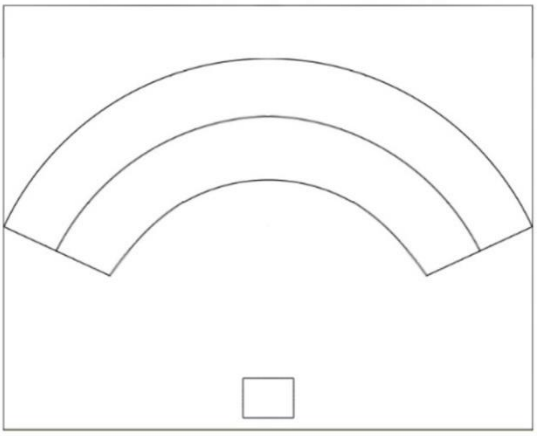
2- Profesyonel bir senfoni orkestrasında ne kadar süredir çalıyorsunuz? .... yıl

3- Kaç yıldır bu orkestrayla çalıyorsunuz? .... yıl

4- Bu salonda kaç defa performans gösterdiniz? Aşağıdakilerden uygun olanını işaretleyiniz.

•1-2 •3-10 •10'dan fazla

5- Bu sahnede genellikle bulunduğunuz konumu aşağıda paylaşılan şemada işaretleyebilir misiniz?



Konuma dair farklı bir yorumunuz bulunuyorsa lütfen ekleyiniz:

6- Performans gösterdiğiniz salonda sizin için önemli olan akustik dışı konular nelerdir?

• Diğer Müzisyenleri Görebilme
• Aydınlatma
• Isıl Konfor
• Şefin Görüş Hattı
• Diğerleri?

Salonun İsmi:………………………………………………………………..

SAHNE TERCİHLERİ

7- Size ayrılan sahne alanıyla ilgili büyüklük tercihiniz nedir?

•Kompakt •Orta •Geniş

8- Fiziksel rahatlık: Bu sahnede çalıyor olmak sizin için rahat ve konforlu mu? Uygun sayıyı işaretleyiniz. (Rahat Değil-1 / Rahat- 10)

1 2 3 4 5 6 7 8 9 10

Tam olarak rahat değilseniz nasıl bir sorun yaşıyorsunuz?

DESTEK

9- Bu salonun akustik özellikleri sayesinde müzikal performansınıza destek olabildiğini düşünüyor musunuz? Uygun sayıyı işaretleyiniz. (Desteklemiyor-1 / Destekliyor-10)

1 2 3 4 5 6 7 8 9 10

KENDİ ENSTRÜMANINI DUYABİLME

10– Genel bir değerlendirme yapacak olursanız, bu salonda çalarken kendi enstrümanınızın sesini diğer enstrümanlardan ayırt edebiliyor ve rahatlıkla duyabiliyor musunuz? Uygun sayıyı işaretleyiniz. (Duyamıyor-1 / Duyamıyor- 10)

1 2 3 4 5 6 7 8 9 10

Dinamiklere (piano, fortissimo v.b.) göre farklılık oluştuğunu düşünüyorsunuz veya farklı bir yorumunuz varsa lütfen ekleyiniz:

11- Salonun akustiği nedeniyle yüksek sesli enstrümanlar herhangi bir dinamikte kendi sesinizi net bir şekilde duymanızı zorlaştırıyor mu?

Sıklıkla Bazen Çok nadiren Hiç

Hangi enstrümanlar duymanızı zorlaştırıyor?

ÇINLAMA SÜRESİ

12- Salondan gelen akustik tepkiyi (odanın çınlaması) nasıl buluyorsunuz?

Seyirci Varken/- Çok Kuru 1 2 3 4 5 6 7 8 9 10 Çok Çınlamalı,Yüksek Reverb

Prova Esnasında/- Çok Kuru 1 2 3 4 5 6 7 8 9 10 Çok Çınlamalı,Yüksek Reverb

13- Çınlıyorsa: grubunuzdaki enstrümanların entonasyonları ve artikülasyonları sizin konumuzdan rahat duyuluyor mu, salonun akustiğinin buna etkisi sizce nasıldır?

14- Olumsuz bir etki oluşturuyorsa, lütfen sesi kısaca tarif ediniz.

- Salonun İsmi:………………………………………………………………..

DİĞER MÜZİSYENLERİ DUYABİLME

15- Diğer enstrümanları rahatlıkla duyabilir musunuz? Uygun sayıyı işaretleyiniz.
(Duyamıyor-1 / Duyuyor- 10)

1 2 3 4 5 6 7 8 9 10

16- Diğer müzisyenlerle senkronize çalmak sizce kolay mıdır? Uygun sayıyı işaretleyiniz.
(Kolay Değil- 1 / Kolay - 10)

1 2 3 4 5 6 7 8 9 10

17- Diğer müzisyenlerle doğru tonlamayı elde etmek sizce kolay mıdır? Uygun sayıyı işaretleyiniz.
(Kolay Değil-1 / Kolay - 10)

1 2 3 4 5 6 7 8 9 10

18- Entonasyon ve birlikte çalma bakımından özellikle iyi duymanızın önemli olduğunu düşündüğünüz müzisyen grupları var mıdır, varsa hangileridir?

DİNAMİKLER

19- Pianissimo, fortissimo gibi farklı icra dinamikleri yeterli bir şekilde elde edilebiliyor mu? Uygun sayıyı işaretleyiniz. (Yetersiz- 1 / Yeterli- 10)

1 2 3 4 5 6 7 8 9 10

Yeterli olmadığını düşündüğünüz dinamikler (fortissimo, pianissimo…) varsa hangileridir?

LOUDNESS/DENGE

20- Özellikle tutti pasajlarda, kendinizi veya diğer grupları duymanızı zorlaştıran ve müziğin dengesini bozan bir enstrüman oluyor mu yoksa ses sizin tarafınızdan dengeli mi algılanıyor? Uygun sayıyı işaretleyiniz. (Dengesiz- 1 / Dengeli- 10)

1 2 3 4 5 6 7 8 9 10

GENEL AKUSTİK İZLENİM

21- Bu salonda performans gösteren bir müzisyen olarak genel akustik izleniminiz nasıldır? Uygun sayıyı işaretleyiniz. (Çok Kötü -1 / Çok İyi- 10)

1 2 3 4 5 6 7 8 9 10

YANSITICI YÜZEYLER

22- Sizin için akustiği olumlu veya olumsuz yönde etkileyen sahneye yakın yansıtıcı yüzeyler var mı? Eğer varsa, bunları nasıl algıladığınızı ve sizi nasıl etkilediğini açıklayınız:

23- Şimdiye kadar çaldıklarınız içinde en iyi akustik ortamı sağladığını düşündüğünüz salon hangisidir? (Şehir/Salon)

APPENDIX B

ENGLISH TRANSLATION OF THE QUESTIONS

1- Which instrument do you play?

2- How many years have you been playing in a professional orchestra? .... year

3- How many years have you been playing with this orchestra? .... year

4- How many times have you performed in this hall? Tick the appropriate one of the following.

5- Can you mark your location in this stage in the diagram shared below?

6- What are the non-acoustic subjects that are important to you in the space you perform in?

7- What is your size preference for the stage where you are performing?

8- Is it easy for you to perform on this stage in terms of physical comfort?
If you think you are not comfortable, what problem do you have?

9- Do you think this hall supports your performance? Can you talk briefly?

10- If you make a general evaluation, can you distinguish the sound of your own instrument from other instruments and hear it?

11- In any dynamic, do loud instruments make it difficult for you to hear your own voice clearly due to the acoustics of the Hall? Which instruments make it difficult for you to hear?

12- How do you think the acoustic response (reverberance) from the volume is?

13- If reverberant: are the intonations and articulations of the instruments in your group comfortable from your position, how do you think the acoustics of the hall affect this?

14- Please briefly describe the sound if it has a negative effect.

15- How often do you have trouble hearing other instruments?

16- Do you think it is easy to play in sync with other musicians in this hall?

17- Do you think it is easy to get the right intonation with other musicians?

18- Are there groups of musicians that you think are particularly important for you to hear well in terms of intonation and playing together, and if so, which ones?

19- Can different performance dynamics such as pianissimo and fortissimo be achieved adequately? If there are dynamics (fortissimo, mezzo-forte, mezzo piano, pianissimo) that you think are not sufficient, which ones? Can you explain?

20- Especially in tutti passages, is there an instrument that makes it difficult for you to hear yourself or other groups and upsets the balance of the music? Or is the sound perceived as balanced by you?

21- As a musician performing in this hall, when you consider all the conditions together, what is your overall impression of the acoustic characteristics of this hall?

22- Are there reflective surfaces close to the stage that affect the acoustics positively or negatively for you? If so, explain how you perceive them and how they affect you:

23- Which Hall do you think provides the best acoustic environment among the ones you have played so far? (City/Hall)