An investigation into the effect of acoustics on vocal strain of Opera singers

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By

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Declaration:

I declare that this thesis is the original work of the author, Ms Gizem Okten except where otherwise specified, or where acknowledgement is made by reference. It was carried out at the School of the Built Environment and Architecture, London South Bank University, under the main supervision of Dr Stephen Dance. The work has not been submitted for another degree or award of any other academic or professional institution.

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London (UK) October 2016

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PhD has been the toughest of all my education life. I am not sure if I could dare if I knew it was going to be this hard. Therefore, for me this page is as important as the research itself as it gives me the chance to thank one more time to those who gave all the support.

To my dear Opera singers of Royal Academy of Music, I wish I could thank all 117 of you name by name here. Thank you not only for your voluntary help but also for your friendship and for letting me be part of your musical adventures. I hope the results of this research will be a guide to create better singing environments for you.

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To my dear family … I dedicate this thesis to you as I wouldn't be able to complete it without your endless support. Thanks a million for always being there, giving me the courage and motivation during the tough times. I love you so much!

To myself … Thanks for saving the world… Please do not find yourself another mission to accomplish, at least for a while. Go with the flow, make your life easier and party!

Cheers to all who made my life easier
during this process!

Gizem Okten

ABSTRACT

Professional classical singing requires dedication and a significant amount of practice in order to properly sing the challenging pieces. Classical singers not only practice to become an expert in their techniques but also must understand the context, emotions and delivery of each musical piece. Acoustics of practice rooms are crucial as the singers spend most of their learning process in these rooms.

Previous research on singers' voice focused on the voice and vocal health issues. This allowed improved treatments and techniques in the clinical practice for singers' vocal health. However, little research has been undertaken on how room acoustics affect the voice dosimetry and perception of classical singers. This research examines singers' objective vocal dosimetry and subjective perception data together with the room acoustic parameters with an aim to find the preferred practice room conditions of the Opera singers. Singers are known to be professional voice users which are a group at risk from voice disorders. Therefore improving their singing environment for their vocal health is as necessary as the improvement of clinical practice.

This research aims to find out the effect of the room environment on the vocal loading parameters and subjective parameters of the Opera singers with a focus on the practice rooms then to find out singers' preferred practicing conditions to suggest target values for the room parameters that show correlation with the singers' parameters. For this purpose, research was undertaken with the kind assistance of 117 Opera singers. First a pilot study was conducted in the Acoustic Laboratories of the London South Bank University in order to determine and validate the methodology of the research, second a Field study in the practice rooms of the Royal Academy of Music was conducted with an aim to find the relationship between singers' data regarding their vocal dose parameters, perception and preferences of the acoustics of the practice rooms and thirdly, as a side study of the research, to find out Opera singers' daily vocal load during a typical working day in order to make a comparison with daily vocal loading of professional voice users.

It was found that there was no significant change in the Opera singers' vocal loading in the laboratory spaces even though these rooms had extreme acoustic conditions in terms of background noise and reverberation. Likewise, no significant change was observed in their vocal loading parameters in the practice rooms. However, students' subjective response to the different acoustic conditions of the practice rooms showed significant change and very strong correlations were observed with the T30 room acoustic parameter at 4k octave band and C80 from 500 Hz to 4 kHz. Using the information a preferred design for practice room acoustics for Opera singers was established based on room dimension, T30, C80 and G parameters at the frequencies showing the greatest correlation with the singers' data that correspond to singers' preferred ratings.

In addition, the results of the side study showed that the Opera singers' daily sound pressure levels due to overall vocal activity including both speech and singing and due to only singing were higher than other professional voice users such as teachers and call-centre operators and these levels were found to be reached over a shorter phonation time which showed that they are exposed to higher vocal loading.

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GLOSSARY OF TERMS

Background noise level ($L_{Aeq,10min}$, dB)	Background noise level measured for 10 minutes when the room under measurement and the adjacent rooms were unoccupied.
Bass Ratio (BR)	It is the ratio of the average reverberation times at 125 Hz and 250Hz octave bands to the average reverberation times at 500 Hz and 1kHz octave bands.
Clarity	Subjective acoustical parameter which is defined as the degree to separate each variation in a sound.
Clarity Index (C80, dB)	The ratio of the energy in the impulse response of the first 80 milliseconds to the energy after 80 milliseconds after the arrival of the direct sound.
Correlation analysis	Is a statistical methodology in order to find the relationship between variables. It is used to explore the significance degree of the correlation and the direction of the correlation between two variables.
Cycle dose (D_c)	The number of vocal fold cycles during phonation.
Descriptive statistics	Is a statistical methodology which defines the characteristics of the collected data.
Distance dose (D_d, m)	The distance that the vocal folds take during phonation.
Early Decay Time (EDT, sec)	The time it takes a sound to decay 10 dB from its initial level normalized to a 60 dB decay time.
Flutter echo	The buzzing sound that is produced due to sound waves bouncing between two reflecting parallel walls.
Formants	In phonetics, it is defined as the resonant frequencies of the vocal tract.
Fundamental frequency (F0, F0average and F0mode, Hz)	Fundamental frequency (F0) is the lowest frequency of a repeating waveform, F0average is the average F0 during the time of phonation and F0mode is the frequency that mostly occurs during phonation.
Loudness	Subjective acoustical parameter which is defined as the perception of the magnitude of sound.
One-way Analysis of Variance (ANOVA tests) and Bonferroni Post-hoc test	Is a statistical method in order to explore whether there's a difference in the results of at least three conditions using one independent variable, it analyses the variance in the data and the means of each group. With ANOVA tests it is possible to find out if there's any difference in groups or subjects, but it doesn't tell which groups are showing the difference. Bonferroni Post-hoc tests are used to explore where the difference occurs between the analyzed groups.
Phonation time (P_t, sec)	It is the time when the vocal folds are vibrating, therefore it is the time when the phonation occurs.
Regression Analysis	Is a statistical prediction method that is used to find out the relationship between a dependent variable and an independent variable. The analysis provides a prediction model which can be used to predict the unknown value from the known value. Linear regression is used throughout this thesis.
Representative background noise level ($L_{Aeq,2min}$, dB)	Background noise level measured for 2 minutes immediately after the data collection for each subject when the adjacent practice rooms were in use and the room under measurement was unoccupied. The aim was to collect the background noise levels representative of the levels during the time of singers' measurements.
Reverberance	Subjective acoustical parameter which is defined as the persistence of sound in the space.
Reverberation time (T30, sec)	The time it takes a sound to decay 30 dB from its initial pressure level until it becomes inaudible and then normalized to a 60 dB decay time.
Singing voice handicap index (SVHI)	A self-assessment tool to measure singer's vocal health via a questionnaire specific to singers.
Sound Strength (G, dB)	The difference of the sound level of a source measured in a room to the level of the same source measured in a free field at a distance of 10 m.
Vocal Range Profile (VRP)	It is the graphical presentation of a participant's frequency and intensity range.

1. CHAPTER 1: INTRODUCTION

1.1. Aims

This research consists of one main and one additional side study:

1. "Effects of room acoustics on semi-professional Opera singers' voice dosimetry and perception" as the main research topic and,
2. "Daily voice dosimetry of semi-professional Opera singers at their education premises" as the secondary research topic.

The main research focuses on the inter-relationship between room and singers' parameters. The author hypothesised that room acoustic parameters affect both the objective vocal loading parameters and the subjective parameters of the singers. The aim was to investigate whether the acoustics of the practice room environment affect singers' objective and subjective data. If so, what room parameters are significantly correlated with the singers' impressions? In addition, what value for the room parameter would be considered preferable by the singers? From this it would be possible to design a desirable practice environment for the vocalists. For the purpose of the study, highly trained semi-professional Opera singers at the Royal Academy of Music were chosen in order to minimise the problems due to singing techniques.

The aim of the secondary study was to collect daily vocal loading data of the singers' in order to compare semi-professional Opera singers' vocal stress during a day at their education premises to that of other occupations known to have significant vocal stress.

The research was undertaken with the voluntary work of a total of 117 singers. 62 singers participated in the pilot stage of the study which was undertaken in the Acoustic Laboratories of London South Bank University whereas 55 singers participated in the field stage of the study which was undertaken at the practice rooms of Royal Academy of Music. Singers' voice dosimetry data was collected via using an Ambulatory Phonation Monitor in four practice rooms mainly used by the singers at the Academy and subjective data were collected via questionnaire together with the preferred ratings of the singers' for each questionnaire parameter. In addition, room acoustic parameters were measured for each room when the rooms were unoccupied.

1.2. Thesis Outline

The research has been divided in the following chapters:

Chapter 1 is an introductory chapter in order to give the reader a general information on the aims, objectives and the outline of the research.

Chapter 2 provides review of the relevant literature regarding vocal loading, vocal loading factors, methods to measure vocal load in clinical and field practice, research on vocal loading in speech and singing. Necessary room acoustic parameters, design parameters for music practice rooms and relevant standards and guidance are presented. In addition, the relationship between room acoustics and voice is given.

Chapter 3 provides information on the methodology of the research including equipment used, measurement site and rooms, subjects, statistical methods used and the stages of data collection.

Chapter 4 provides the results of the statistical analysis of the collected data for each stage of the research. Results of change in singers' voice dosimetry and questionnaire data due to change in the acoustic conditions of the rooms; results of the correlation analysis between the singers' data and room data; results of singers' preferred ratings of the questionnaire parameters and finally the results of the regression analysis between singers' data and room data are presented. Results of daily voice dosimetry of the singers' are also presented in this chapter for only singing activity as well as the overall vocal activity. This chapter provides information on which room parameters are highly correlated with singers' parameters and suggestions are made for what these room parameter values should be in order to achieve singers' preferred ratings with an aim to create preferred practice room conditions,

Chapter 5 reviews the findings of the research and discusses the results in relation with previous findings as well as relevant standards and guidance.

Chapter 6 presents the conclusion and further work of the research.

2. CHAPTER 2: LITERATURE REVIEW

In this chapter general concepts regarding vocal loading and room acoustics will be summarised together with the review of the relevant literature.

2.1. Vocal Loading

Vocal loading is known as the stress inflicted on the vocal folds during phonation. [1, p125] This stress is one of the main reasons for voice disorders, mainly occurring in professions with high vocal needs. Vocal effort describes the changes in this stress by means of frequency and intensity. Vocal effort can be objectively monitored by measuring vocal load, and subjectively by collecting the perceptual input of the subject by using questionnaires.

Factors which might cause a change in vocal intensity and frequency are called the loading factors. Loading factors can be environment-related such as background noise levels, air quality, room acoustics, as well as individual-related such as stress levels, gender, age, and health. [2, 3] Vocal loading, can be decreased or controlled through vocal training by taking enough rests between and after vocal tasks; by taking good health care and by well-designed acoustic environments which support the vocal demands of their users. [4, 5]

2.1.1. Vocal Loading Parameters

Vocal load can be objectively measured by vocal dose parameters such as time dose, distance dose and cycle dose. Time dose (D_t, seconds) is the measure of the total time of phonation. Phonation occurs during the vibration of the vocal folds. The length of time the vocal folds are vibrating is called the "Phonation Time." This is the time when the voice is produced. Time dose equation is shown below (Equation 1, t_p= Performance time; k_v=voicing unit step function, k_v=1 for voicing; k_v=0 for non-voicing). As can be seen it is not dependent on fundamental frequency (F0) or Sound Pressure Level (SPL). [6]

$$D_t = \int_0^{t_p} k_v \, dt$$

Equation 1 [6]

Another dose for quantifying vocal load, Vocal Loading Index (Cycle dose, D_c) was introduced by Rantala and Vilkman(1999). [7] It is the measure of total number of cycles of the vocal folds during phonation. Vibratory properties of the vocal folds determine an individual's fundamental frequency, F0. As can be seen in Equation 2, the fundamental frequency (F0) directly affects the vocal loading index (VLI, kcycles). Higher frequency characteristics of women lead to a higher vocal loading compared to men due to more vocal fold collisions. This might lead to more vocal disorders in women than in men despite the same phonation time. [8]

$$VLI = \frac{1}{1000} \int_{0}^{t_p} k_v \, \mathrm{F}_0 \, dt$$

Equation 2 [6]

Distance dose (D_d, meters) is the measure of the total distance that the vocal fold tissues take during phonation. As can be seen from the Equation 3 **[6]**, distance dose is affected by variations in both the fundamental frequency and the intensity. (Equation 3: factor 4 accounts for the distance travelled by the vocal folds during one cycle of oscillation; A is the amplitude of tissue vibration; F0 is the fundamental frequency).

$$D_d = 4 \int_{0}^{t_p} k_v \, \mathrm{AF}_0 \, dt$$

Equation 3 [6]

2.1.2. Methods for Measuring Vocal Load

2.1.2.1. Clinical Practice

Several methods have been developed by clinicians for diagnosis, evaluation, monitoring and cure of voice disorders for populations at risk. Clinical assessment methods are mainly composed of auditory-perceptual; acoustic; aerodynamic and endoscopic assessments. [9] These might involve interviews with the patients about their vocal history, physical tests, endoscopy, and self-rated questionnaires. [10]

Acoustic assessments examine the frequency and intensity features of voice and the cycle to cycle variations of these features whereas aerodynamic assessments analyze the respiratory features of voice by analyzing the air volume, airflow and subglottal pressures during voice production. [11, 12] Endoscopic imaging is a technique used by clinicians to directly view the vocal fold anatomy to understand and address the irregularities causing vocal problems; some examples of the scanning techniques for imaging are Videolaryngostroboscopy, Video-Kymography and Digital high-speed imaging. [13]

Auditory-perceptual assessment is based on the clinician's observations of voice by listening to the patient during an informal conversation or by following a protocol using a validated rating scale that includes global descriptions for voice assessment. [14] For an accurate evaluation of voice and voice-disorders, perceptual assessments should be evaluated together with objective assessments by a trained clinician using standardized protocols for auditory-perceptual analysis and by carefully examining patient's perception of disorder by using validated self-rating scales in order to minimize biased information. [13]

2.1.2.2. Field Practice

Despite various methods developed for clinical assessment of voice, the need to monitor the patient's daily vocal behavior closely to understand how their every-day environment affects their voice quality, portable devices for field practice have been developed. These devices are dosimeters that are designed to monitor patient's daily vocal load during their daily activity without giving any disturbance. The aim is to measure daily vocal doses (time, distance, and cycle dose), frequency, and intensity variations to correlate daily data with the clinical assessments to address the causes of vocal problems. [15]

These dosimeters, such as Ambulatory Phonation Monitor, are composed of an accelerometer and a small portable data storage case. The accelerometer is glued on the neck of the patient where the vocal folds are located to sense the vocal fold oscillations and is connected with a cable to the data storage case carried by the patient in a waist pocket during monitoring. [16] In addition to their clinical use, these dosimeters also let the researchers examine the effects of different environments such as effects of room acoustics on voice quality.

2.1.3. Relevant Literature on Vocal Load for Speech

With the development of portable accelerometers, it is now possible to monitor subject's daily vocal behavior; occupations which rely on their voice for living such as call-center operators have been investigated by Cantarella et al.[17] The results of their research on 92 call-center operators monitored via APM during a working day indicated a significant positive correlation between phonation time and the average amplitude; no significant difference in phonation time was found between genders but cycle dose and frequency, including both modal and average, in females were found to be significantly higher than males.

Teachers are another occupation that suffer from voice disorders therefore their vocal behavior is particular interest of researchers. According to Rubin [18], one in every five teachers is subject to voice disorders whereas the number decreases to one in every 25 people when general population is considered. Morrow and Connor [19] undertook a comparative study between elementary classroom teachers (N=5) and elementary music teachers (N=7) using an APM in order to find out the typical vocal load of each group via monitoring each participant during five working days (40 hours for each participant). They have compared the mean values of vocal loading parameters (Phonation time, F0average, F0mode, SPL, D_c and D_d) collected for each group and concluded that the elementary music teachers have significantly higher vocal loading compared to elementary classroom teachers.

A similar study by Remacle et al. [20] examined vocal loading of N=32 female teachers of which N=20 were elementary school and N=12 were kindergarten teachers in Belgium in order to see the difference of voice use in each group. The authors monitored the teachers for five working days by using an APM, for an average of 29 occupational hours for each participant and compared the mean results of vocal loading parameters in each group. All measured parameters including F0average, F0mode, SPL, D_c and D_d were found to be higher in kindergarten teachers compared to elementary school teachers.

Bottalico and Astolfi [21] have investigated the daily vocal doses of N=40 (N=36 female, N=4 male) primary school teachers in Italy. The teachers were monitored between one day and three days, each for four hours per day. F0average, SPL, Phonation time percentage was examined separately for males and females. In addition to daily dosimetry, the data was collected from teachers working in six different schools; they have grouped the schools in two due to difference in the acoustic environment of the classrooms then examined the collected voice dosimetry data separately for each group. The teachers were also asked to complete a questionnaire in order to take their subjective ratings of the classrooms. Both objective and subjective results were compared in order to find the effect of the acoustics of the classrooms on the teachers' voice parameters and perception. They have found that there wasn't any significant change in the voice dosimetry results of the two groups due to different acoustics of the environments, but the subjective results showed a significant change. For instance the difference in background noise levels in each group which the mean values were 50.4 dB L_{A90} and 53.3 dB L_{A90} did not make any change in the resulting vocal dosimetry parameters of the teachers but the perception of "background noise intensity" scores were found to be significantly higher in the more reverberant classroom. Likewise "teachers' vocal effort subjective scores were higher in the more reverberant room as they felt they have raised their voice more whereas the "Acoustical quality satisfaction" subjective parameter was rated higher in the less reverberant room. They also found correlation between perceived "voice intensity" and $T30_{mid}$, suggesting an optimum $T30_{mid}$ of between 0.75-0.85 seconds for speech in a classroom.

Football coaches are another example of an occupation with high vocal demands according to a research undertaken by Buckley et al. [22] In their research, using an APM, they have monitored 12 football coaches during their training with the players. According to the authors the results showed that the coaches had such high sound pressure levels (SPL_{mean}= 83.67 dB) during training that are comparable with occupations with high vocal loads such as teachers and opera singers. They considered the phonation time percentage results (19%) as moderate, as it was comparable to preschool teachers (17%) and call center workers (15%).

2.1.4. Relevant Literature on Vocal Load for Singing

Several research studies have been undertaken on the vocal loading of singers with the aim of relating vocal dose parameters to subjective measurements of vocal fatigue. There have been various methodologies used to examine the singing voice.

One methodology by Lamarche et al. [23] examined the singing voice by looking at Vocal Range Profiles (VRP) of 30 female opera singers. The aim was to investigate whether there is a need for a more appropriate VRP protocol specific for singers and to provide more reliable metrics for clinicians to evaluate the singing voice. Singers were given different tasks to evaluate different VRPs such as spontaneous speech task, a counting exercise and singing an aria for at least 1 minute. The results showed that the performance based VRPs were more appropriate to define a singer's vocal use rather than the physiological VRP.

Another methodology was to monitor the singers before, during and after vocal loading (i.e. rehearsals / show / rest-recovery times) focusing on the daily vocal use measured by a dosimeter and on the self-ratings of singers. Specific examples include:

Bowers and Daugherty [24] carried out a questionnaire survey at a high school summer choral camp on 141 choral students to investigate their perception of the change in their vocal health before and after an intense week of singing. The results showed that self-reported vocal problems increased after the intense week of singing.

Carrol et al [25] carried out a two week study on seven classical singers (5 males and 2 females) to compare the objective vocal loading data, obtained using a NCVS (National Center for Voice and Speech) dosimeter, and the subjective data on vocal fatigue. Singers were asked to wear the dosimeter from morning until sleep for a two-week period. They performed four vocal exercises with varying pitch and intensity combinations repeated every two hours during monitoring. Then they were asked to rate their effort and comfort levels on a 10-point scale from best to worst. Results showed that the singer's self-ratings were better only if there is at least 48-hour vocal rest before the vocal loading.

Scholoneger [26] monitored two female graduate teaching-assistant opera singers for nine days before, during and after an intensive week of opera rehearsals using an Ambulatory Phonation Monitor to find out the change in their vocal use and vocal health. The mean phonation time dose (D_t) and average daily distance dose (D_d) were compared depending on different daily activity, such as opera singing, teaching, rehearsal and non-rehearsal times. It was found that higher vocal dose results were seen during personal singing practices rather than the opera rehearsals. The singers had pre and post stroboscopic examinations to further analyze the health conditions after intense rehearsals and answered daily questionnaires together with the singing voice handicap index (SVHI) questionnaire which is a self-assessment tool to measure singer's vocal health. The results of examinations and the collected subjective data for vocal health did not show any significant changes concluding that the singers were aware of the needs of an intense performance and therefore in control of their voices.

Paolillo and Fussi [27] undertook a pilot study on vocal dosimetry of nine musical and ten opera singers in theatres during live performances aiming to get real dosimetry results during before and after a performance. According to authors APM data including vocal doses, SPL and F0 doesn't show the amount of vocal loading right away, therefore they have proposed a ratio they call "Vocal Range Index, VRI" which is calculated by the ratio of cycle dose (D_c) to the distance dose (D_d): D_c/D_d. They examined this ratio to assess vocal loading together with the singer's self-rating for the most difficult moments. They found out the lower D_c/D_d ratio was correlated with the most difficult singing parts (due to singer's subjective evaluation) whereas the higher ratio was related to the rest and recovery times.

Gaskill et al. [28] monitored a total of N=6 graduate vocal performance students for one week using APM. Each singer was monitored for approximately 12 hours a day so that daily voice dosimetry of vocal performance students could be established. In addition, it would allow any change in their voice parameters to be monitored during the week. The data collected was separately examined for daily dosimetry and for singing dosimetry. The singers were also subject to laryngeal imaging and videostroboscopy at the beginning and at the end of the five day period. No significant changes were observed either for the voice parameters collected via APM, or for the laryngeal findings from the beginning to the end of the week.

2.2. Room Acoustics

Room acoustics define the sound field properties of an enclosure. The sound field of a room directly affects the quality of user activities therefore acoustics of a room should be designed properly according to its function. Gade [29] explains the interaction between room design, room objective parameters and user's perception in three main domains; Architectural, Objective and Subjective. Room physical characteristics define the "Architectural Domain" (such as room shape, dimensions etc.) whereas "Objective Domain" is defined by the sound field of the room where the objective parameters are derived via room acoustic measurements and the "Subjective Domain" consists of subjective parameters obtained from listener's subjective evaluations of the measured objective parameters. He underlines the importance of building concrete and validated outcomes from the relation between these three domains.

In room acoustics, an impulse response defines the room's response to a sound coming from a source. An impulse response can be measured with a sound source and a sound level meter by using validated techniques described in standards depending on the aim of the measurement. A sound can reach the listener directly (direct sound) or can first reach the room surfaces then the listener after being reflected (reflected sound) from room surfaces. The objective acoustic parameters of a room can be derived from an impulse response as it contains all acoustic properties of the direct and reflected sound as a function of time, frequency, intensity and directivity. [29] These objective parameters have an equivalent subjective parameter that corresponds to the perception of the listener. The parameters to be considered change depending on the function of a room, therefore relevant parameters should be chosen for a good acoustic design. In the next section, only the relevant parameters to the research will be explained.

2.2.1. Objective and Subjective Acoustic Parameters

In this section objective acoustic parameters will be defined together with their corresponding subjective parameter.

2.2.1.1. Reverberation time (T30), Early Decay Time (EDT) and Reverberance

When sound is propagated from a source it starts losing its initial energy by either being reflected or being absorbed by room surfaces depending on the absorption properties of each surface. The time it takes a sound to decay 60 dB from its initial pressure level until it becomes inaudible, is called the Reverberation time. Measuring 60 dB decay in a real environment is usually not feasible as the sound becomes inaudible, therefore instead 30 dB (T30) or 20 dB decay (T20) is used to measure reverberation time and then extrapolated to T60. [31] The extrapolation is automatically done by most of the sound level meters today and presented in terms of T20 and T30. The decay curve of a sound in a room and the measurement of reverberation time can be seen in Figure 1. [29]

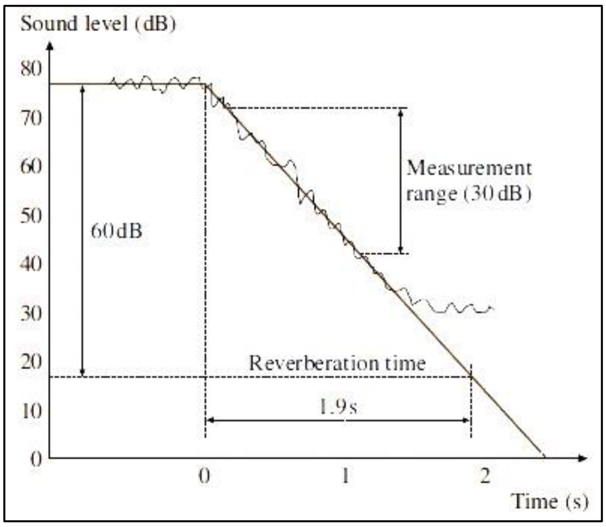

Figure 1 Reverberation Time decay curve [29]

Reverberation time can be predicted by Sabine's formula given in Equation 4 below, where V is the volume of the room (m^3); S is the total surface area of the room (m^2); α is the room absorption and m is the atmospheric absorption (Np/m).

$$T30 = 0.161\left(\frac{V}{\Sigma Si\alpha i + 4mV}\right)$$

Equation 4 [30]

Early Decay Time is defined as the time it takes a sound to decay 10 dB from its initial level, extrapolated to a decay of 60 dB. EDT has found to be more related to the subjective perception of "Reverberance" since reverberation time considers the later part of the decay where the later components of sound is masked during a speech or a performance [29] whereas T30 has found to be more correlated with the physical features [32], but this is not always the case for small sized music rooms. [33]

2.2.1.2. Sound Strength (G) and Loudness

Sound Strength (G, dB) is defined as the difference of the sound level of a source measured in a room to the level of the same source measured in a free field at a distance of 10 m. It is correlated to the subjective perception of "Loudness". Equation 5 shows the formula to measure Sound Strength (G) from measured impulse responses as given in ISO 3382-1 where $P(t)$ is the instantaneous sound pressure of the impulse response measured at the measurement point; $P_{10}(t)$ is the instantaneous sound pressure of the impulse response measured at a distance of 10 m in a free field, L_{pE} and $L_{pE,10}$ are the sound pressure exposure levels of $P(t)$ and $P_{10}(t)$, respectively. [32, p.13]

$$G = 10 \times \log_{10} \frac{\int_0^\infty p^2(t)\,dt}{\int_0^\infty p_{10}^2(t)\,dt}\,\text{dB} = L_{pE} - L_{pE,10}$$

Equation 5 [32]

A valid prediction equation, see Equation 6, can be used for the calculation of expected G, according to Sabine's diffuse field theory [29] where T denotes reverberation time and V denotes the volume of the room. As seen from the formula loudness in a room is inversely proportional to the volume and directly proportional to the reverberation time.

$$G_{exp} = 10 \log_{10}\left(\frac{T}{V}\right) + 45\,\text{dB}$$

Equation 6 [29]

2.2.1.3. Clarity Index (C80) and Clarity; D50 and Definition

Clarity is defined as the degree to separate each variation in a sound. [30] The listener can distinguish the changes in a sound when reflections reach the listener in the first 50-80 milliseconds after the initial direct sound. [29] C80, is the objective parameter that measures the ratio of the energy in the impulse response of the first 80 milliseconds to the energy after 80 milliseconds and is related to the perception of Clarity in music. Clarity Index can be predicted by Equation 7 where C_{te} (dB) is the early to late index, t_e is the early time limit (80 ms for C80, 50 ms for C50) and $P(t)$ is the instantaneous sound pressure of the impulse response measured at the measurement point.

$$C_{t_e} = 10 \times \log \frac{\int_0^{t_e} p^2(t)\,\mathrm{d}t}{\int_{t_e}^{\infty} p^2(t)\,\mathrm{d}t}$$

Equation 7 [32]

A valid prediction equation can be used for the calculation of expected Clarity Index (Cexp, dB), as given in Equation 8, as a function of reverberation time (T).

$$C_{\exp} = 10\log_{10}\left[\exp\left(\frac{1.104}{T}\right) - 1\right]$$

Equation 8 [29]

For music, the choice of the time constraint for determining early and late energy components of an impulse response regarding the 50 ms or the 80 ms periods depends on factors such as music style, composition, rhythm and the type of the instrument. [34]

2.2.1.4. Frequency Bands

Objective acoustic parameters mentioned above should be addressed to a specific frequency or a frequency range since the results are frequency dependent. Frequency components of a sound can be analyzed by creating bands with constant bandwidths from individual frequencies using different methods depending on the aim of analysis.

Constant percentage bandwidth method is one of the mainly used methods. In this method the bandwidth is the constant percentage of a center frequency such as in octave bands which cover frequencies that the upper center frequency is two times of the lower center frequency or as in third octave bands which divides an octave band in three narrower bands. [35]

For room acoustic analysis, Gade [29] suggests the use of octave bands since human perception of a sound is correlated better with octave bands and our ears are not sensitive to extreme variations occurred in narrower bands. Furthermore he suggests to measure and examine room objective parameters for seven center frequencies 63Hz; 125Hz, 250Hz, 500Hz, 1kHz, 2kHz and 4kHz.

2.2.2. Design Parameters for Music Practice Rooms

Practicing is crucial for musicians as the main way they can learn and develop their skills . According to Lamberty [36] weekly use of practice rooms in music schools by music students can reach 40 hours, which proves the importance of these spaces. A practice room can be used by several different instrumentalists from a singer to a bass player, each requiring different acoustic needs, therefore should be designed considering the users of the room.

While designing a small practice room the parameters that are mostly considered can be summarized as: volume, absorption, background noise levels, sound insulation, geometry and flutter echoes.

Reverberation time as mentioned in the previous section is the key parameter in room acoustics design and is directly proportional to the room volume (V) and inversely proportional to the total absorption area of the room. Long reverberation times in smaller volumes, such as in small practice rooms for music, might result in excessive sound levels leading to hearing problems.[37] Therefore rooms should be carefully designed with appropriate volume and absorption considering the number of the users; the sound levels of the instruments to enable the musician practice for long hours efficiently.

Another important design criteria is the sound insulation of these facilities. According to Lamberty's research [36] one of the main problems that the music students face is the background noise levels inside practice rooms due to noise from adjacent practice rooms and the traffic noise coming through the façades. His results show that the musicians can be distracted when the same instrument is played in the adjacent room; therefore he suggested different locations for practice rooms for the same type of instrument.

Geometry of a room shall be considered together with the treatment of the room surfaces since poor geometry and insufficient surface treatments might cause unwanted sounds e.g. flutter echoes which can result in an annoying ringing/buzzing sound.[38] This can be prevented by using absorptive or by using diffusive materials on opposing room surfaces.

Similar to vocal tract and its resonant frequencies which are called formants, rooms have their resonant frequencies called room modes. Room modes create unbalanced frequency responses in small rooms therefore several room dimension ratios based on the smallest length have been proposed to avoid this problem. [39] Room modes will not be discussed in detail, however suggestions for room dimension ratios will be given to enable comparison with the dimensions of the RAM Practice rooms and singer's preferences of the room volumes.

2.2.3. Relevant Standards and Guides: Recommended Values for Acoustic and Design Parameters for Music Practice Rooms

Relevant standards and guidance in literature regarding the acoustic and design parameters of practice rooms for music function are summarized below.

2.2.3.1. Building Bulletin 93 (BB93), Acoustic Design of Schools: performance standards (2015)

BB93[40] first published in 2003 and last published in 2014 with the latest update in 2015, is an acoustic design guide to define minimum acoustic performance standards regarding indoor ambient noise levels, airborne and impact sound insulation and reverberation time for both new-built and refurbished education buildings in the UK. It sets out acoustic criteria for rooms for education purposes including music rooms such as ensemble rooms, recording studios, small and large practice rooms. The aim of the standard is to create intelligible, acoustically healthy learning environments both for students as well as teachers.

The maximum permissible indoor ambient noise levels for large and small practice rooms in a new-built facility is set out as 35dB $L_{Aeq,30min}$ and as 40dB $L_{Aeq,30min}$ for a refurbished room. The reverberation time criteria is given for the T_{mf}, which is the arithmetic average of reverberation times in the 500 Hz, 1 kHz and 2 kHz octave bands. Reverberation time recommended for practice rooms with a volume of maximum 30 m^3 in a new-built facility is $\leq$ 0.6 s, where as it is $\leq$ 0.8 s for a refurbished facility. For larger practice rooms the recommended values are $\leq$ 0.8 s and $\leq$ 1.0 s respectively.

Typical floor area for a practice room/group room is given as 8 m^2 and 25 m^2 for an ensemble room with a requirement of minimum 3m height [37] for both type of rooms. In small rooms, it is recommended to avoid same dimensions for width; length or height as it causes more discrete room modes resulting in a coloured and unbalanced sound; therefore square; hexagonal or octagonal geometries should not be considered in design. The Golden ratio of 1.25:1.6:1 is recommended for the room geometry.

2.2.3.2. Music accommodation in secondary schools, A design guide (2010)

The Music accommodation in secondary schools: A design guide [41] specifically defines acoustic performance criteria for rooms for music function in secondary schools. Practice rooms are considered as group rooms for individual or group practicing and the design criteria is defined regarding the surface finishes, room geometry and size together with indoor ambient noise levels, sound insulation and reverberation time.

According to the guidance a group room shall have a minimum of 8 m^2 floor area for a group of five or more musicians depending on the instrument size; 12-15m^2 floor area is defined as intermediate sized group room where as 20-25m^2 floor area is defined as a large group room or an ensemble room. The minimum room height recommended is 2.7m, but 3.0m shall be preferred for the large group rooms according to the guidance.

For the maximum indoor ambient noise levels the guidance recommends 35dB $L_{Aeq,30min}$ for group rooms (small practice rooms in BB93,2003) and 30dB $L_{Aeq,30min}$ for large group rooms (ensemble rooms in BB93,2003) giving reference to BB93[37] published in 2003. As stated in BB93, in this guidance as well, it is recommended to avoid same dimensions for width; length or height. The recommended reverberation time (T_{mf}) for a group room is less than 0.8 s. giving reference to BB93 [37] published in 2003. The recommended ambient noise levels and reverberation times in this guidance which refer to BB93 published in 2003 has slight differences with the latest BB93.

2.2.3.3. Acoustics of schools: a design guide (November 2015)

Produced by the Institute of Acoustics and the Association of Noise Consultants, this is an additional guidance to support designers on achieving design criteria defined in BB93 published in 2014, for new and refurbished education buildings. [42, 43] The acoustic design criteria for music rooms are referenced to BB93 published in 2014, which are in accordance with the latest update in 2015, setting out the same limits mentioned in Section 2.2.3.1.

2.2.3.4. ANSI/ASA S12.60: 2010 – Part 1

American National Standard Acoustical Performance Criteria, Design Requirements, and Guidelines for Schools [44] is an American standard that defines the acoustic performance criteria for education buildings. It consists of two series Part 1 and Part 2; where the first one defines criteria for permanent education facilities and the later one defines criteria for the relocatable education facilities. Music rooms for teaching and for practice are defined as "Core learning spaces" in Part-1. Music rooms are not mentioned in Part-2 in the definition of "Core learning spaces", therefore only Part-1 is taken into consideration.

The acoustic criteria limits are defined due to the volume and function of the spaces. The function is grouped for "Core learning spaces" which are main areas for teaching and learning such as classrooms, libraries, offices, music rooms and for ancillary learning spaces which are social learning areas rather than formal learning such as cafeterias, gymnasia and relocatable classrooms which can be moved to other places keeping all the structure as it is. Practice rooms for music function are grouped in the "Core learning spaces." For volume (V) of these spaces the acoustic criteria are defined for the following limits: $V \leq 283$ m^3; 283 m^3 < $V \leq 566$ m^3 or 566 m^3 < V.

According to this standard, a practice room falls into the core learning space category with enclosed volume of $V \leq 283$ m^3. The maximum limit for background noise level is given as 35 dB $L_{Aeq,1h}$ and the maximum limit for reverberation time is given as 0.6 s with an advice that the space shall be available for additional sound absorption to reduce the reverberation time to 0.3 s when needed.

2.2.3.5. Norwegian Standard: NS 8178: 2014, Acoustic criteria for rooms and spaces for music rehearsal and performance

Another standard that addresses the acoustic criteria for music rehearsal and performance spaces is the Norwegian Standard [45] published in 2014: Acoustic criteria for rooms and spaces for music rehearsal and performance. This standard focuses on spaces for music function such as practice and rehearsal rooms. The standard also states that it can be used for multi-purpose rooms. The acoustic criteria given in the standard focuses on the type of music rather than the type of building, as in BB93. This standard addresses the acoustic requirements of rooms by grouping music according to the sound power levels of instruments, number of the musicians that will use the room and according to whether the music is acoustical or amplified. For instance, pop and rock music are classified as

“Amplified music”; opera singing is classified as “Acoustical loud music", and vocal ensembles or choirs are classified as “Acoustical quiet music”. Since this research focuses on Opera singing only the criteria given for “Acoustical loud music” will be explained. The standard defines “Acoustical loud music” as the music produced by powerful instruments. The consideration should be given to room size; room height; reverberation times; sound strength depending on the sound power levels and control of flutter echoes. Practice rooms for acoustical loud music shall accommodate maximum two musicians, with a minimum net floor area of $15m^2$; room height of 2.7m and room volume of $40m^3$.

For ambient noise levels, the standard references another Norwegian Standard: NS8175: 2012 [46] which classifies sound quality in the room from Class A to Class D due to indoor sound levels from outdoor sound sources when the rooms are in use. According to the standard, in order to achieve each rating from Class A to Class D, the noise levels should not exceed 24 dB, 27 dB, 30 dB and 34 dB $L_{p,A,T}$ respectively. The reverberation time criteria is given in terms of T_m, the arithmetic average of reverberation times at 500 Hz and 1kHz octave bands, which varies according to the room volume and type of music. In addition, the standard states that it is necessary to provide appropriate reverberation times for each octave band from 63Hz to 4kHz, therefore introduces a factor: $\frac{T}{T\mathrm{m}}$ that is calculated by dividing the reverberation time at each octave band (T) by the average reverberation time of the 500Hz and 1kHz octave bands (T_m). The upper and lower limits for this factor are defined for each octave band in the standard for each type of music. The standard also highlights the importance of appropriate sound strength for the type of the instrument and the number of musicians and states that the high levels might cause hearing damage, whereas low levels might make the music lose its intensity; therefore the standard considers room size, reverberation time and strength parameters together.

2.3. Room Acoustics and User Performance

This section aims to present the relevant literature on room acoustics and the user performance regarding vocal loading. Despite the differences of performances; whether it’s a vocal (speech or singing) or an instrumental performance, the literature given below is relevant to the aim of this research as they show the interaction between the room and the performer considering the performer’s subjective and/or objective results due to changes in the room acoustics.

Brunskog [47] has investigated the change in speaker’s voice levels depending on different room acoustic conditions using different sized lecture rooms with different acoustic properties. Sound power levels of six speakers were measured in six different rooms. After objective measurements, the subjects were given a questionnaire to evaluate each room to get their subjective responses. The results showed no correlation between voice power level and reverberation time or background noise, whilst a significant correlation was found between voice power level, room gain and volume.

Pekkarinen & Viljanen [48] found that the increase of reverberation time increases vocal effort due to lack of intelligibility in classrooms as the voice levels of the teachers showed an increase, whereas Södersten et al. [49], in his studies examined the effect of background noise levels on 10 pre-school teachers working in day care centers and found out that high background noise levels lead to an increase in the sound pressure levels and the fundamental frequency of the teachers which lead to high vocal loading.

Ahlander [50] investigated the effects of room acoustics on the vocal loading of two groups: teachers with self-assessed vocal problems and without vocal problems (N=487). The measurements took place both in the clinical environment and in the real working environment. The site measurements for vocal doses of teachers were measured using APM for one working day to enable comparison between the vocal doses of healthy and unhealthy teachers. The monitoring took place in several rooms with different volumes: small classrooms ($V < 100\ m^3$), medium-size classrooms ($100\ m^3 < V < 500\ m^3$) and sport halls ($V > 3500\ m^3$). Acoustic measurements of each room such as reverberation time, background noise levels, and sound strength were undertaken when the rooms were unoccupied. The results showed an increase in vocal loading with the increasing background noise levels for both groups; but the vocally unhealthy group were more affected by the changes in the acoustic environment. The results showed difference between two groups in the real environment, but no difference in the clinical environment concluding that the voice users are affected by their environment and the vocal problems might increase due to the environment.

Gade [51, 52] in his studies investigated the effect of different room acoustics on musicians by asking the musicians to play in different simulated sound fields in an anechoic chamber, then he continued his research in real concert hall conditions. The results showed that the instrumentalist's performance was correlated with the objective measure of room support.

Bekesy cited by Meyer [53, p.361] undertook a research with a well-trained pianist. He asked the pianist to play the same musical piece in rooms with different absorption and measured the vibration amplitudes of the piano for a comparison to see the adaptation of the pianist to the room acoustic conditions. He found out that the amplitude increased with the decrease in reverberation time.

Olsson and Wahrolen [54] examined the perception of sound for trumpet players in acoustically different practice rooms in order to find the correlation between room acoustic parameters and the musicians' subjective parameters in small rooms. Room measurements were undertaken whilst the rooms were unoccupied; sound levels at players ears were measured binaurally and a nine-point Likert scale questionnaire was used to rate the perception of the players of the rooms. Nine trumpet players played in two different sized practice rooms with two different absorption arrangements using folded and unfolded drapes. The authors found that the practice room size does not affect the perceived sound level of trumpet players but the absorption does affect the level. In addition, they have found that regardless of the differences in measured sound strength (G_{mid}) of each room condition, a small variation was found in measured levels on the players' ears (1-2 dBA) but the players' ratings of sound levels varied significantly between the rooms. The authors explain the reason for the small variation at players' ears as the result of adjusting their performance according to rooms. Another finding of the research is that C80 was found to be highly correlated with the perception of the trumpet players regarding perceived room support. On the other hand, perceived sound level was found to be correlated with Bass Ratio rather than the G_{mid}. G_{mid} was also found to be correlated with the overall impression of the rooms.

Kato et al.[55] investigated the performance adaptation of five musicians including a violinist, two flutists, an oboist and a Baritone opera singer by examining the changes in the sound signals due to change in room acoustic conditions. For the experiment, an anechoic chamber, a simulated small, medium, large hall and a simulated church were used and the signals were recorded close to the instrument or to the mouth of the singer whilst the musicians played imagining they were playing on real stage. The study examined the variation in music tempo for each piece, fundamental frequency vibrato rate, fundamental frequency vibrato extent, intensity vibrato extent, and A-weighted sound pressure level. Statistically significant variations were found between each condition for variable parameters for each musician; for the Baritone opera singer significant differences were found for tempo of the piece in the church condition; fundamental frequency vibrato extent showed significant difference for the anechoic chamber condition and for the church condition whereas no difference was observed between hall conditions. In addition, no variation was found for sound pressure level or the vibrato rate. In addition the opera singer also stated that he did not consciously adapt his singing to the acoustic conditions of the room except for the music tempo. Therefore the author concluded that the musicians might subconsciously adapt their performance.

The French scientist Raoul Husson cited by Hom [56, p.31] investigated the effect of increasing reverberation time on the perception of singer's effort. His findings showed that the singer's perception of their singing effort was minimum when the reverberation time was between three to six seconds, with the optimal close to four seconds.

Hom [56] conducted research on subjective and objective measures of alto, soprano, tenor, and bass choir singers in two acoustically different spaces: a choir rehearsal room and a performance hall. She recorded the choir singing the same piece in each room analysing the results using two methods: third-octave bands and long-term average spectrum (LTAS) for the spectral analysis of the total voicing; which according to Ternström cited by Hom [56, p.14] is a method to average the intensity and frequency properties of the voice over time. The results for the choir's spectral change of the sound pressure level showed a significant increase in the more reverberant room. An interesting finding of her results on the spectral change of sound pressure level of the choir is that difference is observed in the singer's formant region 2-4 kHz (for LTAS results) and in the singer's fundamental frequency region 80-125 Hz (for one-third octave band results). She also surveyed each singer individually using the following questions: perception of individual singing effort; perception of choir singing effort; perception of hearing their own voice and perception of hearing others. Singers (N=11) replied the questions on a 7-point Likert-type scale: 1 indicating "with much less effort than normal", 4 indicating "with normal effort", and 7 indicating "with much more effort than normal". The results of the perception of individual and choir singing effort showed a slight but not a significant increase in the performance hall compared to the rehearsal room; results for singers' perception of hearing their own voice on the other hand showed a significant increase in the performance hall, whereas singers' perception of hearing other choristers was slightly more in the rehearsal room compared to the performance hall but difference was not significant.

Skirlis et al. [57] investigated the change of vocal effort due to imaginary room size using N=8 opera singers. Two recordings were made with each singer in an anechoic chamber; asking the singers to sing as if they are singing in a small hall and then to sing as if they are in a large hall. The analyses were made considering the spectral and temporal changes between the two recordings. The results showed higher sound pressure levels (2-3 dB difference) in the 1 kHz-4 kHz region and shorter singing duration (3.3% difference) in the large imaginary condition compared to the small one.

Sinal and Yılmazer [58] conducted a subjective survey research on the singing effort and preferences of 30 classical singers due to change in reverberation time with an aim to find the optimal reverberation time for the classical singers in practice rooms. Three practice room settings were created for a 128 m^3 (L x W x H: 7.3m x 5.4m x 3.2m) practice room. Room acoustic parameters were measured using simulation software and the room settings were changed accordingly to achieve T_{mf} of 0.6 s, 0.8 s and 1s. Singers were asked to sing in each setting and then were asked to evaluate rooms via questionnaires regarding their singing effort and their room preferences. The singers' overall room experience showed a higher preference for the most reverberant room (1 s), but their results for the best room to practice in was found to be the room with T_{mf} of 0.8s. The authors concluded that the reason for this preference was that the singers required some effort to amplify their voices. Further analysis by grouping singers as either professional (N=13) and amateur (N=17) showed that the more experienced ones preferred less live conditions.

Cabrera et al. [59] investigated the effect of room acoustics on the singing directivity of opera singers (N=6 males, N=2 females). The singers were asked to sing in three rooms: in an anechoic chamber, reverberant chamber and in a recital hall. The same piece was sung by all the singers four times: considering intonation, considering emotion of the piece, singing as if they are in performance, singing imagining they are in a large and then in a small hall.

The results showed that directivity is controlled by the singer due to change in the environment via adapting their spectral properties of their voices to the environment, the directivity was greater for the large hall condition compared to the small one. Another result of the research showed that the directivity of the singer's voice was greater at the singer's formant regions: 2-4 kHz.

Osman [60] in his paper addressed the design requirements of music practice rooms considering room modes; reverberation times; size and proportions of the rooms. He has compared several recommendations given in standards for reverberation times, background noise levels, and ratios for room dimensions. He underlines the importance of considering the instrument type while designing the practice room as different instruments will have different sound power levels and frequency ranges which would require different treatments for the rooms. While applying absorption in the rooms in order to achieve the target reverberation time, he recommends that the reverberation time for 250Hz, 500Hz, 1kHz and 2kHz octave bands are kept within the 10% of the target value with an additional advice that a higher reverberation time at 125Hz compared to the target reverberation time might be acceptable, but a lower value should be avoided whereas for 4kHz octave band a lower value is acceptable but a higher value should be avoided. Since the practice rooms mainly are rectangular in shape with parallel walls he also recommends absorptive and diffusive elements on the walls to avoid room modes and flutter echoes.

Hatlevik [61] investigated the effects of room acoustics on musicians' adaptation through examining the changes in the sound pressure levels of their instrument in four acoustically different rehearsal rooms with volumes of 13.3 m^3, 15.4 m^3, 39.29 m^3, and 58.5 m^3 and with reverberation times of 0.26 s, 0.32 s, 0.75 s, and 1.18 s respectively. Three tasks were given for a total of N=6 singers to repeat in each room: singing, playing the guitar, singing, and playing the guitar at the same time. Recordings were made using microphones placed on the ears and on the nose of the musician and on the guitar in order to measure the sound pressure levels at the ears, at the mouth, and at the guitar. Room measurements were taken regarding reverberation time, early decay time, clarity, strength, and definition. The results showed individual differences on the adaptation of the musicians. The author concluded that the musicians were affected differently by different room parameters: most effective parameter being the reverberation time and the least being the strength.

2.4. Conclusion

The literature review showed that, there have been several research papers on the interaction between an individual's performance and the environment, specifically on the relationship between either two or all of the three following parameters: room parameters and subject's objective and subjective parameters.

Similar studies on room acoustics and user performance were found in the speech literature. They examined the relationship between room acoustics and user's objective voice dosimetry and the subjective parameters altogether with an aim to improve the acoustics of the environment for its' users.

Research on singers on the other hand, have developed methodologies mainly for the clinical practice by either examining voice at the voice clinics or by monitoring the subject's vocal behaviours in field by using accelerometers examining the change in the voice dosimetry parameters of the singers due changes in performance type, rest and singing periods with an aim to find the reasons and cure for voice disorders.

Although there are several research papers on Opera singers, it was found that there's no research in the literature that focus on the interaction between Opera singers and small practice rooms ($\leq$ 50 m^3) through examining voice dosimetry parameters, subjective parameters and room parameters at the same time. This research would aim to suggest preferred practice room conditions for the Opera singers.

One consistent weakness in the previous research was the limited number of singers used in the surveys and measurements. It is hoped that at least 100 trained Opera singers will take part in the experiments.

The knowledge gained from the literature review also provided detailed information on methodology. This will help to form a methodology for the current research such as choosing the right equipment to monitor voice dosimetry of the singers and creating a questionnaire that is appropriate for the aim of the research.

Despite the frequent use of Ambulatory Phonation Monitor (APM) for speech monitoring, research undertaken by Scholoneger [26], Paolillo and Fussi [27], Gaskill et al. [28], Ahlander [50] showed that the device is also used to monitor the singing voice, therefore in order to measure singers' voice dosimetry parameters APM will be selected instrumentation for the voice dosimetry collection.

Questionnaires from Brunskog's [47] study which was developed to find out the correlation between teachers subjective evaluation of classrooms and their measured voice power levels; Hom's [56] study which was developed to find out singers' perception of acoustically two different environments which consists of a performance hall and a rehearsal room and Olsson & Wahloren's [54] study which was developed to investigate the perception of trumpet players to find out the correlation between subjective and objective room parameters in acoustically different practice rooms were examined as an inspiration.

In addition, the relevant standards found in literature for practice rooms also enabled comparison with the suggested criteria for room acoustic parameters in the standards to the results of this research

3. CHAPTER 3: METHODOLOGY

In this chapter the equipment, rooms, subjects; data collection methods and statistical analysis used in the research will be described.

3.1. Equipment

3.1.1. Ambulatory Phonation Monitor (APM)

For the purpose of the study, Ambulatory Phonation Monitor (APM) by KAYPENTAX was used. The device is composed of an accelerometer, which detects the vocal fold vibrations. On one side the accelerometer is attached to the glottis of the subject to where the vocal folds are located by medical glue and on the other side is connected to the data unit by a cable. The device was developed for voice clinics to monitor the daily vocal behaviours of patients in order to determine the reasons of vocal fatigue. For this research, it is used to track the difference in vocal dosimetry data of the subjects in acoustically different environments. The device provides data only for vocal parameters via vocal fold vibrations, which eliminates any other possible intrusive data such as background noise or reverberation. APM includes software which enables uploading and reporting the measured data to a computer after the measurement which includes Phonation time percentage (P_t, %), Sound pressure level (SPL, dB), Frequency (F0average and F0mode, Hz), Cycle Dose (D_c) and Distance dose (D_d, meters). Figure 2 is an example of a singer's vocal dosimetry data shown on the APM software screen which is uploaded after the measurements.

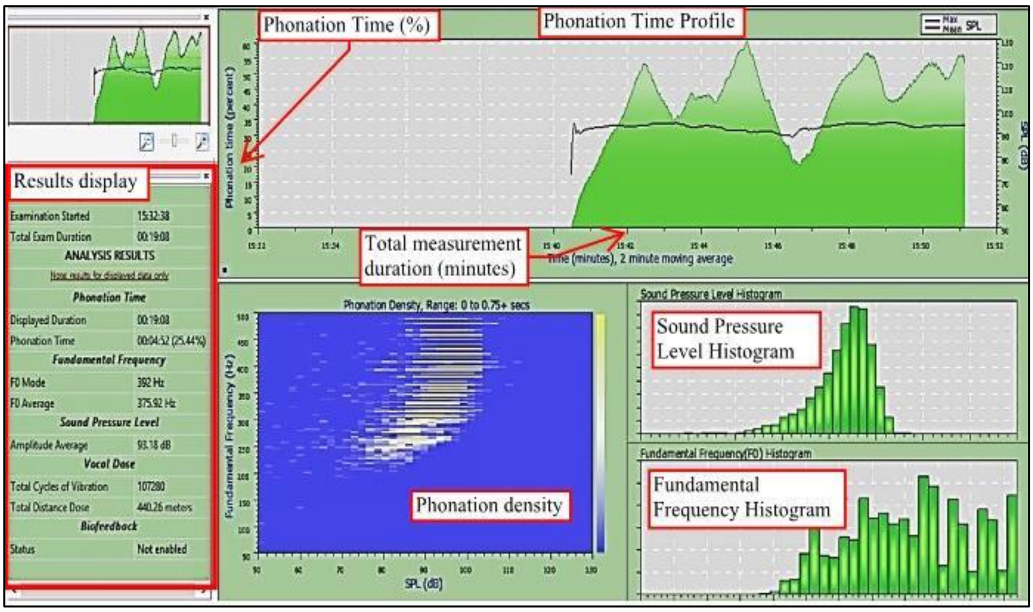

Figure 2 APM software screen, example of a singer's phonation data.

3.1.2. Hemi-dodec sound source with a powered amplifier

Room acoustic parameters were measured using the exponential swept sine (e-sweep) technique using the WINMLS software. A laptop connected to a Norsonic (Nor280) power amplifier linked to a Norsonic (Nor275) hemi-dodecahedron loudspeaker and an Earthworks M30BX class 1 microphone was used.

3.1.3. Sound Level Meter (SLM)

A Class 1, Norsonic 140 sound level meter was used in order to measure background noise levels in each room. It was in calibration and was regularly calibrated using a Class 1 calibrator. It is also used for measuring sound pressure levels of singers in order to calculate sound power levels of singers.

3.2. Measurement Site and Rooms

The measurements were held in two main premises:

- London South Bank University Acoustic Laboratories (Laboratory phase)
- Royal Academy of Music (Field stage)

3.2.1. London South Bank University (LSBU) Acoustic Laboratories

The laboratory phase was undertaken at the acoustic laboratories at London South Bank University. Reverberant, Semi-reverberant, and Anechoic chambers were used for the laboratory phase of the research. Details of each chamber are given below; the layouts of the chambers can be found in Appendix A.

Reverberant chamber is a 202.7 m^3 volume space composed of hard, reflective parallel walls, reflective ceiling, and a reflective concrete floor. The Reverberant chamber changes into a Semi-reverberant chamber when a 10 m^2 absorptive panel composed of 0.25 m deep Rockwool is exposed. The dimensions of the space are 7.6 m x 6.35 m x 4.2 m (L x W x H).

Anechoic chamber is a 202.7 m^3 space composed of 0.75 m deep foam wedges on the walls, ceiling and the floor. Together with the foams the volume of the usable space is 87.4m^3. The chamber is designed to be fully absorptive at frequencies greater than 125 Hz. The dimensions of the usable space are 5.2 m x 4.8 m x 3.5 m (L x W x H).Chamber dimensions are summarized in below Table 1.

Table 1 Dimensions of LSBU acoustic chambers

LSBU Chambers	Length (m)	Width (m)	Height (m)	Volume (m^3)
Anechoic	5.2 m	4.8 m	3.5 m	202.7 m^3 (87.4 m^3 usable space)
Semi reverberant	7.6 m	6.35 m	4.2 m	202.7 m^3
Reverberant	7.6 m	6.35 m	4.2 m	202.7 m^3

3.2.2. Royal Academy of Music (RAM): Practice Rooms

The field stage of the research was undertaken at the Royal Academy of Music between 2013-15. Four acoustically different practice rooms regularly used by the Opera singers were assigned for the research by the academy staff. The layouts of the rooms can be found in Appendix B.

3.2.2.1. York Gate (YG) room

The room is located on the second floor of the York Gate building at RAM. It is a 35.12 m^3 room with painted plasterboard ceiling, painted plasterboard walls, and a thin carpet floor. The furniture in the room consists of a piano, a piano seat, a music stand, and a chair.

3.2.2.2. Lower Ground (LG) room

The room is located on the lower ground floor of the main building at RAM. It is a 14.53m^3 room with painted plasterboard ceiling, painted plasterboard walls, two acoustic wall panels, and a thin carpet floor. The furniture in the room consists of a piano, a piano seat, and a music stand.

3.2.2.3. Dressing (DR) room

The room is located behind Sir Jack Lyons theatre at RAM and is used as a dressing room as well as a daily practice room. It is a 19.5m^3 room with painted plasterboard ceiling, painted plasterboard walls, two acoustic wall panels, and a thin carpet floor. The furniture in the room consists of a piano, a piano seat, and a music stand.

3.2.2.4. T room

The room is located on the third floor of the main building at RAM. It is a 13.94m^3 room with acoustic ceiling, fabric walls, and a carpet floor. The furniture in the room consists of a piano, a piano seat, and a music stand.

Dimensions of RAM practice rooms are summarised in Table 2 below. (Note that the rooms have complex geometries so equivalent rectangular dimensions are provided.)

Table 2 Equivalent rectangular dimensions of RAM music practice rooms

RAM Practice rooms	Length (m)	Width (m)	Height (m)	Volume (m^3)
YG room	5.55	2.19	2.67	35.12
LG room	2.71	2.22	2.42	14.53
DR room	4.35	1.97	2.28	19.5
T room	3.40	1.85	2.22	13.94

3.3. Subjects

The research was undertaken with the voluntary assistance of N=117semi-professional student opera singers from the Royal Academy of Music. The students were between 18-34 years of age range with a minimum of four years singing background, none of the students had any known vocal disorder during the time of the measurements. Data was collected from five different voice types: Soprano, Mezzo-soprano for female; Tenor, Counter-tenor, and Baritone for male voices. Singer profiles will be explained in more detail together with the research stages in the data collection section.

3.4. Statistical Methods

The measurement results were analysed using IBM SPSS Statistics 21. Below are brief descriptions of the statistical methods used throughout the research.

3.4.1. Descriptive statistics

This is a statistical methodology which defines the characteristics of the collected data. It is used to obtain frequency distributions of the categorical data such as subjects' age, gender, voice type etc. whereas for continuous (numeric) data it is used to obtain means, standard deviations, minimum and maximum values.

3.4.2. Correlation Analysis

Correlation analysis is a statistical methodology in order to find the relationship between variables. It is used to explore the significance degree of the correlation and the direction of the correlation between two variables. For the research, the relationship between two continuous variables has been analysed using Pearson product-moment correlation coefficient (r), which varies between -1 and +1, where – indicates negative relationship and + indicates positive relationship between variables. The closer the value to 1 means the stronger the correlation is since 1 indicates perfect correlation and 0 indicates no correlation. In addition, statistical significance level (p-value) was considered in correlation analysis where $p < 0.05$ indicates there's a statistically significant correlation between variables and $p < 0.01$ indicates there's a highly significant correlation between variables, 95% and 99% confidence, respectively.

3.4.3. One-way Analysis of Variance (ANOVA tests)

This is a statistical method in order to explore whether there's a difference in the results of at least three conditions using one independent variable, it analyses the variance in the data and the means of each group. ANOVA tests can be conducted for repeated measures and between groups, where the first one is for the cases when the subjects are the same and the conditions are different, and the second one is for the cases when the subjects are different but the conditions are same.

For the research, one-way repeated ANOVA tests were used in order to see whether there's any difference in same singers' objective and subjective data results collected in acoustically different environments, and one-way between groups ANOVA test was used in order to compare the results of the first laboratory stage to the second laboratory stage which were undertaken with different singers in the same environments.

3.4.4. Bonferroni Post-hoc tests

Although ANOVA test shows whether there's any difference in the results of different conditions or groups, it doesn't show where or which groups the difference is observed. The Bonferroni Post-hoc test is used in order to explore which groups show which difference. For the research, the groups that show difference according to ANOVA tests were identified by using Bonferroni Post-hoc tests.

3.4.5. Regression Analysis

Regression analysis is a statistical prediction method that is used to find out the relationship between a dependent variable and an independent variable. The analysis provides a prediction model which can be used to predict the unknown value from the known value. This methodology was used in order to predict the values of room parameters which correspond to singers' preferred ratings of the subjective parameters.

A summary of the statistical methods used for each stage of the research are given below in **Error! Not a valid bookmark self-reference.**.

Table 3 Statistical methods used for the research stages

Research Stages	Data analysed	Used statistical method
Laboratory stages (LSBU Chambers)	About you Questionnaire	Descriptive Statistics
	Room Questionnaire	One-way repeated measures Anova
		One-way between groups Anova
Field Stage (RAM practice rooms)	About you Questionnaire	Descriptive Statistics
	Room Questionnaire	One-way repeated measures Anova
	Singers' preferred ratings	Descriptive Statistics
	Voice Dosimetry via APM	One-way repeated measures Anova
	Voice Dosimetry via SLM	One-way repeated measures Anova
	Correlation between room questionnaire parameters(subjective data) and measured room acoustic parameters (objective data)	Pearson product-moment correlation coefficient (r)
	Prediction of room parameter values that correspond to singers' preferred ratings	Regression analysis

3.5. Ethical Compliance

Ethical considerations regarding test subjects participation, the store and use of the data collected, possible allergic reactions, and consent were all addressed in the Ethical Approval Document, UREC 1333. The Ethical Approval Document and the Consent form can be found in Appendix C.

3.5.1. Data collection

The data collection for each singer including calibration and removal of the APM; questionnaire completion; voice dosimetry measurements and the time spent to change the rooms took approximately 45 minutes at the first laboratory phase; and about 50minutes in the second laboratory phase and approximately 65 minutes in the field stage. For vocal dosimetry data collection, the APM is attached on the singer's neck while carrying the data unit in a small bag during the measurements. This sometimes can cause tiredness to the singer. All procedures were explained to the singers in detail, and they were informed that they could quit from the measurements any time. A consent form has been signed by each subject volunteering the research. The data was securely stored on university premises.

For daily dosimetry measurements the data collection of each singer took between one to eight hours depending on their daily schedule which involves singers' daily lessons. For these measurements teachers were also informed and their permission sought prior to the measurements to prevent any disruption to the class or to the teacher.

3.5.2. Allergy considerations

APM device is attached to the subject's skin by medical glue and detached at the end of the measurements by a disposable medical adhesive remover, a biologically neutral liquid. The accelerometer is then cleaned by medical alcohol after each measurement before attaching to another subject.

3.5.3. Data protection

Data is protected by the researcher in a secure laptop, only accessible by the researcher and the supervisor. The duration of storage was set to 5 years. An application for ethical approval was submitted in May 2013 and following correspondence with the ethics committee approval was granted in May 2014 (reference UREC 1333). A copy of the ethical approval letter is contained in Appendix C.

3.6. Room Data Collection

In this section the measurements regarding room acoustic parameters will be explained. Room acoustic parameters obtained for the LSBU acoustic chambers were not used for further analysis between room parameters and the singer's data as these rooms do not resemble a real practice room environment, but the room data was measured in order to show the acoustic properties of these chambers as extreme environments to demonstrate the data collection methodology for the Field stage. The parameters obtained via room acoustic measurements undertaken at the Royal Academy of Music practice rooms were further analysed in order to find out the correlation between the room acoustic parameters and the singers' parameters.

3.6.1. Room Acoustic Measurements

Room acoustic measurements of the LSBU chambers and the RAM practice rooms were undertaken using the exponential swept sine (e-sweep) technique, see section 3.1.2, and see Figure 3.

Figure 3 WINMLS measurement

Measurements were undertaken when the rooms when unoccupied at two source (S1, S2) and four receiver (R1, R2, R3, R4) points in all three chambers; YG, DR and T rooms and at two source and three receiver positions in LG room as the room was not big enough for another receiver position. The minimum source-receiver distance was kept at 1.5 m whilst the minimum distance from room surfaces was kept at a minimum of 0.5 m distance according to ISO 140-4:1998 since the room sizes of practice rooms were small, see Table 2 in Section 3.2.2. The receiver height was kept at 1.5 m. Data measured at each source-receiver combination were then averaged for each space. The source-receiver points and the distance from walls can be seen for each chamber and practice room in Appendix D.

3.6.2. Measured and Calculated Room Parameters

In this section, room parameters used in the research will be presented together with their calculation and measurement methods.

3.6.2.1. T30, EDT, C80, G Parameters

Reverberation Time (T30), Early Decay Time (EDT), and Clarity (C80) parameters were measured via WINMLS method for each octave-band from 63 Hz to 4 kHz. Since the practice rooms were very small, instead of measuring Strength (G) parameter, G was calculated for each octave-band frequency by using Equation 9 below according to Sabine's diffuse field theory where V is the volume of the room (m^3), T30 is the measured reverberation time (sec), and G is the calculated strength parameter (dB).

$$G = 10\log_{10}\left(\frac{T30}{V}\right) + 45dB$$

Equation 9

Room absorptions of each practice room were also calculated for each octave band from the measured T30 values for each octave band using Sabine's formula given in Equation 4.

3.6.2.2. Calculations of combined octave-band frequencies

For the frequency-based analysis, which will be explained in Section 3.8, in order to establish whether the average values of octave-band frequencies of the mentioned room parameters might have more correlation with the singer's data than the octave-band frequencies alone, the octave band frequency results of each room parameter were averaged to create octave-band frequency combinations, see table 4. Combinations calculated for analysis are shown in by hatched areas for example: $T30_{(125Hz\text{-}1kHz)}$ means the average of measured T30 at 125Hz, 250Hz, 500Hz and 1kHz. The combinations were only calculated for the RAM practice rooms as the correlation analysis between room data and singer's data were only undertaken for the practice rooms. In further chapters, the calculated and measured parameters will be named together with their relevant octave-band and combined frequencies such as $T30_{(4\ kHz)}$; $G_{(125Hz\text{-}1\ kHz)}$; $EDT_{(125Hz\text{-}1\ kHz)}$. (Note that, for combinations of 500Hz - 1 kHz and 2 kHz and of 63 Hz, 125 Hz and 250 Hz, instead of defining the frequency range, "mid" and "low" definitions were used as these definitions match with that taken in various standards.)

Table 4 Octave Band frequencies and Octave-band frequency combinations used for further frequency-based analysis, hatched areas show the averaged octave band frequencies for each octave band combination.

Octave-band frequency combinations N=9	**Octave Band frequency N=7**						
	63Hz	125Hz	250Hz	500Hz	1kHz	2 kHz	4 kHz
125-250Hz		▨	▨				
250-500 Hz			▨	▨			
500Hz-1k				▨	▨		
1k-2k					▨	▨	
Mid			▨	▨	▨		
Low	▨	▨	▨				
125-500 Hz		▨	▨	▨			
250Hz-1k			▨	▨	▨		
125Hz-1k		▨	▨	▨	▨		

3.6.2.3. Background Noise Levels (L_{Aeq})

Background noise levels were only measured for practice rooms at RAM since there wasn't any significant background noise under laboratory conditions. A NOR140 sound level meter was fixed at a 1.5 m height in each room, $L_{Aeq,10min}$ was measured for each practice room when the rooms were unoccupied and the building was not in use. But after spending a month in the Royal Academy premises during the trial measurements, these levels were found out to be lower than the real practicing environment, as these levels were measured during the late evening when the adjacent practice rooms were unoccupied. Since the aim was to measure the background noise levels at the time when the singer's voice dosimetry measurements were collected, pragmatic 2-minute representative background noise measurements were done immediately after the data collection of each subject when the room under measurement was unoccupied but adjacent practice rooms were in use. Therefore as a result, these 2-minute background noise measurements were deemed more representative and used for the analysis.

In order to find the representative noise levels during the time of singers' measurements, the 2-minute background noise levels ($L_{Aeq,2min}$) collected after each singer (N=55) in each practice room were logarithmically averaged for each room, see Equation 10. These representative background noise levels, L1 to LN, were used for the correlation analysis between the measured background noise level and the singer's perception of the noise levels in the practice rooms.

$$L_{average} = 10\log\left[\left(10^{L1/10} + 10^{L2/10} + 10^{L3/10} + \ldots + 10^{LN/10}\right) \times 1/N\right]$$

Equation 10[35]

3.6.2.4. Noise Rating (NR) Curves

This is a methodology that is used to rate noise in a room by comparing the noise spectrum with noise rating curves on a graph with an aim to make sure that the noise from outside does not have an effect on the activity inside the room. [35] Calculation of NR Curves are given in Annex B of BS8233: 1999, "Sound insulation and noise reduction for buildings – Code of practice". The methodology defined in BS8233:1999 is used throughout the thesis in order to find out noise rating curves of the RAM practice rooms, using logarithmically averaged octave band values of N=55 representative background noise levels for each room.

3.6.2.5. Room Dimensions

Sizes of each room were measured including room length, width, and height; then the area and volume of each room were calculated from these parameters. Since the rooms had complex geometries, equivalent rectangular dimensions are provided.

3.7. Singer's Data Collection in First Laboratory Phase

In this section objective and subjective data collection methodology for singer's voice dosimetry and perception of the rooms will be explained for the first Laboratory phase.

A total of 32 singers participated in the first laboratory phase. The questionnaire design was developed and validated in this stage for the following stages, in addition the first vocal loading measurements were taken at this stage.

3.7.1. Questionnaire Design

The questionnaire was developed through discussions with several experienced singers and by conversations with the Royal Academy of Music Opera Department staff for a deeper understanding of the perception of the acoustic parameters and singers concerns due to their vocal performance based on their singing environment. The final questionnaire was composed of two sections: "About you" section and "Room questionnaire" section.

3.7.1.1. "About You" Questionnaire

"About you" questionnaire consists of seven questions designed to gather information about the singer's personal information such as their age, gender, voice type and their singing background. The questionnaire is given in Appendix E. The singers were asked to complete the questionnaire prior to their voice dosimetry measurements.

3.7.1.2. Room Questionnaire

The "Room questionnaire" was developed to gather information about the singers' perception of the rooms using questions about room acoustic parameters and their performance in each room. This section was composed of nine questions of which the singers were asked to rate on a seven-point Likert-type scale, first five parameters were related to room acoustic parameters and the last four were about their perceived effort and overall impression of the rooms. Questions are listed in Table 5 and the ratings of each question can be found in Table 6.

Table 5 Room Questionnaire parameters

Q1	**Loudness** (How do you perceive your sound level in this room?)
Q2	**Clarity** (How would you rate the degree to which notes are distinctly separated in time and clearly heard?)
Q3	**Reverberance** (How would you rate the persistence of sound in this room?)
Q4	**Background noise** (How would you rate the background noise levels in this room?)
Q5	**Size of the room** (How would you rate the size of this room?)
Q6	**Pleasure of singing in this room** (How would you rate your pleasure of singing in this room?)
Q7	**Voice feeling** (How would you rate your voice feeling in this room?)
Q8	**Singing effort** (How would you rate your effort singing in this room?)
Q9	**Overall Impression** (How would you rate the acoustical quality of this room?)

The main purpose of the "Room questionnaire" was to correlate the subjective data to the measured room data in order to find out room acoustic parameters that are most related to Opera singer's subjective ratings. In order to understand whether the questionnaire language makes sense to singers two extreme environments: Reverberant and Anechoic chambers and a relatively more realistic environment: Semi-reverberant chamber were used with an expectation of extreme answers to the extreme conditions and relatively preferable answers to the Semi-reverberant chamber. The singers were asked to complete the questionnaire right after they finish singing in each room. The original questionnaire can be found in Appendix F.

Table 6 Room Questionnaire: 7-Point Likert-type scale rating and questionnaire parameters

Likert Rating		1	2	3	4	5	6	7
Q1	**Loudness**	extremely weak	very weak	weak	sufficient	loud	very loud	extremely loud
Q2	**Clarity**	extremely unclear	very little clear	a little clear	sufficient	clear	very clear	extremely clear
Q3	**Reverberance**	extremely dry	very dry	dry	balanced	reverberant	very reverberant	extremely reverberant
Q4	**Background noise**	not audible	very weak	weak	acceptable	loud	very loud	extremely loud
Q5	**Size of the room**	extremely small	very small	small	sufficient	large	very large	extremely large
Q6	**Pleasure of singing**	extremely bad	very bad	bad	sufficient	good	very good	extremely good
Q7	**Voice feeling**	extremely weak	very weak	weak	as usual	strong	very strong	extremely strong
Q8	**Singing effort**	extremely less than usual	quite less than usual	less than usual	as usual	more than usual	quite more than usual	extremely more than usual
Q9	**Overall impression**	extremely bad	very bad	bad	sufficient	good	very good	extremely good

3.7.2. Voice Dosimetry measurement design using APM

The aim was to find the best method to collect vocal loading data of the singers which demonstrates their vocal use at the practice rooms for the field stage. The voice dosimetry measurements were undertaken using APM.

APM was attached on the singer as explained in Section 3.1.1. For the accuracy of the data, APM was calibrated for each singer's voice prior to the measurement as described in the APM manual. [62] For calibration process, the device has a microphone fixed at 15 cm from the end of a metal bar placed on the subjects' mouth, as seen in Figure 4 below. The singers were asked to locate their upper lip to the bar and phonate "A" vowel from their quietest level to their loudest until the software shows enough data points to form a linear trend line. The aim of this process is to introduce the full range of the singer to the device. The whole process including the attachment of the device takes five minutes and was repeated prior to vocal dosimetry measurement of each singer. After the completion of calibration process, APM is disconnected from the computer and with the device left attached on the singers.

At the first laboratory phase, "Scales" were chosen as a vocal loading exercise in order to collect voice dosimetry data as this exercise demonstrates their daily exercise in a practice room. The singers were asked to sing scales on "A" vowel for two minutes on a comfortable pitch that they self-selected. For the consistency of the measurements the singers were asked to sing the same scale on the same pitch and on the same vowel in three acoustic chambers: reverberant chamber; semi-reverberant and anechoic chamber, respectively.

Figure 4 APM calibration process

This order was kept the same for each singer. Since the conditions represent extreme environments semi-reverberant chamber was chosen to be the second test environment since the acoustic parameters of the chamber is in between the anechoic and reverberant chambers. To ensure that the singers sing on the same pitch and to remind the singer the start note, a piano application from a smart phone was used and the start note was played prior to the measurement in each room. The total singing duration in each chamber was two minutes non-stop (two-minute scales) and the total measurement duration was six minutes (three chambers).

3.7.3. Analysis of Collected Data

To find out whether there's a statistically significant difference in the singers' objective (voice dosimetry) and the subjective (questionnaire) data among the rooms (chambers) further analysis were made using One-way analysis of variance (ANOVA) test for repeated measures as same people were tested in different conditions. To explore where the difference occurs post-hoc statistical tests were conducted.

3.8. Singer's Data Collection in Second Laboratory Phase

Data collection methods were determined in two Laboratory phases. The design decisions regarding data collection methods started at the first laboratory phase and finalised in the second laboratory phase. The finalised methods were then used in the field stage undertaken at the RAM practice rooms.

A total of 30 singers participated in the second laboratory phase. The questionnaire developed in the first laboratory phase was used in this phase as well, but the voice dosimetry measurements were developed further.

3.8.1. Voice Dosimetry measurement design using APM

The second laboratory phase was performed since the results for voice dosimetry data measured in the first laboratory stage did not show any significant difference in the three extreme acoustic environments. In order to understand whether this might be due to duration or the type of exercise, the singing duration was decided to be increased by an additional two minute to sing a song. Since each singer has different repertoire with different vocal range and since the aim was to compare the scores of the same singer in each room rather than to make a comparison between singers, the singers were asked to choose a song that they are comfortable with and to keep singing the same song for each environment. As in their real practice environment, they were asked to sing the scales first as a warm-up and then the song. For the second laboratory phase, the total singing duration in each chamber was four minutes non-stop (two-minute scales, two-minute song) and the total measurement duration was 12 minutes (three chambers). The data collected with APM for each chamber and each type of singing were separated by selecting the time frames relevant to each measurement using the APM software and then analysed separately. The measurement procedure was the same as the 1st laboratory phase.

3.8.2. Voice Dosimetry measurement design using SLM

Another reason for performing a second laboratory phase was that the first laboratory phase results showed that APM measures the time-average sound pressure level (SPL) data based on voicing duration rather than SPL in octave bands. Therefore for the sound pressure level measurements for each octave band frequency, a sound level meter was decided to be used and sound power levels for each octave band frequency were calculated from the measured sound pressure levels for each singer. Frequency based analysis were conducted separately for males and females in order to examine whether there's any difference in sound power levels between rooms at different frequencies for each gender. As the aim of this phase was to finalize the measurement method for the field stage, consideration was also given to time efficiency and the singers comfort. Since the practice rooms for the field measurements will be booked for only a certain amount of time not long enough to attach, calibrate and detach more than one device for each singer and since the singers will already have APM attached on them; wearing a second device might limit their ability to sing. Therefore instead of a head-worn microphone, a Class 1 NOR140 sound level meter fixed at 1.5 m height and 1.5 m. distance from the singer was used. Before the measurements, the sound level was calibrated with its own calibrator. In each chamber condition, the singers were asked to stand at the same point. The measurement positions in the chambers are given in Appendix G.

3.8.2.1. Singer's Sound Power Level Calculation

In order to calculate sound power levels for each octave band, measured sound pressure levels for each octave band frequency were used. For Reverberant chamber, Sabine's statistical theory of room acoustics[35] was used as seen in Equation 11, where L_{REV} is the measured sound pressure level, Lw is the sound power level and Rc is the room constant.

$$L_{REV} = Lw + 10\log\left(\frac{4}{Rc}\right)$$

Equation 11[35]

Rc was calculated for each octave band using Equation 12 where S is the total area of room surfaces, α is the average sound absorption of those surfaces at each octave band. Sound absorption for each octave band was calculated via Equation 4 using measured T30 values.

$$Rc = \left(\frac{\boldsymbol{S\alpha}}{(\mathbf{1}-\boldsymbol{S\alpha})}\right)$$

Equation 12[35]

For Anechoic chamber, Equation 13 which gives the direct sound pressure level was used: L_{DIRECT} is the direct sound pressure level measured in the anechoic chamber, Lw is the sound power level, Q is the directivity factor, and r is the distance of the receiver from the source (1.5m).

$$L_{DIRECT} = Lw + 10\log\left(\frac{\boldsymbol{Q}}{\boldsymbol{4\pi r^2}}\right)$$
$$= Lw - 20\log r - 11$$

Equation 13[35]

For Semi-reverberant chamber and for all the RAM practice rooms the sound power levels were calculated for each octave band frequency using Equation 14 where L_{TOTAL} is the sum of direct and reverberant sound pressure levels, Lw is the sound power level, r is the distance of receiver from the source and Rc is the room constant. Rc for each room was calculated for each octave band frequency using Equation 12 where S is the total area of room surfaces, α is the average sound absorption of those surfaces at each octave band. Sound absorption for each room at each octave band frequency was calculated via Equation 4 using measured T30 values.

$$L_{TOTAL} = Lw + 10\log\left(\left(\frac{\boldsymbol{Q}}{\boldsymbol{4\pi r^2}}\right) + \left(\frac{\mathbf{4}}{\mathbf{Rc}}\right)\right)$$

Equation 14[35]

3.8.2.2. Analysis of Collected Data

To find out whether there's a statistically significant difference in the singers' objective (voice dosimetry) and the subjective (questionnaire) data among the chambers further analysis were conducted using One-way analysis of variance (ANOVA) test for repeated measurements of the same participants under different test conditions. To explore where the difference occurs post-hoc tests were conducted. In addition, in order to validate that the room questionnaire was clearly understood by the singers, a comparison was made between the room questionnaire results of First Laboratory phase and Second Laboratory phase by conducting One-way between groups analysis of variance (ANOVA) test as the participants were different for each phase.

3.9. Field Stage

The Field stage was undertaken with a total of 74 singers in four practice rooms of the Royal Academy of Music. From this dataset only N=55 were valid to use for the research, therefore data collected from N=24 singers were excluded from the research as the data from APM were erroneous due to reasons such as cable disconnection between the data unit and the accelerometer, insufficient contact between skin and accelerometer, or calibration problems which were not possible to detect earlier as the device appeared to be working properly during the time of the measurements.. The data collection methods for voice dosimetry data and the subjective data were kept as finalized in the second laboratory phase. The APM was attached to the singer and each singer was asked to sing scales and the song exercise for two minutes each and then to complete the questionnaire.

In addition, after completion of the room questionnaire, regardless of the rooms they have sung in, the singers were also asked about what rating they would ideally prefer on the 7-point Likert type scale for each subjective parameter in order to find out Opera singers' preferred ratings and their preferences were separately documented in an Excel sheet. In further analysis, these preferred ratings were targeted for each subjective parameter in order to find out ideal practice room conditions for the Opera singers.

The process consisted of device preparation, calibration, four-minute voice dosimetry measurement, two-minute background noise measurement and questionnaire completion, which approximately took approximately 55 minutes for the four practice rooms, in addition approximately a total of 10 minutes were spent for changing the rooms as the rooms were located in different parts of the academy. Therefore the total measurement process was about 65 minutes for each singer. As participation was voluntary the measurement time had to be scheduled due to each singer's daily program therefore singers were asked to volunteer for about an hour at a time that their voice were relaxed and their schedule was not too busy for the day not to cause any extra tiredness.

For consistency each singer was asked to repeat the same scale exercise and song of their choice at the same pitch and on the same vowel (for scales) in four different practice rooms in the Royal Academy of Music practice rooms.Again, a piano application on a smartphone was used to ensure the same pitch was used by the singer in each room.. In each room the singer was asked to stand at the same point, at least 0.5 m away from the walls due to small size of the rooms. Whilst APM was attached to the singers a Class 1 NOR140 sound level meter fixed at 1.5 m height and at 1.5 m distance from the singer was used to measure sound pressure levels in octave bands Source-receiver measurement points can be seen from the layouts given in Appendix H.

3.9.1. Analysis of Collected Data

To find out whether there's a statistically significant difference in the singers' objective (voice dosimetry) and the subjective (questionnaire) data among the practice rooms further analysis was made using One-way analysis of variance (ANOVA) test for repeated measures as same people were tested in different practice rooms. To explore where the difference occurs post-hoc statistical tests were conducted.

3.9.2 Summary of Singer's Data Collection

Table 7 is a summary of the number of singers participated and the number of measurements undertaken at each stage of the research. A total of N=117 singers have participated in the study, N=32 singers participated at the first laboratory phase each sung "scales" exercise in three chambers and completed "About you" questionnaire (N=32) prior to the measurements and then completed "Room" questionnaire for each chamber (32x3=96); N=30 singers participated at the second laboratory phase each sung "scales" and "song" exercise in three chambers and completed "About you" questionnaire (N=30) prior to the measurements and then completed "Room" questionnaire for each chamber (30x3=90) ; N=55 singers participated at the field stage each sung "scales" and "song" exercise in four practice rooms and completed "About you" questionnaire (N=55) prior to the measurements and then completed "Room" questionnaire for each practice room (55x4=220).

Table 7 Stage summary table, including the number (N) of rooms, number of singers participated and the number of measurements undertaken at each stage.

Stages	Singers N	Rooms N	APM measurement N		SLM measurement N		Questionnaire N	
			Scales	Song	Scales	Song	About you	Room
First Lab.	32	3 Chambers	96	n/a	n/a	n/a	32	96
Second Lab.	30		90	90	90	90	30	90
Field Stage	55	4 Practice rooms	220	220	220	220	55	220

n/a: no measurements undertaken for that stage.

3.10. Singer's Data Collection for Daily Voice Dosimetry

These measurements were taken as a side study of this research with an aim to establish typical daily vocal dosimetry data of semi-professional student Opera singers. This time the singers wore the APM during a whole day at the Academy. A convenient day for each singer was scheduled. The researcher met the singer in the morning prior to his/her first class to attach APM.

A total of 49 singers from the previous study volunteered for this study, therefore same "About you" questionnaire which they have already completed for the previous study was used in order to get their background information. After the calibration process of APM, the singers were followed and monitored during a day including all their classes and breaks in order to take notes on when they speak and when they sing to examine data separately as well as to make sure nothing that might be invalid for the aim of the study occurs. For example, going out of the Academy for other purposes which is not related to their occupational/educational vocal use. Since each singer had a different schedule, monitoring duration varied for each singer from a minimum of one hour to a maximum of eight hours, After monitoring, the data for each singer was uploaded using APM software and examined for "all vocal activity" which includes both singing and speaking activity of the whole monitoring duration and for "singing only" where the speaking parts were excluded by trimming the periods when speaking occurred in order to find out the daily vocal load only caused by singing. A Pearson correlation analysis was also conducted for all singers N=49 between Phonation time (P_t) and the rest of the measured vocal parameters including sound pressure level (SPL), frequency (F0mode, F0average), distance dose (D_d) and cycle dose (D_c) in order to find out which parameters are directly correlated to phonation time since these parameters should be normalised to time dose as the monitoring duration for each singer varied due to their different schedules.

This study allowed the author to gain valuable data on daily vocal dosimetry of semi-professional classical singers at their education environment and to make a comparison with daily vocal dosimetry data found in literature for other occupations which represent professional voice-use.

3.11. Relationship between Room and Singer's parameters

In this section, further statistical analysis is outlined as a summary, details will be explained in detail together with the results in Section 4.6**.** These analysis were only conducted for RAM practice rooms as these are the real environments that the singers are exposed to during their daily practices and the focus of the research.

In order to find the relationship between room and singer's parameters, a Pearson correlation analysis was conducted between room parameters and singers' parameters which showed change between the rooms according to the results of the ANOVA tests. The parameters which showed significant correlation were further analysed via Regression analysis. Preferred ratings collected from each singer were analysed using descriptive statistics for categorical data in order to find frequency distributions. The ratings which showed the highest distribution were set as the preferred ratings of singers. These preferred ratings were then used in the equation obtained via regression analysis between room parameters and the subjective parameters in order to get the corresponding room parameter value as a target.

4. CHAPTER 4: RESULTS

In this chapter the results of room and singers' measurements together with the results of all the analysis conducted for the research will be presented.

4.1. Room Measurement Results for LSBU Chambers

Results of the room measurements for the three chambers at each octave band for both directly measured and calculated parameters are presented inTable 8 to Table 13.

Table 8 Results of Reverberation Time, T30(measured) in octave-bands for each chamber: Reverberant Chamber (RC), Semi-reverberant Chamber (SRC)and Anechoic chamber (AC).

T30(sec)	Octave-band Centre Frequency						
	63Hz	125 Hz	250 Hz	500 Hz	1kHz	2kHz	4kHz
RC	3.86	4.07	3.93	4.35	4.43	3.93	2.87
SRC	1.86	1.65	1.56	1.72	1.76	1.69	1.39
AC	0.14	0.13	0.05	0.04	0.06	0.05	0.04

Table 9 Results of Early Decay Time, EDT(measured) in octave-bands for each chamber: Reverberant Chamber (RC), Semi-reverberant Chamber (SRC)and Anechoic chamber (AC).

EDT(sec)	Octave-band Centre Frequency						
	63Hz	125 Hz	250 Hz	500 Hz	1kHz	2kHz	4kHz
RC	3.33	3.72	3.55	4.28	4.34	3.86	2.49
SRC	1.72	1.46	1.38	1.74	1.77	1.69	1.32
AC	0.32	0.12	0.09	0.07	0.05	0.04	0.05

Table 10 Results of Clarity, C80(measured) in octave-bands for each chamber: Reverberant Chamber (RC), Semi-reverberant Chamber (SRC)and Anechoic chamber (AC).

C80(dB)	Octave-band Centre Frequency						
	63Hz	125 Hz	250 Hz	500 Hz	1kHz	2kHz	4kHz
RC	-4.70	-7.05	-4.55	-5.12	-5.13	-4.75	-1.92
SRC	0.27	0.77	0.92	-0.28	-0.48	-0.45	1.93
AC	30.2	42.4	29.7	64.2	63.3	58.1	51.8

Table 11 Results of Strength, G(calculated) in octave-bands for each chamber: Reverberant Chamber (RC), Semi-reverberant Chamber (SRC)and Anechoic chamber (AC).

G(dB)	Octave-band Centre Frequency						
	63Hz	125 Hz	250 Hz	500 Hz	1kHz	2kHz	4kHz
RC	27.80	28.02	27.87	28.32	28.40	27.87	26.51
SRC	24.62	24.09	23.87	24.28	24.39	24.20	23.35
AC	13.39	13.07	18.92	7.95	9.71	8.92	7.95

Table 12 Results of room absorption, α(calculated) in octave-bands for each chamber: Reverberant Chamber (RC), Semi-reverberant Chamber (SRC)and Anechoic chamber (AC).

α	Octave-band Centre Frequency						
	63Hz	125 Hz	250 Hz	500 Hz	1kHz	2kHz	4kHz
RC	0.04	0.04	0.04	0.03	0.03	0.04	0.05
SRC	0.08	0.09	0.10	0.09	0.09	0.09	0.11
AC	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 13 Results of room constant, R_c(calculated) in octave-bands, calculated for Reverberant Chamber (RC) and Semi-reverberant Chamber (SRC).

R_c	Octave-band Centre Frequency						
	63Hz	125 Hz	250 Hz	500 Hz	1kHz	2kHz	4kHz
RC	9.01	7.76	8.75	7.96	7.75	8.46	12.73
SRC	10.24	15.60	22.88	20.92	20.59	20.92	25.96

4.2. Room Measurement Results for RAM Practice Rooms

Results of the room measurements for the four practice rooms at each octave band for both directly measured and calculated parameters are presented in Table 14 to Table 19.

Table 14 Results of Reverberation Time, T30(measured) in octave-bands for each practice room: YG room, LG room, DR room and T room.

T30(sec)	Octave-band Centre Frequency						
	63Hz	125 Hz	250 Hz	500 Hz	1kHz	2kHz	4kHz
YG	1.56	2.19	1.24	0.80	0.65	0.56	0.49
LG	0.72	0.79	1.00	0.39	0.35	0.30	0.33
DR	0.93	0.85	0.65	0.49	0.41	0.33	0.36
T	0.36	1.03	0.33	0.21	0.23	0.19	0.15

Table 15 Results of Early Decay Time, EDT(measured) in octave-bands for each practice room: YG room, LG room, DR room and T room.

EDT(sec)	Octave-band Centre Frequency						
	63Hz	125 Hz	250 Hz	500 Hz	1kHz	2kHz	4kHz
YG	1.23	1.73	1.15	0.74	0.58	0.52	0.41
LG	0.80	0.33	0.45	0.41	0.42	0.28	0.28
DR	0.57	0.77	0.68	0.50	0.38	0.30	0.31
T	0.24	0.14	0.27	0.23	0.20	0.19	0.15

Table 16 Results of Clarity, C80(measured) in octave-bands for each practice room: YG room, LG room, DR room and T room.

C80(dB)	Octave-band Centre Frequency						
	63Hz	125 Hz	250 Hz	500 Hz	1kHz	2kHz	4kHz
YG	0.50	-0.24	3.01	5.66	7.61	9.19	11.46
LG	4.76	12.25	9.89	12.02	13.07	16.94	17.05
DR	9.39	5.20	5.61	9.81	12.29	15.79	14.95
T	11.98	20.90	16.99	23.10	23.26	26.05	32.88

Table 17 Results of Strength, G(calculated) in octave-bands for each practice room: YG room, LG room, DR room and T room.

G(dB)	Octave-band Centre Frequency						
	63Hz	125 Hz	250 Hz	500 Hz	1kHz	2kHz	4kHz
YG	31.49	32.96	30.47	28.55	27.69	27.06	26.41
LG	31.97	32.36	33.36	29.30	28.85	28.20	28.62
DR	31.79	31.37	30.21	29.00	28.19	27.25	27.63
T	29.06	33.70	28.80	26.80	27.26	26.36	25.32

Table 18 Results of room absorption, α(calculated) in octave-bands for each practice room: YG room, LG room, DR room and T room.

α	Octave-band Centre Frequency						
	63Hz	125 Hz	250 Hz	500 Hz	1kHz	2kHz	4kHz
YG	0.05	0.04	0.06	0.10	0.12	0.14	0.16
LG	0.08	0.08	0.06	0.16	0.17	0.20	0.18
DR	0.07	0.08	0.10	0.14	0.16	0.20	0.19
T	0.18	0.06	0.19	0.30	0.27	0.33	0.41

Table 19 Results of room constant, R_c (calculated) in octave-bands for each practice room: YG room, LG room, DR room and T room.

R_c	Octave-band Centre Frequency						
	63Hz	125 Hz	250 Hz	500 Hz	1kHz	2kHz	4kHz
YG	3.80	2.67	4.86	7.86	9.80	11.56	13.64
LG	3.53	3.20	2.50	7.08	8.01	9.61	8.46
DR	3.63	4.03	5.40	7.41	9.23	12.00	10.69
T	7.67	2.31	8.25	15.10	13.03	17.44	25.44

As explained in the Methodology chapter, the octave-band results were combined in order to investigate whether the octave-band combinations show greater correlation with the singers' subjective data. The results of these combinations for each parameter: T30, EDT, C80, and G are presented in Table 20 to Table 23.

Table 20 Octave-band combination results of Reverberation Time, T30(measured) in octave-bands for each practice room: YG room, LG room, DR room and T room.

T30 (sec)	Octave-band Combinations							
	125-250Hz	250-500Hz	500Hz -1kHz	1 -2 kHz	mid	low	125-500Hz	250Hz - 1kHz	125Hz - 1kHz
YG	1.72	1.02	0.72	0.61	0.67	1.67	1.41	0.90	1.22
LG	0.89	0.69	0.37	0.33	0.35	0.84	0.73	0.58	0.63
DR	0.75	0.57	0.45	0.37	0.41	0.81	0.66	0.51	0.60
T	0.68	0.27	0.22	0.21	0.21	0.57	0.53	0.26	0.45

Table 21 Octave-band combination results of Early Decay Time, EDT(measured) in octave-bands for each practice room: YG room, LG room, DR room and T room.

EDT (sec)	Octave-band Combinations								
	125-250Hz	250-500Hz	500Hz -1kHz	1 -2 kHz	mid	low	125-500Hz	250Hz - 1kHz	125Hz - 1kHz
YG	1.44	0.94	0.66	0.55	0.61	1.37	1.2	0.82	1.05
LG	0.39	0.43	0.41	0.35	0.37	0.53	0.4	0.43	0.43
DR	0.72	0.59	0.44	0.34	0.39	0.67	0.65	0.52	0.58
T	0.2	0.25	0.21	0.19	0.21	0.21	0.21	0.23	0.22

Table 22 Octave-band combination results of Clarity, C80(measured) in octave-bands for each practice room: YG room, LG room, DR room and T room.

C80 (dB)	Octave-band Combinations								
	125-250Hz	250-500Hz	500Hz -1kHz	1 -2 kHz	mid	low	125-500Hz	250Hz - 1kHz	125Hz -1kHz
YG	1.68	4.53	6.74	8.47	5.82	1.32	3.44	5.82	4.91
LG	11.23	11.08	12.58	15.42	11.85	9.93	11.51	11.85	11.95
DR	5.41	8.20	11.22	14.38	10.02	7.17	7.41	10.02	9.23
T	19.37	21.04	23.18	24.88	21.91	17.99	20.99	21.91	21.68

Table 23 Octave-band combination results of G(calculated) in octave-bands for each practice room: YG room, LG room, DR room and T room.

G (dB)	Octave-band Combinations								
	125-250Hz	250-500Hz	500Hz -1kHz	1 -2 kHz	mid	low	125-500Hz	250Hz - 1kHz	125Hz -1kHz
YG	31.89	29.62	28.14	27.39	29.06	31.76	31.04	29.06	30.41
LG	32.89	31.79	29.08	28.54	31.01	32.60	31.99	31.01	31.39
DR	30.83	29.65	28.61	27.75	29.21	31.17	30.30	29.21	29.86
T	31.91	27.91	27.04	26.83	27.71	31.15	30.77	27.71	30.12

Results of background noise levels measured for 10 minutes ($L_{Aeq,10min}$) when the rooms were unoccupied are presented in Table 24 together with the NR curves calculated for each room, see Figure 5; the averaged representative background noise levels measured for two-minutes ($L_{Aeq,2min}$) after each singer's voice dosimetry measurement (N=55) when the rooms were unoccupied are presented in Table 25 together with the NR curves calculated for each room, see Figure 6. Results of measured background noise levels in octave-bands for each representative measurement ($L_{Aeq, 2min}$) can be found in Appendix I.

The results were found to be of the order of 15 dB higher than those of typical practice rooms, NR25, as the measurement were taken during working hours. As explained in the Methodology chapter the logarithmic average of two-minute representative background noise levels for each room were used for further analysis as these levels better represent the levels when the singers voice dosimetry were measured.

Table 24 Background noise levels, measured for 10 minutes for each Ram practice room.

Octave-band Centre Frequency	Background Noise Levels ($L_{eq,10min}$)			
	DR room	LG room	YG room	T room
63 Hz	42.2	40.7	56.3	47.3
125 Hz	32.3	27.7	45.5	43
250 Hz	34.8	28	40.6	31.3
500 Hz	27.7	23.9	35.6	21.3
1 kHz	20.4	18.5	32.4	20.4
2 kHz	20.2	18.4	29.4	18.1
4 kHz	17.7	14.9	20.7	14.1
NR Curve	25	22	32	24
$L_{Aeq,10min}$	30.3	26.5	39.1	30.4

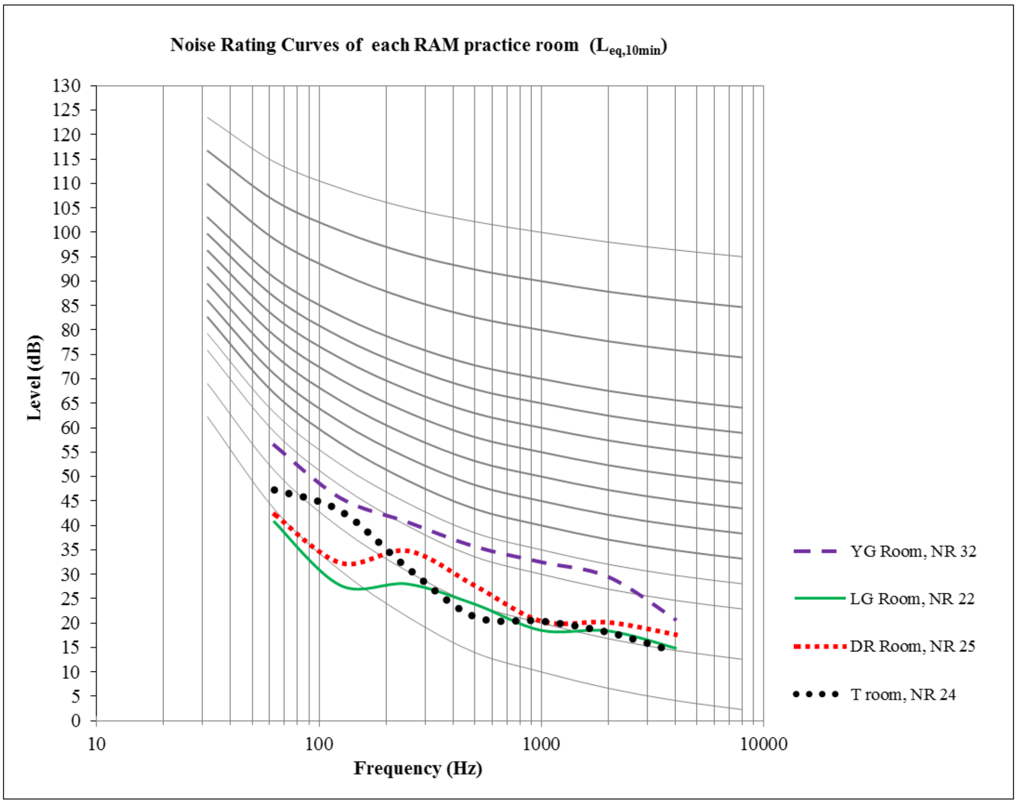

Figure 5 Noise Rating (NR) Curves of each RAM practice room for $L_{eq,10min}$

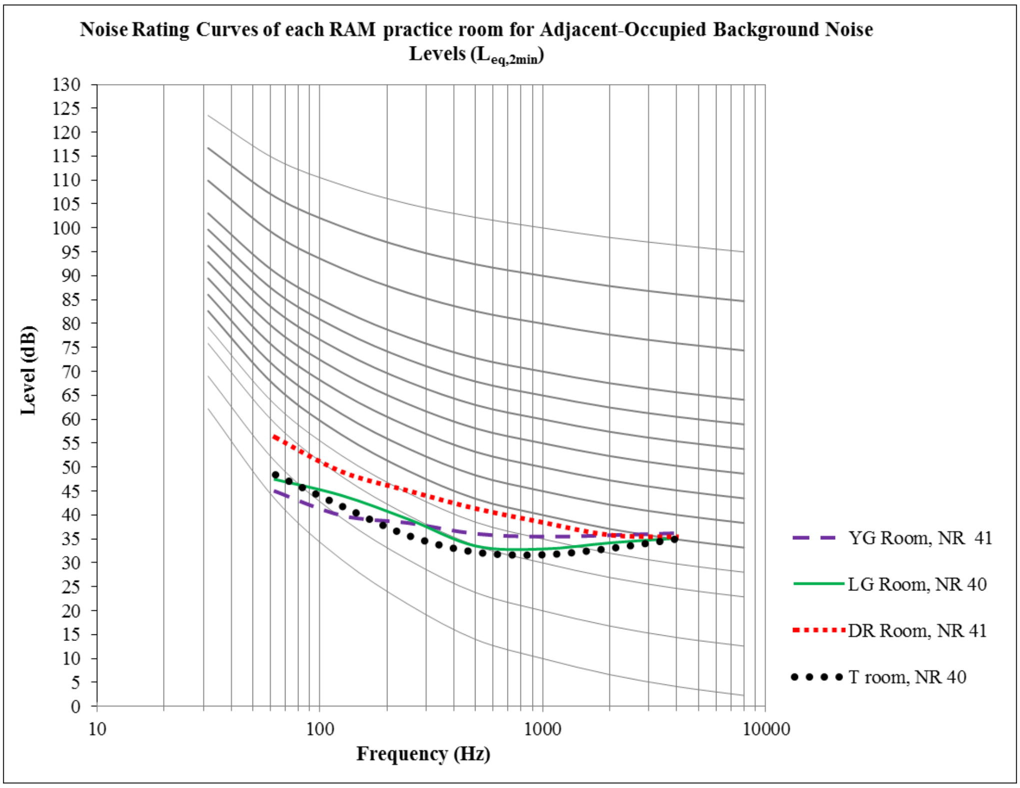

Figure 6 Noise Rating (NR) Curves of each RAM practice room for representative background noise levels for $L_{eq,2min}$

Table 25 Logarithmic average of representative background noise levels of each RAM practice room measured for 2 minutes after each singer N=55

Frequency (Octave-Band)	Averaged levels of Representative Background Noise Levels ($L_{eq,2min}$)			
	DR room	**LG room**	**YG room**	**T room**
63 Hz	56.2	47.4	44.9	48.4
125 Hz	49.0	44.1	39.9	41.8
250 Hz	45.0	39.1	38.3	35.6
500 Hz	41.3	33.5	36.1	32.1
1 k	38.5	32.9	35.5	31.6
2 k	35.8	34.2	35.8	33.0
4 k	35.4	35.1	36.2	34.9
NR Curve	41	40	41	40
$L_{Aeq,\,2min}$	44.8	40.9	42.2	39.9

4.3. Results of Singers' Data collection in First Laboratory Phase

In this section the findings from the collected data for the first laboratory phase will be presented.

4.3.1. About You Questionnaire Results

First Laboratory phase was completed by 32 Opera singers at the LSBU acoustic chambers. Participating singer profiles were obtained via "About You" questionnaire. Results are presented in Table 26 below.

Table 26 "About You" Questionnaire results showing singer profiles participated in the First Laboratory Stage, N=32 singers.

Questions	Answers	N	%
Q1- What is your gender?	Male	11	34.4
	Female	21	65.6
Q2- What is your age?	18_24	25	78.1
	25_29	6	18.8
	30_34	1	3.1
Q3- What is your voice type?	Baritone	6	18.8
	Tenor	5	15.6
	Mezzo Soprano	8	25.0
	Soprano	13	40.6
Q4- How many years have you been singing?	0-5	5	15.6
	5-10	8	25.0
	10-20	18	56.3
	20-30	1	3.1
Q5- For how many years have you been taking singing lessons?	0-5	7	21.9
	5-10	14	43.8
	10-20	11	34.4
Q6- Are you still taking singing lessons?	Yes	32	100
Q7-Do you have any vocal problems?	No	32	100

4.3.2. Room Questionnaire Results

A one-way repeated measures ANOVA test was conducted to compare scores on the results of each question of "Room Questionnaire" for each chamber. Results are given in Table 27 for each questionnaire parameter (Q1-Q9). As can be seen, scores on each questionnaire parameter showed a significant difference based on a one way ANOVA test. Results will be explained below for each questionnaire parameter which used a Bonferroni Post Hoc test to determine the where the difference occur between the groups.

4.3.2.1. Q1- Loudness

To validate that this questionnaire parameter was understood by the singers, the scores were expected to be highest in the Reverberant chamber; lowest in the Anechoic chamber and somewhere in the middle for the Semi-reverberant chamber. The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of "Loudness" scores across the three chambers (p<0.001). The mean scores for Anechoic chamber was found to be significantly lower than the mean scores of Reverberant and Semi-reverberant chambers and the mean scores of Semi-reverberant chamber was found to be significantly lower than the mean scores of Reverberant chamber. In the Reverberant chamber "Loudness" is rated between "6-very loud" and "7-extremely loud" (Mean score: 6.28); whereas in Semi-reverberant chamber it was rated close to "5-loud" (Mean score: 4.94) and in Anechoic chamber it is rated as "3-Weak" (Mean score: 3.13).

Table 27 Results of one-way repeated measures ANOVA test conducted for the validation of room questionnaire taken in three chambers: Anechoic chamber (AC), Reverberant Chamber (RC), Semi-reverberant Chamber (SRC) for N=32 singers.

Questionnaire Parameters	Chambers	N	Mean	SD	Eta Squared	F	p	Diff.
Q1- Loudness	1) RC	32	6.28	0.958	0.685	101.107	**0.000*****	**2<1 3<1,2**
	2) SRC	32	4.94	0.669				
	3) AC	32	3.13	1.008				
Q2- Clarity	1) RC	32	2.78	1.601	0.584	65.283	**0.000*****	**1<2,3 2<3**
	2) SRC	32	4.97	0.695				
	3) AC	32	6.44	1.390				
Q3- Reverberance	1) RC	32	6.66	0.545	0.950	878.465	**0.000*****	**2<1 3<1,2**
	2) SRC	32	4.84	0.628				
	3) AC	32	1.13	0.421				
Q4- Background Noise	1) RC	32	1.41	0.615	0.132	7.053	**0.001****	**3<1,2**
	2) SRC	32	1.25	0.440				
	3) AC	32	1.00	0.000				
Q5- Size of the room	1) RC	32	4.68	0.535	0.113	5.938	**0.004****	**3<1,2**
	2) SRC	32	4.59	0.559				
	3) AC	32	4.25	0.508				
Q6- Pleasure of Singing	1) RC	32	4.41	1.388	0.705	111.039	**0.000*****	**1<2 3<1,2**
	2) SRC	32	5.28	0.813				
	3) AC	32	1.63	0.751				
Q7- Voice Feeling	1) RC	32	5.91	0.856	0.730	125.758	**0.000*****	**2<1 3<1,2**
	2) SRC	32	4.81	0.965				
	3) AC	32	2.34	0.937				
Q8- Singing Effort	1) RC	32	2.47	1.077	0.596	68.575	**0.000*****	**1<2,3 2<3**
	2) SRC	32	3.94	0.759				
	3) AC	32	5.53	1.244				
Q9- Overall Impression	1) RC	32	4.03	1.282	0.702	109.680	**0.000*****	**1<2 3<1,2**
	2) SRC	32	5.28	0.851				
	3) AC	32	1.69	0.738				

*: p<0.05 **: p<0.01: ***: p<0.001

4.3.2.2. Q2- Clarity

To validate that this questionnaire parameter was understood by the singers, the scores were expected to be highest in the Anechoic chamber; lowest in the Reverberant chamber and somewhere in the middle for the Semi-reverberant chamber. The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of "Clarity" scores across the three chambers ($p<0.001$). The mean scores for Reverberant chamber was found to be significantly lower than the mean scores of Semi-Reverberant and Anechoic chambers and the mean scores of Semi-reverberant chamber was found to be significantly lower than the mean scores of Anechoic chamber. In Reverberant chamber "Clarity" is rated between "2-very little clear" and "3-a little clear" (Mean score: 2.78); whereas in Semi-reverberant chamber it is rated close to "5-clear" (Mean score: 4.97) and in Anechoic chamber it was rated between "6-very clear" and "7-extremely clear" (Mean score: 6.44).

4.3.2.3. Q3- Reverberance

To validate this questionnaire parameter, the scores were expected to be highest in the Reverberant chamber; lowest in the Anechoic chamber and somewhere in the middle for the Semi-reverberant chamber. The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of "Reverberance" scores across the three chambers ($p<0.001$). The mean scores for Anechoic chamber was found to be significantly lower than the mean scores of Reverberant and Semi-reverberant chambers and the mean scores of Semi-reverberant chamber was found to be significantly lower than the mean scores of Reverberant chamber. In Reverberant chamber "Reverberance" is rated between "6-very reverberant" and "7-extremely reverberant" (Mean score: 6.66); whereas in Semi-reverberant chamber it is rated close to "5-reverberant" (Mean score: 4.84) and in Anechoic chamber it is rated close to "1-extremely dry" (Mean score: 1.13).

4.3.2.4. Q4- Background noise

As the laboratory environments is a controlled environment with no significant background noise and since the Reverberant and Semi-reverberant conditions were created in the same room applying different room absorption, the noise levels of Reverberant and Semi-reverberant chambers were expected to show no significant difference, but due to extreme room absorption of the Anechoic chamber the scores were expected to be significantly lower in the Anechoic chamber. The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of "Background noise" scores across the three chambers ($p<0, 01$). The mean scores for Anechoic chamber was found to be significantly lower than the mean scores of Reverberant and Semi-reverberant chambers. There was no significant change in scores between Reverberant and Semi-reverberant chambers. In Reverberant and Semi-reverberant chambers "Background noise" is rated between "1-not audible" and "2-very weak" (Mean scores: 1.41; 1.25 respectively); and in Anechoic chamber it is rated as "1-not audible" (Mean score: 1.00).

4.3.2.5. Q5- Size of the room

The Reverberant and Semi-reverberant conditions were created in the same room without any change in the room dimensions; although the Anechoic chamber has the same dimensions with the Reverberant and Semi-reverberant chambers the usable space is smaller due to foam wedges. The expectation was to see no change between the scores for Reverberant and Semi-reverberant chambers and a decrease in the scores for Anechoic chamber. The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of "Size of the room" scores across the three chambers ($p<0.01$). The mean scores for Anechoic chamber was found to be significantly lower than the mean scores of Reverberant and Semi-reverberant chambers. There was no significant change in scores between Reverberant and Semi-reverberant chambers. In Reverberant and Semi-reverberant chambers "Size of the room" is rated close to "5-large" (Mean scores: 4.68; 4.59 respectively); and in Anechoic chamber it is rated between "4-sufficient" and "5-large" (Mean score: 4.25) closer to "4-sufficient" rating.

4.3.2.6. Q6- Pleasure of Singing

The results of the ANOVA test indicated that there was a statistically significant difference in "Pleasure of Singing" scores across the three chambers ($p<0.001$). The mean scores for Anechoic chamber was found to be significantly lower than the mean scores of Reverberant and Semi-reverberant chambers and the mean scores of Semi-reverberant chamber was found to be significantly higher than the mean scores of Reverberant chamber. Pleasure of singing in Reverberant chamber is rated between "4-sufficient" and "5- good" (Mean score: 4.41), whereas in Semi-reverberant chamber it is rated between "5-good" and "6-very good" (Mean score: 5.28) and in Anechoic chamber rated between "1-extremely bad" and "2-very bad" (Mean score: 1.63).

4.3.2.7. Q7- Voice feeling

The results of the ANOVA test indicated that there was a statistically significant difference in "Voice feeling" scores across the three chambers ($p<0.001$). The mean scores for Anechoic chamber was found to be significantly lower than the mean scores of Reverberant and Semi-reverberant chambers and the mean scores of Reverberant chamber was found to be significantly higher than the mean scores of Semi-reverberant chamber indicating that the singers felt their voice was stronger in Reverberant chamber compared to Semi-reverberant chamber. Voice feeling in Reverberant chamber is rated close to "6-very strong" (Mean score: 5.91), whereas in Semi-reverberant chamber it is rated close to "5-strong" (Mean score: 4.81) and in Anechoic chamber rated between "2-very weak" and "3-weak" (Mean score: 2.34).

4.3.2.8. Q8- Singing effort

The results of the ANOVA test indicated that there was a statistically significant difference in "Singing effort" scores across the three chambers ($p<0.001$). The mean scores for

Anechoic chamber was found to be significantly higher than the mean scores of Reverberant and Semi-reverberant chambers and the mean scores of Semi-reverberant chamber was found to be significantly higher than the mean scores of Reverberant chamber. Singing effort in Reverberant chamber is rated between “2-quite less than usual” and “3- less than usual” (Mean score:2.47), whereas in Semi-reverberant chamber it is rated close to “4-as usual” (Mean score:3.94) and in Anechoic chamber rated between “5-more than usual” and “6-quite more than usual” (Mean score:5.53).

4.3.2.9. Q9- Overall Impression

The results of the ANOVA test indicated that there was a statistically significant difference in “Overall impression” scores across the three chambers ($p<0,001$). The mean scores for Anechoic chamber was found to be significantly lower than the mean scores of Reverberant and Semi-reverberant chambers and the mean scores of Semi-reverberant chamber was found to be significantly higher than the mean scores of Reverberant chamber. Overall impression of Reverberant chamber is rated “4-sufficient” (Mean score: 4.03), whereas in Semi-reverberant chamber it is rated between “5-good” and “6-very good” (Mean score: 5.28) and in Anechoic chamber rated between “1-extremely bad” and “2-very bad” (Mean score: 1.69).

4.3.2.10. Conclusion

The results for the first five questions (Q1-Q5) related to room conditions were as expected and the scores were sensible for each environment showing that the room parameters were clear and well-understood by the singers. For the last four questions related to singer’s evaluation of their singing pleasure, effort, voice feeling and overall impression, the expectation was to see a significant change in scores between chambers, to discover singer’s ratings and to compare if their subjective scores were in accordance with the objective voice dosimetry data. A significant change seen in all questionnaire parameters was expected due to significant change in room acoustic conditions. Therefore the questionnaire was adopted for the next stage of the research.

4.3.3. Voice Dosimetry Results measured with APM

A one-way repeated measures ANOVA test was conducted to compare voice dosimetry scores in each chamber, results for singing the "scales" can be seen in Table 28 below. The expectation was to see a significant change in vocal dosimetry parameters of singers parallel to the subjective data results, as can be seen from Table 28 no significant difference in any APM measured vocal parameter was found.

Despite the significant change in room acoustics between chambers and the subjective data, voice dosimetry results did not show any significant change, probably due to the highly trained nature of the subjects, which can been seen from the consistent nature of the Phonation time (P_t), and Phonation percentage. Therefore a second Laboratory phase was conducted for the voice dosimetry data collection with amendments on vocal loading exercise and measurement method, as explained in the Methodology chapter.

Table 28 Results of one-way repeated measures ANOVA test conducted for the voice dosimetry parameters measured with APM in three chambers: Anechoic chamber (AC), Reverberant Chamber (RC) and Semi-reverberant Chamber (SRC) for N=32 singers singing "Scales".

Voice Dosimetry Parameters	Chambers	N	Mean	SD	Eta Squared	F	p	Diff
P_t (sec)	1) RC	32	104.41	7.129	0.005	0.230	0.795	-
	2) SRC	32	103.41	7.111				
	3) AC	32	103.34	6.870				
P_t (%)	1) RC	32	87.45	5.881	0.007	0.317	0.729	-
	2) SRC	32	86.59	5.902				
	3) AC	32	86.34	5.838				
F0mode	1) RC	32	333.50	135.841	0.004	0.178	0.837	-
	2) SRC	32	324.13	135.048				
	3) AC	32	314.00	120.367				
F0average	1) RC	32	379.20	133.502	0.000	0.001	0.990	-
	2) SRC	32	377.92	138.263				
	3) AC	32	379.56	137.079				
SPL	1) RC	32	89.23	10.055	0.002	0.114	0.892	-
	2) SRC	32	89.39	10.837				
	3) AC	32	88.23	10.665				
D_c	1) RC	32	39595.19	14137.039	0.000	0.005	0.995	-
	2) SRC	32	39271.44	14976.879				
	3) AC	32	39311.25	14858.160				
D_d	1) RC	32	151.33	76.598	0.005	0.238	0.788	-
	2) SRC	32	155.16	80.487				
	3) AC	32	142.19	74.493				

- : no significant difference p>0.05

4.4. Results of Singers' Data collection in Second Laboratory Phase

4.4.1. About You Questionnaire Results

Second Laboratory phase was completed by 30 Opera singers at the LSBU acoustic chambers. Singer profiles participated in this stage were obtained via "About You" questionnaire. Results are presented in Table 29 below.

Table 29 "About You" Questionnaire results showing singer profiles participated in the Second Laboratory Stage, N=30 singers.

Questions	Answers	N	%
Q1- What is your gender?	Male	17	56.7
	Female	13	43.3
Q2- What is your age?	18_24	27	90
	25_29	3	10
Q3- What is your voice type?	Baritone	5	16.7
	Tenor	8	26.7
	Counter Tenor	4	13.3
	Mezzo Soprano	2	6.7
	Soprano	11	36.7
Q4- How many years have you been singing?	0-5	3	10
	5-10	13	43.3
	10-20	14	46.7
Q5- For how many years have you been taking singing lessons?	0-5	5	16.7
	5-10	16	53.3
	10-20	9	30
Q6- Are you still taking singing lessons?	Yes	30	100
Q7-Do you have any vocal problems?	No	30	100

4.4.2. Room Questionnaire Results

A one-way repeated measures ANOVA test was conducted to compare scores on the results of each question of "Room Questionnaire" for each chamber. Results are given in Table 30 for each questionnaire parameter (Q1-Q9). As can be seen, scores on each questionnaire parameter showed a significant difference. The results of each questionnaire parameter are explained below using the identical analysis technique as use in Phase 1.

4.4.2.1. Q1- Loudness

The results of the Anova test indicated that there was a statistically significant difference in the subjective evaluation of "Loudness" scores across the three chambers ($p<0.001$). The mean scores for Anechoic chamber was found to be significantly lower than the mean scores of Reverberant and Semi-reverberant chambers and the mean scores of Semi-reverberant chamber was found to be significantly lower than the mean scores of Reverberant chamber. In Reverberant chamber "Loudness" is rated between "6-very loud" and "7-extremely loud" (Mean score: 6.40); whereas in Semi-reverberant chamber it is rated close to "5-loud" (Mean score: 4.80) and in Anechoic chamber it is rated close to"3-Weak" (Mean score: 2.90).

Table 30 Results of one-way repeated measures ANOVA test conducted for the room questionnaire scores of the second laboratory stage undertaken in three chambers: Anechoic chamber (AC), Reverberant Chamber (RC) and Semi-reverberant Chamber (SRC) for N=30 singers.

Questionnaire Parameters	Chambers	N	Mean	SD	Eta Squared	F	p	Diff.
	1) RC	30	6.40	0.621				
Q1- Loudness	2) SRC	30	4.80	0.551	0.834	218.330	**0.000*****	**2<1 3<1,2**
	3) AC	30	2.90	0.759				
	1) RC	30	2.47	1.408				
Q2- Clarity	2) SRC	30	4.93	0.521	0.646	79.398	**0.000*****	**1<2,3 2<3**
	3) AC	30	5.97	1.189				
	1) RC	30	6.57	0.728				
Q3- Reverberance	2) SRC	30	4.83	0.834	0.874	302.431	**0.000*****	**2<1 3<1,2**
	3) AC	30	1.37	0.928				
	1) RC	30	1.43	0.817				
Q4-Background Noise	2) SRC	30	1.20	0.407	0.105	5.080	**0.008****	**3<1**
	3) AC	30	1.00	0.000				
	1) RC	30	4.63	0.615				
Q5- Size of the room	2) SRC	30	4.60	0.675	0.258	15.152	**0.000*****	**3<1,2**
	3) AC	30	3.77	0.774				
	1) RC	30	4.00	1.365				
Q6-Pleasure of Singing	2) SRC	30	5.20	0.961	0.492	42.150	**0.000*****	**1<2 3<1,2**
	3) AC	30	2.27	1.363				
	1) RC	30	5.63	1.245				
Q7- Voice Feeling	2) SRC	30	4.70	0.915	0.592	63.030	**0.000*****	**2<1 3<1,2**
	3) AC	30	2.53	1.106				
	1) RC	30	2.70	1.179				
Q8- Singing Effort	2) SRC	30	3.87	0.434	0.515	46.114	**0.000*****	**1<2,3 2<3**
	3) AC	30	5.20	1.215				
	1) RC	30	3.83	1.315				
Q9-Overall Impression	2) SRC	30	5.17	0.874	0.475	39.430	**0.000*****	**1<2 3<1,2**
	3) AC	30	2.33	1.446				

*: p<0.05 **: p<0.01 ***: p<0.001

4.4.2.2. Q2- Clarity

The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of "Clarity" scores across the three chambers (p<0.001). The mean scores for Reverberant chamber was found to be significantly lower than the mean scores of Semi-Reverberant and Anechoic chambers and the mean scores of Semi-reverberant chamber was found to be significantly lower than the mean scores of Anechoic chamber. In Reverberant chamber "Clarity" is rated between "2-very little clear" and "3-a little clear" (Mean score: 2.47); whereas in Semi-reverberant chamber it is rated close to "5-clear" (Mean score: 4.93) and in Anechoic chamber it is rated close to"6-very clear" (Mean score: 5.97).

4.4.2.3. Q3- Reverberance

The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of "Reverberance" scores across the three chambers (p<0.001). The mean scores for Anechoic chamber was found to be significantly lower than the mean scores of Reverberant and Semi-reverberant chambers and the mean scores of Semi-reverberant chamber was found to be significantly lower than the mean scores of Reverberant chamber. In Reverberant chamber "Reverberance" is rated between "6-very reverberant" and "7-extremely reverberant" (Mean score: 6.57); whereas in Semi-reverberant chamber it is rated close to "5-reverberant" (Mean score: 4.83) and in Anechoic chamber it is rated between "1-extremely dry" and "2-very dry" (Mean score: 1.37).

4.4.2.4. Q4- Background noise

The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of "Background noise" scores across the three chambers ($p<0.01$). The mean scores for Anechoic chamber was found to be significantly lower than the mean scores of Reverberant and Semi-reverberant. There was no significant change in scores between Reverberant and Semi-reverberant chambers. In Reverberant and Semi-reverberant chambers "Background noise" is rated between "1-not audible" and "2-very weak" (Mean scores: 1.43; 1.20 respectively); and in Anechoic chamber it is rated as "1-not audible" (Mean score: 1.00).

4.4.2.5. Q5- Size of the room

The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of "Size of the room" scores across the three chambers ($p<0.01$). The mean scores for Anechoic chamber was found to be significantly lower than the mean scores of Reverberant and Semi-reverberant. There was no significant change in scores between Reverberant and Semi-reverberant chambers. In Reverberant and Semi-reverberant chambers "Size of the room" is rated close to "5-large" (Mean scores: 4.63; 4.60 respectively); and in Anechoic chamber it is rated close to "4-sufficient" (Mean score: 3.77).

4.4.2.6. Q6- Pleasure of Singing

The results of the ANOVA test indicated that there was a statistically significant difference in "Pleasure of Singing" scores across the three chambers ($p<0.001$). The mean scores for Anechoic chamber was found to be significantly lower than the mean scores of Reverberant and Semi-reverberant chambers and the mean scores of Semi-reverberant chamber was found to be significantly higher than the mean scores of Reverberant chamber. Pleasure of singing in Reverberant chamber is rated as "4-sufficient" (Mean score: 4.00), whereas in Semi-reverberant chamber it is rated between "5-good" and "6-very good" (Mean score: 5.20) and in Anechoic chamber rated between "2- very bad" and "3-bad" (Mean score: 2.27).

4.4.2.7. Q7- Voice feeling

The results of the ANOVA test indicated that there was a statistically significant difference in "Voice feeling" scores across the three chambers ($p<0.001$). The mean scores for Anechoic chamber was found to be significantly lower than the mean scores of Reverberant and Semi-reverberant chambers and the mean scores of Reverberant chamber was found to be significantly higher than the mean scores of Semi-reverberant chamber indicating that the singers felt their voice was stronger in Reverberant chamber compared to Semi-reverberant chamber. Voice feeling in Reverberant chamber is rated between "5-strong" and “6-very strong” (Mean score: 5.63), whereas in Semi-reverberant chamber it is rated between “4-as usual” and “5-strong” (Mean score: 4.70) and in Anechoic chamber rated between “2-very weak” and “3-weak” (Mean score: 2.53).

4.4.2.8. Q8- Singing effort

The results of the ANOVA test indicated that there was a statistically significant difference in “Singing effort” scores across the three chambers ($p<0.001$). The mean scores for Anechoic chamber was found to be significantly higher than the mean scores of Reverberant and Semi-reverberant chambers and the mean scores of Semi-reverberant chamber was found to be significantly higher than the mean scores of Reverberant chamber. Singing effort in Reverberant chamber is rated between “2-quite less than usual” and “3- less than usual” (Mean score:2.70), whereas in Semi-reverberant chamber it is rated between “3-less than usual” and “4-as usual” (Mean score:3.87) and in Anechoic chamber rated between “5-more than usual” and “6-quite more than usual” (Mean score:5.20).

4.4.2.9. Q9- Overall Impression

The results of the ANOVA test indicated that there was a statistically significant difference in “Overall impression” scores across the three chambers ($p<0.001$ The mean scores for Anechoic chamber was found to be significantly lower than the mean scores of Reverberant and Semi-reverberant chambers and the mean scores of Semi-reverberant chamber was found to be significantly higher than the mean scores of Reverberant chamber. Overall impression of Reverberant chamber is rated between “3-bad” and “4-sufficient” (Mean score: 3.83), whereas in Semi-reverberant chamber it is rated between “5-good” and “6-very good” (Mean score: 5.17) and in Anechoic chamber it is rated between “2- very bad” and “3-bad” (Mean score: 2.33).

4.4.2.10. Conclusion

The questionnaire results of second phase group were consistent with the first laboratory phase group. To understand whether the variations of the results between groups are negligible or significant, a one-way between groups ANOVA test was conducted for each question (Q1-Q9). As can be seen from Table 31 the question scores of each group did not show any significant variation ($p>0.05$) supporting that the questions were clear and well-understood by the singers, therefore valid to use for the Field stage.

Table 31 Results of one-way between groups ANOVA test conducted for the questionnaire scores of the 1st laboratory stage group (N=32) and the 2nd laboratory stage group (N=30).

Questionnaire Parameters	Group	Mean	SD	t	p
Q1- Loudness	1)1st laboratory stage group	4.78	1.571	0.352	0.725
	2) 2nd laboratory stage group	4.70	1.575		
Q2- Clarity	1)1st laboratory stage group	4.73	1.976	0.976	0.330
	2) 2nd laboratory stage group	4.46	1.837		
Q3- Reverberance	1)1st laboratory stage group	4.21	2.375	-0.137	0.891
	2) 2nd laboratory stage group	4.26	2.325		
Q4- Background Noise	1)1st laboratory stage group	1.22	0.463	0.103	0.918
	2) 2nd laboratory stage group	1.21	0.551		
Q5- Size of the room	1)1st laboratory stage group	4.51	0.562	1.747	0.083
	2) 2nd laboratory stage group	4.33	0.793		
Q6- Pleasure of Singing	1)1st laboratory stage group	3.77	1.866	-0.195	0.846
	2) 2nd laboratory stage group	3.82	1.726		
Q7- Voice Feeling	1)1st laboratory stage group	4.35	1.753	0.258	0.797
	2) 2nd laboratory stage group	4.29	1.698		
Q8- Singing Effort	1)1st laboratory stage group	3.98	1.629	0.253	0.801
	2) 2nd laboratory stage group	3.92	1.432		
Q9- Overall Impression	1)1st laboratory stage group	3.67	1.787	-0.435	0.664
	2) 2nd laboratory stage group	3.78	1.688		

4.4.3. Voice Dosimetry Results measured with Ambulatory Phonation Monitor

Results of the APM measurements undertaken with 30 singers in three chambers singing "song" and "scales" are analyzed separately in order to see whether there will be a significant difference in singer's voice dosimetry results with the new vocal loading exercise (song) and to compare the results of second laboratory group with the first group to check consistency.

A one-way repeated measures ANOVA test was conducted to compare voice dosimetry scores in each chamber for each exercise. Analysis results for "scales" and "song" exercises can be seen in Table32 and Table 33 respectively. Despite the significant change in the chambers acoustic conditions and the additional two-minute "song" exercise, singer's voice dosimetry results did not show any significant change showing consistency with the first stage findings.

Table32 Results of one-way repeated measures ANOVA test conducted for the voice dosimetry parameters measured with APM in three chambers: Anechoic chamber (AC), Reverberant Chamber (RC) and Semi-reverberant Chamber (SRC) for N=30 singers singing "scales" for two minutes.

Voice Dosimetry Parameters	Chambers	N	Mean	SD	Eta Squared	F	p	Diff
P_t (sec)	1) RC	30	101.20	10.084	0.000	0.003	0.997	-
	2) SRC	30	101.30	10.007				
	3) AC	30	101.10	7.653				
P_t (%)	1) RC	30	84.76	8.333	0.001	0.032	0.969	-
	2) SRC	30	84.99	8.417				
	3) AC	30	84.48	6.381				
F0mode	1) RC	30	300.40	149.962	0.003	0.146	0.865	-
	2) SRC	30	314.00	168.170				
	3) AC	30	323.60	182.375				
F0average	1) RC	30	373.28	169.262	0.000	0.004	0.996	-
	2) SRC	30	375.10	172.389				
	3) AC	30	371.08	170.322				
SPL	1) RC	30	84.66	7.219	0.003	0.121	0.886	-
	2) SRC	30	84.98	6.630				
	3) AC	30	85.54	7.195				
D_c	1) RC	30	37236.43	16065.254	0.000	0.016	0.985	-
	2) SRC	30	37616.27	16817.819				
	3) AC	30	36872.37	16023.519				
D_d	1) RC	30	127.10	49.878	0.002	0.078	0.925	-
	2) SRC	30	126.64	37.268				
	3) AC	30	130.92	50.010				

- : no significant difference between chambers, p>0.05

Table 33 Results of one-way repeated measures ANOVA test conducted for the voice dosimetry parameters measured with APM in three chambers: Anechoic chamber (AC), Reverberant Chamber (RC) and Semi-reverberant Chamber (SRC) for N=30 singers singing "song" for two minutes.

Voice Dosimetry Parameters	Chambers	N	Mean	SD	Eta Squared	F	p	Diff
P_t (sec)	1) RC	30	97.67	5.762	0.004	0.193	0.825	-
	2) SRC	30	96.70	7.373				
	3) AC	30	96.90	5.797				
P_t (%)	1) RC	30	81.76	4.764	0.003	0.117	0.890	-
	2) SRC	30	81.22	5.816				
	3) AC	30	81.17	4.825				
F0mode	1) RC	30	355.60	156.159	0.002	0.096	0.909	-
	2) SRC	30	348.00	143.701				
	3) AC	30	365.20	156.926				
F0average	1) RC	30	369.30	148.790	0.000	0.017	0.983	-
	2) SRC	30	367.53	147.278				
	3) AC	30	374.46	153.295				
SPL	1) RC	30	85.51	6.962	0.002	0.084	0.919	-
	2) SRC	30	85.58	7.122				
	3) AC	30	86.19	7.078				
D_c	1) RC	30	36224.37	14527.146	0.001	0.025	0.975	-
	2) SRC	30	35662.57	14307.988				
	3) AC	30	36486.07	14928.304				
D_d	1) RC	30	126.88	36.166	0.004	0.188	0.829	-
	2) SRC	30	126.07	36.093				
	3) AC	30	132.40	55.369				

- : no significant difference between chambers, p>0.05

4.4.4. Voice Dosimetry Results measured with Sound Level Meter

Frequency based analysis results for sound power levels of female and male singers will be given in this section for “scales” and “song” exercises.

4.4.4.1. Frequency based results for “female” singers singing “scales” in each chamber

Table 34 shows the results of ANOVA test conducted for sound power levels of female singers (N=13) in three chambers. A significant difference was found in the 63 Hz, 125 Hz, 2 kHz and 4 kHz octave bands whilst singing the scales exercise. The significant change observed in 63 Hz and 125 Hz octave bands between the reverberant chamber and anechoic chamber; and between the semi-reverberant chamber and anechoic chamber suggests that reverberant and semi-reverberant chambers are susceptible to transient background noise events more than the anechoic chamber rather than being related to significant change in singer’s voice levels, therefore these octave-band frequency results will not be considered.

Sound power levels of female singers whilst singing scales were significantly higher (about 6 dB) in Anechoic chamber than the Semi-reverberant chamber at 2 kHz octave band and were again significantly higher (about 5-6 dB) in Anechoic chamber than the Semi-reverberant and Reverberant chambers at 4 kHz octave band frequencies.

There was no significant change between chambers for female singers for the rest of the octave bands. When I checked the dominant energy content in the spectrum, the mean Lw shows that the energy is mainly at 500 Hz and 1 kHz octave band frequencies for the female singers while singing the “scales” exercise.

The standard deviation (SD) in the mean Lw between the chambers was found out to be 1.3 dB at 500 Hz and 0.95 dB at 1 kHz octave band frequencies as seen in Table 35. The negligible amount of variation in the sound power levels suggests that the female singers are in control of their voice whilst singing the “scales” exercise despite the extreme change between the chamber’s acoustic conditions.

Table 34 Results of one-way repeated measures ANOVA test conducted for sound power levels (Lw) of "female" singers singing "scales" in three chambers: Anechoic chamber (AC), Reverberant Chamber (RC) and Semi-reverberant Chamber (SRC) for N=13 female singers.

Octave Band	Chamber	N	Mean	SD	Eta	F	p	Diff.
63 Hz	1) RC	13	50.18	2.438	0 .617	31.444	**0.000**	3<1,2
	2) SRC	13	49.09	2.282				
	3) AC	13	42.14	3.771				
125 Hz	1) RC	13	46.23	1.603	0.819	88.239	**0.000**	3<1,2
	2) SRC	13	44.27	1.991				
	3) AC	13	35.32	3.093				
250 Hz	1) RC	13	58.84	9.074	0.019	0.378	0.688	-
	2) SRC	13	55.39	10.388				
	3) AC	13	57.39	11.999				
500 Hz	1) RC	13	87.06	4.857	0.057	1.170	0.321	-
	2) SRC	13	86.07	4.395				
	3) AC	13	88.64	4.176				
1 kHz	1) RC	13	92.55	4.071	0.026	0.513	0.603	-
	2) SRC	13	91.35	4.664				
	3) AC	13	93.23	6.000				
2 kHz	1) RC	13	79.50	6.237	0.158	3.648	**0.035**	3>2
	2) SRC	13	78.54	6.851				
	3) AC	13	84.94	7.168				
4 kHz	1) RC	13	75.37	3.875	0.241	6.194	**0.005**	3>1,2
	2) SRC	13	74.49	4.481				
	3) AC	13	80.07	5.101				

- : no significant difference between chambers, p>0.05

Table 35 Standard Deviation (SD) of sound power levels (Lw, dB) between chambers at female singers' dominant frequency whilst singing "scales".

Dominant Frequency	Chamber	Mean Lw (dB)	SD
500 Hz	1) RC	87.06	1.30
	2) SRC	86.07	
	3) AC	88.64	
1 kHz	1) RC	92.55	0.95
	2) SRC	91.35	
	3) AC	93.23	

4.4.4.2. Frequency based results for "male" singers singing "scales" in each chamber

Table 36 shows the results of ANOVA test conducted for sound power levels of male singers (N=17) in three chambers. A significant difference was seen at 63 Hz and 500 Hz octave bands whilst singing the scales exercise. The significant change in sound power levels at 63 Hz suggest that reverberant chamber is susceptible to transient background noise events more than the anechoic chamber rather than being related to significant change in singer's voice levels, therefore these octave-band frequency results will not be considered.

Sound power levels of male singers whilst singing scales were significantly higher (about 5 dB) in Anechoic chamber than the Semi-reverberant chamber at 500Hz octave band. There's no significant change found between chambers for male singers for the rest of the octave bands. When I checked the dominant energy content in the spectrum, the mean Lw shows that the energy is mainly at 500 Hz and 1 kHz octave band frequencies for the male singers while singing the “scales” exercise. The standard deviation (SD) in the mean Lw between the chambers was found to be 2.26 dB at 500 Hz and 0.96 dB at 1 kHz octave band as seen in Table 37. The negligible amount of variation in the sound power levels suggests that the male singers are in control of their voice whilst singing the “scales” exercise despite the extreme change between the chamber’s acoustic conditions.

Table 36 Results of one-way repeated measures ANOVA test conducted for sound power levels (Lw) of “male” singers singing “scales” in three chambers: Anechoic chamber (AC), Reverberant Chamber (RC) and Semi-reverberant Chamber (SRC) for N=17 male singers.

Octave Band	Chamber	N	Mean Lw (dB)	SD	Eta Squared	F	p	Diff.
63 Hz	1) RC	17	49.51	2.271	0.205	6.195	0.004	1>3
	2) SRC	17	46.65	5.997				
	3) AC	17	43.32	6.151				
125 Hz	1) RC	17	60.27	10.841	0.012	0.290	0.749	-
	2) SRC	17	57.20	13.098				
	3) AC	17	59.75	13.613				
250 Hz	1) RC	17	71.01	9.571	0.029	0.714	0.495	-
	2) SRC	17	68.12	12.757				
	3) AC	17	72.26	8.286				
500 Hz	1) RC	17	84.38	4.696	0.120	3.258	**0.047**	3>2
	2) SRC	17	82.57	4.865				
	3) AC	17	87.07	5.861				
1 kHz	1) RC	17	85.49	4.547	0.023	0.575	0.566	-
	2) SRC	17	83.68	4.871				
	3) AC	17	85.13	6.122				
2 kHz	1) RC	17	69.42	9.920	0.047	1.178	0.317	-
	2) SRC	17	68.51	9.765				
	3) AC	17	73.40	9.926				
4 kHz	1) RC	17	70.86	11.776	0.042	1.061	0.354	-
	2) SRC	17	69.41	11.146				
	3) AC	17	74.86	10.963				

- : no significant difference between chambers, p>0.05

Table 37 Standard Deviation (SD) of sound power levels (Lw, dB) between chambers at male singers’ dominant frequency whilst singing “scales”.

Dominant Frequency	Chamber	Mean Lw (dB)	SD
500 Hz	1) RC	84.38	2.26
	2) SRC	82.57	
	3) AC	87.07	
1 kHz	1) RC	85.49	0.96
	2) SRC	83.68	
	3) AC	85.13	

4.4.4.3. Frequency based results for “female” singers singing “song” in each chamber

Results of one-way repeated ANOVA analysis for sound power levels of females whilst singing “song” exercise in each chamber are given in Table 38. A significant difference was again seen at 63 Hz, 2 kHz and 4 kHz octave bands whilst singing the song exercise. The significant change in sound power levels at 63 Hz suggest that reverberant and semi-reverberant chambers are susceptible to transient background noise events more than the anechoic chamber rather than being related to significant change in singer's voice levels, therefore these octave-band frequency results will not be considered. Sound power levels of female singers whilst singing song were significantly higher (about 5 dB) in Anechoic chamber than the Semi-reverberant chamber and the Reverberant chamber at 2 kHz octave band and were again significantly higher (about 5 dB) in Anechoic chamber than the Semi-reverberant chamber at 4 kHz octave band. There was no significant change found between chambers for female singers for the rest of the octave bands. When I checked the dominant energy content in the spectrum, the mean Lw shows that the energy was mainly at 500 Hz and 1 kHz octave bands for the female singers while singing the "song" exercise. The standard deviation (SD) in the mean Lw between the chambers is found out to be 1.79 dB at 500 Hz and 0.81 dB at 1 kHz octave band as shown in 05

Table 39, again demonstrating great vocal control.

Table 38 Results of one-way repeated measures ANOVA test conducted for sound power levels (Lw) of "female" singers singing "song" in three chambers: Anechoic chamber (AC), Reverberant Chamber (RC) and Semi-reverberant Chamber (SRC) for N=13 female singers.

Octave Band	Chamber	N	Mean Lw (dB)	SD	Eta Squared	F	p	Diff.
63 Hz	1) RC	13	49.01	4.726	0.386	12.242	**0.000**	3<1,2
	2) SRC	13	48.75	2.098				
	3) AC	13	42.47	4.508				
125 Hz	1) RC	13	45.27	6.267	0.121	2.676	0.081	-
	2) SRC	13	44.93	2.079				
	3) AC	13	39.95	9.777				
250 Hz	1) RC	13	61.69	8.866	0.013	0.250	0.780	-
	2) SRC	13	60.91	8.303				
	3) AC	13	63.31	10.318				
500 Hz	1) RC	13	87.72	5.009	0.102	2.221	0.122	-
	2) SRC	13	86.44	4.290				
	3) AC	13	89.97	4.099				
1 kHz	1) RC	13	85.24	7.377	0.010	0.187	0.830	-
	2) SRC	13	84.66	7.096				
	3) AC	13	86.26	6.467				
2 kHz	1) RC	13	79.36	4.488	0.256	6.714	**0.003**	3>1,2
	2) SRC	13	79.18	4.290				
	3) AC	13	84.50	4.305				
4 kHz	1) RC	13	72.37	5.900	0.191	4.605	**0.016**	3>2
	2) SRC	13	71.41	5.900				
	3) AC	13	77.59	5.583				

- : no significant difference p>0.05

Table 39 Standard Deviation (SD) of sound power levels (Lw, dB) between chambers at female singers' dominant frequency whilst singing "song".

Dominant Frequency	Chamber	Mean Lw (dB)	SD
500 Hz	1) RC	87.72	1.79
	2) SRC	86.44	
	3) AC	89.97	
1 kHz	1) RC	85.24	0.81
	2) SRC	84.66	
	3) AC	86.26	

4.4.4.4. Frequency based results for "male" singers singing "song" in each chamber

Results of one-way repeated ANOVA analysis for sound power levels of males whilst singing "song" exercise in each chamber are given in Table 40. A significant difference was seen at 500 Hz and 2 kHz octave bands whilst singing the song exercise. Sound power levels of male singers whilst singing song were significantly higher (about 7 dB) in Anechoic chamber than the Semi-reverberant chamber and the Reverberant chamber at both 500 Hz and 2 kHz octave bands. There was no significant change found between chambers for male singers for the rest of the octave band center frequencies.

Table 40 Results of one-way repeated measures ANOVA test conducted for sound power levels (Lw) of "male" singers singing "song" in three chambers: Anechoic chamber (AC), Reverberant Chamber (RC) and Semi-reverberant Chamber (SRC) for N=17 male singers.

Octave Band	Chamber	N	Mean	SD	Eta	F	p	Diff.
63 Hz	1) RC	17	49.27	2.026	0.112	3.014	0.058	-
	2) SRC	17	46.39	5.719				
	3) AC	17	44.68	7.360				
125 Hz	1) RC	17	58.04	10.582	0.024	0.594	0.556	-
	2) SRC	17	54.70	10.879				
	3) AC	17	58.86	13.672				
250 Hz	1) RC	17	74.72	5.376	0.099	2.640	0.082	-
	2) SRC	17	71.42	7.418				
	3) AC	17	76.30	6.001				
500 Hz	1) RC	17	84.18	4.142	0.216	6.626	**0.003**	**3>2**
	2) SRC	17	80.62	5.944				
	3) AC	17	87.59	6.395				
1 kHz	1) RC	17	81.81	5.192	0.079	2.066	0.138	-
	2) SRC	17	77.96	7.575				
	3) AC	17	82.74	8.627				
2 kHz	1) RC	17	74.87	6.883	0.126	3.447	**0.040**	**3>2**
	2) SRC	17	72.07	8.083				
	3) AC	17	79.05	8.329				
4 kHz	1) RC	17	71.06	10.327	0.082	2.144	0.128	-
	2) SRC	17	67.43	10.597				
	3) AC	17	75.06	11.280				

-: no significant difference p>0.05

When I checked the dominant energy content in the spectrum, the mean Lw shows that the energy was mainly at 500 Hz and 1 kHz octave bands for the male singers while singing the "song" exercise. The standard deviation (SD) in the mean Lw between the chambers is found out to be 3.49 dB at 500 Hz and 2.53 dB at 1 kHz octave band as can be seen in Table 41. Here, there appears to be variation in male vocal performance.

Table 41 Standard Deviation (SD) of sound power levels (Lw, dB) between chambers at female singers' dominant frequency whilst singing "song".

Dominant Frequency	Chamber	Mean	SD
500 Hz	1) RC	84.18	3.49
	2) SRC	80.62	
	3) AC	87.59	
1 kHz	1) RC	81.81	2.53
	2) SRC	77.96	
	3) AC	82.74	

4.4.4.5. Conclusion of Laboratory Phases

The objective data collected with APM for voice dosimetry did not show any significant change between chambers for neither of the first or the second laboratory groups. The additional two-minute "song" exercise did not make any significant change in the voice dosimetry data collected via APM, but the informal interviews with the singers showed that the singers were already feeling tired by the end of the 12 minute singing duration (four minute singing in three chambers).The frequency based data collected during second laboratory stage via SLM showed that there's significant change in sound power levels of male and female singers at different octave band frequencies for both "scales" and "song" exercises.

Sound power levels which show significant difference at 63Hz and 125 Hz are not considered since the difference is observed between reverberant, semi-reverberant chambers and the anechoic chamber which suggests that reverberant and semi-reverberant chambers are susceptible to transient background noise events more than the anechoic chamber. A statistically significant difference was observed at 500 Hz, 2 kHz octave bands for males and at 2 kHz and 4 kHz octave bands for female singers between the chambers. The standard deviation (SD) of the energy content at the singers' dominant frequencies which are 500 Hz and 1 kHz for both males and females suggests that both genders are less consistent at their singing at 500 Hz and females are more consistent at their singing than the males at both frequencies as can be seen from Table 42.

Table 42 Standard Deviation (SD) of sound power levels (Lw,dB) of female and male singers singing "scales" and "song".

Exercise type	Lw, Scales		Lw, Song	
Dominant Frequency	SD, Female	SD, Male	SD, Female	SD, Male
500 Hz	1.30 dB	2.26 dB	1.79 dB	3.49 dB
1 kHz	0.95 dB	0.96 dB	0.81 dB	2.53 dB

The subjective data collected via questionnaire showed a significant change between chambers for both laboratory groups for all the questionnaire parameters with expected results showing that the questionnaire parameters are well understood by the singers and valid for use in the Field stage. The laboratory measurements form the exploratory stage in order to create a validated questionnaire, and to see the changes in Opera singer's voice dosimetry when introduced to extreme acoustic conditions. This allows an efficient method for data collection to be trialed ready for the Field stage. The results showed that the subjective data and the frequency based objective data collected via SLM were significantly affected by the change in room acoustic conditions, but the objective data obtained via APM showed no change with the change in room acoustic conditions. Although the results show that the focus should be on the subjective data and the frequency based objective data collected via SLM, being aware there are more variables in the real environment which might cause significant change in voice dosimetry of singers, the APM measurement procedure was decided to be used for the Field stage together with SLM measurement with no changes made to duration considering singer's comfort as they will be subject to a total of 16 minutes of singing in four practice rooms at the Field stage. There was also a pragmatic reason in that as room availability was extremely limited at the Royal Academy of Music.

4.5. Results of Field Stage

In this section results of collected data in the Field stage will be presented.

4.5.1. 'About You' Questionnaire Results

The field stage was undertaken with a total of 55 singers at the practice rooms of RAM. Singer profiles participated in this stage were obtained via "About You" questionnaire. Results are presented in Table 43 below.

Table 43 "About You" Questionnaire results showing singer profiles participated in the Field Stage, N=55 singers.

Questions	Answers	N	%
Q1- What is your gender?	Male	20	36.36
	Female	35	63.64
Q2- What is your age?	18_24	37	67.27
	25_29	17	30.91
	30_34	1	1.82
Q3- What is your voice type?	Baritone	10	18.18
	Tenor	8	14.55
	Counter Tenor	2	3.64
	Mezzo Soprano	10	18.18
	Soprano	25	45.45
Q4- How many years have you been singing?	0-5	6	10.7
	5-10	22	41.1
	10-20	26	46.4
	20-30	1	1.8
Q5- For how many years have you been taking singing lessons?	0-5	8	14.55
	5-10	31	56.36
	10-20	16	29.09
Q6- Are you still taking singing lessons?	Yes	55	100
Q7-Do you have any vocal problems?	No	55	100

4.5.2. Room Questionnaire Results

A one-way repeated measures ANOVA test was conducted to compare scores on the results of each question of "Room Questionnaire" for each practice room followed by a Bonferroni Post Hoc analysis to find the differences between groups. Results are given in Table 44 for each questionnaire parameter (Q1-Q9) and will be explained below for each questionnaire parameter.

4.5.2.1. Q1- Loudness

The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of “Loudness” scores across the practice rooms ($p<0.001$). The mean scores for the T room was found to be significantly lower than the mean scores of YG, DR and LG rooms and the mean scores of LG room was found to be significantly higher than the mean scores of DR room. There was not any significant difference between YG and LG or YG and DR rooms. In DR room “Loudness” is rated between “4-sufficient” and “5-loud” closer to “5” (Mean score:4.73) ; whereas in LG room it is rated between “5-loud” and “6-very loud” closer to “5-loud” rating (Mean score:5.24), in T room the rating is between “3-Weak” and “4-sufficient” closer to “4-sufficient” rating (Mean score:3.93) and in YG room the rating is between “4-sufficient” and “5-loud” closer to “5-loud” rating (Mean score:4.85). The room with the highest loudness rating was found to be the LG room followed by YG, DR and T room respectively**.**

4.5.2.2. Q2- Clarity

The results of the ANOVA test indicated that there was no statistically significant difference in the subjective evaluation of “Clarity” scores across the practice rooms ($p>0.05$).

4.5.2.3. Q3- Reverberance

The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of “Reverberance” scores across the practice rooms ($p<0.001$). The mean scores for T room was found to be significantly lower than the mean scores of YG, DR, and LG rooms. In T room “Reverberance” is rated close to “2-very dry” (Mean score: 2.05) and close to “4-balanced” in DR and LG rooms (Mean scores: 4.07 in both rooms) whereas in YG room it is rated between “4-sufficient” and “5-reverberant” closer to “5-reverberant” rating (Mean score: 4.60). The room with the highest rating for “Reverberance” parameter is found to be the YG room followed by LG, DR and T room respectively**.**

4.5.2.4. Q4- Background noise

The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of “Background noise” scores across the practice rooms ($p<0.001$). The mean scores for YG room is found to be significantly higher than the mean scores of LG and T rooms whereas mean scores of DR room is found to be significantly higher than LG and T rooms. There was not any significant difference between YG and DR rooms. In T room “background noise” is rated close to “3-weak” (Mean score: 3.20) and close to “4-acceptable” in LG room (Mean scores: 3.57) whereas in YG and DR rooms it is rated between “4-acceptable” and “5-loud” (Mean scores: 4.25, 4.60 respectively) The noisiest room is found to be the DR room followed by YG, LG and T rooms respectively.

4.5.2.5. Q5- Size of the room

The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of "Size of the room" scores across the practice rooms ($p<0.001$). The mean scores for YG room is found to be significantly higher than the mean scores of DR, LG and T rooms whereas mean scores of DR room is found to be significantly higher than LG and T rooms. The size of YG room is rated close to "4-sufficient" (Mean score: 3.93) and close to "3-small" in DR room (Mean scores: 3.11) whereas in LG and T rooms it is rated between "2-very small" and "3- small" (Mean scores: 2.33, 2.58 respectively). The largest room is found to be the YG room followed by DR, T and LG rooms respectively.

Table 44 Results of one-way repeated measures ANOVA test conducted for the room questionnaire scores of the field stage undertaken at the RAM practice rooms: T room (T), York Gate Room (YG), Dressing Room (DR), Lowerground Room (LG) for N=55 singers.

Questionnaire	Rooms	N	Mean	SD	Eta	F	p	Diff.
Q1- Loudness	1)DR	55	4.73	0.781	0.228	21.135	0.000***	1>3 2>1,3 4>3
	2)LG	55	5.24	0.867				
	3)T	55	3.93	1.120				
	4)YG	55	4.85	0.731				
Q2- Clarity	1)DR	55	4.40	0.955	0.019	1.355	0.390	-
	2)LG	55	4.57	1.175				
	3)T	55	4.80	1.406				
	4)YG	55	4.73	0.912				
Q3- Reverberance	1)DR	55	4.07	1.345	0.414	50.164	0.000***	3<1,2,4
	2)LG	55	4.07	1.226				
	3)T	55	2.05	1.145				
	4)YG	55	4.60	0.935				
Q4-Background Noise	1)DR	55	4.60	1.118	0.203	18.284	0.000***	1>2,3 4>2,3
	2)LG	55	3.57	1.092				
	3)T	55	3.20	1.339				
	4)YG	55	4.25	1.086				
Q5- Size of the room	1)DR	55	3.11	0.956	0.352	38.848	0.000***	1>2,3 4>1,2,3
	2)LG	55	2.33	0.911				
	3)T	55	2.58	0.658				
	4)YG	55	3.93	0.790				
Q6-Pleasure of Singing	1)DR	55	3.85	1.145	0.351	38.803	0.000***	1>3 2>3 4>1,2,3
	2)LG	55	3.80	1.203				
	3)T	55	2.60	0.974				
	4)YG	55	4.80	0.951				
Q7- Voice Feeling	1)DR	55	4.09	0.776	0.333	35.766	0.000***	3<1,2,4
	2)LG	55	4.19	1.065				
	3)T	55	2.89	0.809				
	4)YG	55	4.51	0.836				
Q8- Singing Effort	1)DR	55	4.16	0.898	0.227	21.001	0.000***	3>1,2,4
	2)LG	55	4.11	0.965				
	3)T	55	5.05	0.803				
	4)YG	55	3.84	0.739				
Q9- Overall Impression	1)DR	55	3.87	1.171	0.358	39.904	0.000***	1>3 2>3 4>1,2,3
	2)LG	55	3.81	1.260				
	3)T	55	2.56	1.014				
	4)YG	55	4.84	0.898				

*: p<0.05 **: p<0.01 ***: p<0.001 - : no correlation p>0.05

4.5.2.6. Q6- Pleasure of singing

The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of "Pleasure of singing" scores across the practice rooms ($p<0.001$). The mean scores for YG room is found to be significantly higher than the mean scores of DR, LG and T rooms whereas mean scores of DR and LG room was found to be significantly higher than T room. There wasn't any significant difference between DR and LG room scores. Pleasure of singing in YG room is rated close to "5-good" (Mean score: 4.80) and close to "4-sufficient" in DR and LG rooms (Mean scores: 3.85, 3.80 respectively) whereas T room is rated between "2- very bad" and "3-bad" (Mean score: 2.60). The highest rated room for pleasure of singing parameter is found to be the YG room followed by DR, LG and T rooms respectively.

4.5.2.7. Q7- Voice feeling

The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of "Voice feeling" scores across the practice rooms ($p<0.001$). The mean scores for T room was found to be significantly lower than the mean scores of YG, LG, and DR rooms. There wasn't any significant difference between YG, LG, and DR room scores. "Voice feeling" in YG and LG room is rated between "4-as usual" and "5-strong" (Mean score: 4.51 and 4.19 respectively) and rated close to "4-as usual" in DR room (Mean score: 4.09) whereas in T room it is rated between "2-very weak" and "3-weak" (Mean score: 2.89). The highest rated room for voice feeling parameter is found to be the YG room followed by LG, DR, and T rooms respectively.

4.5.2.8. Q8- Singing Effort

The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of "Singing effort" scores across the practice rooms ($p<0.001$). The mean scores for T room was found to be significantly higher than the mean scores of YG, LG, and DR rooms. There wasn't any significant difference between YG, LG, and DR room scores. "Singing effort" in DR and LG room is rated close to "4-as usual" (Mean score: 4.16 and 4.11 respectively) and in YG room rated between "3-less than usual" and "4-as usual" (Mean score: 3.84) again closer to "4-as usual" rating whereas in T room it is rated "5-more than usual" (Mean score: 5.05). The highest rated room for singing effort parameter is found to be the T room followed by DR, LG, and YG rooms respectively.

4.5.2.9. Q9- Overall Impression

The results of the ANOVA test indicated that there was a statistically significant difference in the subjective evaluation of "Overall Impression" scores across the practice rooms ($p<0.001$). The mean scores for YG room is found to be significantly higher than the mean scores of LG, DR and T rooms; the mean scores of LG and DR room was found to be significantly higher than the scores of T room but there wasn't any significant difference between DR and LG room scores. "Overall impression" in YG room is rated close to "5-

good" (Mean score: 4.84), LG and DR rooms are rated close to "4-sufficient" (Mean score: 3.81 and 3.87 respectively) and T room is rated between "2-very bad" and "3-bad" (Mean score: 2.56). The highest rated room is found to be the YG room followed by DR, LG and T rooms respectively.

4.5.2.10. Conclusion

Results show that the larger and more reverberant YG room got the highest ratings regarding pleasure of singing, voice feeling and overall impression whereas the most absorbent T room had the lowest ratings. The questionnaire results also show that singers felt as they sang with more effort in the more absorbent T room and with less effort in YG room compared to the other rooms. All subjective parameters that show significant difference between rooms are further examined for the analysis of the room and the singer data. Clarity parameter is excluded as it did not show any statistically significant change between rooms.

4.5.3. Voice Dosimetry Results measured with APM

A one-way repeated measures ANOVA test was conducted to compare voice dosimetry scores in practice rooms for "scales" and for "song" exercise separately, results can be seen in Table 45 and Table 46 respectively. The results did not show any significant difference between rooms for either of the exercises.

Table 45 Results of one-way repeated measures ANOVA test conducted for the voice dosimetry parameters measured with APM at the RAM practice rooms: T room (T), York Gate Room (YG), Dressing Room (DR), Lowerground Room (LG) for N=55 singers singing "scales" for two minutes.

Voice Dosimetry	Rooms	N	Mean	SD	Eta	F	p	Diff
P_t (sec)	1)DR	55	100.61	10.749	0.003	0.203	0.894	-
	2)LG	55	101.61	7.947				
	3)T	55	101.29	7.536				
	4)YG	55	101.86	6.752				
P_t (%)	1)DR	55	84.47	8.426	0.003	0.186	0.906	-
	2)LG	55	85.04	6.581				
	3)T	55	85.04	6.090				
	4)YG	55	85.48	5.473				
F0mode	1)DR	55	346.94	126.766	0.003	0.216	0.885	-
	2)LG	55	352.08	144.523				
	3)T	55	339.84	129.714				
	4)YG	55	331.76	129.713				
F0average	1)DR	55	389.19	132.074	0.000	0.016	0.997	-
	2)LG	55	387.79	133.657				
	3)T	55	390.99	132.100				
	4)YG	55	385.26	132.439				
SPL	1)DR	55	87.63	7.531	0.004	0.835	0.835	-
	2)LG	55	87.34	7.190				
	3)T	55	87.69	6.505				
	4)YG	55	88.56	6.210				
D_c	1)DR	55	39210.06	13985.208	0.000	0.009	0.999	-
	2)LG	55	39438.31	13861.135				
	3)T	55	39681.47	13697.203				
	4)YG	55	39413.43	14039.088				
D_d	1)DR	55	142.06	54.759	0.002	0.138	0.937	-
	2)LG	55	140.87	51.093				
	3)T	55	141.71	50.646				
	4)YG	55	146.81	44.814				

Table 46 Results of one-way repeated measures ANOVA test conducted for the voice dosimetry parameters measured with APM at the RAM practice rooms: T room (T), York Gate Room (YG), Dressing Room (DR), Lowerground Room (LG) for N=55 singers singing "song" for two minutes.

Voice Dosimetry	Rooms	N	Mean	SD	Eta	F	p	Diff
P_t (sec)	1)DR	55	97.31	6.121	0.001	0.052	0.984	-
	2)LG	55	97.47	6.338				
	3)T	55	97.35	6.450				
	4)YG	55	97.78	7.095				
P_t (%)	1)DR	55	81.69	4.885	0.001	0.049	0.986	-
	2)LG	55	82.06	5.140				
	3)T	55	81.72	5.317				
	4)YG	55	81.84	5.790				
F0mode	1)DR	55	386.61	133.330	0.000	0.006	0.999	-
	2)LG	55	388.08	133.742				
	3)T	55	389.31	136.909				
	4)YG	55	390.04	136.714				
F0average	1)DR	55	404.07	125.960	0.000	0.013	0.998	-
	2)LG	55	406.09	126.731				
	3)T	55	401.19	124.560				
	4)YG	55	403.37	125.655				
SPL	1)DR	55	87.81	7.848	0.006	0.408	0.748	-
	2)LG	55	87.25	7.617				
	3)T	55	88.17	7.303				
	4)YG	55	88.85	6.707				
D_c	1)DR	55	39508.88	12538.994	0.000	0.009	0.999	-
	2)LG	55	39816.51	12709.432				
	3)T	55	39429.29	12799.964				
	4)YG	55	39618.69	12912.412				
D_d	1)DR	55	142.15	48.485	0.003	0.219	0.883	-
	2)LG	55	140.39	48.826				
	3)T	55	144.68	49.682				
	4)YG	55	147.92	48.779				

- : no significant difference p>0.05

4.5.4. Voice Dosimetry Results measured with Sound Level Meter

The frequency based results collected using the SLM will be presented for males and females separately below. The sound pressure levels of singers measured via SLM in octave bands were used in order to calculate sound power levels of singers in each room, than the results were statistically compared using one-way repeated ANOVA tests.

4.5.4.1. Frequency based results for "female" singers singing "scales" in each practice room

Table 47 below shows the results of ANOVA test conducted for sound power levels of female singers (N=35) in RAM practice rooms. A significant difference is seen at 63 Hz, 125 Hz octave bands but the mean values of sound power levels at 63 Hz and 125 Hz suggest that the difference between rooms is due to background noise levels rather than singer's voice levels, therefore these octave-bands will not be considered. Sound power levels of female singers whilst singing scales did not show any significant change between rooms at any octave bands above 125 Hz. When we check the dominant energy content in the spectrum, the mean Lw shows that the energy is mainly at 500 Hz and 1kHz octave bands for the female singers while singing the "scales" exercise. The standard deviation (SD) in the mean Lw between the practice rooms shows that the amount of variation in sound power levels between rooms is very small as can be seen in Table 48 for instance 0.90 dB at 500 Hz and 0.48 dB at 1kHz.

Table 47 Results of one-way repeated measures ANOVA test conducted for sound power levels (Lw) of "female" singers singing "scales" in RAM practice rooms: T room (T), York Gate Room (YG), Dressing Room (DR), Lowerground Room (LG) for N=35 singers.

Octave Band	Chamber	N	Mean	SD	Eta	F	p	Diff.
63 Hz	1)DR	35	41.30	5.391	0.538	52.786	**0.000**	4>1,2,3 1< 2,3,4 2<3,4
	2)LG	35	41.13	4.669				
	3)T	35	48.13	3.749				
	4)YG	35	52.38	3.930				
125 Hz	1)DR	35	36.24	6.786	0.290	18.539	**0.000**	4>1,2,3
	2)LG	35	36.18	6.734				
	3)T	35	36.35	7.249				
	4)YG	35	46.03	6.035				
250 Hz	1)DR	35	62.52	4.136	0.034	1.588	0.198	-
	2)LG	35	60.39	4.402				
	3)T	35	60.71	5.109				
	4)YG	35	61.09	3.930				
500 Hz	1)DR	35	87.51	5.583	0.021	0.988	0.401	-
	2)LG	35	88.71	5.549				
	3)T	35	88.04	5.572				
	4)YG	35	86.58	4.569				
1 kHz	1)DR	35	91.21	5.546	0.006	0.260	0.854	-
	2)LG	35	91.80	4.907				
	3)T	35	90.98	5.457				
	4)YG	35	90.73	5.306				
2 kHz	1)DR	35	78.50	7.767	0.006	0.260	0.854	-
	2)LG	35	78.55	7.242				
	3)T	35	78.72	7.388				
	4)YG	35	77.30	7.854				
4 kHz	1)DR	35	74.98	6.516	0.089	0.362	0.780	-
	2)LG	35	75.91	5.630				
	3)T	35	75.78	6.260				
	4)YG	35	74.59	6.413				

- : no significant difference p>0.05

Table 48 Standard Deviation (SD) of sound power levels (Lw, dB) between practice rooms at female singers' dominant frequency whilst singing "scales".

Dominant Frequency	Chamber	MeanLw (dB)	SD
500 Hz	1)DR	87.51	0.90 dB
	2)LG	88.71	
	3)T	88.04	
	4)YG	86.58	
1 kHz	1)DR	91.21	0.48 dB
	2)LG	91.80	
	3)T	90.98	
	4)YG	90.73	

4.5.4.2. Frequency based results for "male" singers singing "scales" in each practice room

Table 49 shows the results of ANOVA test conducted for sound power levels of male singers (N=20) in RAM practice rooms. A significant difference was found at 63 Hz, octave band but the mean values of sound power levels at 63 Hz octave band suggest that the difference between rooms is due to background noise levels rather than singer's voice levels, therefore this octave-band will not be considered. Sound power levels of male singers whilst singing scales did not show any significant change between rooms at any octave bands above 63 Hz octave band.

Table 49 Results of one-way repeated measures ANOVA test conducted for sound power levels (Lw) of "male" singers singing "scales" exercise in RAM practice rooms: T room (T), York Gate Room (YG), Dressing Room (DR), Lowerground Room (LG) for N=20 singers.

Octave Band	Chamber	N	Mean	SD	Eta	F	p	Diff.
63 Hz	1)DR	20	39.96	3.509	0.442	20.083	**0.000**	3>1,2 4>1,2 2>1
	2)LG	20	42.92	6.088				
	3)T	20	48.10	5.837				
	4)YG	20	51.31	4.479				
125 Hz	1)DR	20	56.64	9.371	0.025	0.660	0.579	-
	2)LG	20	55.86	7.249				
	3)T	20	53.77	6.791				
	4)YG	20	54.00	7.310				
250 Hz	1)DR	20	68.86	4.519	0.057	1.519	0.216	-
	2)LG	20	68.48	4.794				
	3)T	20	66.01	5.131				
	4)YG	20	68.51	4.618				
500 Hz	1)DR	20	85.01	4.617	0.018	0.453	0.716	-
	2)LG	20	84.16	4.290				
	3)T	20	85.55	4.343				
	4)YG	20	84.23	4.431				
1 kHz	1)DR	20	86.46	5.497	0.009	0.219	0.883	-
	2)LG	20	85.49	5.470				
	3)T	20	85.23	5.644				
	4)YG	20	86.13	5.048				
2 kHz	1)DR	20	76.29	7.882	0.002	0.060	0.981	-
	2)LG	20	75.73	8.947				
	3)T	20	75.31	9.007				
	4)YG	20	75.26	8.801				
4 kHz	1)DR	20	75.25	6.748	0.002	0.062	0.980	-
	2)LG	20	74.36	7.498				
	3)T	20	74.97	7.268				
	4)YG	20	75.13	6.820				

- : no significant difference p>0.05

When the dominant energy content in the spectrum was analyzed, the mean Lw shows that the energy is mainly at 500 Hz and 1kHz octave bands for the male singers while singing the "scales" exercise. The standard deviation (SD) in the mean Lw between the practice rooms shows that the amount of variation in sound power levels between rooms is again very small as can be seen in Table 50, 0.66 dB at 500 Hz and 0.57 dB at 1 kHz.

Table 50 Standard Deviation (SD) of sound power levels (Lw, dB) between practice rooms at male singers' dominant frequency whilst singing "scales" exercise.

Dominant Frequency	Chamber	Mean	SD
500 Hz	1)DR	85.01	0.66 dB
	2)LG	84.16	
	3)T	85.55	
	4)YG	84.23	
1 kHz	1)DR	86.46	0.57 dB
	2)LG	85.49	
	3)T	85.23	
	4)YG	86.13	

4.5.4.3. Frequency based results for "female" singers singing "song" in each practice room

Results of one-way repeated ANOVA analysis for sound power levels of females whilst singing "song" exercise in each practice room are given in Table 51. Again, the 63 Hz and 125 Hz octave band data will be ignored as the sound power levels suggest that the difference is due to background noise levels. Sound power levels of female singers whilst singing song did not show any significant change between rooms at any octave bands above 125 Hz.

Table 51 Results of one-way repeated measures ANOVA test conducted for sound power levels (Lw) of "female" singers singing "song" exercise in RAM practice rooms: T room (T), York Gate Room (YG), Dressing Room (DR), Lowerground Room (LG) for N=35 singers.

Octave Band	Chamber	N	Mean	SD	Eta	F	p	Diff.
63 Hz	1)DR	35	41.46	4.610	0.524	49.972	**0.000**	4>1,2,3 3>1,2
	2)LG	35	41.39	4.275				
	3)T	35	47.73	3.933				
	4)YG	35	51.68	4.041				
125 Hz	1)DR	35	36.72	6.109	0.293	18.796	**0.000**	4>1,2,3
	2)LG	35	35.97	6.002				
	3)T	35	36.21	7.039				
	4)YG	35	45.45	5.802				
250 Hz	1)DR	35	62.50	7.142	0.031	1.447	0.232	-
	2)LG	35	60.66	4.876				
	3)T	35	61.77	5.417				
	4)YG	35	63.48	5.740				
500 Hz	1)DR	35	87.15	5.618	0.056	2.667	0.050	-
	2)LG	35	89.89	3.847				
	3)T	35	88.84	3.902				
	4)YG	35	88.16	2.828				
1 kHz	1)DR	35	86.83	4.749	0.011	0.521	0.668	-
	2)LG	35	87.72	4.147				
	3)T	35	86.47	4.495				
	4)YG	35	86.94	3.872				
2 kHz	1)DR	35	79.89	4.946	0.007	0.332	0.802	-
	2)LG	35	80.60	4.319				
	3)T	35	80.00	4.382				
	4)YG	35	79.59	3.669				
4 kHz	1)DR	35	73.48	4.321	0.004	0.159	0.923	-
	2)LG	35	74.08	4.268				
	3)T	35	74.07	4.621				
	4)YG	35	73.74	4.004				

- : no significant difference p>0.05

When the dominant energy content in the spectrum was analysed, the mean Lw shows that the energy is mainly at 500 Hz and 1 kHz octave bands for the female singers while singing the "song" exercise. The standard deviation (SD) in the mean Lw between the practice rooms shows that the amount of variation in sound power levels between rooms is again very small as can be seen in Table 52, 1.15 dB at 500 Hz and 0.53 dB at the 1 kHz octave band.

Table 52 Standard Deviation (SD) of sound power levels (Lw, dB) between practice rooms at female singers' dominant frequency whilst singing "song".

Dominant Frequency	Chamber	Mean	SD
500 Hz	1)DR	87.15	1.15 dB
	2)LG	89.89	
	3)T	88.84	
	4)YG	88.16	
1 kHz	1)DR	86.83	0.53 dB
	2)LG	87.72	
	3)T	86.47	
	4)YG	86.94	

4.5.4.4. Frequency based results for "male" singers singing "song" in each practice room

Results of one-way repeated ANOVA analysis for sound power levels of females whilst singing "song" exercise in each practice room are given in Table 53. Again, 63 Hz octave band has been excluded from the analysis as the sound power levels suggest that the difference is due to background noise levels.

Sound power levels of male singers whilst singing song did not show any significant change between rooms at any octave bands above 63 Hz octave band. When the dominant energy content in the spectrum was analysed, the mean Lw shows that the energy was mainly at 500 Hz and 1 kHz octave bands for the male singers while singing the "song" exercise. The standard deviation (SD) in the mean Lw between the practice rooms shows that the amount of variation in sound power levels between rooms is again very small as can be seen in Table 54, 0.53 dB at 500 Hz and 0.44 dB at the 1 kHz octave band.

4.5.5. Conclusion of Field Stage

In accordance with the first and second laboratory phases, voice dosimetry results measured with APM did not show any significant change. The frequency based voice dosimetry results measured with SLM showed difference between rooms only for the lower frequencies 63Hz and 125 Hz, but the levels at these frequencies suggest that the change is due to background noise levels rather than the singer's sound power levels. The mean values of sound power levels at higher octave-band frequencies from 250Hz to 4 kHz suggest that the levels are related to singer's levels, but the results did not show any statistical change between rooms.

The standard deviation (SD) of the energy content at the singers' dominant frequencies, 500 Hz and 1 kHz for both males and females, shows that the variation in sound power levels for both genders are negligible, as can be seen from

Table 55. Neither of the objective voice dosimetry data collected from singers using the APM or SLM at the Field stage showed any significant change, but the subjective data, as in the laboratory stage showed significant change.

Therefore for the next stage of the research, the analysis focused on the effect of room acoustics on the singer's subjective data by examining the relationship between the measured room parameters and the subjective "Room questionnaire" parameters which showed significant change between rooms in order to find out correlated parameters and to discover Opera singers' "preferred" values for practice rooms. Since subjective "Clarity" parameter did not show any significant difference between the rooms, it is excluded from further analysis.

Table 53 Results of one-way repeated measures ANOVA test conducted for sound power levels (Lw) of "male" singers singing "song" exercise in RAM practice rooms: T room (T), York Gate Room (YG), Dressing Room (DR), Lowerground Room (LG) for N=20 singers.

Octave Band	Chamber	N	Mean	SD	Eta	F	p	Diff.
63 Hz	1)DR	20	40.91	2.723	0.463	21.822	**0.000**	3>1,2 4>1,2
	2)LG	20	43.60	5.497				
	3)T	20	47.87	4.409				
	4)YG	20	51.68	5.038				
125 Hz	1)DR	20	54.70	9.851	0.076	2.072	0.111	-
	2)LG	20	53.77	8.054				
	3)T	20	49.59	7.338				
	4)YG	20	55.87	8.551				
250 Hz	1)DR	20	72.39	4.383	0.066	1.789	0.156	-
	2)LG	20	72.42	3.842				
	3)T	20	69.87	3.621				
	4)YG	20	71.69	4.143				
500 Hz	1)DR	20	83.22	4.548	0.013	0.334	0.801	-
	2)LG	20	83.61	4.162				
	3)T	20	83.72	3.887				
	4)YG	20	82.55	3.724				
1 kHz	1)DR	20	81.71	5.172	0.006	0.163	0.921	-
	2)LG	20	81.41	4.570				
	3)T	20	80.67	5.000				
	4)YG	20	81.14	4.769				
2 kHz	1)DR	20	77.81	6.093	0.003	0.083	0.969	-
	2)LG	20	77.78	6.429				
	3)T	20	77.36	6.136				
	4)YG	20	76.95	6.423				
4 kHz	1)DR	20	73.36	5.773	0.002	0.061	0.980	-
	2)LG	20	72.79	5.653				
	3)T	20	73.42	5.717				
	4)YG	20	72.90	5.982				

- : no significant difference p>0.05

Table 54 Standard Deviation (SD) of sound power levels (Lw, dB) between practice rooms at male singers' dominant frequency whilst singing "song".

Dominant Frequency	Chamber	Mean	SD
500 Hz	1)DR	83.22	0.53 dB
	2)LG	83.61	
	3)T	83.72	
	4)YG	82.55	
1 kHz	1)DR	81.71	0.44 dB
	2)LG	81.41	
	3)T	80.67	
	4)YG	81.14	

Table 55 Standard Deviation (SD) of sound power levels (Lw,dB) of female and male singers singing "scales" and "song" exercises.

Exercise type	Scales		Song	
Dominant Frequency	**SD, Female**	**SD, Male**	**SD, Female**	**SD, Male**
500 Hz	0.90 dB	0.66 dB	1.15 dB	0.53 dB
1 kHz	0.46 dB	0.57 dB	0.53 dB	0.44 dB

4.6. Analysis Results between Room and Singers' Data

Further analysis was conducted for the Field stage. In this section each analysis conducted according to the results of ANOVA tests which were previously presented in Section 4.5 will be explained together with their results.

4.6.1. Results of Pearson Correlation Analysis between room data and singer's subjective data

According to the results of one-way repeated measures ANOVA tests conducted for singer's data, the parameters that showed significant difference between RAM practice rooms further analysed together with Pearson Correlation Analysis in order to find the correlation between room data and the singers' data. Since the voice dosimetry data of the singers collected both with APM and SLM did not show any statistically significant change according to the ANOVA analysis, only singer's subjective data were used in order to find the relationship between room parameters and subjective parameters. For the subjective parameters, "Clarity" parameter did not show any significant change between rooms therefore this parameter is excluded from further analysis.. Pearson Correlation analysis was conducted for N=8 subjective parameters completed by N=55 singers in each practice room and N=70 room parameters collected for each practice room including L_{Aeq}; room length, height, width, area, volume and C80, G, T30 and EDT parameters for each octave band frequency (N=7) and for each octave band frequency combination (N=9). The parameters analysed are given in Table 56. Significant correlations were found between the following subjective and objective parameters as given in Table 57, + meaning a positive correlation, - a negative one.

Results of the Pearson correlation analysis are given in Table 58 for all statistically significant correlations (for more detail for the statistical results please see Appendix J). As can be seen from the table, for the frequency-based room parameters, significance level of correlations were frequency dependent. For example, Reverberance subjective parameter showed different levels of correlation with the C80 room parameter at different frequencies such as $C80_{(4\,kHz)}$,$C80_{(1\,kHz)}$,$C80_{(250Hz\text{-}1\,kHz)}$. In order to find the highest correlated frequency of these room parameters, parameters were grouped according to their significance degree (p) as Group 1, 2 and 3 from highest to lowest correlation: $p \leq 0.01$, $0.01 < p \leq 0.02$ and $0.02 < p \leq 0.05$ respectively. These groups were used in the regression analysis which will be explained in Section 4.6.3.

Table 56 Room and singer's parameters analysed with Pearson Correlation analysis in order to explore the relationships.

<table>
<tr><th>Room Data
N=70 parameter</th><th>Singer's Subjective Data (Questionnaire)
N=8 parameter</th></tr>
<tr><td><u>T30</u>
$T30_{(63Hz)}$, $T30_{(125Hz)}$, $T30_{(250Hz)}$, $T30_{(500Hz)}$, $T30_{(1\,kHz)}$, $T30_{(2\,kHz)}$, $T30_{(4\,kHz)}$, $T30_{(125\text{-}250Hz)}$, $T30_{(250\text{-}500Hz)}$, $T30_{(500Hz\text{-}1\,kHz)}$, $T30_{(1\,kHz\text{-}2\,kHz)}$, $T30_{(mid)}$, $T30_{(low)}$, $T30_{(125\text{-}500Hz)}$, $T30_{(250Hz\text{-}1\,kHz)}$, $T30_{(125Hz\text{-}1\,kHz)}$</td><td rowspan="10">Loudness
Reverberance
Background noise
Size of the room
Pleasure of singing
Voice feeling
Singing Effort
Overall Impression</td></tr>
<tr><td><u>EDT</u>
$EDT_{(63Hz)}$, $EDT_{(125Hz)}$, $EDT_{(250Hz)}$, $EDT_{(500Hz)}$, $EDT_{(1\,kHz)}$, $EDT_{(2\,kHz)}$, $EDT_{(4\,kHz)}$, $EDT_{(125\text{-}250Hz)}$, $EDT_{(250\text{-}500Hz)}$, $EDT_{(500Hz\text{-}1\,kHz)}$, $EDT_{(1\,kHz\text{-}2\,kHz)}$, $EDT_{(mid)}$, $EDT_{(low)}$, $EDT_{(125\text{-}500Hz)}$, $EDT_{(250Hz\text{-}1\,kHz)}$, $EDT_{(125Hz\text{-}1\,kHz)}$</td></tr>
<tr><td><u>C80</u>
$C80_{(63Hz)}$, $C80_{(125Hz)}$, $C80_{(250Hz)}$, $C80_{(500Hz)}$, $C80_{(1\,kHz)}$, $C80_{(2\,kHz)}$, $C80_{(4\,kHz)}$, $C80_{(125\text{-}250Hz)}$, $C80_{(250\text{-}500Hz)}$, $C80_{(500Hz\text{-}1\,kHz)}$, $C80_{(1\,kHz\text{-}2\,kHz)}$, $C80_{(mid)}$, $C80_{(low)}$, $C80_{(125\text{-}500Hz)}$, $C80_{(250Hz\text{-}1\,kHz)}$, $C80_{(125Hz\text{-}1\,kHz)}$</td></tr>
<tr><td><u>G</u>
$G_{(63Hz)}$, $G_{(125Hz)}$, $G_{(250Hz)}$, $G_{(500Hz)}$, $G_{(1\,kHz)}$, $G_{(2\,kHz)}$, $G_{(4\,kHz)}$, $G_{(125\text{-}250Hz)}$, $G_{(250\text{-}500Hz)}$, $G_{(500Hz\text{-}1\,kHz)}$, $G_{(1\,kHz\text{-}2\,kHz)}$, $G_{(mid)}$, $G_{(low)}$, $G_{(125\text{-}500Hz)}$, $G_{(250Hz\text{-}1\,kHz)}$, $G_{(125Hz\text{-}1\,kHz)}$</td></tr>
<tr><td>L_{Aeq}</td></tr>
<tr><td>Room Area</td></tr>
<tr><td>Room Volume</td></tr>
<tr><td>Room Width</td></tr>
<tr><td>Room Length</td></tr>
<tr><td>Room Height</td></tr>
</table>

Table 57 Correlation results for objective room parameters and subjective questionnaire parameters: + shows positive correlation,− shows negative correlation and n/c shows no correlation.

Subjective Parameters (Questionnaire)	Objective Parameters (Room)									
	T30	EDT	C80	G	L_{Aeq}	Room Area	Room Volume	Room Width	Room Length	Room Height
Reverberance	+	n/c	–	n/c	n/c	n/a	n/c	n/c	n/c	n/c
Loudness	n/c	n/c	n/c	+	n/c	n/c	n/c	n/c	n/c	n/c
Background noise	n/c	n/c	n/c	n/c	+	n/c	n/c	n/c	n/c	n/c
Size of the room	n/c	n/c	n/c	n/c	n/c	+	+	n/c	+	n/c
Pleasure of singing	+	+	–	n/c	n/c	n/c	n/c	n/c	n/c	n/c
Voice feeling	+	n/c	–	n/c	n/c	n/c	n/c	n/c	n/c	n/c
Singing effort	–	–	+	n/c	n/c	n/c	n/c	n/c	n/c	n/c
Overall impression	+	+	–	n/c	n/c	n/c	n/c	n/c	n/c	n/c

Table 58 Results of Pearson correlation analysis grouped for all correlated parameters from highest to lowest significance degree. (n/c : no correlation)

Groups	Group 1 $p \leq 0.01$		Group 2 $0.01 < p \leq 0.02$		Group 3 $0.02 < p \leq 0.05$	
Subjective Parameters	Room Parameter	Sig.2-tailed	Room Parameter	Sig.2-tailed	Room Parameter	Sig.2-tailed
Reverberance	C80 (4 kHz)	.004	C80 (1 kHz) C80(500Hz-1 kHz) C80 (500Hz) C80 (mid) C80(250Hz-1 kHz)	.012 .012 .014 .016 .016	C80(250-500Hz) C80(125-1kHz) C80(1 kHz -2kHz) C80 (125-500Hz) C80 (2 kHz) T30(4 kHz)	.022 .026 .031 .040 .043 .045
Loudness	n/c	n/c	n/c	n/c	G(250-500Hz) G(500Hz) G(500Hz-1kHz)	.047 .048 .048
Background noise	n/c	n/c	n/c	n/c	$L_{Aeq,2min}$	.044
Size of the room	Room length	.007	Room area	.012	Room volume	.035
Pleasure of singing	C80 (2kHz) T30(4kHz) C80 (1kHz-2kHz) EDT (4kHz) EDT(500Hz-1kHz) EDT (1kHz) C80(low)	.001 .002 .003 .004 .007 .009 .010	C80 (1kHz) EDT (1kHz-2kHz) C80(500Hz-1kHz) EDT(mid) C80 (mid) C80(250Hz-1kHz) C80(125Hz-1kHz)	.014 .017 .017 .018 .018 .018 .019	T30(250Hz-1kHz) T30(250-500Hz) C80 (500Hz) EDT (500Hz) C80 (250-500Hz) EDT (250Hz-1kHz) C80 (125-500Hz) T30(500Hz) T30(63Hz) T30(500Hz-1kHz) T30(mid) EDT(63Hz) T30(1kHz-2kHz) C80 (125Hz) T30(1kHz) C80 (250Hz) C80(125-250Hz) T30(2kHz) C80 (4kHz)	.021 .022 .023 .025 .027 .028 .030 .037 .039 .039 .039 .042 .044 .044 .045 .045 .046 .048 .049
Voice feeling	n/c	n/c	C80 (4kHz) C80 (1kHz) C80(500Hz-1kHz) C80 (500Hz) C80 (mid) C80(250Hz-1kHz)	.011 .013 .015 .020 .020 .020	C80(1kHz-2kHz) C80 (250-500Hz) C80(125Hz-1kHz) C80 (2kHz) T30(4kHz)	.030 .030 .033 .042 .045
Singing effort	C80 (4kHz) C80 (1kHz)	.009 .009	C80(500Hz-1kHz) C80 (500Hz) C80 (mid) C80(250Hz-1kHz) C80(1kHz-2kHz) C80(125Hz-1kHz)	.011 .016 .016 .016 .024 .027	C80 (125-500Hz) C80 (250-500Hz) C80 (2kHz) T30(4kHz) EDT (4kHz) C80(low) EDT (1kHz)	.025 .032 .035 .037 .047 .049 .050
Overall impression	C80 (2kHz) T30(4kHz) C80 (1kHz-2kHz) EDT (4kHz) EDT(500Hz-1kHz) C80(low) EDT (1kHz)	.001 .002 .003 .004 .008 .009 .010	C80 (1kHz) C80(500Hz-1kHz) C80(250Hz-1kHz) C80 (mid) EDT (1kHz-2kHz) C80(125Hz-1kHz) EDT(mid) T30(250Hz-1kHz) T30(250-500Hz)	.013 .016 .017 .017 .018 .018 .019 .022 .024	C80 (500Hz) EDT (500Hz) C80 (250-500Hz) C80(125-500Hz) EDT (250Hz-1kHz) T30(500Hz) T30(63Hz) T30(500Hz-1kHz) T30(mid) C80 (125Hz) C80 (250Hz) EDT(63Hz) C80 (125-250Hz) T30(1kHz-2kHz) T30(1kHz) C80(4kHz)	.022 .025 .025 .028 .029 .038 .040 .040 .041 .043 .044 .044 .045 .046 .047 .047

4.6.2. Results of singers' preferred ratings for each Subjective Parameter

As explained in Section 3.11, preferred ratings for each questionnaire parameter were collected from each singer. Table 59 presents the results of the descriptive statistics for the preferred ratings of each singer for each subjective parameter. Only the preferred ratings of the 7-point Likert type scale are presented.

Table 59 Results of descriptive statistics showing the preferred ratings of N=55 singers for each subjective parameter. (Ratings 1-7)

Subjective Parameter	Preferred rating	N	%
Loudness	Sufficient (4)	32	58.2
	Loud (5)	23	41.8
Reverberance	A little reverberant (3)	2	3.6
	Balanced (4)	34	61.8
	Reverberant (5)	19	34.5
Size of the room	Sufficient (4)	22	40.0
	Large (5)	33	60.0
Background noise	Not audible (1)	2	3.6
	Very weak (2)	30	54.5
	Weak (3)	23	41.8
Pleasure of singing	Good (5)	28	50.9
	Very good (6)	27	49.1
Voice feeling	As usual (4)	35	63.6
	Strong (5)	20	36.4
Singing Effort	As usual (4)	55	100.0
Overall Impression	Good (5)	25	45.5
	Very good (6)	30	54.5

According to the results 58.2% of the singers preferred "Loud" rating and 41.8% of the singers preferred "Sufficient" rating for Loudness parameter; 3.6% of the singers preferred "A little reverberant", 61.8% of the singers preferred "Balanced" and 34.5% of the singers preferred "Reverberant" rating for the Reverberance subjective parameter. "Sufficient" rating was preferred by 40% of the singers and "Large" rating was preferred by 60% of the singers for the Size of the room subjective parameter. For Background noise subjective parameter, 3.6% of the singers preferred "not audible", 54.5% preferred "very weak", and 41.8% preferred "weak" ratings. 50.9%, 49.1% of the singers preferred "Good" and "Very good" ratings respectively for the Pleasure of singing subjective parameter. 63.6% of the singers preferred "As usual" rating and 36.4% of the singers preferred "Strong" rating for the voice feeling parameter. All of the 55 singers (100%) preferred "As usual" rating for the Singing effort parameter. 45.5% of the singers preferred "Good" rating and 54.5% of the singers preferred "Very good" rating for the Overall impression subjective parameter.

All preferred ratings for each parameter were used for the regression analysis in order to find the target values of correlated room parameters corresponding to these ratings with the exception of "A little reverberant" rating for Reverberance parameter and "Not audible" parameter for the Background noise parameter since only a few of the singers preferred these ratings. Preferred ratings of subjective parameters which were used in the regression analysis are presented in Table 60 below.

Table 60 Preferred ratings of singers for each subjective parameter, ratings 1-7

Subjective parameters	Ratings of subjective parameters	
Loudness	4 (sufficient)	5 (loud)
Reverberance	4 (balanced)	5 (reverberant)
Background noise	2 (very weak)	3 (weak)
Size of the room	4 (sufficient)	5 (large)
Pleasure of singing	5 (good)	6 (very good)
Voice feeling	4 (as usual)	5 (strong)
Singing effort	4 (as usual)	
Overall impression	5 (good)	6 (very good)

4.6.3. Results of Regression Analysis between room data and singer's subjective data

As previously explained, according to the results of Pearson Correlation analysis, correlated parameters were grouped according to their significance degree (p) as there were three levels of significance observed; from highest to lowest $p \leq 0.01$, $0.01 < p \leq 0.02$ and $0.02 < p \leq 0.05$ as Group1, Group 2 and Group 3 respectively. All of the correlated parameters in Group 1 and 2 were examined for the regression analysis for each subjective parameter as they showed the highest correlation. The room parameters in Group 3 were only examined for the highest correlated parameter when there was no correlation in Group 1 and 2. Lower correlations in Group 3 examined if and only if they have an effect on the target ratings of the subjective parameter in consideration due to common correlations which will be explained in the next section.

4.6.3.1. Common Correlations

As can be seen from Table 58 in Section 4.6.1, different subjective parameters were found to show correlation with the same room parameters according to the results of Pearson Correlation analysis. From all eight subjective parameter: Reverberance, Pleasure of singing, Voice feeling, Singing effort and the Overall impression showed common correlation. From the room parameters that showed common correlation with a number of these subjective parameters, only the ones that showed correlation with all five subjective parameters were further examined through regression analysis in order to find the minimum and maximum values of these room parameters that provide the target ratings for all their common subjective parameters. The subjective paramaters and room parameters that show common correlation are presented in Table 61.

Table 61 Subjective parameters and the room parameters that show common correlation, + : parameters that show correlation, n/c : no correlation.

Room Parameters	Subjective Parameters				
	Reverberance	Voice feeling	Singing effort	Pleasure of singing	Overall impression
C80 **(500Hz)**	+	+	+	+	+
C80 **(1kHz)**	+	+	+	+	+
C80 **(2 kHz)**	+	+	+	+	+
C80 **(4 kHz)**	+	+	+	+	+
C80 **(1 kHz -2 kHz)**	+	+	+	+	+
C80 **(500Hz-1kHz)**	+	+	+	+	+
C80 **(mid)**	+	+	+	+	+
C80 **(250-500 Hz)**	+	+	+	+	+
C80 **(250-1 kHz)**	+	+	+	+	+
C80 **(125Hz-1 kHz)**	+	+	+	+	+
T30 **(4 kHz)**	+	+	+	+	+
C80 (125-500Hz)	+	n/c	+	+	+
C80 (125-250Hz)	n/c	n/c	n/c	+	+
C80 (low)	n/c	n/c	n/c	+	+
EDT(4 kHz)	n/c	n/c	+	+	+
EDT(1 kHz)	n/c	n/c	+	+	+
EDT(500Hz-1k)	n/c	n/c	n/c	+	+
EDT(1 kHz -2 kHz)	n/c	n/c	n/c	+	+
EDT (mid)	n/c	n/c	n/c	+	+
T30 (250-500Hz)	n/c	n/c	n/c	+	+
T30 (250Hz-1 kHz)	n/c	n/c	n/c	+	+

4.6.3.2. Correlations that are not common

In addition to common correlations, “Loudness”, “Background noise” and “Size of the room” subjective parameters were separately examined as they showed correlation with only one objective room parameter which was not common. For these parameters only the correlations that showed the highest significance were examined via regression analysis such as “Background noise” subjective parameter and “L_{Aeq}” objective room parameter or “Loudness” subjective parameter and “G” objective room parameter. However, for “Size of the room” subjective parameter although it showed highest correlation with the “Room length” objective room parameter, “Room area” and “Room volume” parameters were also considered in order to find the singers’ preferred room dimensions.

4.6.3.3. Parameters chosen for Regression Analysis

The subjective and their correlated room parameters selected for regression analysis are presented in Table 62. Regression analysis was conducted by considering the room parameters as independent variables (x-axis) as they are not dependent on the subjective parameters and by considering the subjective parameters as dependent variables (y-axis) as they depend on the room parameters. Therefore y-axis of the regression analysis graphs show the mean values of each question answered by N=55 singers for each practice room N=4 (YG, LG, DR, T rooms) on a 7-point Likert-type scale. The x-axis shows the corresponding room parameter values for each answer obtained via regression analysis. For example, for regression analysis results of Reverberance subjective parameter and C80 (4kHz) room parameter, as shown in Figure 7.

Table 62 Room parameters chosen for the regression analysis for each subjective parameter.

Subjective parameters	Room parameters
Loudness	$G_{(250\text{-}500Hz)}$
Background noise	LAeq,2min
Size of the room	Room length Room area Room volume
Common parameters	
Subjective	**Objective**
Reverberance Pleasure of singing Voice feeling Singing Effort Overall Impression	$C80_{(500Hz)}$ $C80_{(1kHz)}$ $C80_{(2kHz)}$ $C80_{(4kHz)}$ $C80_{(1kHz\text{-}2kHz)}$ $C80_{(500Hz\text{-}1kHz)}$ $C80_{(250Hz\text{-}500Hz)}$ $C80_{(250Hz\text{-}1kHz)}$ $C80_{(125Hz\text{-}1kHz)}$ $C80_{(mid)}$ $T30_{(4kHz)}$

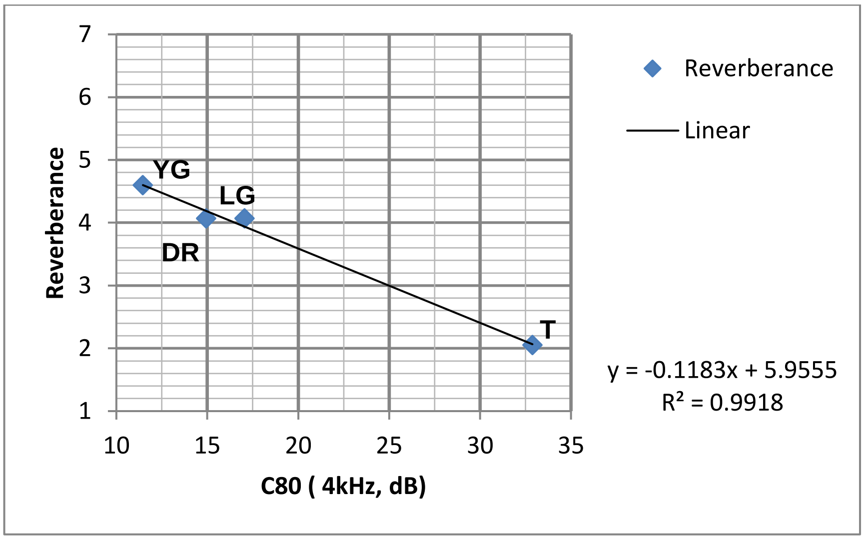

Figure 7 Example for regression model between Reverberance subjective parameter and $C80_{(4kHz)}$ room parameter.

4.6.4. Results of Regression Analysis for each Subjective Parameter

Results of regression analysis will be presented in this section for each subjective parameter and its correlated room parameters as given in Table 62. Target values for each room parameter for the preferred ratings of subjective parameters will be presented.

4.6.4.1. Results for "Loudness" subjective parameter

Table 63 shows the Pearson Correlation analysis for the Loudness parameter. The highest correlation for Loudness was found to be the strength parameter for the average of 250-500 Hz octave bands, therefore $G_{(250\text{-}500Hz)}$ has been chosen for further analysis. As can be seen from the results, the Loudness subjective parameter showed a high degree of positive correlation with G $_{(250\text{-}500Hz)}$ room parameter.

Table 63 Pearson Correlation results for Loudness parameter and chosen room parameter for the regression analysis.

Subjective Parameter	Room parameter	Pearson Correlation	P Sig. 2-tailed
Loudness	$G_{(250\text{-}500Hz)}$, dB	.953	.047

Table 64 shows the predicted values of G $_{(250\text{-}500Hz)}$ room parameter by using regression equation in order to obtain "sufficient" (4) and "loud" (5) ratings for the subjective Loudness parameter. According to the results, the preferred rating for G $_{(250\text{-}500Hz)}$ was found to be 27.66dB in order to get a "sufficient" rating and increases to 30.69dB for the "loud" rating. A regression model between these parameters is shown in Figure 8. The detailed regression analysis results of all the room parameters at different frequencies that showed correlation for this subjective parameter can be found in Appendix K.

Table 64 Predicted values of $G_{(250\text{-}500Hz)}$ room parameter corresponding to the subjective "sufficient" (4) and "loud"(5) preferred ratings of Loudness subjective parameter.

Room parameters	Regression Equation	Questionnaire	Room parameter	Questionnaire	Room parameter
		y (sufficient)	x (predicted)	y (loud)	x (predicted)
$G_{(250\text{-}500Hz)}$, dB	y = 0.3297x - 5.1194	4	27.66 dB	5	30.69 dB

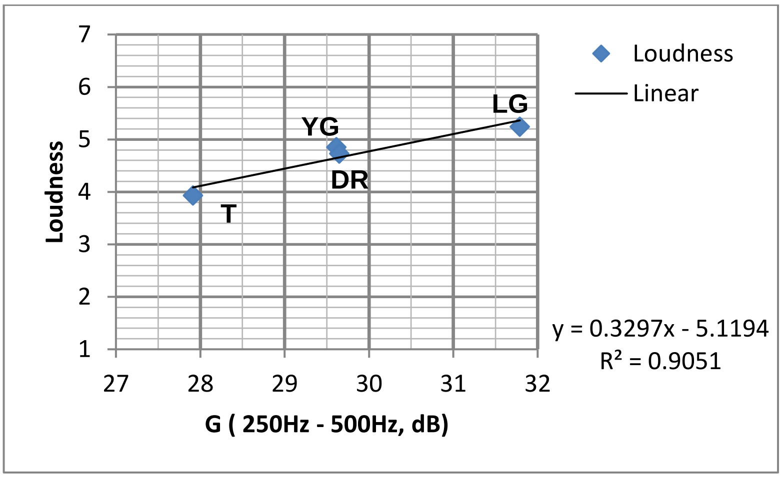

Figure 8 Regression model between subjective Loudness parameter and G $_{(250\text{-}500Hz)}$ room parameter. Points show mean values for Loudness parameter answered via N=55 singers in each practice room.

4.6.4.2. Results for "Reverberance" subjective parameter

Table 65 shows the Pearson Correlation analysis result for the correlated parameters chosen for Reverberance parameter. As can be seen from the results, the Reverberance subjective parameter showed negative correlation with several octave bands and octave-band combinations for the C80 room parameter. A lower level of positive correlation was found for the T30 parameter. The highest correlation was found for 4kHz octave-band for both C80 parameter and the T30 parameters, regression analysis results for the frequencies that show highest correlation are given in Figure 9 and Figure 10 for $C80_{(4kHz)}$ and $T30_{(4kHz)}$ respectively.

Table 65 Pearson Correlation results for Reverberance parameter and chosen room parameters for the regression analysis.

Subjective Parameter	Room parameter	Pearson Correlation	P Sig. 2-tailed
Reverberance	$C80_{(4kHz)}$	-.996	.004
	$C80_{(1kHz)}$	-.988	.012
	$C80_{(500Hz-1kHz)}$	-.988	.012
	$C80_{(500Hz)}$	-.986	.014
	$C80_{(250Hz-1kHz)}$	-984	.016
	$C80_{(mid)}$	-.984	.016
	$C80_{(250Hz-500Hz)}$	-.978	.022
	$C80_{(125Hz-1kHz)}$	-974	.026
	$C80_{(1kHz-2kHz)}$	-.969	.031
	$C80_{(2kHz)}$	-.957	.043
	$T30_{(4 kHz)}$	.955	.045

Table 66 shows the predicted values of the room parameters at their highest correlated frequency according to regression analysis in order to obtain preferred "balanced" (4) and "reverberant" (5) ratings for the subjective Reverberance parameter. According to the results, predicted values for the C80 room parameter at 4 kHz was found to be 8.08 dB in order to reach the "reverberant" rating, increasing to 16.53dB in order to obtain "balanced" rating.

For T30 room parameter at 4 kHz the "balanced" rating was reached at 0.37sec and increases to 0.5sec in order to reach the "reverberant" rating. The Reverberance parameter will be further examined with other subjective parameters that showed common correlation in the next section. The detailed regression analysis results of all the room parameters at different frequencies that showed correlation for this subjective parameter can be found in Appendix L.

Table 66 Predicted values of C80(4kHz) and T30(4kHz) room parameters corresponding to the subjective "balanced" (4) and "sufficient"(5) preferred ratings of Reverberance subjective parameter.

Room parameters	Regression Equation	Reverberance rating	Room parameter	Reverberance rating	Room parameter
		y balanced	x predicted	y reverberant	x predicted
$C80_{(4kHz)}$, dB	$y = -0.1183x + 5.9555$	4	16.53 dB	5	8.08 dB
$T30_{(4kHz)}$, sec	$y = 7.6794x + 1.1441$	4	0.37 sec	5	0.50 sec

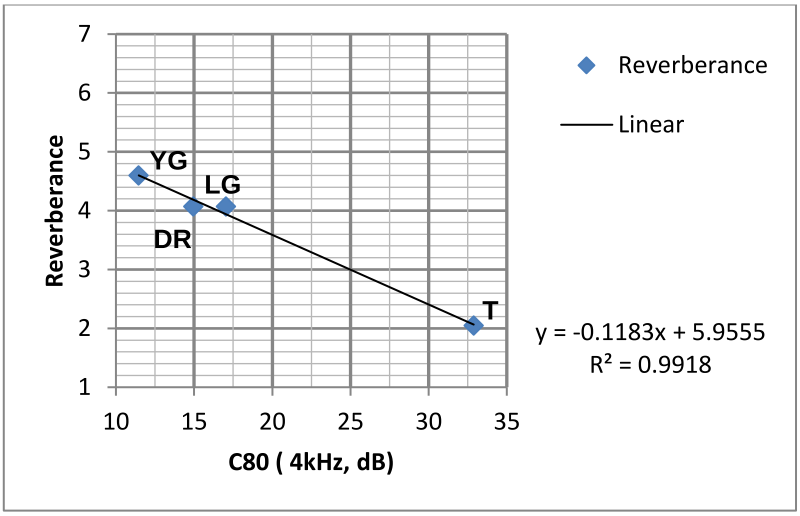

Figure 9 Regression model between subjective Reverberance parameter and C80$_{(4kHz)}$ room parameter. Points show mean values for Reverberance parameter answered via N=55 singers in each practice room.

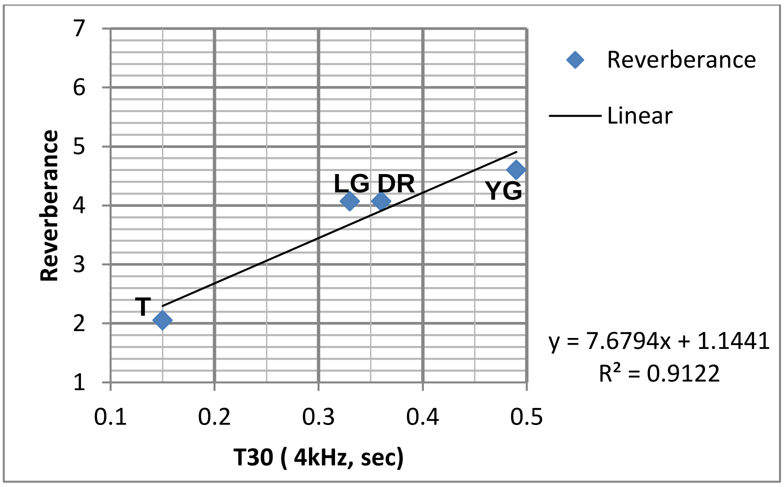

Figure 10 Regression model between subjective Reverberance parameter and T30$_{(4kHz)}$ room parameter. Points show mean values for Reverberance parameter answered via N=55 singers in each practice room.

4.6.4.3. Results for "Size of the room" subjective parameter

Table 67 and Table 68 shows the predicted values of the correlated room parameters by using regression equation in order to obtain "sufficient" (4) and "large" (5) preferred ratings for the subjective "Size of the room" parameter respectively. Since values for room-width and room-height parameters did not show any correlation with the "Size of the room" subjective parameter, these parameters were calculated from the predicted values of the room length, volume and area parameters which did show a correlation. According to the results, the "sufficient" size preferred rating for a practice room was obtained when the room volume was 35.43 m^3, with a room area, room length, height and width of 13.28 m^2, 5.78 m; 2.30 m and 2.67 m respectively. Preferred "large" size rating for a practice room was obtained when the room volume was 49.9 m^3, with a room area, room length, height, and width of 18.01 m^2, 7.53 m; 2.77 m and 2.39 m respectively. The detailed regression analysis results of all the room parameters at different frequencies that showed correlation for this subjective parameter can be found in Appendix K.

Table 67 Predicted values of room parameters corresponding to the "sufficient" (4) preferred rating for size of the room subjective parameter. n/a shows the parameters that are calculated from predicted values of room parameters that showed correlation.

Room parameters	Regression Equation	Questionnaire y (sufficient)	Room parameter x (predicted)
Room length	y = 0.5708x + 0.703	4	5.78 m
Room area	y = 0.2115x + 1.191	4	13.28 m^2
Room volume	y = 0.0691x + 1.5521	4	35.43 m^3
Calculated height	n/a	n/a	2.67 m
Calculated width	n/a	n/a	2.30 m

Table 68 Predicted values of room parameters corresponding to the "large" (5) preferred rating for size of the room subjective parameter. n/a shows the parameters that are calculated from predicted values of room parameters that showed correlation.

Room parameters	Regression Equation	Questionnaire y (large)	Room parameter x (predicted)
Room length	y = 0.5708x + 0.703	5	7.53 m
Room area	y = 0.2115x + 1.191	5	18.01 m^2
Room volume	y = 0.0691x + 1.5521	5	49.90 m^3
Calculated height	n/a	n/a	2.77 m
Calculated width	n/a	n/a	2.39 m

4.6.4.4. Results of "Background noise" subjective parameter

Table 69 shows the Pearson Correlation analysis result for the subjective Background noise parameter and the measured $L_{Aeq,2min}$ representative background noise level, as can be seen from the results; it showed a positive relationship with the measured $L_{Aeq,2min}$ room parameter.

Table 69 Pearson Correlation results for subjective Background noise parameter and measured representative background noise level (L_{Aeq}) room parameter.

Subjective Parameter	Room parameter	Pearson Correlation	P Sig. 2-tailed
Background noise	$L_{Aeq,2min}$	.956	.044

Table 70 shows the predicted values of L_{Aeq} by using the regression equation in order to obtain "very weak" (2) and "weak" (3) preferred ratings and "acceptable" (4) rating in order to find out the maximum acceptable level for the subjective Background noise parameter. According to the results, in order to reach "very weak" background noise subjective rating the level was found to be 35.3 dBA, increasing to 38.8 dBA in order to reach "weak" rating and the maximum acceptable level for background noise was found to be 42.3 dBA.

Regression model between these parameters can be seen in Figure 11. The detailed regression analysis results for this subjective parameter can be found in Appendix K.

Table 70 Predicted values of room parameters corresponding to the preferred "very weak"(2), "weak"(3) preferred ratings of singers and the maximum "acceptable"(4) rating for background noise subjective parameter.

Room parameters	Regression Equation	Questionnaire y (ratings)	Room parameter x (predicted)
L_{Aeq}	y = 0.2867x - 8.1235	2 (very weak)	35.3 dBA
L_{Aeq}		3 (weak)	38.8 dBA
L_{Aeq}		4 (acceptable)	42.3 dBA

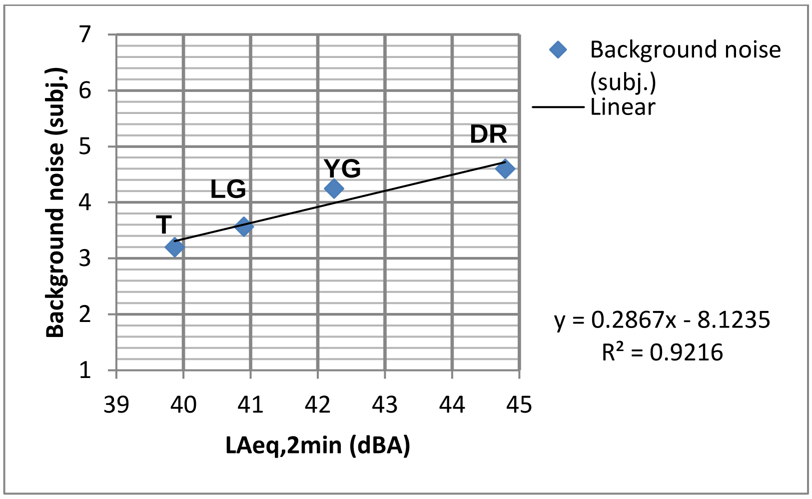

Figure 11 Regression model between subjective Background noise parameter and measured representative background noise level: LAeq,2min as the room parameter. Points show mean values for subjective Background noise parameter answered via N=55 singers in each practice room.

4.6.4.5. Results for "Pleasure of singing" subjective parameter

Table 71 shows the Pearson Correlation analysis result for the correlated parameters chosen for Pleasure of singing parameter. As can be seen from the results, the Pleasure of singing subjective parameter showed negative correlation with several octave bands and octave-band combinations for C80 room parameter and a positive correlation with EDT and T30 parameters.

The highest correlation was observed at 2 kHz for C80 and at 4 kHz for T30 and EDT parameters. Regression analysis results for the octave bands that show highest correlation for each parameter are given in Figure 12, Figure 13 and Figure 14 for $C80_{(2kHz)}$ and $T30_{(4kHz)}$ and $EDT_{(4kHz)}$ respectively. Table 72 shows the predicted values of the room parameters at their highest correlated frequency according to regression analysis in order to obtain "good" (5) and "very good" (6) preferred ratings for the subjective Pleasure of singing parameter. According to the results C80 parameter at 2 kHz octave band was found to be 7.45 dB in order to obtain "good" rating, whereas the level decreases to -0.3 dB in order to reach "very good" rating for pleasure of singing subjective parameter.

Table 71 Pearson Correlation results for Pleasure of singing parameter and chosen room parameters for the regression analysis.

Subjective Parameter	Room parameter	Pearson Correlation	P (Sig. 2-tailed)
Pleasure of singing	$C80_{(2kHz)}$	-.999	.001
	$T30_{(4kHz)}$	.998	.002
	$EDT_{(4kHz)}$	.996	.004
	$C80_{(1kHz-2kHz)}$	-.997	.003
	$EDT_{(500Hz-1kHz)}$	.993	.007
	$EDT_{(1kHz)}$	.991	.009
	$C80_{(low)}$	-.990	.010
	$C80_{(1kHz)}$	-.986	.014
	$C80_{(mid)}$	-.982	.018
	$C80_{(500Hz-1kHz)}$	-.983	.017
	$EDT_{(1kHz-2kHz)}$	.983	.017
	$EDT_{(mid)}$	.982	.018
	$C80_{(250Hz-1kHz)}$	-.982	.018
	$C80_{(125Hz-1kHz)}$	-.981	.019
	$T30_{(250Hz-1kHz)}$	.979	.021
	$T30_{(250-500Hz)}$	.978	.022
	$C80_{(500Hz)}$	-.977	.023
	$C80_{(250Hz-500Hz)}$	-.973	.027
	$C80_{(4kHz)}$	-.951	.049

For T30 parameter at the 4 kHz octave band a “good” rating was found out to be at 0.53sec increasing to 0.68 sec for the “very good” rating; whereas for EDT parameter at the same frequency the “good” rating is found to be at 0.44 sec, increasing to 0.55sec in order to reach the “very good” rating for pleasure of singing rating. The “acceptable” (4) rating was also examined for the pleasure of singing subjective parameter in order to find the maximum acceptable value for C80 parameter and the minimum acceptable values for the T30 and EDT parameters.

As can be seen in Table 73 the results showed that the maximum acceptable value for $C80_{(2kHz)}$ room parameter was found to be 15.16 dB and the minimum acceptable values for $T30_{(4kHz)}$ and $EDT_{(4kHz)}$ were found to be 0.37 sec, 0.32 sec respectively. Pleasure of singing parameter will be further examined with other subjective parameters that showed common correlation Section 4.6.5. For the detailed regression analysis results of all the frequencies of room parameters that showed correlation with pleasure of singing please see Appendix M.

Table 72 Predicted values of room parameters corresponding to preferred ratings of singers for pleasure of singing parameter.

Room parameters	Regression Equation	Pleasure of singing rating	Room parameter	Pleasure of singing rating	Room parameter
		y good	x predicted	y very good	x predicted
$C80_{(2kHz)}$, dB	y = -0.1298x + 5.9673	5	7.45 dB	6	-0.3 dB
$T30_{(4kHz)}$, sec	y = 6.4183x + 1.6284	5	0.53sec	6	0.68sec
$EDT_{(4kHz)}$, sec	y = 8.372x + 1.3555	5	0.44 sec	6	0.55 sec

Table 73 Predicted values of room parameters corresponding to "acceptable"(4) rating for pleasure of singing parameter.

Room parameters	Regression Equation	Pleasure of singing rating	Room parameter
		y acceptable	x predicted
$C80_{(2kHz)}$, dB	y = -0.1298x + 5.9673	4	15.2 dB
$T30_{(4kHz)}$, sec	y = 6.4183x + 1.6284	4	0.37sec
$EDT_{(4kHz)}$, sec	y = 8.372x + 1.3555	4	0.32 sec

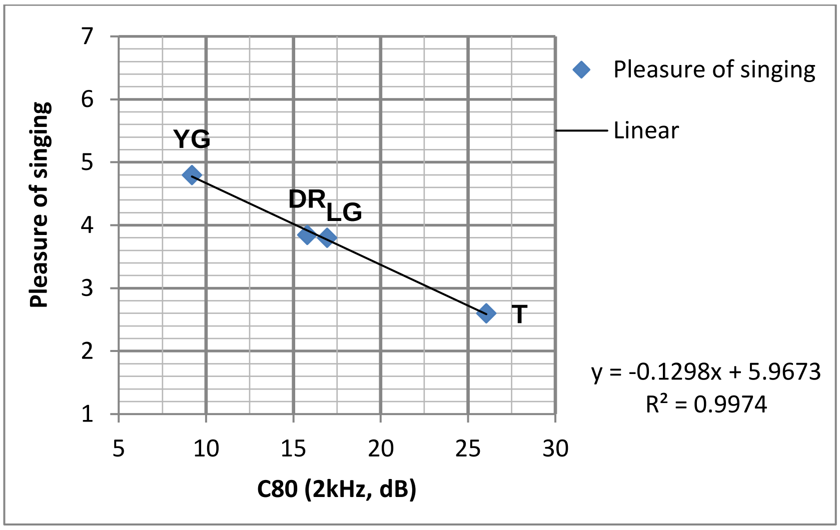

Figure 12 Regression model between subjective Pleasure of singing parameter and $C80_{(2kHz)}$ room parameter. Points show mean values for Pleasure of singing parameter answered via N=55 singers in each practice room.

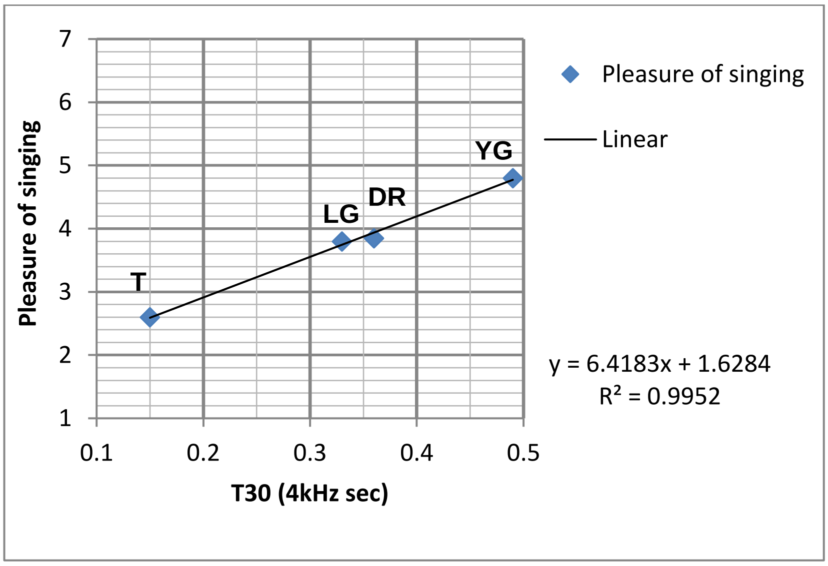

Figure 13 Regression model between subjective Pleasure of singing parameter and $T30_{(4kHz)}$ room parameter. Points show mean values for Pleasure of singing parameter answered via N=55 singers in each practice room.

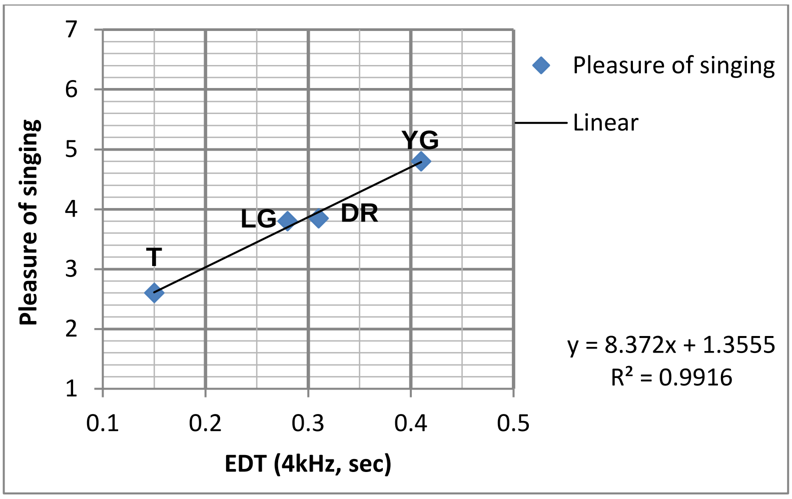

Figure 14 Regression model between subjective Pleasure of singing parameter and EDT(4kHz) room parameter. Points show mean values for Pleasure of singing parameter answered via N=55 singers in each practice room.

4.6.4.6. Results for "Voice feeling" subjective parameter

Table 74 shows the Pearson Correlation analysis results for the correlated parameters chosen for Voice feeling parameter. As can be seen from the results, Voice feeling subjective parameter showed a negative correlation with several octave band and octave-band combinations for the C80 room parameter and a lower positive correlation with the T30 parameter. The highest correlation was observed at 4 kHz octave band for both the C80 and T30 parameters. For the voice feeling parameter, "as usual", and "strong" ratings both have been examined as the "desired" rating since both were preferable for the singers as explained in the methodology chapter. Regression analysis results for the frequencies that show highest correlation for each parameter are given in Figure 15 and Figure 16 for $C80_{(4kHz)}$ and $T30_{(4kHz)}$ respectively.

Table 74 Pearson Correlation results for Voice feeling parameter and chosen room parameters for the regression analysis.

Subjective Parameter	Room parameter	Pearson Correlation	P Sig. 2-tailed
Voice feeling	$C80_{(4kHz)}$	-.989	.011
	$C80_{(1kHz)}$	-.987	.013
	$C80_{(500Hz-1kHz)}$	-.985	.015
	$C80_{(500Hz)}$	-.980	.020
	$C80_{(mid)}$	-.980	.020
	$C80_{(250Hz-1kHz)}$	-.980	.020
	$C80_{(1kHz-2kHz)}$	-.970	.030
	$C80_{(250Hz-500Hz)}$	-.970	.030
	$C80_{(125Hz-1kHz)}$	-.967	.033
	$C80_{(2kHz)}$	-.958	.042
	$T30_{(4kHz)}$	.955	.045

Table 75 shows the predicted values of the room parameters at their highest correlated frequency according to the regression analysis in order to obtain "as usual" (4) and "strong" (5) preferred ratings for the subjective Voice feeling parameter. According to the results, "as usual" (4) rating was obtained when the C80 parameter at the 4 kHz octave band was

18.01 dB and "strong"(5) rating was obtained when the level decreases to 4.49 dB. For T30 parameter at 4 kHz, the "as usual" rating was obtained when the level was 0.35sec and increases to 0.56sec in order to obtain the "strong" rating. Voice feeling parameter will be further examined with other subjective parameters that showed common correlation in Section 4.6.5. For the detailed regression analysis results of all the correlated frequencies please see Appendix N.

Table 75 Predicted values of room parameters corresponding to "as usual"(4) and "strong" preferred ratings for voice feeling subjective parameter.

Room parameters	Regression Equation	Voice feeling rating	Room parameter	Voice feeling rating	Room parameter
		y as usual	x predicted	y strong	x predicted
$C80_{(4kHz)}$, dB	y = -0.074x + 5.3325	4	18.01dB	5	4.49 dB
$T30_{(4kHz)}$, sec	y = 4.8391x + 2.311	4	0.35 sec	5	0.56 sec

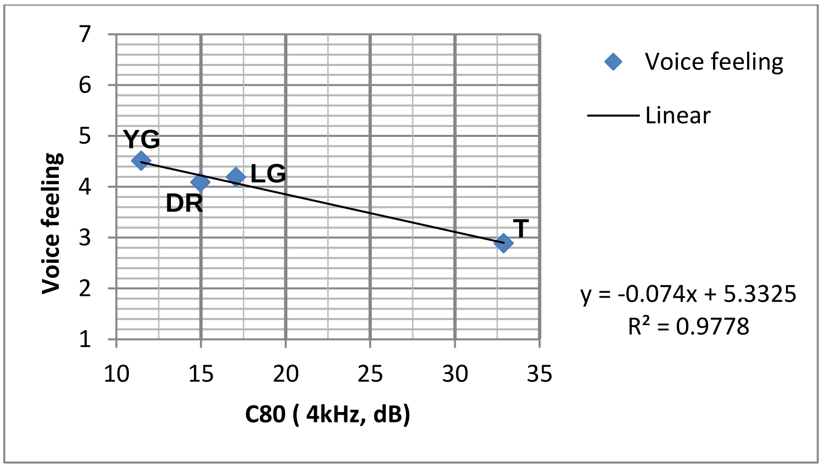

Figure 15 Regression model between subjective Voice feeling parameter and $C80_{(4kHz)}$ room parameter. Points show mean values for Voice feeling parameter answered via N=55 singers in each practice room.

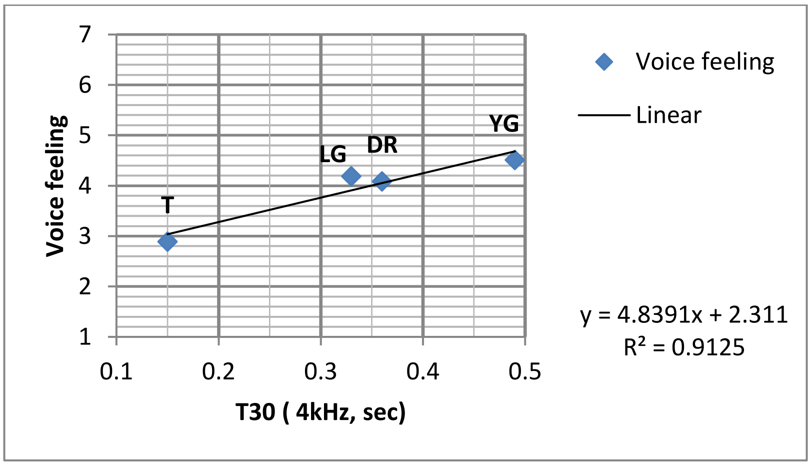

Figure 16 Regression model between subjective Voice feeling parameter and $T30_{(4kHz)}$ room parameter. Points show mean values for Voice feeling parameter answered via N=55 singers in each practice room.

4.6.4.7. Results for "Singing effort" subjective parameter

Table 76 shows the Pearson Correlation analysis result for the correlated parameters chosen for singing effort parameter. As can be seen from the results, the singing effort subjective parameter showed a higher positive correlation with several octave bands and octave-band combinations for C80 room parameter and a lower negative correlation with T30 and EDT parameters. The highest correlation was observed at 4 kHz for all C80, T30, and EDT parameters. Table 77 shows the predicted values of the room parameters at their highest correlated frequency by using the regression equation in order to obtain "as usual" (4) rating for the subjective Singing effort parameter as this is considered as the "desired" rating as explained in the methodology chapter.

Table 76 Pearson Correlation results for Singing effort parameter and chosen room parameters for the regression analysis.

Subjective Parameter	Room parameter	Pearson Correlation	P Sig. 2-tailed
Singing effort	$C80_{(4kHz)}$	.991	.009
	$C80_{(1kHz)}$	.991	.009
	$C80_{(500Hz-1kHz)}$	.989	.011
	$C80_{(500Hz)}$	.984	.016
	$C80_{(mid)}$	.984	.016
	$C80_{(250Hz-1kHz)}$	.984	.016
	$C80_{(1kHz-2kHz)}$	.976	.024
	$C80_{(250Hz-500Hz)}$	.975	.025
	$C80_{(125Hz-1kHz)}$	.973	.027
	$C80_{(2kHz)}$	.965	.035
	$T30_{(4kHz)}$	-.963	.037
	$EDT_{(4kHz)}$	-.953	.047
	$EDT_{(1kHz)}$	-.950	.050

Regression analysis results for the frequencies that showed the highest correlation for each parameter are given in Figure 17, Figure 18 and Figure 19 for $C80_{(4kHz)}$, $T30_{(4kHz)}$ and $EDT_{(4kHz)}$ respectively. According to the results, the "as usual" rating at 4 kHz was obtained at 13.79 dB for C80; at 0.41 sec for T30 and 0.35 sec for EDT room parameters. Singing effort parameter will be further examined with other subjective parameters that showed common correlation in Section 4.6.5. For the detailed regression analysis results of all the correlated frequencies please see Appendix O.

Table 77 Predicted values of room parameters corresponding to the "as usual"(4) preferred rating for singing effort subjective parameter.

Room parameters	Regression Equation	Singing effort rating	Room parameter
		y as usual	x predicted
$C80_{(4kHz)}$, dB	y = 0.055x + 3.2413	4	13.79 dB
$T30_{(4kHz)}$, sec	y = -3.6127x + 5.4912	4	0.41 sec
$EDT_{(4kHz)}$, sec	y = -4.6759x + 5.6343	4	0.35 sec

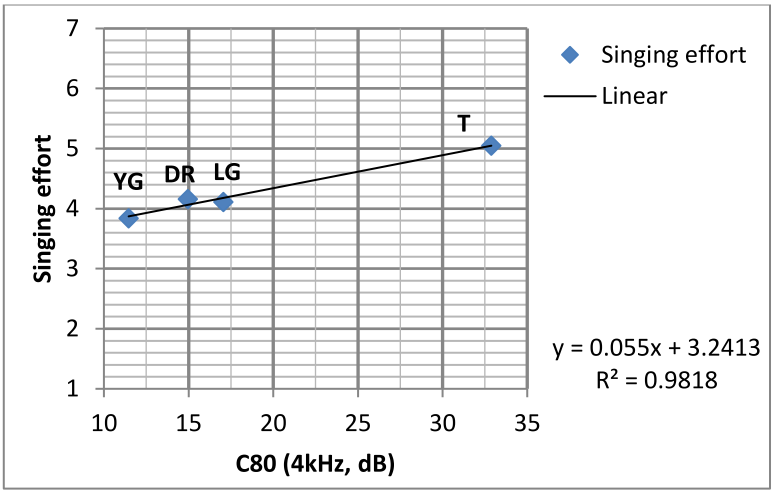

Figure 17 Regression model between subjective Singing efffort parameter and C80 $_{(4kHz)}$ room parameter. Points show mean values for Singing effort parameter answered via N=55 singers in each practice room.

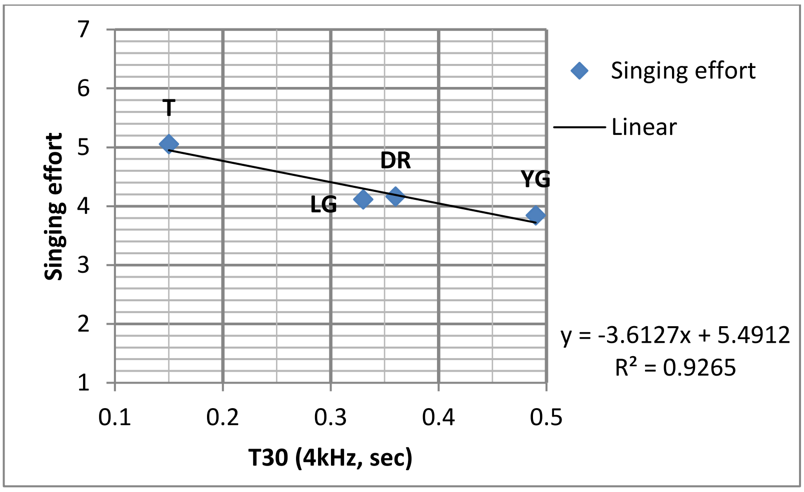

Figure 18 Regression model between subjective Singing efffort parameter and T30 $_{(4kHz)}$ room parameter. Points show mean values for Singing effort parameter answered via N=55 singers in each practice room.

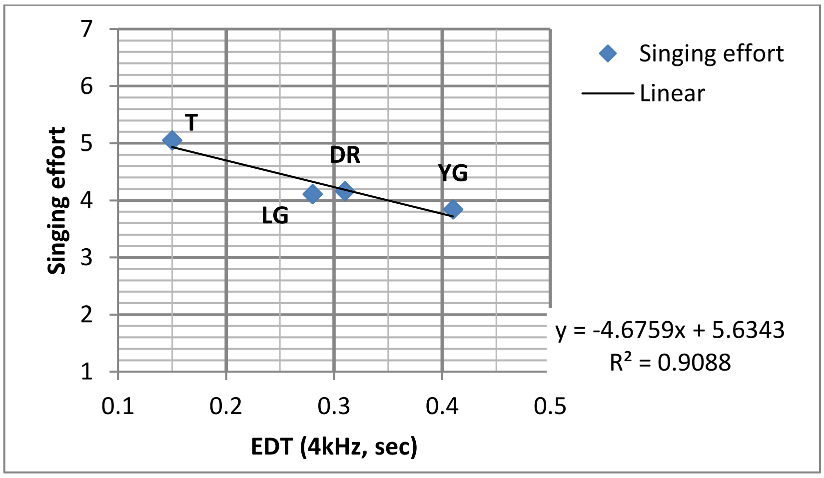

Figure 19 Regression model between subjective Singing efffort parameter and EDT $_{(4kHz)}$ room parameter. Points show mean values for Singing effort parameter answered via N=55 singers in each practice room.

4.6.4.8. Results for "Overall impression" subjective parameter

Table 78 shows the Pearson Correlation analysis results for the correlated parameters chosen for overall impression parameter. As can be seen from the results, the overall impression subjective parameter showed negative correlation with several octave bands and octave-band combinations for C80 room parameter and positive correlation with T30 and EDT parameters. The highest correlation has been observed at 2 kHz octave band for C80 parameter and at 4 kHz for both the T30 and EDT parameters.

Table 79 shows the predicted values of the room parameters at their highest correlated frequency by using regression equation in order to obtain "good"(5) and "very good" (6) preferred ratings of singers for the subjective Overall impression parameter. Regression analysis results for the frequencies that show highest correlation for each parameter are given in Figure 20, Figure 21 and Figure 22 for $C80_{(2kHz)}$, $T30_{(4kHz)}$ and $EDT_{(4kHz)}$ respectively.

Table 78 Pearson Correlation results for Overall impression parameter and chosen room parameters for the regression analysis.

Subjective Parameter	Room parameter	Pearson Correlation	P Sig. 2-tailed
Overall impression	$C80_{(2kHz)}$	-.999	.001
	$T30_{(4kHz)}$	.998	.002
	$EDT_{(4kHz)}$	.996	.004
	$C80_{(1kHz-2kHz)}$	-.997	.003
	$C80_{(low)}$	-.991	.009
	$EDT_{(500Hz-1kHz)}$	.992	.008
	$EDT_{(1kHz)}$	.990	.010
	$C80_{(1kHz)}$	-.987	.013
	$C80_{(500Hz-1kHz)}$	-.984	.016
	$C80_{(250Hz-1kHz)}$	-.983	.017
	$C80_{(mid)}$	-.983	.017
	$C80_{(125Hz-1kHz)}$	-.982	.018
	$EDT_{(1kHz-2kHz)}$	.982	.018
	$EDT_{(mid)}$	.981	.019
	$C80_{(500Hz)}$	-.978	.022
	$T30_{(250Hz-1kHz)}$	.978	.022
	$T30_{(250-500Hz)}$	.976	.024
	$C80_{(250Hz-500Hz)}$	-.975	.025
	$C80_{(4kHz)}$	-.953	.047

"Good" rating was obtained for $C80_{(2\ kHz)}$ at 7.85 dB; for $T30_{(4\ kHz)}$ and $EDT_{(4\ kHz)}$ at 0.52 sec and 0.43sec, respectively. In order to obtain "very good" rating at the same frequencies C80 decreases to 0.42 dB; T30 and EDT increases to 0.67 sec and 0.54 sec, respectively. "Acceptable" (4) rating was also examined for the overall impression subjective parameter in order to find out the maximum acceptable value for C80 parameter and the minimum acceptable values for the T30 and EDT parameters.

As can be seen in Table 80 the results showed that the maximum acceptable value for $C80_{(2kHz)}$ room parameter was found to be 15.28 dB and the minimum acceptable values for $T30_{(4kHz)}$ and $EDT_{(4kHz)}$ were found to be 0.37sec and 0.31sec, respectively. Overall impression subjective parameter will be further examined with other subjective parameters that showed common correlation in Section 4.6.5.For the detailed regression analysis results of all the correlated frequencies please see Appendix P.

Table 79 Predicted values of room parameters corresponding the subjective "good"(5) and "very good" (6) preferred ratings for overall impression subjective parameter.

Room parameters	Regression Equation	Overall impression rating	Room parameter	Overall impression rating	Room parameter
		y good	x predicted	y very good	x predicted
$C80_{(2kHz)}$, dB	y = -0.1346x + 6.0571	5	7.85 dB	6	0.42 dB
$T30_{(4kHz)}$, sec	y = 6.6582x + 1.5562	5	0.52 sec	6	0.67 sec
$EDT_{(4kHz)}$, sec	y = 8.6846x + 1.2732	5	0.43 sec	6	0.54 sec

Table 80 Predicted values of room parameters corresponding to "acceptable"(4) rating for overall impresiion subjective parameter.

Room parameters	Regression Equation	Pleasure of singing rating	Room parameter
		y acceptable	x predicted
$C80_{(2kHz)}$, dB	y = -0.1298x + 5.9673	4	15.28 dB
$T30_{(4kHz)}$, sec	y = 6.4183x + 1.6284	4	0.37 sec
$EDT_{(4kHz)}$, sec	y = 8.372x + 1.3555	4	0.31 sec

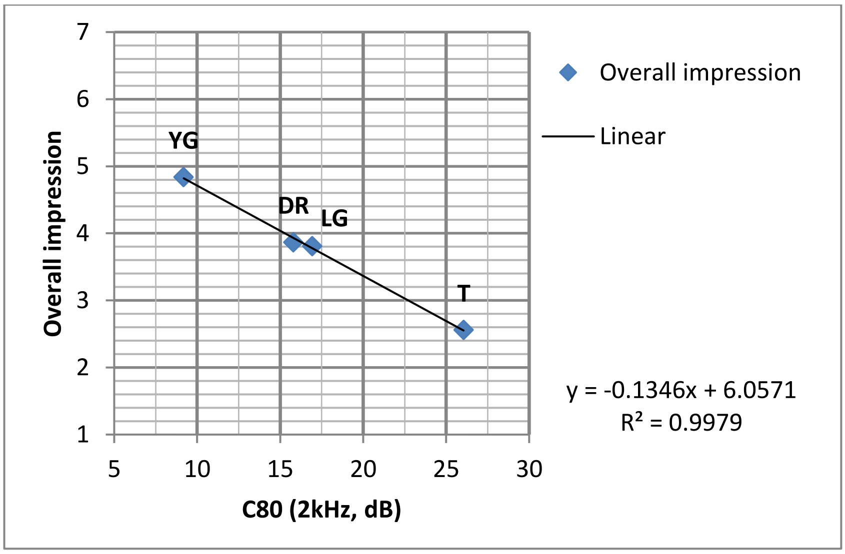

Figure 20 Regression model between subjective Overall impression parameter and $C80_{(2kHz)}$ room parameter. Points show mean values for Overall impression parameter answered via N=55 singers in each practice room.

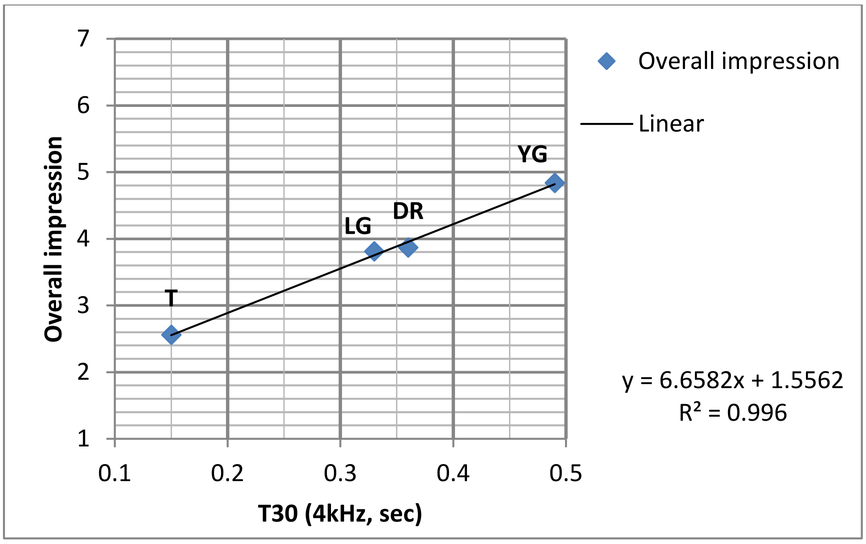

Figure 21 Regression model between subjective Overall impression parameter and T30 $_{(4kHz)}$ room parameter. Points show mean values for Overall impression parameter answered via N=55 singers in each practice room.

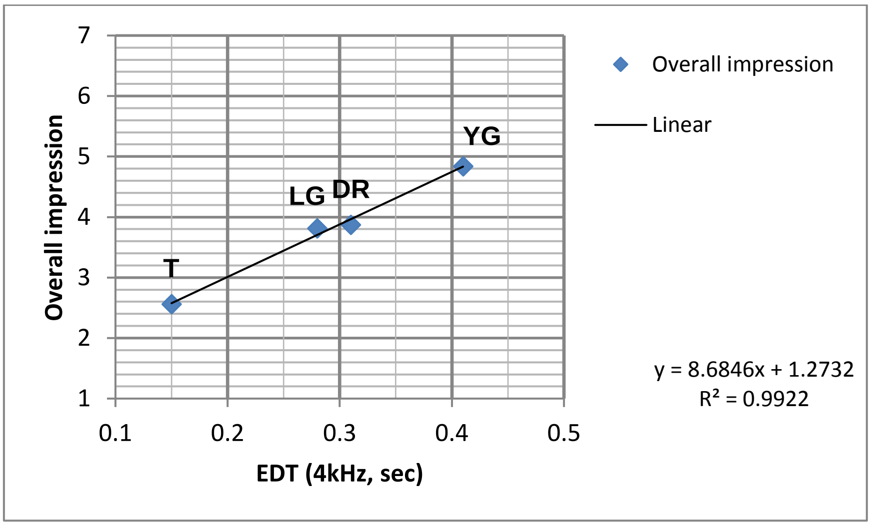

Figure 22 Regression model between subjective Overall impression parameter and EDT $_{(4kHz)}$ room parameter. Points show mean values for Overall impression parameter answered via N=55 singers in each practice room.

4.6.5. Results for Common Correlations

As can be seen from the previous section, in most cases the same room parameter showed correlation with more than one subjective parameter giving different target values for each subjective parameter. Therefore these common room parameters were examined together in order to find the maximum and minimum limits which will provide the target ratings for all their correlated subjective parameters. The five subjective parameters which showed correlations with same room parameters were : Reverberance, Pleasure of singing, Voice feeling, Singing effort and Overall impression. The objective room parameters that showed common correlation with these subjective parameters are given in Table 61. As seen from Table 61, C80, T30 and EDT parameters at different frequencies showed common correlation with different subjective parameters. From these room parameters, only the ones that showed common correlation with all of the five subjective parameters were further examined, the remaining room parameters that showed common correlation with only three or less subjective parameters were eliminated as the aim was to set preferred values for all five subjective parameters. Therefore EDT was eliminated for all frequency ranges as it showed correlation with only a maximum of three subjective parameters; for T30 only the 4kHz octave-band was examined since only it showed correlation with all five subjective parameters; for C80 room parameter, $C80_{low}$, $C80_{(125\text{-}500Hz)}$, and $C80_{(125\text{-}250Hz)}$ were eliminated and the remaining combinations were further examined.

The room parameter values corresponding to preferred ratings of singers for each subjective parameter were calculated using equations obtained via regression analysis. For the "reverberance" parameter, the preferred ratings were "balanced" (4) and "reverberant" (5), therefore the minimum target rating for this parameter was set as 4 and the maximum target rating as 5 (4≤ reverberance ≤ 5); for the "voice feeling" parameter the preferred ratings were "as usual" (4) and "strong" (5) therefore the minimum target rating for this parameter was set as 4 and the maximum target rating as 5 (4≤ Voice feeling ≤ 5); for the pleasure of singing and overall impression parameters the preferred ratings were "sufficient" (4), "good" (5) and "very good" (6) therefore the minimum target rating for these parameters was set as "sufficient" (4) and the maximum target rating was set as "very good" (6) (4≤ Pleasure of singing ≤ 6; 4≤ Overall impression ≤ 6).

For the "singing effort" parameter on the other hand, all the singers preferred "as usual" (4) rating. If "as usual" rating was chosen as the sole criterion for designing the practice room, then this rating alone wouldn't be able to satisfy the ratings of the other subjective parameters preferred by the singers, therefore a range was introduced as a target which includes values corresponding to "as usual" rating for singing effort parameter and the closest values to "as usual" rating which provide the target ratings for the rest of the parameters. The results of the parameters further examined in order to set out target ratings are presented below.

4.6.5.1. $C80_{(500Hz)}$

Table 81 gives target values of the $C80_{(500Hz)}$ room parameter calculated through regression analysis in order to obtain preferred ratings for each of its correlated subjective parameter. The target range for $C80_{(500Hz)}$ room parameter was found to be $5.14dB \leq C80_{(500Hz)} \leq 8.47dB$ as the values in this range provide the preferred range for the "reverberance" subjective parameter which was 4 (balanced) ≤ reverberance ≤ 5 (reverberant); preferred range for "voice feeling" parameter which was 4 (as usual) ≤ voice feeling ≤ 5 (strong) and the range between "sufficient"(4) rating as the minimum acceptable rating and "good"(5) as the preferred rating for "pleasure of singing" and "overall impression" subjective parameters. For "pleasure of singing" and "overall impression" parameters the preferred "very good" (6) rating was not reached as the $C80_{(500Hz)}$ levels corresponding to this rating does not provide preferred ratings for the rest of the subjective parameters.

Table 81 Results for C80 $_{(500Hz)}$ values corresponding to subjective parameter rating

Subjective parameter	Common Room parameter	Likert scale ratings		
		4	5	6
Reverberance	C80 $_{(500Hz)}$, dB	11.45	**5.14**	-1.16
Pleasure of Singing		10.64	2.17	-6.29
Overall		10.77	2.62	-5.53
Voice Feeling		11.79	1.08	-9.64
Singing effort		**8.47**	22.86	37.25
Result Target Range	**min**	**5.14 dB**		
	max	**8.47 dB**		

4.6.5.2. C80 $_{(1kHz)}$

Table 82 gives the values calculated according to regression analysis results for C80 parameter at the 1 kHz octave band for each of its correlated subjective parameters considering their rating. The target range for C80$_{(1kHz)}$ room parameter was found to be 6.34dB $\leq$C80$_{(1kHz)}\leq$ 10.39dB as the values in this range provide the preferred range for the "reverberance" subjective parameter which was 4(balanced)≤reverberance ≤5(reverberant); preferred range for "voice feeling" parameter which was 4 (as usual) ≤ voice feeling ≤ 5 (strong) and the range between "sufficient"(4) rating as the minimum acceptable rating and "good"(5) as the preferred rating for "pleasure of singing" and "overall impression" subjective parameters. For "pleasure of singing" and "overall impression" parameters the preferred "very good" (6) rating was not reached as the C80$_{(1kHz)}$ levels corresponding to this rating does not provide preferred ratings for the rest of the subjective parameters.

Table 82 Results for C80 $_{(1kHz)}$ values corresponding to subjective parameter rating

Subjective parameter	Common Room parameter	Likert scale ratings		
		4	5	6
Reverberance	C80 $_{(1kHz)}$, dB	12.27	**6.34**	0.42
Pleasure of Singing		12.29	4.88	-2.53
Overall		12.42	5.27	-1.87
Voice Feeling		13.31	3.89	-5.52
Singing effort		**10.39**	23.05	35.71
Result Target Range	**min**	**6.34 dB**		
	max	**10.39 dB**		

4.6.5.3. C80 $_{(2kHz)}$

Table 83 gives the values calculated according to regression analysis results for C80 parameter at the 2 kHz octave band for each of its correlated subjective parameter considering their rating. The target range for C80$_{(2kHz)}$ room parameter was found to be 8.61dB $\leq$C80$_{(2kHz)}\leq$ 13.02dB as the values in this range provide the preferred range for the "reverberance" subjective parameter which was 4(balanced)≤ reverberance ≤5 (reverberant); preferred range for "voice feeling" parameter which was 4 (as usual) ≤ voice feeling ≤ 5 (strong) and the range between "sufficient"(4) rating as the minimum acceptable rating and "good"(5) as the preferred rating for "pleasure of singing" and "overall impression" subjective parameters. For "pleasure of singing" and "overall impression" parameters the preferred “very good” (6) rating was not reached as the $C80_{(2kHz)}$ levels corresponding to this rating does not provide preferred ratings for the rest of the subjective parameters.

Table 83 Results for $C80_{(2kHz)}$ values corresponding to subjective parameter rating

Subjective parameter	Common Room parameter	Likert scale ratings		
		4	**5**	**6**
Reverberance	$C80_{(2kHz)}$, dB	15.04	**8.61**	2.17
Pleasure of Singing		15.16	7.45	-0.25
Overall		15.28	7.85	0.42
Voice Feeling		16.18	5.98	-4.23
Singing effort		**13.02**	26.68	40.34
Result Target Range	**min**	**8.61 dB**		
	max	**13.02 dB**		

4.6.5.4. $C80_{(4kHz)}$

The target range for $C80_{(4kHz)}$ room parameter was found to be 8.08dB $\leq C80_{(4kHz)} \leq$ 13.79dB as the values in this range provide the preferred range for the “reverberance” subjective parameter which was 4(balanced)≤ reverberance ≤5 (reverberant); preferred range for “voice feeling” parameter which was 4 (as usual) ≤ voice feeling ≤ 5 (strong) and the range between “sufficient”(4) rating as the minimum acceptable rating and “good”(5) as the preferred rating for “pleasure of singing” and “overall impression” subjective parameters. For “pleasure of singing” and “overall impression” parameters the preferred “very good” (6) rating was not reached as the $C80_{(4kHz)}$ levels corresponding to this rating does not provide preferred ratings for the rest of the subjective parameters.

Table 84 gives the values calculated according to regression analysis results for C80 parameter at 4 kHz for each of its correlated subjective parameter considering their rating. The target range for $C80_{(4kHz)}$ room parameter was found to be 8.08dB $\leq C80_{(4kHz)} \leq$ 13.79dB as the values in this range provide the preferred range for the “reverberance” subjective parameter which was 4(balanced)≤ reverberance ≤5 (reverberant); preferred range for “voice feeling” parameter which was 4 (as usual) ≤ voice feeling ≤ 5 (strong) and the range between “sufficient”(4) rating as the minimum acceptable rating and “good”(5) as the preferred rating for “pleasure of singing” and “overall impression” subjective parameters.

For “pleasure of singing” and “overall impression” parameters the preferred “very good” (6) rating was not reached as the $C80_{(4kHz)}$ levels corresponding to this rating does not provide preferred ratings for the rest of the subjective parameters.

Table 84 Results for C80 $_{(4kHz)}$ values corresponding to each subjective parameter rating

Subjective parameter	Common Room parameter	Likert scale ratings		
		4	5	6
Reverberance	C80 $_{(4kHz)}$, dB	16.53	**8.08**	-0.38
Pleasure of Singing		16.46	5.40	-5.66
Overall		16.64	6.00	-4.64
Voice Feeling		18.01	4.49	-9.02
Singing effort		**13.79**	31.98	50.16
Result Target Range	**min**	**8.08 dB**		
	max	**13.79 dB**		

4.6.5.5. C80 $_{(1kHz-2kHz)}$

The target range for C80$_{(1kHz-2kHz)}$ room parameter was found to be 7.52 dB ≤C80$_{(1kHz-2kHz)}$ ≤ 11.73dB as the values in this range provide the preferred range for the "reverberance" subjective parameter which is 4(balanced)≤ reverberance ≤5 (reverberant); preferred range for "voice feeling" parameter which is 4 (as usual) ≤ voice feeling ≤ 5 (strong) and the range between "sufficient"(4) rating as the minimum acceptable rating and "good"(5) as the preferred rating for "pleasure of singing" and "overall impression" subjective parameters. For "pleasure of singing" and "overall impression" parameters the preferred "very good" (6) rating was not reached as the C80$_{(1kHz-2kHz)}$ levels corresponding to this rating does not provide preferred ratings for the rest of the subjective parameters.

Table 85 gives the values calculated according to regression analysis results for C80 parameter at 1 kHz-2 kHz octave-band combination for each of its correlated subjective parameter considering their rating. The target range for C80$_{(1kHz-2kHz)}$ room parameter was found to be 8dB ≤C80$_{(1kHz-2kHz)}$≤ 12 dB as the values in this range provide the preferred range for the "reverberance" subjective parameter which is 4(balanced)≤ reverberance ≤5 (reverberant); preferred range for "voice feeling" parameter which is 4 (as usual) ≤ voice feeling ≤ 5 (strong) and the range between "sufficient"(4) rating as the minimum acceptable rating and "good"(5) as the preferred rating for "pleasure of singing" and "overall impression" subjective parameters. For "pleasure of singing" and "overall impression" parameters the preferred "very good" (6) rating was not reached as the C80$_{(1kHz-2kHz)}$ levels corresponding to this rating does not provide preferred ratings for the rest of the subjective parameters.

Table 85 Results for C80 $_{(1kHz-2kHz)}$ values corresponding to each subjective parameter rating

Subjective parameter	Common Room parameter	Likert scale ratings		
		4	5	6
Reverberance	C80 $_{(1kHz-2kHz)}$, dB	14.0	**8.0**	1
Pleasure of Singing		14.0	6.44	-1.12
Overall		14.12	6.83	-0.45
Voice Feeling		15.0	5.14	-4.73
Singing effort		**12.0**	25	38
Result Target Range	**min**	**8 dB**		
	max	**12 dB**		

4.6.5.6. C80 $_{(500Hz-1kHz)}$

Table 86 gives the values calculated according to regression analysis results for $C80_{(500Hz-1kHz)}$ parameter for each of its correlated subjective parameter considering their rating. The target range for $C80_{(500Hz-1kHz)}$ room parameter was found to be $5dB \leq C80_{(500Hz-1kHz)} \leq 9.55dB$ as the values in this range provide the preferred range for the “reverberance” subjective parameter which was 4(balanced)≤ reverberance ≤5 (reverberant); preferred range for “voice feeling” parameter which was 4 (as usual) ≤ voice feeling ≤ 5 (strong) and the range between “sufficient”(4) rating as the minimum acceptable rating and “good”(5) as the preferred rating for “pleasure of singing” and “overall impression” subjective parameters. For “pleasure of singing” and “overall impression” parameters the preferred “very good” (6) rating was not reached as the $C80_{(500Hz-1kHz)}$ levels corresponding to this rating does not provide preferred ratings for the rest of the subjective parameters.

Table 86 Results for C80 $_{(500Hz-1kHz)}$ values corresponding to each subjective parameter rating

Subjective parameter	Common Room parameter	Likert scale ratings		
		4	5	6
Reverberance	C80 $_{(500Hz-1kHz)}$, dB	12.0	**5.0**	-1
Pleasure of Singing		11.57	3.71	-4.15
Overall		11.69	4.12	-3.45
Voice Feeling		12.63	2.67	-7.29
Singing effort		**9.55**	22.94	36.32
Result Target Range	**min**	**5.0 dB**		
	max	**9.55 dB**		

4.6.5.7. C80 $_{(mid)}$

Table 87 gives the values calculated according to regression analysis results for $C80_{(mid)}$ parameter for each of its correlated subjective parameter considering their rating. The target range for $C80_{(mid)}$ room parameter was found to be $6.78dB \leq C80_{(mid)} \leq 11.09dB$ as the values in this range provide the preferred range for the “reverberance” subjective parameter which is 4(balanced)≤ reverberance ≤5 (reverberant); preferred range for “voice feeling” parameter which is 4 (as usual) ≤ voice feeling ≤ 5 (strong) and the range between “sufficient”(4) rating as the minimum acceptable rating and “good”(5) as the preferred rating for “pleasure of singing” and “overall impression” subjective parameters.

For “pleasure of singing” and “overall impression” parameters the preferred “very good” (6) rating was not reached as the $C80_{(mid)}$ levels corresponding to this rating does not provide preferred ratings for the rest of the subjective parameters.

Table 87 Results for C80 $_{(mid)}$ values corresponding to each subjective parameter rating

Subjective parameter	Common Room parameter	Likert scale ratings		
		4	5	6
Reverberance	C80 $_{(mid)}$, dB	13.08	**6.78**	0.47
Pleasure of Singing		13.15	5.43	-2.29
Overall		13.28	5.84	-1.60
Voice Feeling		14.18	4.17	-5.84
Singing effort		**11.09**	24.53	37.98
Result Target Range	**min**	**6.78 dB**		
	max	**11.09 dB**		

4.6.5.8. C80 $_{(250Hz-500Hz)}$

Table 88 gives the values calculated according to regression analysis results for C80$_{(250Hz-500Hz)}$ parameter for each of its correlated subjective parameter considering their rating. The target range for C80$_{(250Hz-500Hz)}$ room parameter was found to be 2.85dB ≤C80$_{(250Hz-500Hz)}$≤ 7.21dB as the values in this range provide the preferred range for the "reverberance" subjective parameter which is 4(balanced)≤ reverberance ≤5 (reverberant); preferred range for "voice feeling" parameter which is 4 (as usual) ≤ voice feeling ≤ 5 (strong) and the range between "sufficient"(4) rating as the minimum acceptable rating and "good"(5) as the preferred rating for "pleasure of singing" and "overall impression" subjective parameters. For "pleasure of singing" and "overall impression" parameters the preferred "very good" (6) rating was not reached as the C80$_{(250Hz-500Hz)}$ levels corresponding to this rating does not provide preferred ratings for the rest of the subjective parameters.

Table 88 Results for C80 $_{(250Hz-500Hz)}$ values corresponding to each subjective parameter rating

Subjective parameter	Common Room parameter	Likert scale ratings		
		4	5	6
Reverberance	C80 $_{(250Hz-500Hz)}$, dB	9.27	**2.85**	-3.58
Pleasure of Singing		9.30	1.23	-6.84
Overall		9.43	1.66	-6.11
Voice Feeling		10.39	0.10	-10.18
Singing effort		**7.21**	21.00	34.79
Result Target Range	**min**	**2.85 dB**		
	max	**7.21 dB**		

4.6.5.9. C80 $_{(250Hz-1 kHz)}$

Table 89 gives the values calculated according to regression analysis results for C80$_{(250Hz-1kHz)}$ parameter for each of its correlated subjective parameter considering their rating. The target range for C80$_{(250Hz-1kHz)}$ room parameter was found to be 4.38dB ≤C80$_{(250Hz-1kHz)}$≤8.58dB as the values in this range provide the preferred range for the "reverberance" subjective parameter which is 4(balanced)≤ reverberance ≤5 (reverberant); preferred range for "voice feeling" parameter which is 4 (as usual) ≤ voice feeling ≤ 5 (strong) and the range between "sufficient"(4) rating as the minimum acceptable rating and "good"(5) as the preferred rating for "pleasure of singing" and "overall impression" subjective parameters.

For “pleasure of singing” and “overall impression” parameters the preferred “very good” (6) rating was not reached as the $C80_{(250Hz\text{-}1kHz)}$ levels corresponding to this rating does not provide preferred ratings for the rest of the subjective parameters.

Table 89 Results for $C80_{(250Hz\text{-}1kHz)}$ values corresponding to each subjective parameter rating

Subjective parameter	Common Room parameter	Likert scale ratings		
		4	5	6
Reverberance	$C80_{(250Hz\text{-}1kHz)}$, dB	10.54	**4.38**	-1.78
Pleasure of Singing		10.57	2.85	-4.86
Overall		10.69	3.26	-4.17
Voice Feeling		11.62	1.80	-8.03
Singing effort		**8.58**	21.77	34.96
Result Target Range	**min**	**4.38 dB**		
	max	**8.58 dB**		

4.6.5.10. C80 (125Hz-1 kHz)

Table 90 gives the values calculated according to regression analysis results for $C80_{(125Hz\text{-}1kHz)}$ parameter for each of its correlated subjective parameter considering their rating. The target range for $C80_{(125Hz\text{-}1kHz)}$ room parameter was found to be $3.50dB \leq C80_{(125Hz\text{-}1kHz)} \leq 7.91dB$ as the values in this range provide the preferred range for the “reverberance” subjective parameter which is 4(balanced)≤ reverberance ≤5 (reverberant); preferred range for “voice feeling” parameter which is 4 (as usual) ≤ voice feeling ≤ 5 (strong) and the range between “sufficient”(4) rating as the minimum acceptable rating and “good”(5) as the preferred rating for “pleasure of singing” and “overall impression” subjective parameters. For “pleasure of singing” and “overall impression” parameters the preferred “very good” (6) rating was not reached as the $C80_{(125Hz\text{-}1kHz)}$ levels corresponding to this rating does not provide preferred ratings for the rest of the subjective parameters.

Table 90 Results for $C80_{(125Hz\text{-}1kHz)}$ values corresponding to each subjective parameter rating

Subjective parameter	Common Room parameter	Likert scale ratings		
		4	5	6
Reverberance	$C80_{(125Hz\text{-}1kHz)}$, dB	9.98	**3.50**	-2.98
Pleasure of Singing		10.03	1.99	-6.06
Overall		10.16	2.42	-5.33
Voice Feeling		11.12	0.75	-9.61
Singing effort		**7.91**	21.80	35.69
Result Target Range	**min**	**3.50 dB**		
	max	**7.91 dB**		

4.6.5.11. Conclusion

As can be seen from Table 81 to Table 90, all subjective parameters require different levels of C80 in order to obtain preferred ratings of the singers. Therefore the maximum and minimum values that is either in the preferred range of singers or that at least provide a “sufficient” rating for all of the subjective parameters are chosen as the target range for C80 room parameter for each examined octave band. The maximum value was chosen as the value that provides “as usual” (4) preferred rating for the “singing effort” parameter as the higher level means “more effort”; for the minimum value, the value that provides the closest rating to “as usual” (4) rating for “singing effort” subjective parameter which also provides the preferred or at least the sufficient rating for the rest of the parameters is chosen. The reason for choosing the “singing effort” parameter as the main target subjective parameter is that all the singers preferred only one rating for this subjective parameter whereas for the other parameters the ratings varied, as explained previously in the methodology chapter.

The target range found for the C80 room parameter in octave bands when all common subjective parameters considered together are given in Figure 23. As mentioned before, the aim was to provide the preferred ratings of the singers for each parameter; when this is not possible the aim was to provide at least the sufficient ratings. Figure 24 to Figure 28 show the C80 values corresponding to each rating and where the target range is located between these ratings for each subjective parameter: Reverberance, Pleasure of singing, Overall impression, Voice feeling and Singing effort respectively.

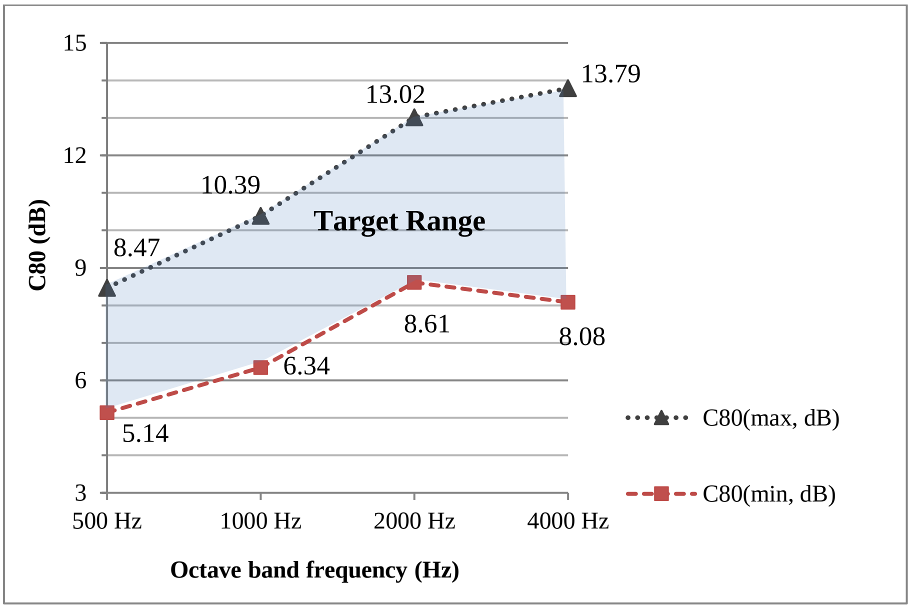

Figure 23 Target range maximum and minimum levels for C80 parameter for each octave band that provide target ratings for all common subjective parameters.

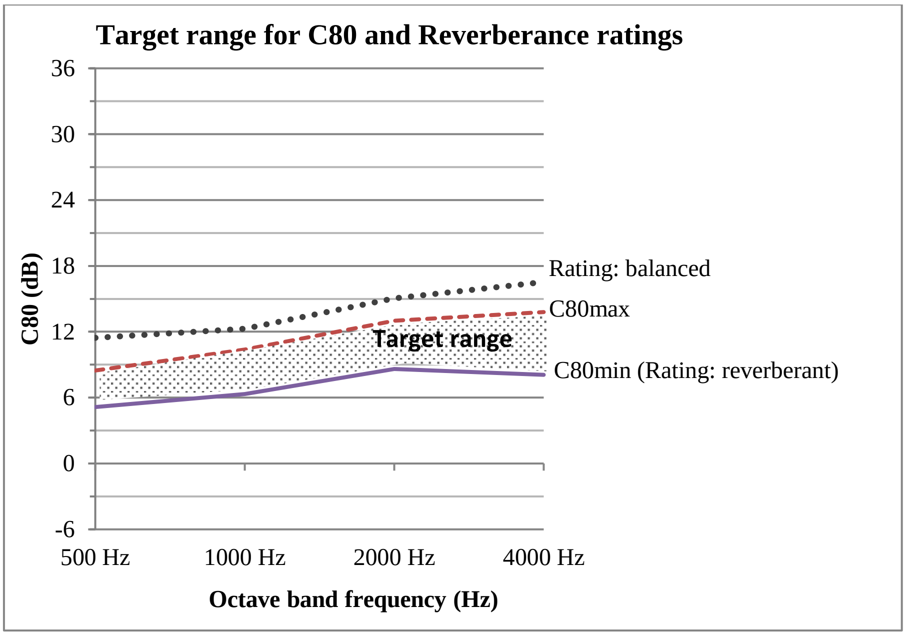

Figure 24 Target range maximum and minimum levels for C80 parameter for each octave band that provide target ratings for all common subjective parameters and reverberance ratings.

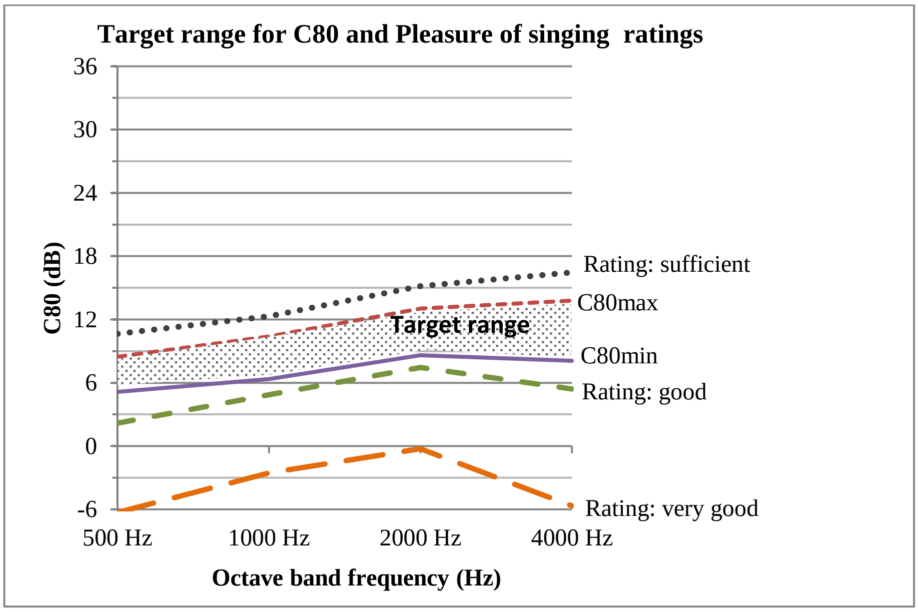

Figure 25 Target range maximum and minimum levels for C80 parameter for each octave band that provide target ratings for all common subjective parameters and pleasure of singing ratings.

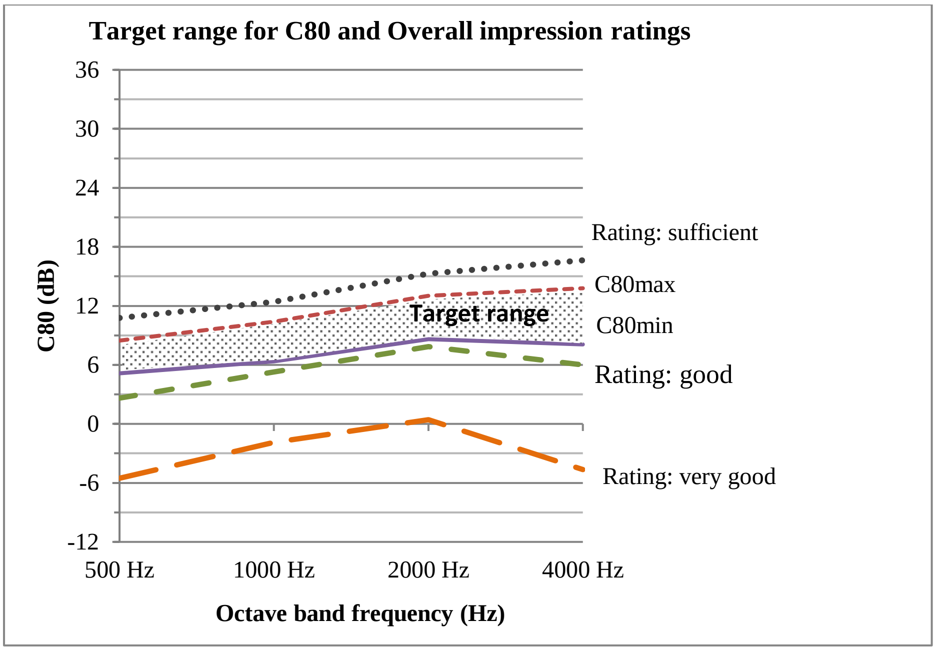

Figure 26 Target range maximum and minimum levels for C80 parameter for each octave band that provide target ratings for all common subjective parameters and overall impression ratings.

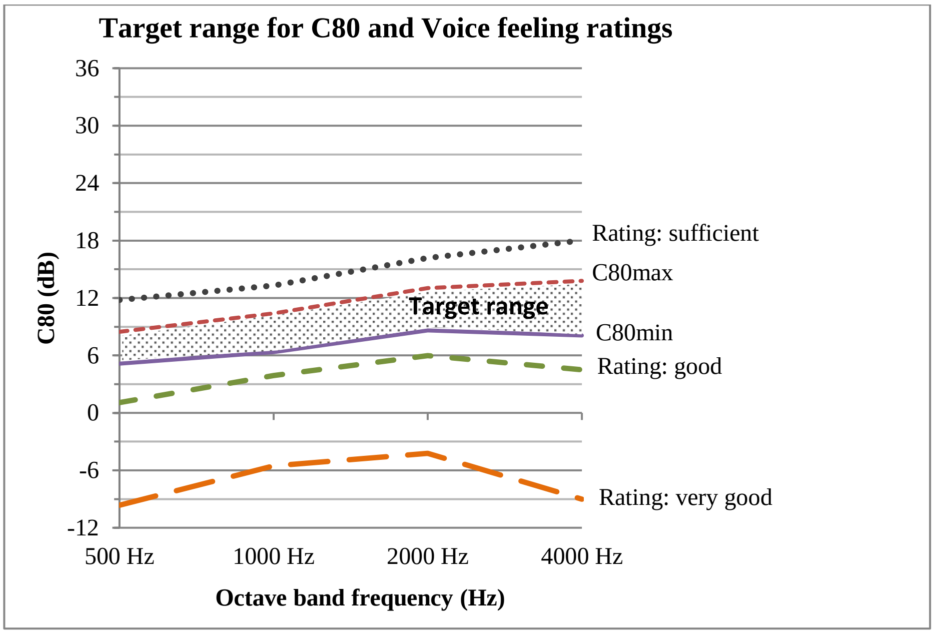

Figure 27 Target range maximum and minimum levels for C80 parameter for each octave band that provide target ratings for all common subjective parameters and voice feeling ratings.

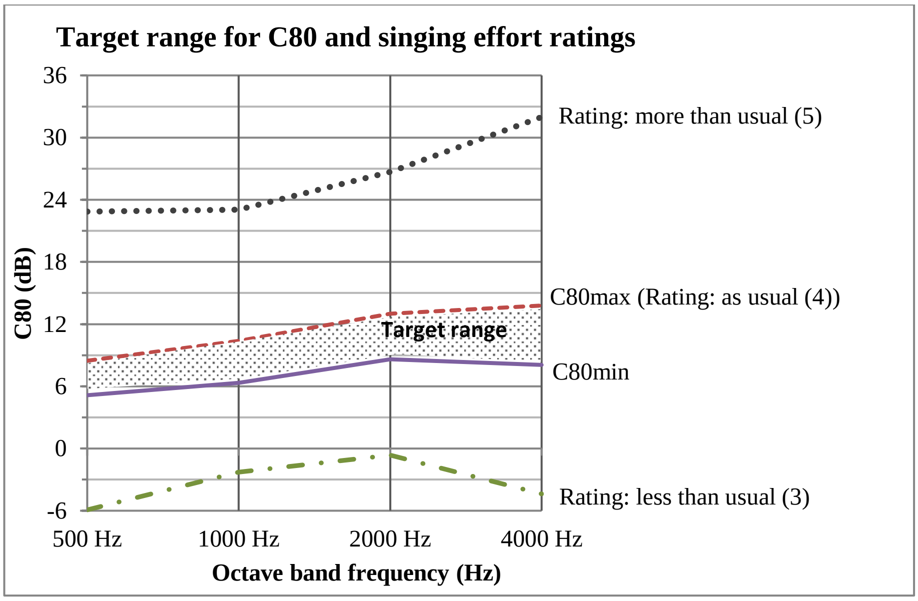

Figure 28 Target range maximum and minimum levels for C80 parameter for each octave band that provide target ratings for all common subjective parameters and singing effort ratings.

4.6.6. Results for T30 $_{(4kHz)}$ room parameter

T30 room parameter showed correlation with all five of the subjective parameters for the 4kHz octave-band, therefore T30 only at this frequency is further examined. Table 91 gives the values calculated according to regression analysis results for T30 at 4kHz for each of its correlated subjective parameter considering their rating. As can be seen from the table, all subjective parameters require a different duration of $T30_{(4kHz)}$ in order to obtain the preferred ratings of singers. Therefore the maximum and minimum values that are either in the preferred range or provide a "sufficient" rating for the subjective parameters were chosen as the target range.

The minimum value for $T30_{(4kHz)}$ was chosen as the value that provides "as usual" (4) preferred rating for the "singing effort" parameter as the lower value means "more effort"; for the maximum value, the value that provides the closest rating to "as usual" (4) rating for "singing effort" subjective parameter which also provides the preferred or at least the sufficient rating for the rest of the parameters chosen.

The target range for $T30_{(4kHz)}$ room parameter was found to be $0.41sec \leq T30_{(4kHz)} \leq 0.50sec$ as the values in this range provides the preferred range for the "reverberance" subjective parameter which is 4(balanced)≤ reverberance ≤5 (reverberant); preferred range for "voice feeling" parameter which was 4 (as usual) ≤ voice feeling ≤ 5 (strong) and provides a range between "sufficient"(4) rating and "good"(5) rating for "pleasure of singing" and "overall impression" subjective parameters. For "pleasure of singing" and "overall impression" parameters the preferred "very good" (6) rating was not reached as the $T30_{(4kHz)}$ levels corresponding to this rating does not provide preferred ratings for the rest of the subjective parameters. Figure 29 shows the target range set for $T30_{(4kHz)}$ together with the subjective ratings that they correspond to for each subjective parameter.

Table 91 Results for $T30_{(4kHz)}$ values corresponding to each subjective parameter rating

Subjective parameter	Common Room parameter	Likert scale ratings 4	5	6
Reverberance	$T30_{(4kHz)}$, sec	0.37	**0.50**	0.63
Pleasure of Singing		0.37	0.53	0.68
Overall		0.37	0.52	0.67
Voice Feeling		0.35	0.56	0.76
Singing effort		**0.41**	0.14	0
Result Target Range	**Min**	**0.41 sec**		
	Max	**0.50 sec**		

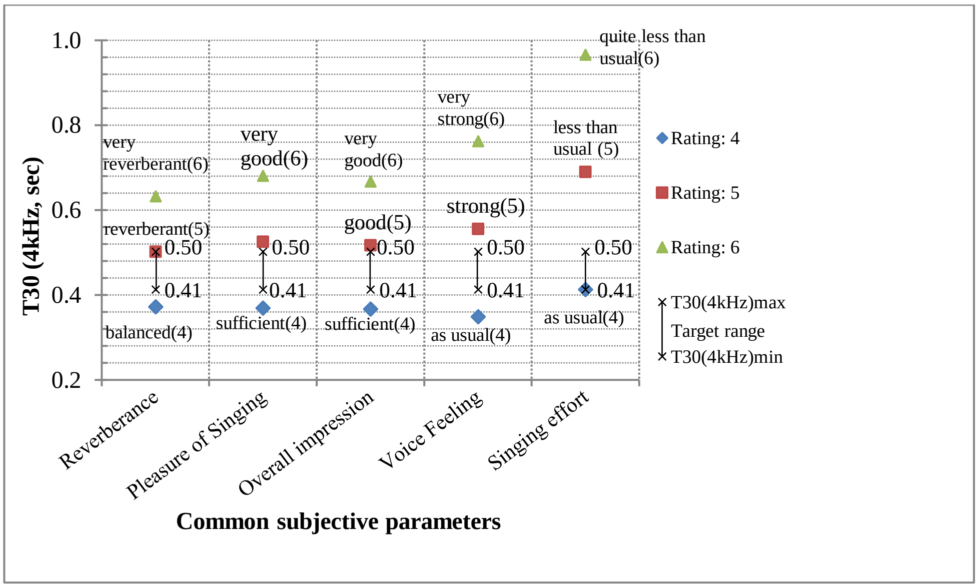

Figure 29 Target range, maximum and minimum values of T30(4kHz) parameter that provide target ratings for all common subjective parameters. The numbers (4), (5) and (6) are the rating points from the 7-point likert type scale used in the questionnaire given with their corresponding subjective ratings.

4.7. Results of Singers' Data Collection for Daily Voice Dosimetry

In this section results of daily voice dosimetry data collected from 49 singers at the Royal Academy of Music during a whole day will be presented as collected using the APM.

4.7.1. 'About You' Questionnaire Results

Singer profiles participated in this stage were obtained via "About You" questionnaire. Results are presented in Table 92 for the 49 singers who volunteered for this study.

Table 92 "About You" Questionnaire results showing singer profiles participated in the collection of daily voice dosimetry study, N=49 singers.

Questions	Answers	N	%
Q1- What is your gender?	Male	16	32.7
	Female	33	67.3
Q2- What is your age?	18_24	34	69.4
	25_29	14	28.6
	30_34	1	2.0
Q3- What is your voice type?	Baritone	6	12.2
	Tenor	8	16.3
	Counter Tenor	2	4.1
	Mezzo Soprano	9	18.4
	Soprano	24	49.0
Q4- How many years have you been singing?	0-5	5	10.2
	5-10	19	38.8
	10-20	24	49,0
	20-30	1	2.0
Q5- For how many years have you been taking singing lessons?	0-5	6	12.2
	5-10	28	57.1
	10-20	15	30.6
Q6- Are you still taking singing lessons?	Yes	49	100.0
Q7-Do you have any vocal problems?	No	49	100.0

4.7.2. Daily Voice Dosimetry Results due to all vocal activity

The average number of monitoring hours of N=49 singers showed that a semi-professional Opera singer spends on average approximately five hours (05:03:45, std. ± 01:44:22) at his/her education premises and approximately an average of one hour (01:08:56, std. ± 00:25:52) of this duration is spent for phonation including both speech and singing.

The daily voice dosimetry results due to all vocal activity for each singer are summarised in Table 93. The daily mean dosimetry results and the standard deviations for all singers are summarised in Table 94 for phonation time (P_t, sec,%) sound pressure level (SPL, dB) and distance dose (D_d, m) parameters and separately given for F0average, F0mode and D_c parameters in Table 95 for each gender. As in Cantarella et al.'s [17] study, frequency related parameters: F0average, F0mode and D_c were found to be higher in females than males. This is not a surprise due to shorter vocal fold structure of females which results in higher vibratory characteristics.

As mentioned in the methodology chapter the measurement duration varied due to different schedules of the singers. For such cases, different methods in literature can be found in order to normalize the variations due to different daily schedules of subjects such as monitoring the subjects for a whole week [19] or normalizing the data to a time dose [20, 21]where only the voiced segments of the total monitoring duration is taken into account.

As shown in Equation 2 and Equation 3, D_d and D_c voice parameters are dependent on the phonation time (P_t or D_t). In the current study, the Pearson Correlation analysis results also showed that the parameters that were significantly correlated to time dose (Phonation time, P_t) were D_d and D_c and no correlation was found for F0average, F0mode and SPL as can be seen in Table 96 and Figure 30 to Figure 34 for each parameter respectively. Therefore the results of the singers' measured voice parameters regarding D_d and D_c were normalised to time dose (P_t, phonation time) as the monitoring duration were different for each singer. In order to normalise the parameters the following formula was adapted from Remacle et al.'s [20]study:

$$\frac{(\text{ParameterS1xPtS1}) + (\text{ParameterS2xPtS2}) + .. + (\text{ParameterS49xPtS49})}{PtS1 + PtS2 + PtS3 + .. + PtS49}$$

Equation 15

where Parameter S represents the value of the parameter for the each singer (i.e. S1: first singer, S2:second singer), PtS represents the time dose value (phonation time) for each singer. The average number of monitoring hours of N=49 singers showed that a semi-professional Opera singer spends approximately an average of five hours (05:03:45, std. ± 01:44:22) at his/her education premises and approximately an average of one hour (01:08:56, std. ± 00:25:52) of this duration is spent for phonation including both speech and singing.

The result shows that the mean daily Phonation time percentage (P_t %) of the Opera singers is 24.1% (std. ± 7.6), F0mode is 255 Hz (std. ± 128 Hz), F0average is 333.25 Hz (std. ± 102.62); SPL is 85.45 dB (std. ± 5.71) and D_d is 5.45 km (std. ± 2.37). The results showed that daily mean D_c for all vocal activity for females is 1.948 million (std. ± 0.66) and 0.86 million (std. ±0.3) for males. F0mode is 150 Hz (std. ± 53 Hz) and F0average is 199.43 Hz (std. ± 32.95) for males whereas for females the result is 306 Hz (std. ± 123) for F0mode and 398.13 Hz (std. ± 44.65) for F0average.

Table 93 Voice dosimetry results of each monitored singer (N=49) for "All vocal activity" including both speaking and singing.

Singer	Total Measurement Duration (hh:mm:ss)	P_t (hh:mm:ss)	P_t (%)	F0mode (Hz)	F0average (Hz)	SPL (dB)	D_c	D_d (meters)
1	01:07:03	00:24:19	19.25	206	371.73	73.98	542599	1055.22
2	01:56:04	00:35:21	33.51	470	404.84	80.27	857329	1972.01
3	01:56:56	00:39:50	21.95	182	446.21	83.03	1059522	2952.63
4	02:27:04	00:47:01	27.51	116	175.91	78.19	496264	2319.62
5	02:37:10	00:41:38	14.35	230	388.27	72.95	970059	1689.33
6	02:48:56	00:59:38	20.91	230	399.23	88.36	1426996	5761.09
7	02:51:09	01:09:42	15.39	176	184.22	87.53	770183	5303.85
8	03:10:06	00:43:56	21.61	116	179.52	81.03	473359	2514.15
9	03:18:44	01:08:04	15.62	470	498.62	89.71	2033520	6223.19
10	03:19:42	01:06:27	26.32	470	436.21	82.14	1739458	4991.71
11	03:26:24	00:35:01	24.66	470	439.21	87	923078	2983.93
12	03:43:10	00:26:01	26.95	128	179.23	81.46	279841	1589.37
13	03:48:16	01:09:13	33.76	206	305.02	83.65	1266637	4187.61
14	03:52:12	01:22:01	18.04	542	462.97	79.14	2277504	5056.01
15	03:55:59	01:03:56	10.8	470	455.6	75.47	1733913	3176.95
16	04:07:34	01:24:54	12.94	470	416.34	79.83	2120480	11737.44
17	04:15:02	00:36:47	15.39	296	295.29	92.82	648806	7693.24
18	04:22:09	00:50:28	20.01	230	390.15	78.92	1177883	2818.86
19	04:29:11	01:30:12	30.04	470	454.92	80.5	2458956	5485.68
20	04:50:09	01:03:40	19.44	152	193.64	86.94	739740	5546.99
21	04:50:50	01:20:00	27.16	230	374.62	92.02	1798544	8423.23
22	04:58:41	00:42:52	17.77	254	330.28	72.9	848956	1718.33
23	05:02:33	01:03:15	19.97	350	430.94	73.39	1635486	3195.27
24	05:05:15	00:46:57	29.45	470	436.45	79.72	1226394	2674.47
25	05:08:17	01:06:36	18.05	116	181.61	90.58	725779	5692.23
26	05:18:13	00:49:43	25.07	248	235.68	85.63	702648	4555.32
27	05:29:39	01:26:45	23.39	152	200.37	83.23	1043061	5536.52
28	05:37:53	01:23:19	23.01	470	432.27	89.03	2154584	8212.8
29	05:39:58	01:31:38	11.73	206	394.86	90.8	2166279	9294.46
30	05:49:59	01:58:08	15.78	230	420.66	82.2	2977542	7774.47
31	05:52:54	01:03:39	20.94	116	167.79	94.63	640831	6137.59
32	05:59:18	00:38:47	24.45	206	315.56	74.25	734504	1762.68
33	06:02:52	00:46:56	19.25	254	357.34	71.3	1006473	1919.17
34	06:03:39	00:40:48	33.51	176	191.47	78.98	468895	2510.01
35	06:11:07	01:14:15	21.95	206	394.34	80.6	1757120	5058.5
36	06:16:28	01:53:06	27.51	128	214.46	84.45	1454828	8772.82
37	06:17:39	01:13:25	14.35	206	365.1	78.42	1606028	3655.22
38	06:17:55	01:42:39	20.91	230	419.24	79.45	2565869	5925.27
39	06:24:05	01:08:14	15.39	182	366.73	86.8	1499414	5785.72
40	06:28:24	01:17:34	21.61	128	181.18	75.32	843049	3308.98
41	06:49:58	02:00:44	15.62	398	386.33	79.5	2798861	6419.88
42	06:53:16	01:14:36	26.32	104	170.26	82.35	762181	4457.09
43	07:00:42	01:45:28	24.66	128	204.1	78.72	1290472	5508.84
44	07:11:56	01:41:02	26.95	254	392.33	85.1	2377629	7708.66
45	07:20:41	01:41:24	33.76	206	358.78	83.52	2177228	6657.94
46	07:32:24	00:53:04	18.04	116	236.15	74.57	743498	2347.12
47	07:32:28	01:11:22	10.8	206	327.47	81.71	1402233	4778.48
48	08:00:39	01:40:37	12.94	230	385.72	80.61	2328101	5946.7
49	08:23:04	02:02:59	15.39	182	379.98	76.61	2799674	6182.8

Table 94 Mean values and standard deviations of daily voice dosimetry results of all N=49 singers for "All vocal activity".

	Monitoring	P_t (sec)	P_t (%)	SPL (dB)	D_d (m)
Mean	05:03:45	01:08:56	24.10	85.45	5.45
Std	01:44:22	00:25:52	7.6	5.71	2.37

Table 95 Mean values and standard deviations of mean daily voice dosimetry results of different genders (N=16 Male, N=33 Female) for "All vocal activity".

	F0mode (Hz)		F0average (Hz)		D_c (million)	
	Male	Female	Male	Female	Male	Female
Mean	150	306	199.43	398.13	0.86	1.94
Std	53	123	32.95	44.65	0.3	0.66

Table 96 Pearson Correlation analysis results between Phonation time (P_t) and the rest of the measured vocal dosimetry parameters for N=49 singers for "All vocal activity"

Parameters		F0 mode	F0 average	SPL	D_c	D_d
P_t	Pearson Corr.	.001	.142	.133	.810**	.709**
	Sig. (2-tailed)	.992	.331	.362	.000	.000

Significance **: p<0.01

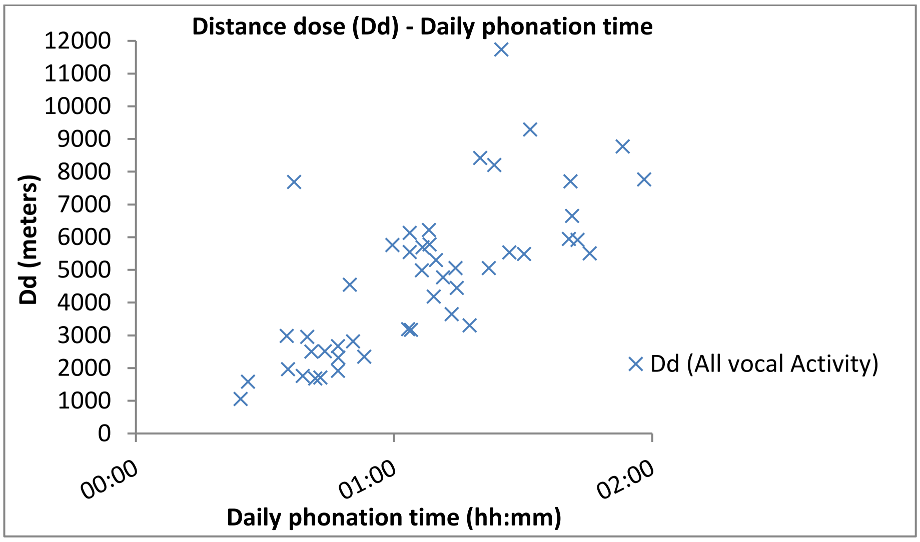

Figure 30 Change in D_d (Distance dose) for each singer (N=49) with the increase in phonation time for all vocal activity.

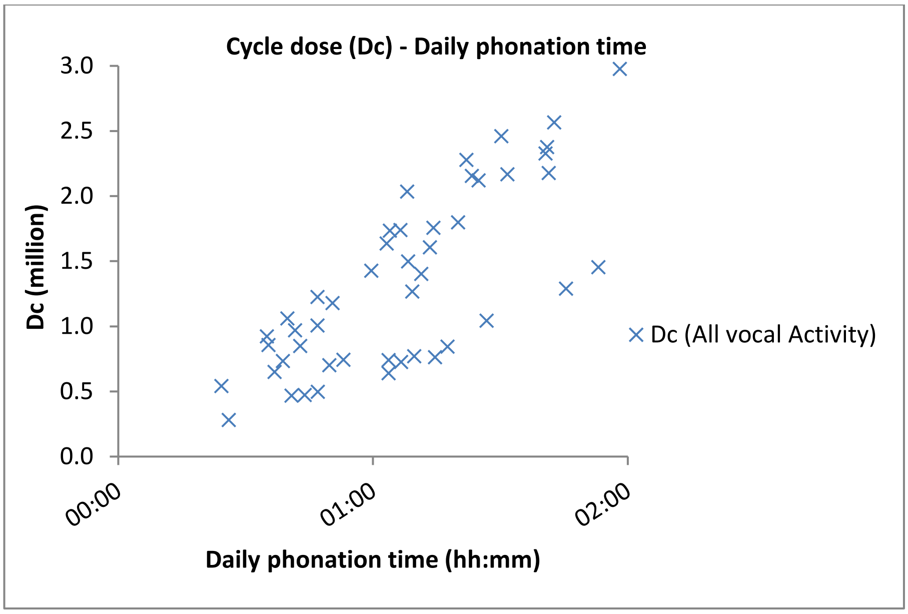

Figure 31 Change in D_c (Cycle dose) for each singer (N=49) with the increase in phonation time for all vocal activity.

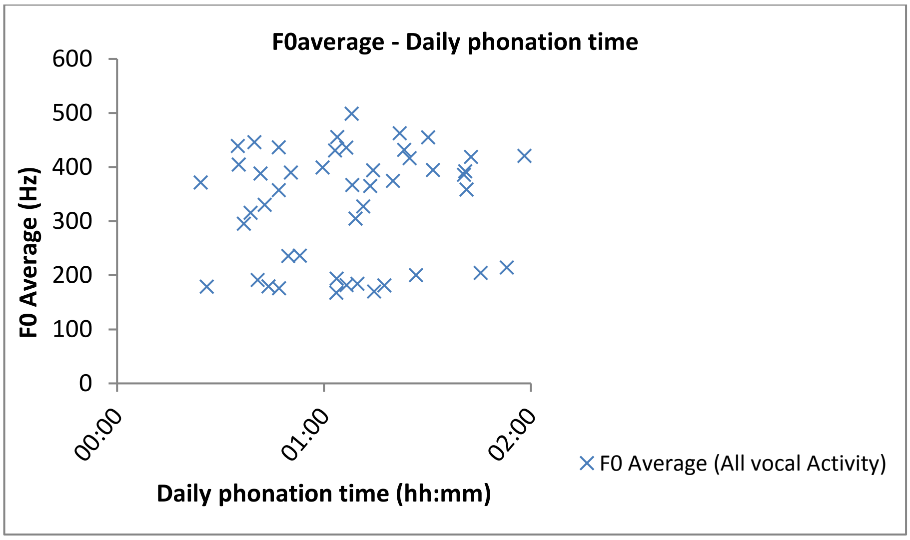

Figure 32 Change in F0average for each singer (N=49) with the increase in phonation time for all vocal activity.

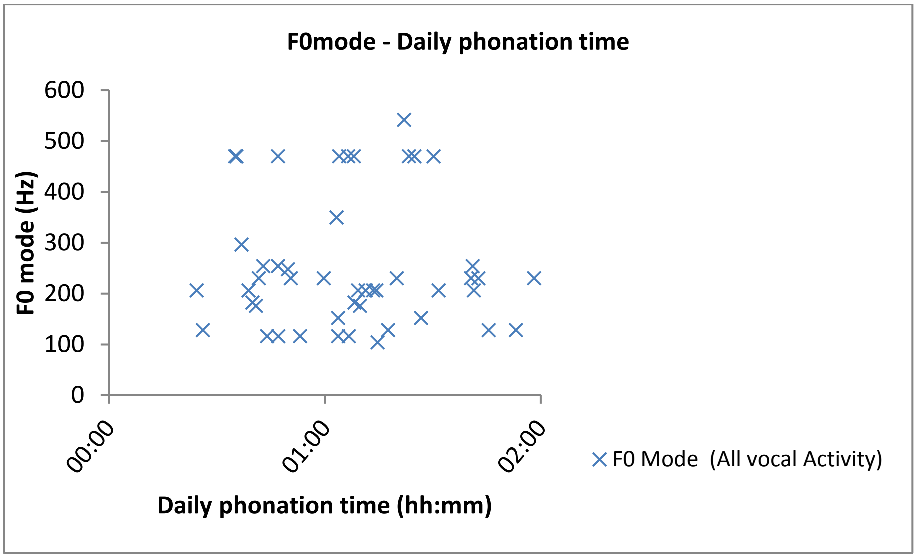

Figure 33 Change in F0mode for each singer (N=49) with the increase in phonation time for all vocal activity.

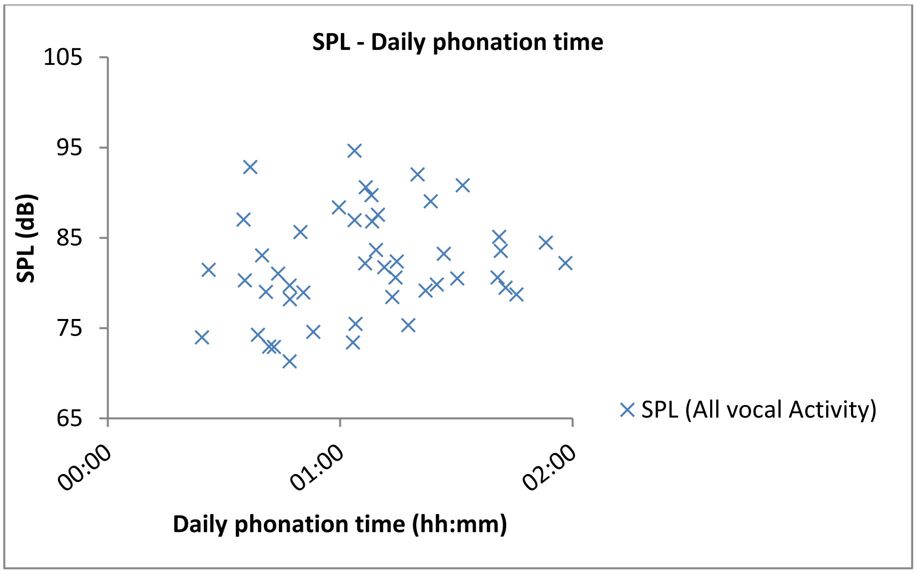

Figure 34 Change in SPL (Sound pressure level) for each singer (N=49) with the increase in phonation time for all vocal activity.

4.7.3. Daily Voice Dosimetry Results due to only singing activity

Table 97 presents the daily voice dosimetry results of each singer due to only singing activity i.e. speaking parts were trimmed from "all vocal activity" data. Pearson correlation analysis results between Phonation time for singing and the rest of the parameters are presented in Table 98. D_d and D_c were found to be correlated with singing phonation time (Pt). Therefore singing activity results regarding the D_c and D_d parameters were normalised to time dose (P_t). Figure 35 to Figure 39 summarise the change in D_c, D_d, F0average, F0mode snd SPL with the increase in daily phonation time for each N=49 singer for only singing activity respectively.

Table 97 Daily voice dosimetry results of each singer (N=49) due to only singing .

Singer	Total Measurement Duration (hh:mm:ss)	P_t (hh:mm:ss)	F0mode (Hz)	F0average (Hz)	SPL (dB)	D_c	D_d (meters)
1	01:07:03	00:13:00	494	470.42	81.16	376336	790.69
2	01:56:04	00:23:00	470	487.09	84.13	681880	1583.51
3	01:56:56	00:29:00	470	523.28	88.6	928478	2710.55
4	02:27:04	00:25:00	224	206.57	83.42	317421	1632.09
5	02:37:10	00:24:00	470	476.83	77.64	714568	1274.07
6	02:48:56	00:37:00	470	486.18	96.64	1079108	4811.73
7	02:51:09	00:46:00	176	205.11	93.32	566587	4387.93
8	03:10:06	00:30:00	188	195.97	86.41	363785	2166.7
9	03:18:44	00:56:00	470	535.2	91.6	1810958	5586.48
10	03:19:42	00:46:00	470	501.98	87.3	1414063	4331.22
11	03:26:24	00:27:00	470	489.86	90.49	809328	2684.98
12	03:43:10	00:17:00	128	194.72	87.63	200313	1302.73
13	03:48:16	00:23:00	398	448.9	90.74	631814	2110.28
14	03:52:12	00:58:00	542	531.49	83.32	1850908	4239.25
15	03:55:59	00:40:00	470	544.2	77.1	1299886	2232
16	04:07:34	01:05:00	470	472.85	82.55	1855458	10375.15
17	04:15:02	00:25:00	296	322.47	94.34	483089	5643.42
18	04:22:09	00:35:00	470	438.84	82.43	936280	2336.84
19	04:29:11	01:02:00	470	523.37	83.85	1968885	4412.99
20	04:50:09	00:47:00	176	206.89	91.77	588357	4939.25
21	04:50:50	00:50:00	398	444.13	98.93	1340383	6804.68
22	04:58:41	00:24:00	278	366.38	76.71	540587	1192.77
23	05:02:33	00:47:00	398	475.03	76.16	1348197	2754.63
24	05:05:15	00:31:00	470	527.37	84.55	1005219	2251.65
25	05:08:17	00:42:00	224	206.19	96.16	528989	4589.14
26	05:18:13	00:42:00	248	251.09	89.34	641247	4366.44
27	05:29:39	00:45:00	248	233.21	86.56	640307	3426.66
28	05:37:53	01:06:00	470	484.04	93.72	1922175	7606.62
29	05:39:58	00:54:00	518	501.22	99.88	1637523	7681.04
30	05:49:59	01:10:00	590	520.48	86.19	2193483	5685.44
31	05:52:54	00:39:00	212	193.38	99.42	453234	4659.48
32	05:59:18	00:28:00	206	343.42	78.68	590119	1558.54
33	06:02:52	00:16:00	374	396.46	76.68	396678	819.84
34	06:03:39	00:31:00	176	205.65	81.56	388305	2175.32
35	06:11:07	00:47:00	470	468.51	86.93	1348124	4220.83
36	06:16:28	01:01:00	248	260.95	92.82	960224	6618.9
37	06:17:39	00:32:00	470	473.2	83.89	911821	2095.51
38	06:17:55	00:50:00	518	535.75	83.56	1599904	3596.48
39	06:24:05	00:34:00	470	473.42	93.63	985684	3955.77
40	06:28:24	00:20:00	248	239.84	83.53	293697	1312.36
41	06:49:58	01:14:00	398	465.4	82.31	2073262	4735.79
42	06:53:16	00:44:00	188	197.38	90.62	526943	3565.94
43	07:00:42	01:04:00	224	236.52	83.97	910547	4249.45
44	07:11:56	01:09:00	398	452.03	91.58	1874596	6701.86
45	07:20:41	00:32:00	398	486.47	95.45	958579	3652.33
46	07:32:24	00:22:00	398	377.01	82.71	516919	1643.78
47	07:32:28	00:34:00	398	413.32	92.59	852117	3485.37
48	08:00:39	01:07:00	470	453.43	84.21	1838728	4809.14
49	08:23:04	01:10:00	470	473.1	81.48	1999924	4557.8

Table 98 Pearson Correlation analysis results between Phonation time and the rest of the measured vocal dosimetry parameters for N=49 singers for "Singing Only".

		F0mode	F0average	SPL	D_c	D_d
Pt	Pearson Corr.	.255	.222	.156	.842**	.770**
	Sig. (2-tailed)	.077	.126	.284	.000	.000

Significance *: p<0.05 **: p<0,01

The number of monitoring hours of N=49 singers showed that a semi-professional Opera singer spends approximately an average of five hours (05:03:45, std. ± 01:44:22) at his/her education premises and approximately an average of 42 minutes (00:41:58, std. ± 00:16:43) of this duration is spent for phonation only for singing. The results showed that daily mean Phonation time percentage (P_t %) of the Opera singers for singing is 15.47% (std. ± 6.14); SPL is 91.67 dB (std. ± 6.35) and D_d is 4.38 km (std. ± 2.05). The results showed that the daily mean D_c due to singing for females is 1.48 million (std. ± 0.03) and 0.59 million (std. ±0.03) for males. F0mode is 225 Hz (std. ± 61 Hz) and F0average is 233.3 Hz (std. ± 51.13) for males whereas for females the result is 447 Hz (std. ± 71) for F0mode and 475.26 Hz (std. ± 46.8) for F0average.The daily mean values and the standard deviations of the daily voice dosimetry results due to singing are summarised in Table 99 and seperately summarised in Table 100 for F0average, F0mode and D_c parameters for each gender.

Table 99 Mean values and standard deviations of mean daily voice dosimetry results of N=49 singers for "Singing Only".

	Monitoring duration (hh:mm:ss)	P_t (hh:mm:ss)	P_t (%)	SPL (dB)	D_d (normalised) (km)
Mean	05:03:45	00:41:58	15.47	91.67	4.38
Std	01:44:22	00:16:43	6.14	6.35	2.05

Table 100 Mean values and standard deviations of mean daily voice dosimetry results of N=49 singers for "Singing Only".

	F0mode (Hz)		F0average (Hz)		D_c (million)	
	Male	Female	Male	Female	Male	Female
Mean	225	447	233.3	475.26	0.59	1.48
Std	61	71	51.13	46.8	0.03	0.03

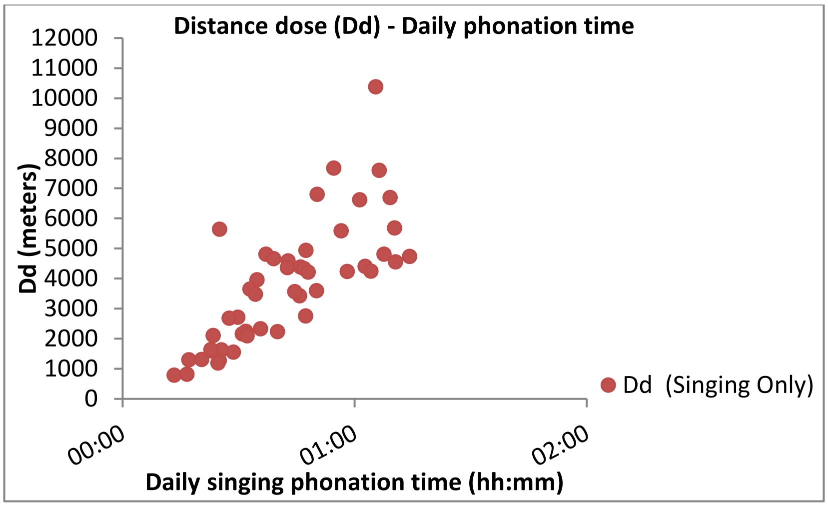

Figure 35 Change in D_d (Distance dose) for each singer (N=49) with the increase in phonation time for singing activity only.

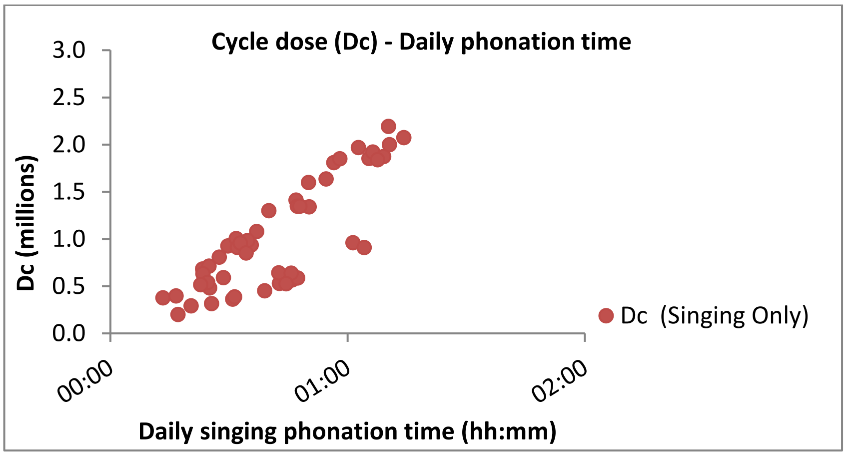

Figure 36 Change in D_c (Cycle dose) for each singer (N=49) with the increase in phonation time for singing activity only.

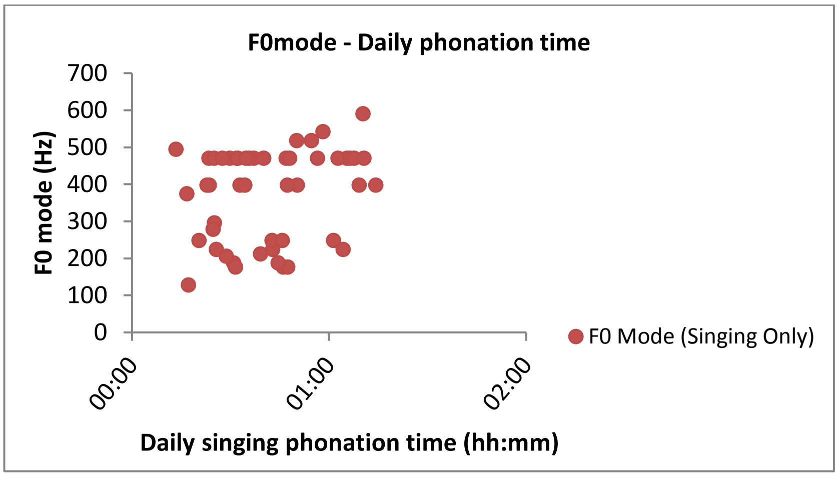

Figure 37 Change in F0mode for each singer (N=49) with the increase in phonation time for singing activity only.

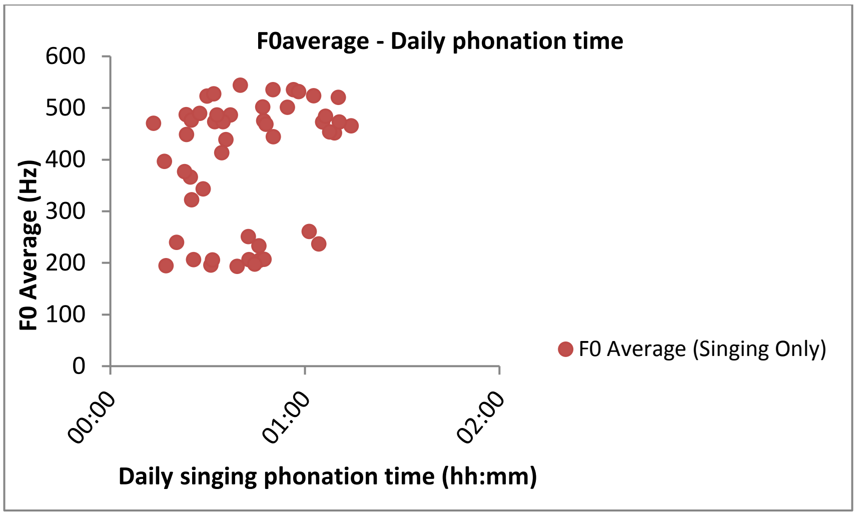

Figure 38 Change in F0average for each singer (N=49) with the increase in phonation time for singing activity only.

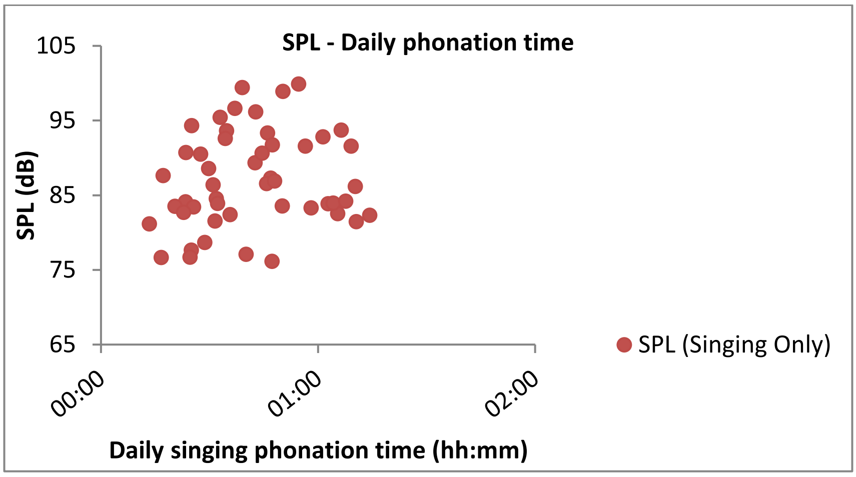

Figure 39 Change in SPL (Sound pressure level) for each singer (n=49) with the increase in phonation time for singing activity only.

5. CHAPTER 5: DISCUSSION

The aim of this research was to understand the changes in Opera singers' objective and subjective responses due to change in the acoustics of their practicing environment. This would allow the relationship between room parameters and the subject's parameters to be determined so that a preferable practicing environment for the Opera singers could be designed. The following questions were investigated:

1. Does the acoustics of the practice room environment affect Opera singers' vocal loading and vocal effort?
2. Does the acoustics of the practice room environment affect Opera singers' perception of the rooms and their vocal comfort?
3. What are the room parameters that are significantly correlated with Opera singers' parameters?
4. What are the maximum and minimum values of the correlated room parameters in order to design preferred practice room conditions?
5. What is the daily vocal loading of a semi-professional Opera singer at their education premises?

These questions will be answered in the section, including objective and subjective analysis, which will then be discussed and further analysed. In this chapter only the results of Field stage will be discussed; results from Laboratory stages will be mentioned only where necessary as they formed the pilot study of the research. Despite the valuable insights of the study, it is necessary to understand that the results are peculiar to the participants, practice rooms, and methods used for this research.

To date, similar research examining the effects of environment on voice dosimetry and perception are mostly found for teachers and their teaching environment. [47, 48, 50] Research found for singers on the other hand, examine the change in voice dosimetry and perception due to change in the acoustics of larger volumes such as different sized performance halls, rehearsal rooms, anechoic or reverberant chambers using different methodologies.[55, 56, 57, 58, 59] This research makes a difference as it examines the effect of room acoustics on singers' voice dosimetry and perception focusing on smaller volumes: practice rooms. In addition, the use of APM for singers' voice dosimetry collection in literature was found for collecting data for clinical use to monitor singers' daily voice use to address the reasons for vocal problems or to follow the changes in dose due to change in performance style or loading and rest periods [26, 27] rather than examining the effects of room as investigated in this research. The study was undertaken with the voluntary work of a total of N=117 (N=62 in Laboratory stage, N=55 in Field stage) semi-professional student Opera singers of Royal Academy of Music who were very well trained in singing, without any known vocal problems during the time of the measurements and who had good hearing ability, so as to be sensitive to changes to their acoustic environment [63]

5.1. Objective Voice Dosimetry Results

Vocal effort is described as the physiological changes in voice production due to change in communication distance, noise or the environment [64, 65] whereas vocal comfort is the psychological outcome of vocal effort meaning the subjective perception of effort.[64, 66] One of the main findings of this research is that none of the objectively measured voice dosimetry parameters of the Opera singers showed any significant change between practice rooms for either genders or the different singing exercises due to change in room acoustic conditions. This means that the Opera singers' vocal effort did not change with the acoustics of the environment see Table 45 and Table 46.

Thomasson and Sundberg [67] states that for singers in order to be able to repeat the same tasks constantly in the same manner, singers should be able to control the variables that affect phonation via control of their breathing as this lets them keep the changes in their subglottal pressure consistent. According to Sundberg [68] subglottal pressure is necessary as singers control their pitch and loudness via changing their subglottal pressure, moreover Operatic singers are very consistent in their voice use as they are able to use their voice very systematically that the random changes in subglottic pressure is minimised therefore offering more vocal control. This might explain the consistency in their voice dosimetry results singing the same task in different environments as all the singers participated in the study were highly trained semi-professional Opera singers. Moreover, the informal conversations with the Opera singers and their teachers during the research showed that singers are taught to sing with their usual effort regardless of the acoustic environment as they perform in variety of spaces. Hence, while they try to avoid singing with extra effort due to health reasons they also avoid singing with less effort as this might lead them to struggle when they have to sing in acoustically poor spaces. This confirms Hylton's advice for singers to keep singing the same way regardless of the change in the environment as cited by Hom. [56]

Research by Sinal and Yilmazer [58] emphasises that Opera singers are advised on not to practice in live room conditions by their instructors as they should not get used to sing with less effort than usual as this might cause problems projecting their voice to the audience in larger environments where they will need to put more effort. According to Titze [69] "vocal laziness" might occur due to electronic amplification or improved room acoustics as these might decrease the magnitude of vocal fold acceleration. This explains why Opera singers' do not prefer singing in conditions where they might sing with less effort. All mentioned reasons above are in agreement with the Opera singers' subjective "singing effort" preference of this research as they did not prefer to sing with "less effort" but with "as usual" effort, see Table 59. Sound pressure levels of the Opera singers measured via APM directly from vocal fold vibrations showed less than 1 dB difference and the results of power spectrum analysis at singer's dominant frequencies, 500 Hz and 1k, showed less than 1.2dB difference between the practice rooms, see

Table 55. Likewise results of the research undertaken by Cabrera et al. [59] on Opera singers and by Kato et al.[56] on a Baritone opera singer also did not show any significant change in sound pressure levels due to change in the acoustics of the environment despite they have used larger room conditions. In Cabrera's [59] study, sound pressure levels of individual singers measured via head mounted microphone in acoustically different rooms were quite consistent within 3dB, and the difference in sound pressure levels was found to be higher at 2 kHz - 4kHz octave band region which is explained as the singers' singing formant region with its 3kHz centre frequency seen mainly in trained singers by the author. The singing formant frequencies help singers to increase the amplitude and loudness of their voice without any extra effort since they adjust their voice levels according to spectral features of the vocal tract without using any extra lung pressure. [65]

The reason for the higher change in sound pressure levels at singer's formant frequencies in Cabrera's research may be explained by the large difference of room conditions as they used an anechoic chamber, a reverberation chamber and a recital hall (8000 m^3 volume) where the singers tried to cope with extremely dry and extremely live room conditions and a hall condition where they need to project their voice to the audience area. However, the results of the Field stage of this study showed higher difference in sound power levels at 500 Hz between practice rooms for both genders and for both singing exercises, see

Table 55. This might be due to smaller volumes of the rooms with realistic sound fields where the singers might not have felt the need to increase the amplitude of their voice.

5.2. Subjective voice dosimetry Results

In contrast with the results of the objective data, significant changes were observed in singers' subjective data due to change in the acoustics of the environment, see Table 44. The results showed that the room significantly affected the perception and therefore the vocal comfort of the Opera singers, but not their vocal loading and their vocal effort. According to Bottalico and Astolfi [21] correlation between voice dosimetry parameters and vocal comfort is still a research area due to a lack of exact results.

The results of their research on 40 teachers in acoustically different classrooms showed significant change in subjective data regarding the acoustics of the environment and teachers' perception of their vocal effort. However, the objective data regarding teachers' voice dosimetry parameters did not show any significant change which is parallel to the findings of this research.

Despite that there was no significant change in singers' measured voice dosimetry data, the results of the subjective questionnaire showed that the singers felt as they were singing with more effort in the less reverberant practice room condition (T room) and as a result subjective ratings for "Pleasure of singing", "Voice feeling" and "Overall impression" parameters were significantly lower compared to the other practice rooms, see Table 44.

The Pearson Correlation analysis results between room parameters and singers' subjective data showed that "Singing effort" subjective parameter was inversely proportional to reverberation time (T30) and directly proportional to clarity (C80) room parameters whereas "Pleasure of singing", "Voice feeling" and "Overall impression" were found to be directly proportional to T30 and inversely proportional to C80 room parameters, see Table 57. Sinal and Yilmazer's [58] findings on Opera singers' perception of sound quality in rehearsal rooms showed that an increase in reverberation time decreased Opera singer's perceived singing effort; therefore, they suggested that preferred reverberation time of Opera singers is singing effort dependent. This is in line with the findings of this study.

Moreover, when we look through the subjective data results collected for all the practice rooms, we see that two practice rooms showed a significant difference among the others: YG and the T room. The overall impression rating of the YG room was significantly better than the other practice rooms with a rating very close to "good" rating but it's worth mentioning that none of the rooms were rated "good" which shows that the rooms were sufficient but not ideal for the singers, see Table 44. The mean values of each subjective parameter rating for the YG room show that the ratings for this room was mainly in the preferred range of singers or at least was providing the "sufficient" ratings for all of the subjective parameters, except for the background noise levels which was rated between "acceptable" and "loud" but closer to the "acceptable", see Table 44.

On the other hand T room ratings were significantly lower than the other practice rooms for all of the subjective parameters, except for the singing effort parameter which was rated "more than usual" and overall the room was rated between "very bad" and "bad". When we compare the measured room parameters for these rooms we see that a significant difference is seen for T30, C80 parameters at each octave band where $T30_{mid}$ in YG room is 0.67sec and in T room it is 0.21 sec (see Table 20) and $C80_{mid}$ in YG room is 7.49 dB and 24.13 dB in the T room, see

Table 22. The measured octave band results for reverberation time (T30) and clarity index (C80) for each room is presented in Figure 40 and Figure 41 for comparison.

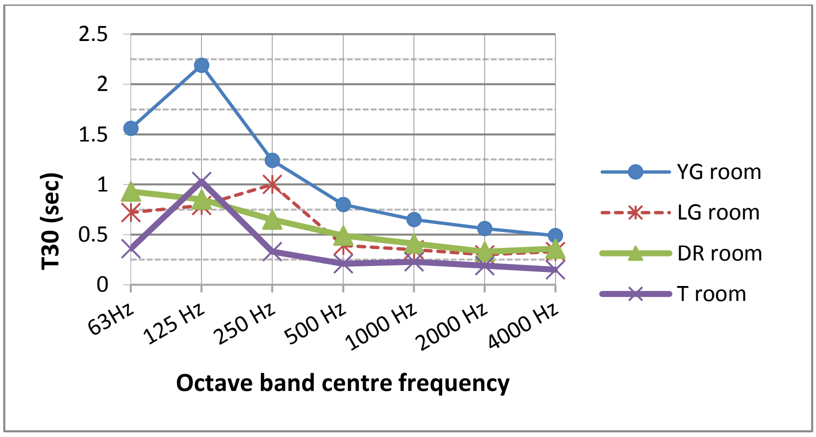

Figure 40 Measured reverberation time, T30(s) in octave bands for each practice room

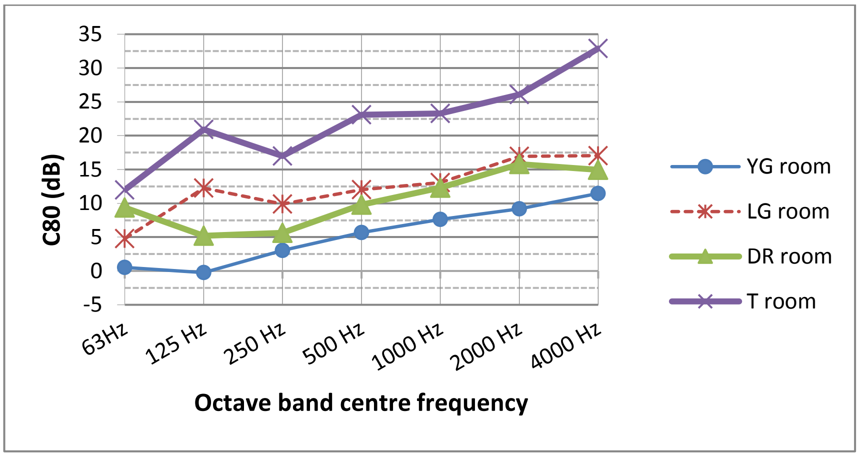

Figure 41 Measured Clarity Index, C80(dB) in octave bands for each practice room

5.3. Comparison of Results to Existing Standards

This section considers the objective results with those of the Norwegian Standard, ANSI/ASA S12.60, and BB93. The focus will be on the room acoustic parameters: Reverberation Time, Sound Strength, Clarity Index, Sound Power Levels, and Background Noise Levels. In addition, the practice room dimensions will be discussed with a view to room modes.

5.3.1. Reverberation Time Parameter

The Norwegian Standard (NS8178) classifies opera singing as "loud music" and the required mean reverberation time T_m (average of 500 Hz and 1k) is defined for the upper and lower limits relative to room volume. Figure 42[45, p.14]which is taken from the standard shows the limits of Tm for different types of music in performance halls and rehearsal rooms, limits for acoustical loud music in rehearsal rooms is shown in the red shaded area.

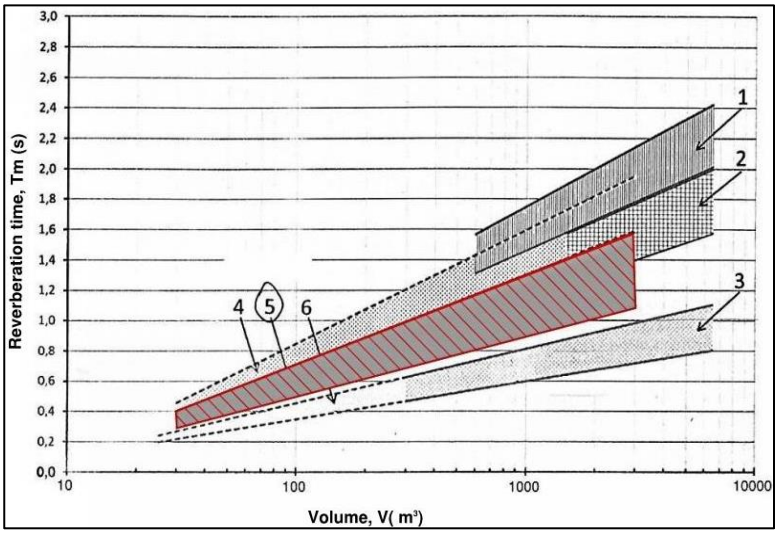

Figure 42 Limits for Reverberation time, Tm, relative to net room volume according NS8178:2014, red shaded area apply to acoustical loud music for rehearsal rooms.

In order to make a comparison, the maximum and minimum limits for T_m according to NS8178 are calculated for each practice room. Table 101 below shows the measured Tm values for each practice room and the minimum and maximum allowed limits of Tm for RAM practice rooms according to NS8178 relevant to room volume.

Table 101 Room volumes, mean reverberation times calculated for 500 Hz and 1k ($T30_{(500Hz\text{-}1kHz)}$ or T_m) octave bands for RAM practice rooms and minimum and maximum limits of T_m relevant to room volume according to NS8178.

Rooms	Volume	T_m (measured)	T_m (minimum and maximum limits, NS8178)
YG	35.12	0.72	0.3 sec≤ T_m ≤0.43 sec
LG	14.53	0.37	0.15 sec≤ T_m ≤0.17sec
DR	19.5	0.45	0.23 sec≤ T_m ≤0.27 sec
T	13.94	0.22	0.13 sec≤ T_m ≤0.16 sec

As seen from the table, the Tm values of all the practice rooms are higher than the maximum allowable limits according to NS8178. When we look at the subjective data results of “Room Questionnaire” for “Reverberance” subjective parameter, we see that the YG room was rated between “balanced” and “reverberant”; the LG and DR rooms were rated as “balanced” and the T room was rated as “very dry”. Considering singers preferred ratings for “Reverberance” parameter which was preferred for both “balanced” and “reverberant” ratings and considering that the T room with Tm of 0.22 sec was rated as “very dry” we can see that the limits required by NS8178 fall somewhere between “very dry” and “extremely dry” ratings which are well below than opera singer’s preferences.

Unlike NS8178, reverberation time for middle frequencies (T_{mid}) is defined as the average of 500 Hz, 1kHz and 2kHz octave bands in BB93:2015, ANSI/ASA S12.60 and in Music accommodation in secondary schools: A design guide. Table 102 below shows the maximum $T30_{mid}$ limits for music practice rooms relevant to their volumes according to each standard/guidance together with the measured values of each RAM practice room. As seen from the table the allowable maximum limits are higher than the NS8178 maximum limits and all of the RAM practice rooms show compliance with the required maximum values with the exception of YG room marginally exceeding the maximum limits of ANSI/ASA S12.60 by 0.07 sec.

Another finding of this research is that reverberation time plays a big role on the singer’s perception only at the 4 kHz octave band. $T30_{(4kHz)}$ was found to show correlation for all subjective parameters including: “Reverberance”, “Voice feeling”, “Singing effort”, “Pleasure of singing” and “Overall impression” rather than the middle frequencies ($T30_{(500Hz\text{-}1kHz)}$ and $T30_{mid}$), see Table 61. The target range suggested for $T30_{(4kHz)}$ is based on the results of singers’ preferred ratings of “Size of the room” subjective parameter for "sufficient" and "large" ratings which correspond to 0.41 sec for 35 m^3 and 0.5sec for 50m^3 room volumes respectively.

Table 102 Required reverberation times ($T30_{mid}$, sec) of music practice rooms according to different standards/guidances and T30mid values of RAM practice rooms

Standard / Guidance	Room Volume	$T30_{mid}$
BB93:2015 [40] (new built)	≤ 30 m^3	≤ 0.6
	> 30 m^3	≤ 0.8
BB93:2015[40] (refurbished)	≤ 30 m^3	≤ 0.8
	> 30 m^3	≤1.0
Music accommodation in secondary schools, A design guide (2010) [41]	≤ 30 m^3	≤ 0.8
	> 30 m^3	
ANSI/ASA S12.60[44]	≤ 283 m^3	≤ 0.6
RAM Practice Rooms	**Room Volume**	**$T30_{mid}$**
YG	35.12	0.67
LG	14.53	0.35
DR	19.5	0.41
T	13.94	0.21

Since the standards only make reference to T_m or T_{mid} values it is not possible to compare these values with the existing literature. Acoustics of schools: a design guide [44] recommends a constant reverberation time over middle and high frequencies whereas an increase of 25% is allowed for low frequencies, see Figure 43.[44. p.51] Since the results of this research did not show correlation with T30 at middle frequencies for all the common subjective parameters, T30 at 4kHz is suggested for singers' preferred room conditions assuming that the reverberation time is constant over middle and high frequencies as recommended by the guidance. An interesting point that worth mentioning is that when $T30_{(4kHz)}$ is assumed to be constant across middle frequencies, the suggested values of $T30_{(4kHz)}$ for 35 m^3 and for 50 m^3 room volumes by this research is in agreement with the suggested values of T_m for the same volumes by NS8178 which is between 0.3-0.43 sec for 35 m^3 and between 0.4-0.53sec for 50m^3 rehearsal room volumes for loud music.

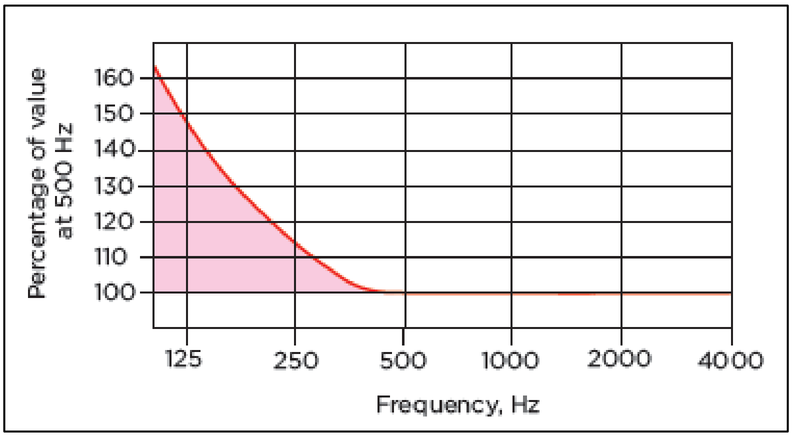

Figure 43 Reverberation time percentage increase in low frequencies recommended especially for rooms for music function by Acoustics of schools: a design guide [43]

According to NS8178, the upper and lower limits of reverberation time at each octave band frequency should be checked by the $\frac{T}{Tm}$ factor, where T is the reverberation time at the frequency of interest and Tm is the average of the reverberation time at 500 Hz and 1 kHz octave bands. Below Figure 44[45, p.38] is taken from the standard, showing the limits for acoustic loud music in rehearsal rooms with an advice to stay in the shaded region.

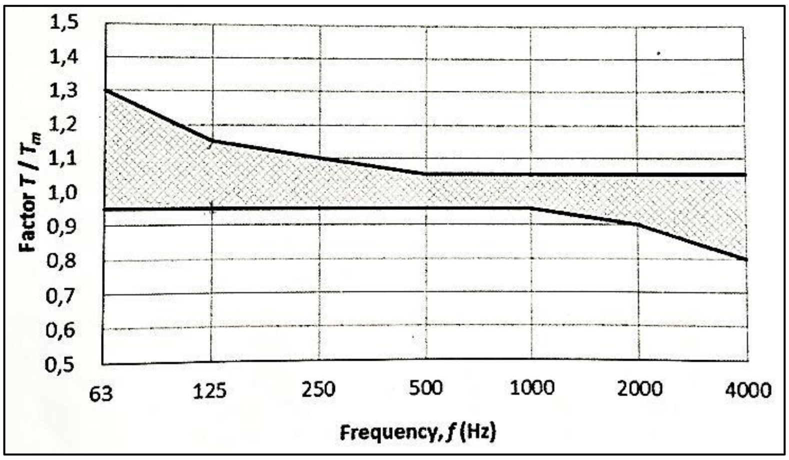

Figure 44 $\frac{T}{Tm}$ limits for each octave band for acoustical loud music for rehearsal rooms according to NS8178:2014.[45]

For a comparison, $\frac{T}{Tm}$ factor is calculated for each octave band for each RAM practice room, as shown in Figure 45 and Table 103. According to this standard, for acoustic loud music this factor should not exceed 1.05 and should not be below 0.8 at the 4 kHz octave band. As seen from Table 103, the factor for YG and T rooms are below the required minimum value (0.8) at 4 kHz. Interestingly, the value of this factor is found to be the same at the 4kHz octave band for the T room which received the lowest rating score and for the YG room which received the highest rating score from the singers for “Pleasure of singing”, “Voice feeling” and “Overall impression” subjective parameters.

Moreover, if we consider the values of this factor at 500 Hz and 1 kHz octave bands as these are the bands defining the required reverberation time, Tm, according to the standard, we can see that the best rated YG room exceeds the maximum limit at 500 Hz (1.11) and is below the minimum limit at 1kHz (0.90) whereas the worst rated T room achieves exactly the same minimum required limit at 500 Hz (0.95) and the maximum required limit at 1kHz (1.05) therefore it is a question whether providing these target values for this factor provides the preferred conditions in practice rooms for Opera singers.

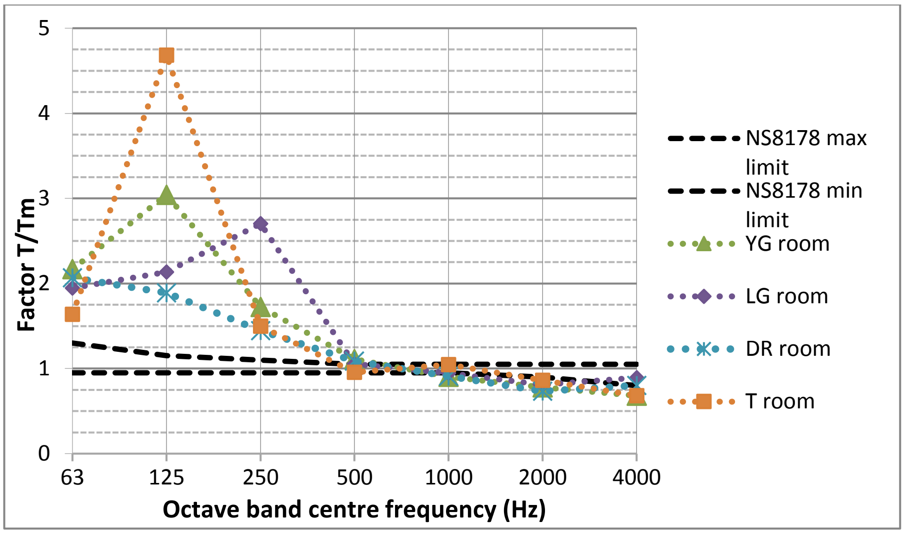

Figure 45 $\frac{T}{Tm}$ values of RAM practice rooms compared to NS8178 limits for each octave band.

Table 103 $\frac{T}{Tm}$ values of RAM practice rooms compared to NS8178 limits for each octave band.

Frequency (Hz)	NS 8178 T/Tm limits		RAM practice room T/Tm values			
	Max	**Min**	**YG room**	**LG room**	**DR room**	**T room**
63	1.3	0.95	2.17	1.95	2.07	1.64
125	1.15	0.95	3.04	2.14	1.89	4.68
250	1.1	0.95	1.72	2.70	1.44	1.50
500	1.05	0.95	**1.11**	1.05	1.09	**0.95**
1000	1.05	0.95	**0.90**	0.95	0.91	**1.05**
2000	1.05	0.9	0.78	0.81	0.73	0.86
4000	1.05	0.8	**0.68**	0.89	0.80	**0.68**

5.3.2. Sound Strength Parameter

Similar to Tm; sound strength (G) is also defined relative to room volume and reverberation time (Tm) in NS8178. Based on the results of this research, "Loudness" impression was found to show the highest correlation with sound strength (G) at the average of 250-500 Hz octave bands, $G_{(250\text{-}500Hz)}$. Although the correlation analysis results showed less significance, G at the average of 500Hz-1k octave bands $G_{(500\text{-}1k)}$ was also examined in order to make a comparison with the suggested values by NS8178, as G values in the standard are relative to Tm. As the standard only provides a diagram, the recommended Sound strength values for loud music for RAM practice room volumes and singers' preferred practice room volumes were found by extrapolation using Figure 46 [45, p.18] as taken from the standard, assuming that all the rooms had the suggested Tm values according to the standard. Figure 46 shows upper and lower limits of reverberation time depending on the music type; volume and sound strength in rehearsal rooms. The upper limit for loud music is shown by "2"; whereas the lower limit for loud music is shown by line "3".

From the diagram we can see suggested levels vary between 21-25 dB for the volumes in consideration which vary between 13 m^3 to 50 m^3. These levels recommended by the standard are found to be below the levels that correspond to “sufficient” subjective ratings for “Loudness” parameter by the singers. When we look at the subjective scores of “Loudness” parameter in the T room (see Table 44, Section 4.5.2.), as it has the lowest ratings and has the smallest volume (13.94 m^3) among the other practice rooms, despite the room has $G_{(500Hz\text{-}1k)}$ of 27.04 dB it is rated below “sufficient” rating, moreover the room actually has longer T_m then the suggested maximum.

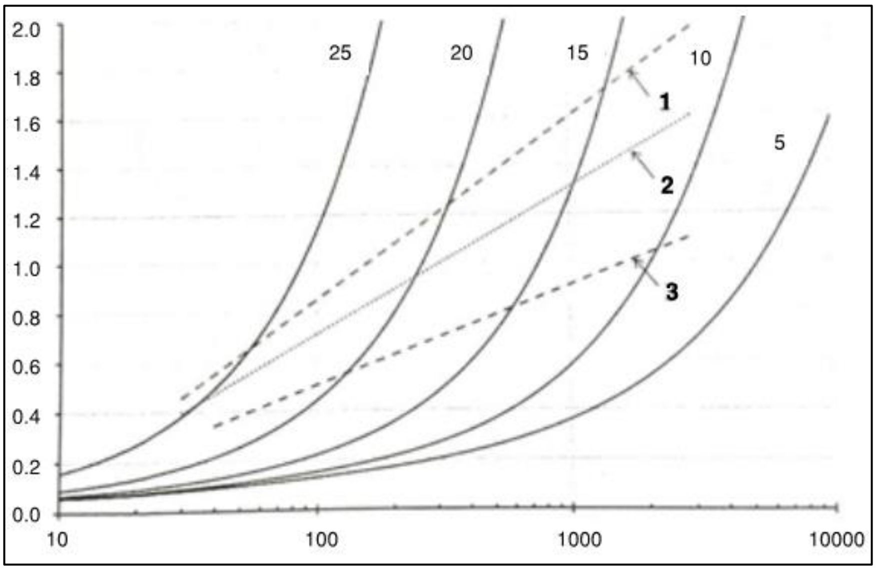

Figure 46 Upper and lower limits of reverberation time in rehearsal rooms depending on the room volume and strength. Limits for acoustical loud; quite music and amplified music: loud music is denoted by lines 2 and 3.[38]

Table 104 presents the Pearson correlation analysis results between Loudness subjective parameter and $G_{(250\text{-}500Hz)}$, as well as the $G_{(500Hz\text{-}1k)}$ room parameter in order to show the difference of significance degree and the suggested levels by this research which correspond to singers’ preferred subjective ratings: sufficient (4) and loud (5) according to the regression analysis results. These suggested levels for “sufficient” and “loud” preferred ratings for “Loudness” subjective parameter are suggested relative to preferred ratings of “Size of the room” and “Reverberance” subjective parameters: for the corresponding values of “sufficient”(4) and “reverberant”(5) ratings for the “Reverberance” subjective parameter and for the corresponding values of “sufficient”(4) and “large”(5) ratings for “Size of the room” parameter see Table 66, Table 67 and Table 68.

In order to obtain “sufficient” loudness in a 35 m^3 sufficient sized practice room with a T30 of 0.41 sec. “sufficient” reverberation time (assuming the reverberation time is constant across all frequencies), $G_{(250\text{-}500Hz)}$ is calculated to be 27.7 dB and this level can increase up to 30.7 dB in a 50 m^3 practice room with 0.5 sec of reverberation time as a maximum. These results correspond to upper limit for preferred ratings of singers in a practice room for each subjective parameter. As can be seen, the levels are significantly higher than the recommended values in NS8178.

Table 104 Pearson correlation analysis results between $G_{(500Hz\text{-}1k)}$, $G_{(250\text{-}500Hz)}$ and Loudness subjective parameter together with the resgression analysis results corresponding to singers' prefered ratings.

Subjective parameter	Room parameter	Pearson Corr.	Sig. 2 tailed	Likert scale rating	
				4 (sufficient)	5 (loud)
Loudness	$G_{(250\text{-}500Hz)}$, dB	.953	.047	27.66	30.69
	$G_{(500Hz\text{-}1k)}$, dB	.952	.048	27.07	28.74

5.3.3. Room Dimensions and Room Modes

A further finding of this study has found that the "Size of the room" subjective parameter shows at significant correlation with the objective room parameter "Room length" followed by "Room area" and then the "Room volume". According to the research results, "size of the room" subjective parameter was preferred for "sufficient" and "large" ratings which correspond to 35 m^3 and 50 m^3 respectively.

Table 105 shows the minimum dimensions recommended by the standards for small practice rooms and this research's findings based on singer's preferred ratings. As explained in the Literature Review chapter, room modes are necessary to avoid in the design of small rooms as they cause colorization of the sound.

Below Table 106 summarises the recommended room dimension ratios in literature normalised for equal height taken from Osman's study [60, p.2] which are suggested to prevent room modes and the ratios found in this research based on singer's preferred room dimensions corresponding to "sufficient" and "large" preferred ratings of "size of the room" subjective parameter which are also normalised for equal height. As can be seen from the table, the room dimension ratios according to singers' preferred dimensions of the rooms do not match any of the recommended room dimension ratios, therefore singers' preferred room dimensions were further examined.

Table 105 Minimum dimensions of a small practice room recommended by the standards and singer's preferred dimensions according to research results.

Standard / Guidance	Room volume		Room area		Room height	
	Small	Medium (ensemble)	Small	Medium (ensemble)	Small	Medium (ensemble)
BB93:2015[40]	≥ 30 m^3		8 m^2	20 m^2	≥ 3 m	
Music accommodation in secondary schools, A design guide (2010) [41]	≥ 30 m^3		8 m^2	12 - 15 m^2	2.7m - 3 m	
NS8178[45]	≥ 40 m^3	≥ 60 m^3	≥ 15 m^2		≥ 2.7 m	≥ 3.5 m
Research results	**Room volume**		**Room area**		**Room height**	
Preferred Ratings	**Sufficient**	**Large**	**Sufficient**	**Large**	**Sufficient**	**Large**
Singer's preferred dimensions	**35 m^3**	**50 m^3**	**13 m^2**	**18 m^2**	**2.67 m**	**2.77 m**

Table 106 Recommended room dimension ratios for small rooms in literature taken from Osman's study[60, p.2] compared to the room dimension ratios according to preferred room dimensions by the Opera singers corresponding to "sufficient" and "large" preferred ratings of "Size of the room" subjective parameter according to the results of this research.

Name of the Ratio in Literatute	Ratio of Room Dimensions normalised for equal height (height:width:length)
Harmonic	1:2:3
V.O.Knudsen	1:1.88:2.5
European	1:1.67:2.67
J.E.Volkmann	1:1.6:2.5
Golden Ratio	1:1.25:1.6
Golden Section	1:1.63:2.63
P.E. Sabine	1:1.5:2.5
Sepmeyer 1	1:1.14:1.39
Sepmeyer 2	1:1.28:1.54
Sepmeyer 3	1:1.6:2.33
Louden	1:1.4:1.9
BBC Prototype	1:1.51:2.06
Singer's preferred ratings for size of the room	**Corresponding room dimension ratios normalised for equal height**
Sufficient size	1:0.86:2.16
Large size	1:0.9:2.82

In order to check whether these dimensions might cause any room modes, Schroeder's cut off frequency was calculated as this is the minimum frequency limit where below this limit the sound is subject to room modes which lead to peaks at resonance frequencies of the room [70] . Therefore, the aim was to check whether the spectral energy of the singers fall below or above this frequency in the preferred room conditions.

Schroeder's cut off frequency was calculated for both of the "large" and "sufficient" size dimension options according Equation 16 [71] below, where *fs* is the Schroeder's cut off frequency, V is the volume (m^3) of the room and T (Hz) is the reverberation time of the room at the frequency of interest, maximum spectral power.

$$fs = 2000 \text{ x} \sqrt{V/T}$$

Equation 16

Cut off frequency is calculated according to singer's preferred room dimensions and preferred reverberation times. Since singers preferred both "large" and "sufficient" ratings for "size of the room" subjective parameter and preferred both "balanced" and "reverberant" ratings for the "reverberance" subjective parameter, dimensions and reverberation times corresponding to each rating obtained via regression analysis were used to calculate Schroeder's cut off frequency for two cases: large-reverberant room case and sufficient-balanced room case. Since T30 at 4 kHz was found to be of primary importance regarding the singers' perception and since correlation with T30 was found for all of the common subjective parameters only at the 4 kHz octave band, the values obtained via regression analysis is assumed to be constant across all the middle and high frequencies as previously explained . Table 107 below shows the calculated cut off frequencies of the preferred room conditions by the Opera singers.

Table 107 Cut off frequencies of rooms calculated via using singer's preferred room volume and reverberation times

Parameter	Preferred rating	Corresponding values
Room size	Sufficient size	35 m^3
	Large size	50 m^3
Reverberance	Balanced	0.41 sec
	Reverberant	0.56 sec
Examined room case		**Calculated cut off frequency**
Sufficient-balanced case		216.47
Large-reverberant case		211.66

5.3.4. Sound Power Levels

Cabrera et al. [59] found that Opera singers had the highest sound power levels at 1 kHz octave band for female singers and at 500Hz octave band for male singers while singing the same song exercise in anechoic chamber, reverberant chamber, and recital hall conditions. The results of spectral analysis of singers' sound power levels of this research points out the same octave bands as containing the highest energy levels. However, differences did occur due to difference in room conditions, methodologies, and aim of the studies. The results of this research showed that the frequencies that contain the highest energy levels varied due to different singing exercises and found at 500 Hz octave band for "song" exercise and at 1 kHz octave band for "scales" exercise for both genders as presented in the results chapter, see Table 47, Table 49, Table 51 and Table 53. For both gender and exercise, the singers' dominant frequencies are found to be above the cut off frequencies obtained by using singers' preferred room dimensions and the reverberation times for both "sufficient-balanced" case and the "large-reverberant" case therefore we can conclude that the preferred dimensions of the singers are not subject to room modes, see Discussion Chapter Section 5.3.3.

5.3.5. Background Noise Levels

The research results regarding the background noise levels in the practice rooms showed that the maximum acceptable noise level was found to be 42.3 dBA whilst 35.3-38.8 dBA range is preferred by the Opera singers. Table 108 below compares the recommended background noise levels for practice rooms according to different standards and according to the findings of the research. As can be seen from the table, the recommended maximum level of 35 dBA according to BB93:2015 for new-built music practice rooms; Music accommodation in secondary schools, A design guide (2010) and ANSI/ASA S12.60 is just below "very weak" subjective rating by 0.3 dBA.

According to BB93:2015, the recommended maximum level of 40 dBA for refurbished music practice rooms is above the "weak" subjective rating by 1.2 dBA, higher than the singers preferred levels but still below the maximum acceptable level based on the results of this research, interestingly the same level is recommended as “satisfactory” level by the Australian/New Zealand standard: “Acoustics – Recommended design sound levels and reverberation times for building interiors” AS/NZS 2107:2010[72] ; the standard recommends 45 dBA as a maximum level which exceeds the “acceptable” limit based on the results of this study and corresponds to “loud” subjective rating which is 45.8 dBA according to the results of this study. When we look at the recommended level by NS 8178, we see that the levels are below the singers’ preferred ratings. As seen from Table 106, maximum limits vary depending on the standard. When the singer’s preferred ratings are considered based on the results of this research, it is safer not to exceed 35.3 dBA background noise levels which corresponds to very weak in a music practice room although 42.3 dBA is found to be acceptable by the singers.

Table 108 Recommended maximum background noise levels for practice rooms by standards/guidance and the recommended levels according to research results.

Standard / Guidance			$\mathbf{L_{Aeq}}$
BB93:2015[40] (new built)			35 dBA
BB93:2015 [40](refurbished)			40 dBA
Music accommodation in secondary schools, A design guide (2010) [41]			35 dBA
ANSI/ASA S12.60[44]			35 dBA
NS 8178[45]			27 - 30 dBA
AS/NZS 2107:2000[72]			40 dBA – satisfactory level
			45 dBA – maximum level
Research results			
Ratings	**Preferred ratings**		**Maximum tolerable rating**
	very weak	weak	acceptable
$\mathbf{L_{Aeq}}$	35.3 dBA	38.8 dBA	42.3 dBA

5.3.6. Clarity Index

Another significant finding of the present research is that C80 room parameter was found to be the key objective parameter that is correlated to singers’ subjective ratings among all other examined room parameters. This can be seen from the high degree of significance in the correlation observed across all octave bands from 500 Hz to 4kHz for the “Reverberance” subjective parameter as well as for all of the common subjective parameters: “Pleasure of singing”, “Voice feeling”, “Singing effort” and “Overall impression”, see Table 65, Table 71, Table 74, Table 76, Table 78. Despite the fact that C80 parameter is generally used in the analysis of concert hall acoustics [30], the results show that C80 plays an important role in the perception of Opera singers in small rooms. Similarly, Olsson and Wahrolen’s [54] research on Trumpet players showed significant correlation between C80 and perception of the sound quality in small rehearsal rooms.

5.3.7. Daily Voice Dosimetry

Singers are not the only professional voice users who rely on their voice for living, teachers, politicians, telephone operators, lawyers are also known to be in this group.[73] Therefore as presented in the Literature Review chapter, several researchers have collected data on voice dosimetry of different groups of occupational voice users by using accelerometers, such as APM or similar, during different monitoring durations then presented the mean daily dosimetry results as the daily vocal dose of the occupation. Titze [69, P.4] describes vocal dose as: "…acoustic vocal power integrated over the performance time" and describes performance time as "…daily time involved in occupational vocal activities." Therefore examples below are chosen from research which focuses on daily occupational vocal activities of the occupations in consideration.

The aim of the daily voice dosimetry study in this research was to determine the daily voice dosimetry of 49 semi-professional Opera singers in their education environment and to compare the daily vocal behaviour of Opera singers to other occupations which use their voice as a primary tool at work. It is necessary to note that the aim is not to make a statistical comparison but to give a general idea of the daily vocal loading of different occupations. The results of the current research showed that a semi-professional Opera singers' daily mean phonation time (P_t, hh:mm:ss) for all vocal activity including speech and singing was 68.94 min and for only singing activity was 41.96 min. Table 109 summarises the results of similar research on different occupations from the literature. As can be seen from the table, the highest daily mean phonation time is observed in the Elementary music teachers (107.86 min) followed by Graduate vocal performance students (93.57min); by Elementary classroom teachers (76.9min) and then by the Opera singers' for their all vocal activity (68.94 min.). The results of the current research for Opera singers all vocal activity is found to be similar to the results of Call-centre operators (64.07min).

The results of the current research regarding the Phonation time percentage (P_t, %) showed that the daily mean phonation time percentage of the semi-professional Opera singers is 24.1% for all vocal activity and 15.47% for only singing activity. Table 110 summarises the results of similar research on different occupations in literature. As seen from the table, the results of daily mean Pt% for all vocal activity of Opera singers including both speech and singing are similar to the results of male (25.1%) and female (25.9%) primary school teachers, Kindergarten teachers and to the results of graduate vocal performance students for only singing phonation. The results of singing phonation time percentage of the Opera singers on the other hand are found to be less than the rest of the occupations with the exception of Call-centre operators who showed a similar result (14.74%).

Table 109 Voice dosimetry results of current research and of different occupations in literature regarding daily mean Phonation time (Pt).

Reference	N	Subjects and description	Pt (min)	Pt (hh:mm:ss)
Current Study	49	Opera Singers (Daily mean Pt for all vocal activity)	68.94	01:08:56
		Opera Singers (Daily mean Pt for singing only)	41.96	00:41:58
Cantarella et al. [17]	92	Call centre Operators (Daily mean Pt)	64.07	01:04:04
Morrow and Connor [19]	5	Elementary classroom teachers (Daily mean Pt)	76.9	01:16:54
	7	Elementary music teachers (Daily mean Pt)	107.86	01:47:52
Buckley et al. [22]	12	Football coaches (Daily mean Pt % during training only)	13.4	00:13:24
Gaskill et al. [28]	6	Graduate vocal performance students (Daily mean Pt % for singing only)	93.57	01:33:34

Table 110 Voice dosimetry results of current research and of different occupations in literature regarding daily mean Phonation time percentage (P_t, %).

Reference	N	Subjects and description	P_t (%)
Current Study	49	Opera Singers (Daily mean P_t % for all vocal activity)	24.1
		Opera Singers (Daily mean P_t %for singing only)	15.47
Cantarella et al. [17]	92	Call centre Operators (Daily mean P_t %)	14.74
Remacle et al. [20]	20	Elementary classroom teachers (Daily mean P_t %)	19.6
	12	Kindergarten teachers (Daily mean P_t %)	21.4
Buckley et al. [22]	12	Football coaches (Daily mean P_t % during training only)	19.25
Gaskill et al. [28]	6	Graduate vocal performance students (Daily mean P_t % for singing only)	23.66
Bottalico and Astolfi [21]	36	Female Primary school teachers (Daily mean P_t %)	25.9
	4	Male Primary school teachers (Daily mean P_t %)	25.1

The daily mean results of F0average of the Opera singers are examined separately for males and females in the current study see results in Table 95 and Table 100 for all vocal activity and only singing respectively. Below Table 111 summarises the daily mean results of current study together with the results found for other occupations in literature. We can see that male Opera singers' daily mean F0average for all vocal activity (199.43Hz) is very similar to Call-centre operators' (192.73Hz). Female Opera singers' daily mean F0average values for both all vocal activity and only singing activity are found to be higher than all the listed occupations below. The daily mean sound pressure level (SPL, dB) results of the Opera singers are presented in Table 112 together with the results found for other occupations. As can be seen, the highest daily sound pressure levels are observed in Opera singers due to both, all vocal activity (85.45 dB) and only singing activity (91.67 dB) followed by the Football coaches during their training with the players (83.7 dB) followed by the Elementary music teachers (82.9 dB).

Table 111 Voice dosimetry results of current research and of different occupations in literature regarding daily mean F0average (Hz).

Reference	N	Subjects and description	F0average (Hz)
Current Study (all vocal activity)	16	Male Opera Singers (Daily mean F0average for all vocal activity)	199.43
	33	Female Opera Singers (Daily mean F0average for all vocal activity)	398.13
Current Study (singing only)	16	Male Opera Singers (Daily mean F0average for singing only)	233.3
	33	Female Opera Singers (Daily mean F0average for singing only)	475.26
Cantarella et al. [17]	92	Call centre Operators (Daily mean F0average)	191.73
Remacle et al.[20]	20	Elementary classroom teachers (Daily mean F0average)	253
	12	Kindergarten teachers (Daily mean F0average)	268
Buckley et al. [22]	12	Football coaches (Daily mean F0average during training only)	150
Gaskill et al. [28]	6	Graduate vocal performance students (Daily mean F0average for overall phonation)	287
Bottalico and Astolfi [21]	36	Female Primary school teachers (Daily mean F0average)	240
	4	Male Primary school teachers (Daily mean F0average)	149.6

The daily mean Cycle dose (D_c, million) results of the Opera singers are presented in Table 113 together with the results found for other occupations. As can be seen, the highest D_c is observed in Graduate vocal performance students (1.65 million) Elementary music teachers (1.63 million) which is very close to Opera singers' for all vocal activity (1.61million). Opera singers' D_c for only singing activity (1.21 million) on the other hand showed very similar results to Kindergarten teachers' (1.20 million). The daily mean Distance dose (D_d, km) results of the Opera singers are presented in Table 114 together with the results found for other occupations in literature. As can be seen, the highest D_d is observed in Elementary music teachers (7 km) followed by Opera singers' daily mean results for all vocal activity (5.45km) and then by Graduate vocal performance students (5.30km) then by the Kindergarten teachers (4km).

Table 112 Voice dosimetry results of current research and of different occupations in literature regarding daily mean Sound pressure level (SPL, dB)

Reference	N	Subjects and description	SPL (dB)
Current Study	49	Opera Singers (Daily mean SPL for all vocal activity)	85.45
	33	Opera Singers (Daily mean SPL for singing only)	91.67
Cantarella et al. [17]	92	Call centre Operators (Daily mean SPL)	70.2
Morrow and Connor [19]	5	Elementary classroom teachers (Daily mean SPL)	77.2
	7	Elementary music teachers (Daily mean SPL)	82.9
Remacle et al. [20]	5	Elementary classroom teachers (Daily mean SPL)	79.9
	7	Kindergarten teachers (Daily mean SPL)	81.7
Buckley et al. [22]	12	Football coaches (Daily mean SPL during training only)	83.7
Gaskill et al. [28]	6	Graduate vocal performance students (Daily mean SPL for overall phonation)	79
Bottalico and Astolfi [21]	36	Female Primary school teachers (Daily mean SPL)	62.1
	4	Male Primary school teachers (Daily mean SPL)	57.7

Table 113 Voice dosimetry results of current research and of different occupations in literature regarding daily mean Cycle Dose (D_c, million)

Reference	N	Subjects and description	D_c (million)
Current Study	49	Opera Singers (Daily mean D_c for all vocal activity)	1.61
	33	Opera Singers (Daily mean D_c for singing only)	1.21
Cantarella et al. [17]	92	Call centre Operators (Daily mean D_c)	0.72
Morrow and Connor [19]	5	Elementary classroom teachers (Daily mean D_c)	1.06
	7	Elementary music teachers (Daily mean D_c)	1.63
Remacle et al. [20]	5	Elementary classroom teachers (Daily mean D_c)	1.14
	7	Kindergarten teachers (Daily mean D_c)	1.20
Gaskill et al. [28]	6	Graduate vocal performance students (Daily mean D_c for overall phonation)	1.65

Various daily voice dosimetry studies of different occupations can be found in literature. The occupations listed above such as singers, teachers, sport coaches, call-centre operators are just a few of these examples and represent occupations with high vocal tasks which are in the risk group who might suffer from voice disorders.[28, 69, 73] The vocal doses from different investigations of the same type of occupation might vary due to use of different subjects, conditions etc. Therefore, it is necessary to note that the comparison made with other occupations should not be generalised, but should give an idea on semi-professional Opera singers' daily voice use at their education premises regarding their all vocal activity and singing activity.

Table 114 Voice dosimetry results of current research and of different occupations in literature regarding daily mean F0average

Reference	N	Subjects and description	D_d (km)
Current Study	49	Opera Singers (Daily mean D_d for all vocal activity)	5.45
	33	Opera Singers (Daily mean D_d for singing only)	4.38
Cantarella et al. [17]	92	Call centre Operators (Daily mean D_d)	1.97
Morrow and Connor [19]	5	Elementary classroom teachers (Daily mean D_d)	3.69
	7	Elementary music teachers (Daily mean D_d)	7.00
Remacle et al. [20]	5	Elementary classroom teachers (Daily mean D_d)	4.00
	7	Kindergarten teachers (Daily mean D_d)	4.60
Gaskill et al. [28]	6	Graduate vocal performance students (Daily mean D_c for overall phonation)	5.30

As a highlight, Figure 47 shows daily mean sound pressure levels and phonation time of Opera singers together with examples from other occupations. As can be seen from the figure, Opera singers have significantly higher levels of sound pressure levels due to both singing and overall vocal activity reached in a shorter period of phonation time compared to most of the other examples of occupations.

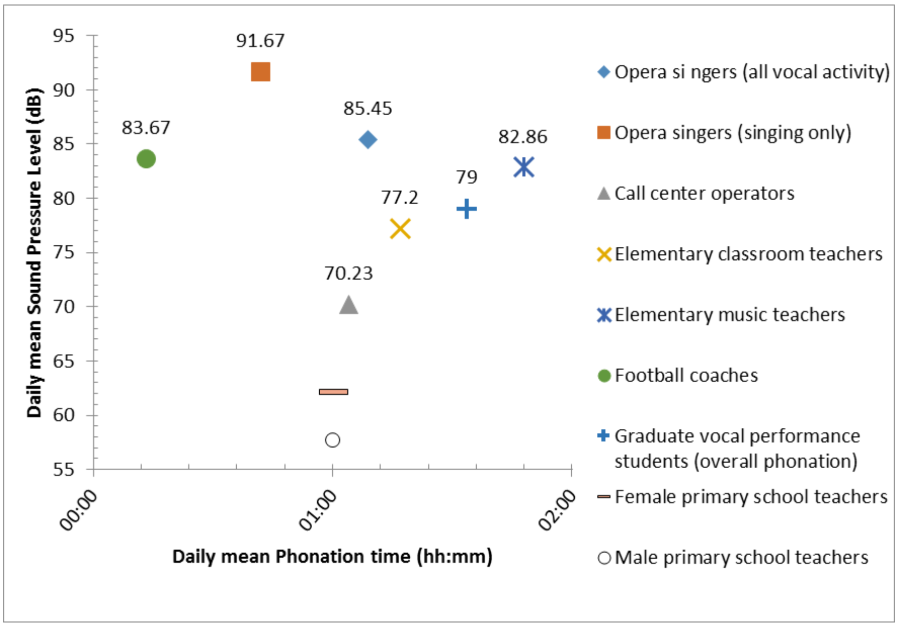

Figure 47 Daily mean sound pressure levels and daily mean phonation time of semi-professional Opera singers and other occupation examples.

5.4. Conclusion

A summary is given in order to highlight the key points of agreement and disagreement between the findings of the current research and those discovered from the literature discussed in the previous sections of this chapter.

The results of the current research showed that Opera singers' objective voice dosimetry data did not show any significant change due to change in the acoustics of the practice rooms whereas the results of the subjective data showed significant change. Although the occupations in consideration are different, similar results are seen in the research of Bottalico and Astolfi's [21] conducted on teachers which also found no significant change in voice dosimetry data but showed significant change in subjective data of teachers in acoustically different classrooms.

The consistency in the Opera singers' objective voice dosimetry results supports Thomasson and Sundberg's [67] and Sundberg's [68] statements on trained singers' ability to sing consistently by systematic use of their voice as the results showed that they were able to repeat same tasks constantly in same manner regardless of the change in the acoustics of the environment.

According to the results of this research, singers' subjective data showed that the Opera singers preferred singing with their "as usual" effort instead of singing with less effort than usual. This is in agreement with Sinal and Yilmazer's [58] research observations on Opera singers which state that the singers avoid singing with less effort and instead, prefer singing with some effort since according to the authors this might cause problems projecting their voice to the audience in large environments. In addition, according to their research results, increase in reverberation time decreased Opera singers' perception of singing effort which again is in agreement with the findings of the current study.

There are only a few standards on the acoustics of music practice rooms. These standards give design criteria for room volumes, reverberation times relevant to room volumes, and background noise levels. In addition, NS8178 also gives design criteria for the sound strength parameter relevant to room volumes of practice rooms and type of music.

According to the results of the Opera singers' subjective ratings, a constant reverberation time across middle and high frequencies relevant to room volumes are recommended by the current research. This suggests a minimum size for a practice room of 35 m^3 with a reverberation time of 0.41 sec, and a maximum of 50 m^3 with a reverberation time of 0.50 sec. . These design criteria are found to be in agreement with the reverberation time values relevant to room volumes suggested by all of the following standards: BB93:2015 both for new built and refurbished, Music accommodation in secondary schools, A design guide (2010), ANSI/ASA S12.60 and NS8178: 2014.

The suggested values for sound strength parameter at the average of 500 Hz and 1kHz octave bands ($G_{500Hz-1kHz}$) relevant to room volumes by the current research is found to be significantly higher than the values suggested by NS8178 for the same room volumes for the practice rooms for loud music which includes Operatic singing.

Regarding the background noise levels, the current research suggests not to exceed 35.3 dBA noise level which corresponds to “very weak” subjective rating based on the singers’ subjective data, and where this is not possible the maximum allowable limit is suggested to be 38.8 dBA which corresponds to “weak” subjective rating which both levels are found to be in the Opera singers’ preferred rating range. The suggested maximum level of 35.3 dBA is found to be slightly higher than the suggested levels by BB93:2015 for new built practice rooms and by Music accommodation in secondary schools, A design guide (2010) which both suggests 35 dBA of maximum background noise level, whereas 38.8 dBA is found to be below the recommended maximum limit of 40 dBA for refurbished practice rooms by BB93:2015 and recommended by AS/NZS 2107:2000 as the satisfactory level. Maximum noise levels recommended by NS8178 (27-30 dBA) on the other hand is found to be significantly lower than the recommendations of the current research while the recommendation for maximum level of 45 dBA by AS/NZS 2107:2000 is found to be significantly higher than the recommended levels of the current research.

6. CHAPTER 6: CONCLUSION

This research investigated:

1- The effects of room acoustics on the vocal loading and perception of semi-professional Opera singers in practice rooms and,
2- Daily mean voice dosimetry of semi-professional Opera singers at their education premises.

For the first study, change in the singers' data due to change in the acoustics of the rooms were examined via ANOVA analysis and it is found that singers' objective voice dosimetry data was not affected by the acoustics of the rooms, however the subjective data showed significant change. Therefore subjective data became the focus of the research and correlation analysis were conducted between room parameters and singers' subjective parameters in order to find which room parameters significantly affect which of the singers' subjective parameters. Regression analysis was conducted between room parameters and the subjective parameters that showed significant correlation and suggestions were made regarding the target values for the room parameters that correspond to singers' preferred ratings in order to achieve preferred practice room conditions for the singers.

For the second study daily voice dosimetry of the singers was collected from 49 participants during a whole day at the Royal Academy of Music and Opera singers' daily voice dosimetry at their education premises was determined.

6.1. Effects of room acoustics on the vocal loading and perception of the semi-professional Opera singers

This study investigated the relationship between the room acoustic parameters and singers' objective and subjective parameters regarding their voice dosimetry data and their perception of the acoustics of the rooms in particular in practice rooms.

A total of 117 semi-professional Opera singers have volunteered to participate in the study. Methodology and the questionnaire design were validated in the laboratory stages with 62 singers at the Acoustic laboratories of London South Bank University as a pilot study. The main study was undertaken at the Royal Academy of Music with a total of 55 singers in their practice environment where four specific practice rooms at the Academy were selected as the test environment.

Voice dosimetry data was collected directly from skin vibrations via an Ambulatory Phonation Monitor (APM). A room questionnaire was prepared in order to collect singers' subjective data and the singers' were asked to complete after singing in each room. In addition, room measurements were undertaken separately. The singer's data and the room data were analysed together in order to find out the correlation between room acoustic parameters and the singer's parameters with an aim to discover which room parameters are significantly effective on the singer's voice dosimetry parameters and perception. The parameters which have shown significant correlation were further analysed using regression techniques to predict the target values of these parameters which correspond to singers' "preferred" ratings in practice rooms.

I have hypothesized that singers' objective voice dosimetry results and their perception of the acoustics of the practice rooms as well as their perception regarding their vocal effort would show a significant change due to change in the acoustics of their practicing environment. However, results showed no significant change in voice dosimetry results of the singers due to change in the acoustic conditions of the practice rooms, but subjective results derived from the room questionnaire showed significant change. The subjective parameters included Loudness, Reverberance, Background noise, Size of the room, Pleasure of singing, Voice feeling, Singing effort, and Overall impression. Clarity subjective parameter did not show any significant change therefore excluded from the further analysis. Conclusions drawn from this study for each subjective parameter will be explained below.

6.1.1. Loudness subjective parameter

Loudness subjective parameter was found to show a significant positive correlation with sound strength (G) parameter; the highest significance was observed for G at the average of 250Hz and 500Hz octave bands ($G_{(250\text{-}500Hz)}$, p= 0.047 Sig-2 tailed). Singers have preferred both "Sufficient" and "Loud" ratings for Loudness subjective parameter. Regression analysis results showed that in order to achieve "sufficient" rating scores the levels should be around 27.7 dB and can increase up to 30.7 dB in order to achieve "loud" rating as a maximum limit, see Table 64.

6.1.2. Size of the room subjective parameter

Size of the room subjective parameter showed positive correlation with Room area, room volume and room length parameters. The highest correlation was observed for the room length parameter (p=0.007, Sig-2 tailed) followed by the room area (p=.012, Sig-2 tailed) and room volume (p=.035, Sig-2 tailed). Regression analysis was conducted in order to get the values which correspond to singers preferred ratings of "sufficient" and "large" size. The results showed that in order to achieve "sufficient" rating, the practice room should be minimum ~35m3; with a room area, room length, height and width of 13.28 m^2, 5.78 m; 2.30 m and 2.67 m respectively. Preferred rating for "large" size for a practice room was obtained when the room volume was increased to ~50 m^3, with a room area, room length, height, and width of 18.01 m^2, 7.53 m; 2.77 m and 2.39 m respectively. The preferred dimensions of the singers' were not found to be subject to room modes as singers' dominant frequencies for both genders were found to be above the cut off frequencies obtained by using singers' preferred room sizes and reverberation times found via regression analysis.

6.1.3. Background noise subjective parameter

Regarding the background noise levels of the practice rooms, first the 10 minute background noise levels ($L_{Aeq,10min}$) were measured in each room when the rooms were unoccupied. As these levels were found to be lower than the levels during the time of the measurements and as the aim was to collect singers' subjective ratings of the noise levels of the practice rooms, a representative background noise level of two minutes ($L_{Aeq,2min}$) were measured right after each singers' measurement was completed in each room when the rooms were unoccupied, but adjacent rooms were in use. These levels were found to better represent the noise levels during the time of the singers' measurements since the noise levels were quickly varying due to varying practices in the adjacent practice rooms. These representative levels were used for the further analysis. Subjective background noise parameter showed a significant positive correlation with the $L_{Aeq,2min}$ (p=.044, Sig. 2-tailed) room parameter, see Table 69. Singers preferred either of the "very weak" or "weak" ratings and the regression analysis results showed that "very weak" subjective rating is achieved when the level is 35.3 dBA and increases up to 38.8 dBA to achieve "weak" subjective rating. The results also showed that the maximum "acceptable" rating for the background noise is 42.3 dBA, but it is important to note that this is not the preferred rating of the singers, only examined in order to find the maximum acceptable levels by the singers in the practice rooms. According to the results of this research, the recommended background noise level is 35.3 dBA, where it's not possible to achieve the criteria the level can be relaxed to 38.8 dBA as a maximum.

6.2. Objectives

Following are the highlights of the findings of this research:

1- Objectively measured voice dosimetry data of semi-professional Opera singers do not change due to change in the acoustics of their practicing environment; however perception of the singers were significantly affected due to acoustics of the practice rooms.

2- Reverberation time (T30) and Clarity Index (C80) was found to be key room acoustic parameters that effect singers' perception of the room as well as perception of their singing effort.

3- T30 at the 4 kHz octave band is found to play a key role on singers' perception rather than the middle frequencies ($T30_{mid}$) as used in the guidance.

4- C80 room parameter on the other hand found to be correlated to singers' perception in all octave bands from 500 Hz to 4 kHz.

5- Room parameters that show significant correlation with singers' perception are investigated.

6- The frequencies of these room parameters that showed highest correlation with the perception of the singers are investigated,

7- Suggestions are made for the target ranges of these room parameters in order to design preferred practice room conditions for the singers.
8- Daily voice dosimetry data of the singers due to only singing and overall vocal activity was investigated and daily sound pressure levels due to both all vocal activity and only singing activity were found to be higher and reached in a shorter period of phonation time compared other occupations known to be professional voice users..

The following sections summarize overall conclusions of both the main and side study in detail.

6.2.1. Common Correlations

The rest of the subjective parameters including: Reverberance, Pleasure of singing, Voice feeling, Singing effort, and Overall impression showed correlation with common room parameters: T30 and C80. Reverberance, Pleasure of singing, Voice feeling and Overall impression subjective parameters showed significantly positive correlation with T30 room parameter and negative correlation with C80 parameter, whereas Singing effort showed significant positive correlation with C80 and negative correlation with T30 room parameters.

When examined separately each subjective parameter showed correlation with several frequencies of the same room parameter, but as the aim was to establish target limits that provide the preferred subjective ratings of the singers for all parameters, these subjective parameters examined together with the room parameters at the frequencies that are common and significantly correlated for all of these subjective parameters.

According to the results of this research, amongst all examined frequencies for T30 parameter, the 4 kHz octave band was found to be better correlated to singers' perception than any of the other examined frequencies as it showed significant correlation with all of the subjective parameters. This study suggests considering this octave band while designing a practice room for the use of Opera singers since it is found to be directly correlated to singers' perception of their singing effort, voice feeling, pleasure of singing and overall impression of the room. In order to find the target values for T30 at 4 kHz, regression analysis was conducted for each of the subjective parameter. Another important finding of the research was that the Opera singers' prefer singing with their usual effort regardless of the acoustic conditions of the environment as this helps them to protect their vocal health against acoustically poor spaces, as well as to prevent vocal laziness due to support from the room. As a result they prefer not to practice in rooms where they feel support from the room, or in rooms where they feel the need for more effort.

Regarding the preferred ratings of each subjective parameter, singers' preferred more than one rating for all except for the "vocal effort" subjective parameter which the singers only preferred singing with "as usual" effort. Therefore a lower and upper range was established for the $T30_{(4kHz)}$ room parameter based on "as usual" vocal effort. As a result, the target range for $T30_{(4kHz)}$ was found to be 0.41-0.5 seconds. Another finding from this investigation was the importance of C80 (Clarity Index) room parameter on singers' perception in the practice rooms. Despite the common use of T30 parameter for defining room acoustic conditions, it was found that C80 was more correlated with the subjective data than T30. Higher correlations were observed for C80 than T30 at a number of different frequencies correlated with each of the mentioned five subjective parameter including C80 at 500 Hz, 1 kHz, 2 kHz and 4 kHz octave bands, whereas for T30 the only correlation was found at 4 kHz octave band. Therefore in the design of practice rooms for the Opera singers, consideration shall also be given to C80 parameter. Following the same methodology as used to determine the upper and lower T30 values the target range for C80 was found for each octave band that showed correlation with all five subjective parameters. Target range for $C80_{(500Hz)}$ was found to be 5.14 -8.47 dB; $C80_{(1\ kHz)}$ was found to be 6.34 - 10.39 dB; $C80_{(2kHz)}$ was found to be 8.61-13.02 dB and $C80_{(1\ kHz)}$ was found to be 8.08 -13.79 dB. The target range, maximum, and minimum values of C80 at each correlated octave band and their corresponding subjective ratings can be seen from Figure 23 to Figure 28 in the Results Chapter.

6.3. Daily mean voice dosimetry of the semi-professional Opera singers

This was the side study of the research and allowed the author to gain valuable data on daily vocal dosimetry of semi-professional classical singers at their education environment and to make a comparison with other occupations known as professional voice users. The conclusions drawn from the measured daily mean voice dosimetry data of 49 semi-professional Opera singers are summarized below.

It was found that a semi-professional Opera singer spends an average of approximately five hours at their education premises, an average of approximately 42 minutes of this duration the vocal folds vibrate only due to singing; whereas approximately 68 minutes of this duration the vocal folds vibrate due to all vocal activity including singing and speaking.

Daily mean voice dosimetry results of the semi-professional Opera singers showed that the singers' vocal folds were exposed to high levels of vocal loading during the day due to both singing and overall vocal activity and were found to be no less than, but mostly higher than the other occupation examples which are known as the professional voice users.

7. CHAPTER 7: FUTURE WORK

There have been several conclusions drawn from the main study. Correlation between the room parameters and subjective data of the singers were found and suggestions were made regarding room acoustic parameters as well as size and dimensions of the rooms in order to achieve preferred practice room conditions for semi-professional Opera singers.

Further work could focus on the architectural design considerations of the preferred practice room conditions: such as type, area and location of the materials to be used in order to achieve the suggested room parameter values. A 3D acoustic model of the practice room can be created and the sound field auralised using the singers' recordings which were collected in the Anechoic chamber during the laboratory stage for the future use. Using the auralisations the sound field in the practice room can be judged by the semi-professional Opera singers in order to establish whether the singers are happy with the resulting sound.

In addition, since this study solely focused on the singers, future work could investigate the preferred conditions when an accompanist from different type of instruments such as a piano player, violinist etc. join the singer in a practice room as this is common practice in small practice rooms. It should be stated that singers were observed to be practicing alone most of the time during this multi-year study. Moreover, the research also can be extended to different type of singers: such as Jazz singers or Musical singers as this research only examined Opera singers.

Daily voice dosimetry data of 49 semi-professional Opera singers have been collected as a side study of this research. Due to time constraint, the results were examined for the daily mean values of all singers and used to make a general comparison with other occupations known as professional voice users. For future work this data can be statistically analyzed separately for different genders, different voice types as well as for different time frames rather than the whole day and can be statistically compared to other occupations. Daily voice dosimetry data is mostly found in clinical research, focusing on subjects in their working environment to establish the reasons for voice disorders. Therefore the voice dosimetry data collected would provide valuable information on vocal behavior of the singers at their educational environment at a pre-professional stage giving an insight on the levels of vocal loading they are exposed to during their daily activities. This could be used in clinical research.

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APPENDIX A

LSBU Acoustic Chamber Layouts

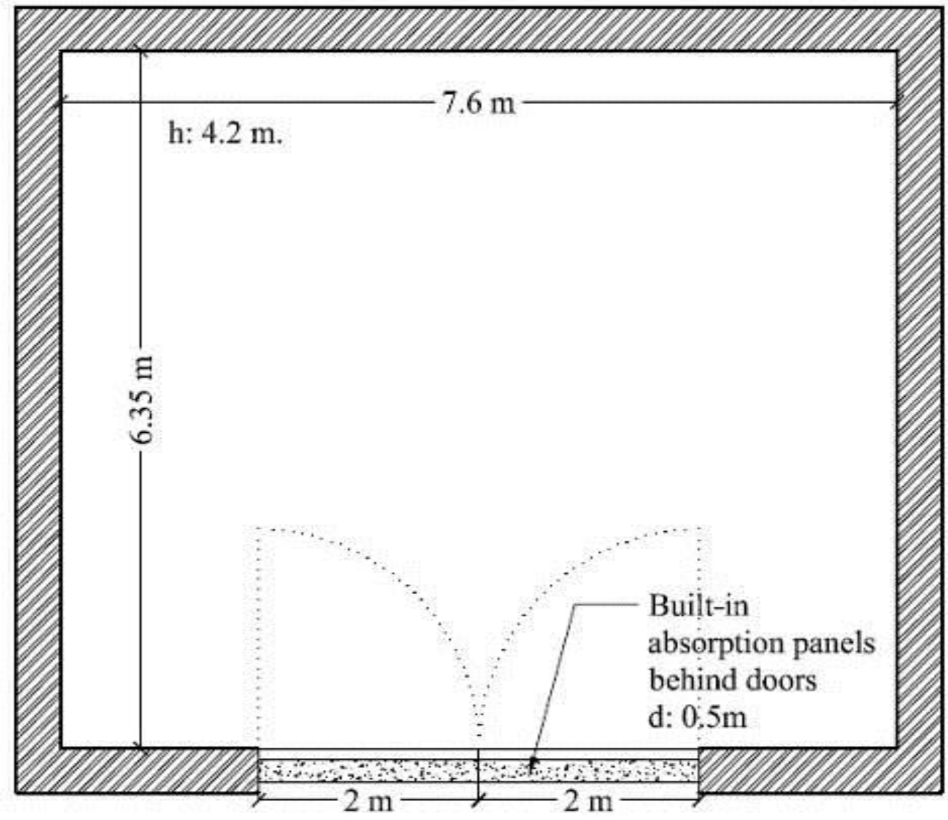

Figure A.1 Reverberant (doors closed) and Semi-reverberant (doors open) chambers

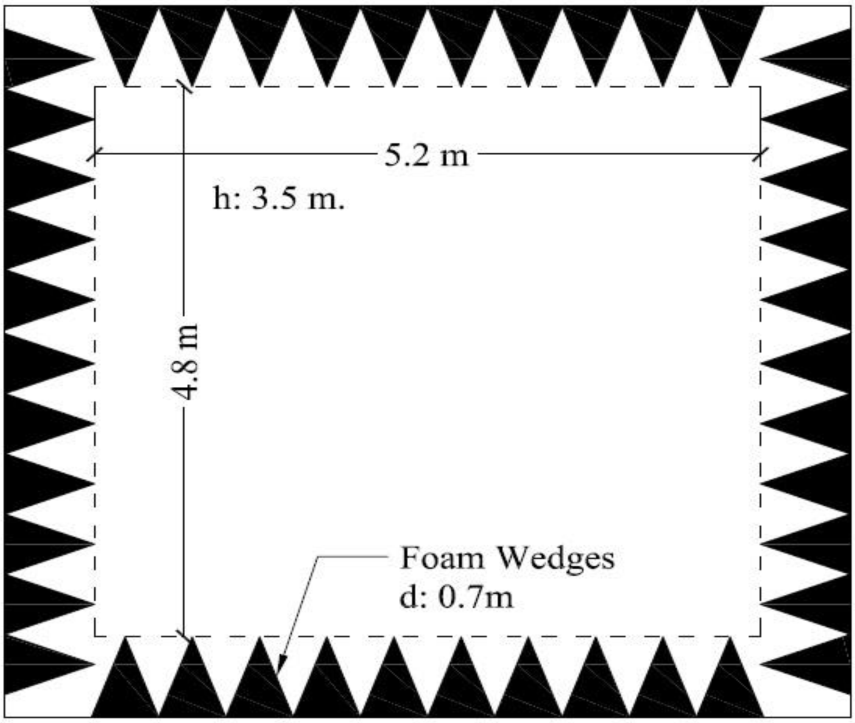

Figure A.2 Anechoic Chamber

APPENDIX B

RAM Practice Room Layouts

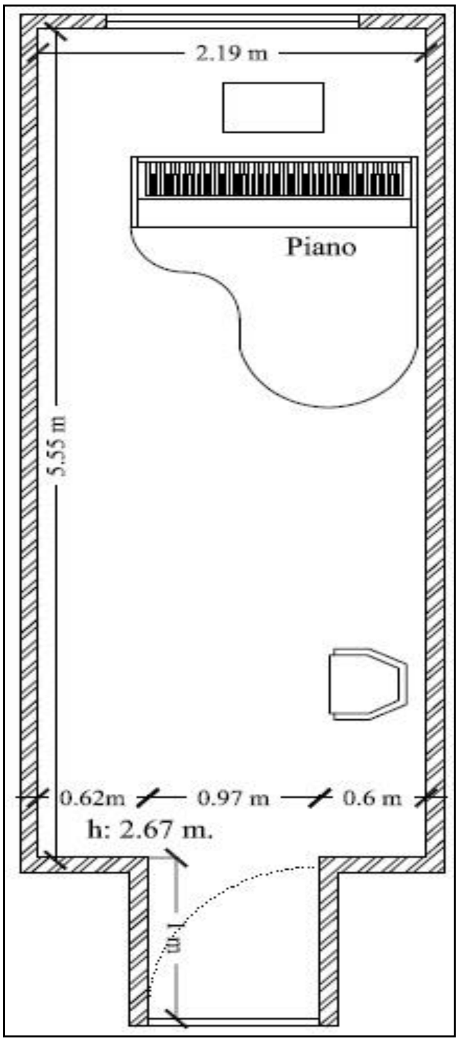

Figure B.1 York Gate room (YG)

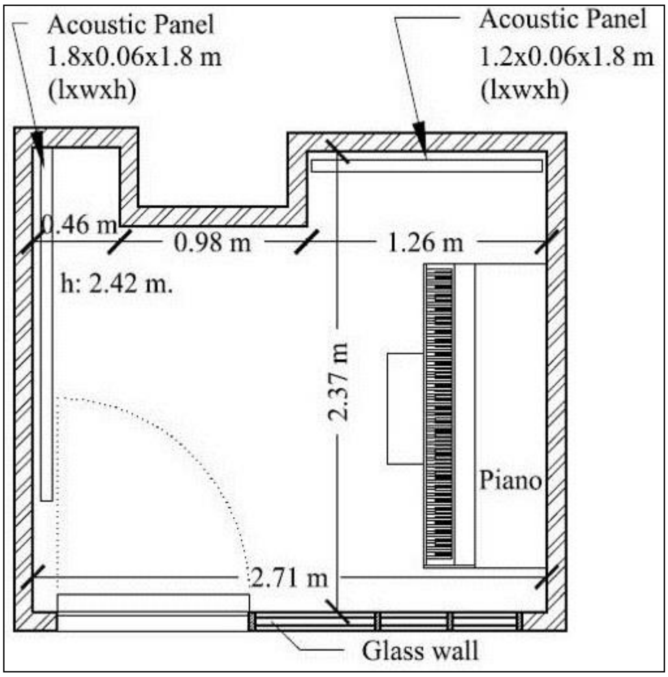

Figure B.2 Lower Ground room (LG)

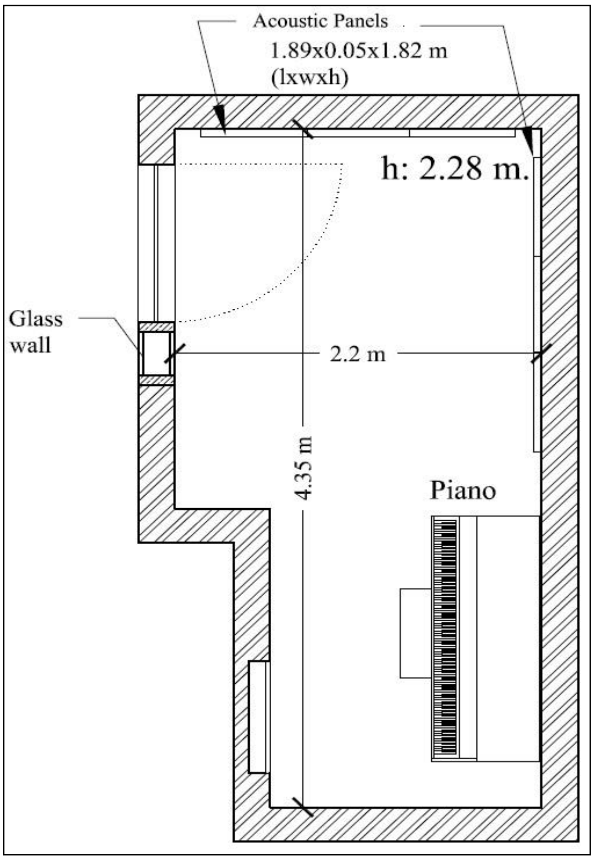

Figure B.3Dr room

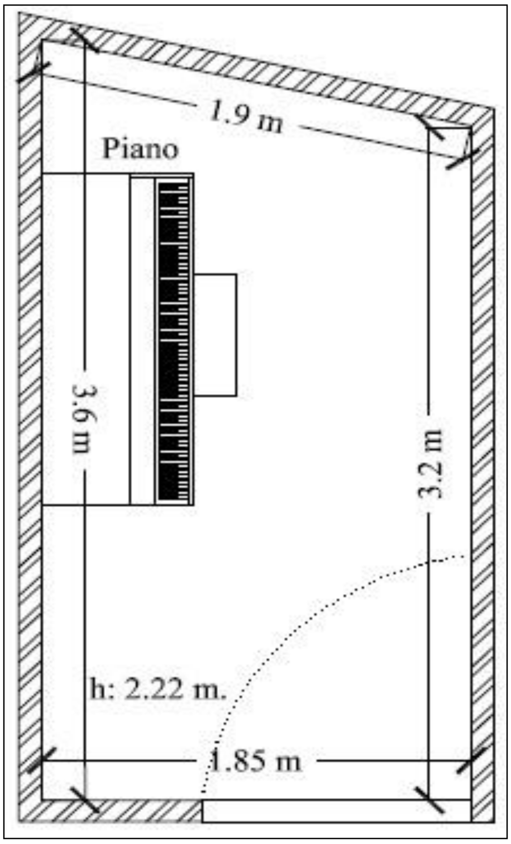

Figure B.4 T room

APPENDIX C

Ethical Approval (UREC 1333) and Consent Form

London South Bank
University

Direct line: 020-7815 6025
E-mail: mitchen5@lsbu.ac.uk
Ref: UREC 1333

Gizem Okten
23 Courtfield Gardens
London
SW5 0PD

Tuesday 13 May 2014

Dear Gizem,

RE: An investigation into the effect of acoustic design of singing spaces on signers

Thank you for submitting this proposal and for your response to the reviewers' comments.

I am pleased to inform you that Full Chair's Approval has been given by Chair on behalf of the University Research Ethics Committee.

I wish you every success with your research.

Yours sincerely,

N Mitchell

Nicola Mitchell

Secretary, LSBU Research Ethics Committee

cc:

Prof Shushma Patel, Chair, LSBU Research Ethics Committee

ETHICS CHECKLIST

Please answer ALL questions in Table 1 – tick YES or NO

TABLE 1: WILL YOUR RESEARCH STUDY........?		YES	NO
1	Involve direct and/or indirect contact with human participants?	☐	☐
2	Involve analysis of pre-existing or collection of data which contains sensitive* or personal information?	☐	☐
3	Have a risk of compromising confidentiality and/or anonymity?	☐	☐
4	Involve health risks to any party, including the researcher?	☐	☐
5	Require Criminal record Check and/or involve any external organisation for which separate and specific ethics clearance is required?	☐	☐

If you have answered YES to any question in Table 1, please fill in Table 2

TABLE 2: WILL YOUR RESEARCH STUDY........?		YES	NO
6	Contain elements which you OR your supervisor are NOT trained to conduct?	☐	☐
7	Involve health risks to any party, including the researcher?	☐	☐
8	Use intrusive or invasive procedures? For example attaching equipment to a subject's body	☐	☐
9	Induces pain, psychological stress or anxiety or causes prolonged physical harm or negative consequences beyond the risks encountered in normal life?	☐	☐
10	Involve data collection taking place without participant's knowledge and consent at the time?	☐	☐
11	Involve any deliberate deception or covert observation of people in non-public places	☐	☐
12	Use any information OTHER than that which is freely available in the public domain?	☐	☐
13	Involve collection of relevant material** from living or deceased on premises without HTA licence for analysis within 48h? (refer to Human Tissue Act 2004)	☐	☐
14	Involve participants who are unable to give informed consent? (e.g. children, learning disabilities; refer to Mental Capacity Act 2005, sec 30-33)	☐	☐
15	Involve a risk to the researcher or participants due to exposure to ionising radiation? (refer to Ionising Radiation (Medical exposure regulations 2000)	☐	☐
16	Involve a trial on clinical populations (recruitment of patients or staff through NHS settings)?	☐	☐
17	Involve analysis of DNA in material from living collected after 01/09/06? (refer to Human Tissue Act 2004, sect45)	☐	☐
18	Involve storage of relevant material** from living or deceased on premises without HTA licence (for >48h)? (refer to Human Tissue Act 2004)	☐	☐
19	Involve trial of a medicinal product? (refer to MHRA algorithm 2004)	☐	☐
20	Involve trial of a non-CE marked or modified medical device? (refer to Medical Devices Regulation 2002)	☐	☐

CLASSIFICATION **The following guidance will help classify the risk level of your study:**	**Tick the box which applies to your project**
If you answered **NO** to all questions in Table 1, your study is classified as **Class 1** (e.g. literature reviews will be Class 1).	☐
If you answered **YES** to any question from 1-12 and **NO** to all questions 13-20, your study is classified as **Class 2. Send to the Faculty Ethics Committee**	☐
If you answered **YES** to any question from 13-20, your study is classified as **Class 3. Send to the University Ethics Committee**	☐

APPLICANT DETAILS:			
Your name (if a group project, include all names here)			
Course			
Department			
STATUS:			
• Undergraduate student	☐	• MSc/MSc(R) student	☐
• Master by Research student	☐	• Staff member	☐
• Other (give details)			
IF THIS IS A STUDENT PROJECT:			
• Student ID			
• Course title with award			
• Student email			
• Research Supervisor's name Or Director of Studies' name			
THE PROJECT/STUDY:			
Project /study title			
Start date of project			
Expected completion date of project			
Is the project externally funded			

DECLARATION AND SIGNATURE/S:			
I confirm that I will undertake this project as detailed above and no substantial amendments to the project will be made without further approval.			
Signed		*Date*	

FOR CLASS 1 STUDENT PROJECTS:					
Agreement from the Module Leader or Director of Studies for the project: *I have discussed the ethical issues arising from the project. I approve this project.*					
Name		*Signed*		*Date*	

ETHICAL PRACTICE – GUIDELINES FOR ESBE STUDENTS

These Code of Practice Guidelines are based on those of the internationally renowned design consultancy IDEO.. They have collated a series of principles that guide investigators in their interactions with people, which have been adapted from various established human and social research methods. (See IDEO Methods Cards for further information in the Perry Library - 745.40222 IDE).

Whether you project is in Class 1, 2 or 3 as an investigator you should do the following

1. approach people with courtesy
2. identify yourself, your intent. and what you are looking for
3. describe how you will use this information and why it's valuable
4. get permission to use the information and any photos or video you take
5. keep all the information you gather confidential
6. let people know they can decline to answer questions or stop participating at any time
7. maintain a non-judgmental, relaxed, and enjoyable atmosphere
8. ensure that your research activity is safe and that it does not inconvenience, offend or harm the participant in any way; (this includes issues like obstructing movement in corridors or on pavements).

Additionally, you will destroy the data once the work is complete, unless it is published. In this case your supervisor will arrange for safe-keeping of the data for 5 years.

By signing this form you indicate that you have read and will follow these guidelines in order to undertake your proposed activity

Investigator (staff or student) please print name

……………………………………………………………………………………………

Signed……………………………………………………………………………Date………………

Supervisor / Ethics representative please print name

……………………………………………………………………………………………

Signed……………………………………………………………………………Date………………

ETHICAL PRACTICE

Written Consent Form for Participants

London South Bank University
Faculty of Engineering, Science and the Built Environment (ESBE)

Investigator………………………………………………………………………………………

Project title & overview …………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

Course / year…………………………………………………………………………………

Supervisor……………………………………………………………………………………

I understand that I am volunteering freely to participate in this project, which will be conducted by the investigator under the supervision of the member of staff indicated.

By signing this form I am indicating that the student investigator has

1. has identified him/herself
2. has explained the nature of the project, his/her intent and what he/she is looking for
3. has described how this information will be used and why it's valuable
4. has assured me that the research activity is safe and will not inconvenience, offend or harm me in any way and that I may withdraw at any time.
5. the student has assured me that all the information gathered is confidential

I grant permission for the student to use the information and any photos and/or video taken

Participant……………………………………………………………………………………………

Signed……………………………………………………………………..Date……………………………………

APPENDIX D

Source – Receiver Points for Room Measurements Undertaken in LSBU Chambers and RAM Practice Rooms

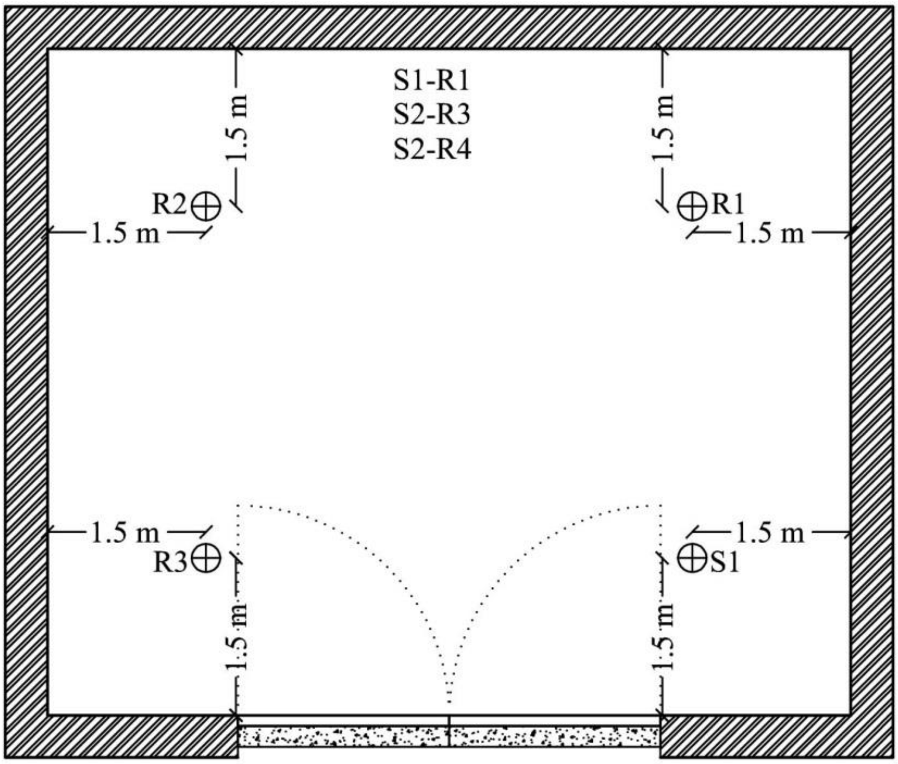

Figure D. 1Source (S1) - Receiver Points at Semi reverberant and Reverberant chambers

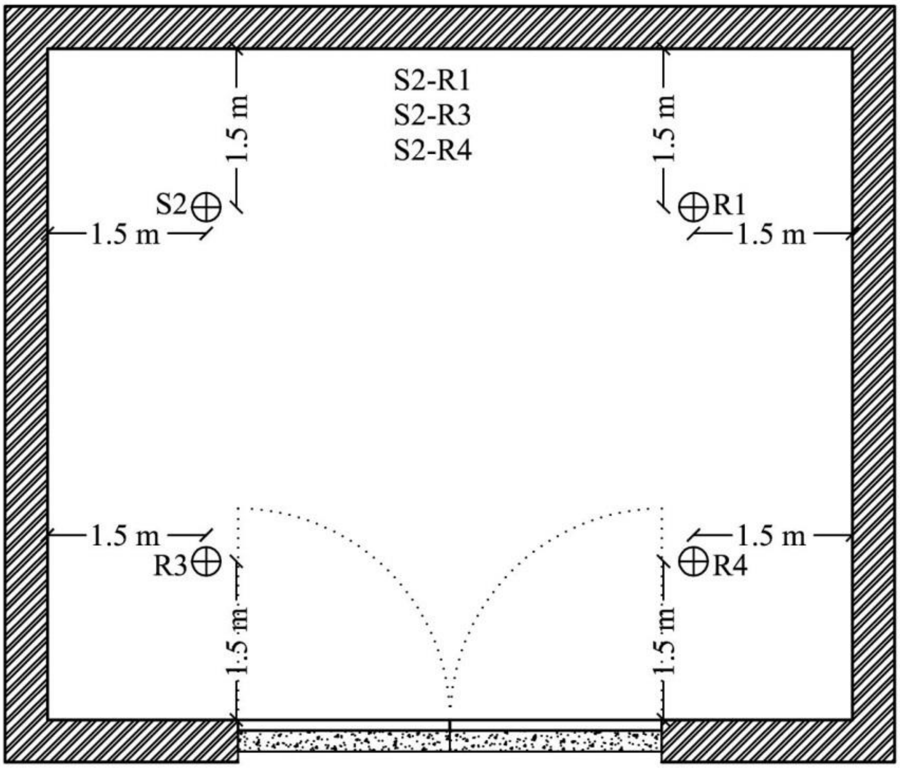

Figure D. 2 Source (S2) - Receiver Points at Semi reverberant and Reverberant chambers

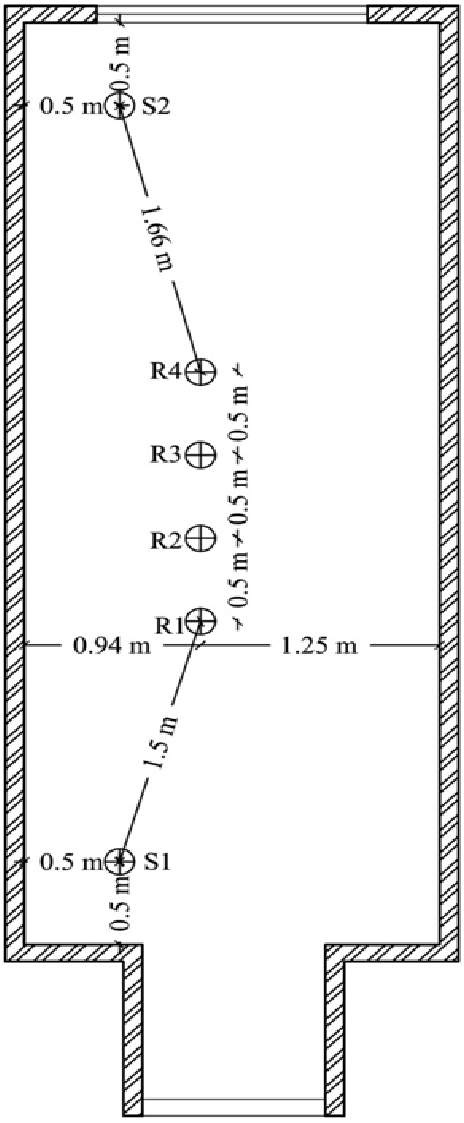

Figure D. 3 Source-Receiver Points in YG room

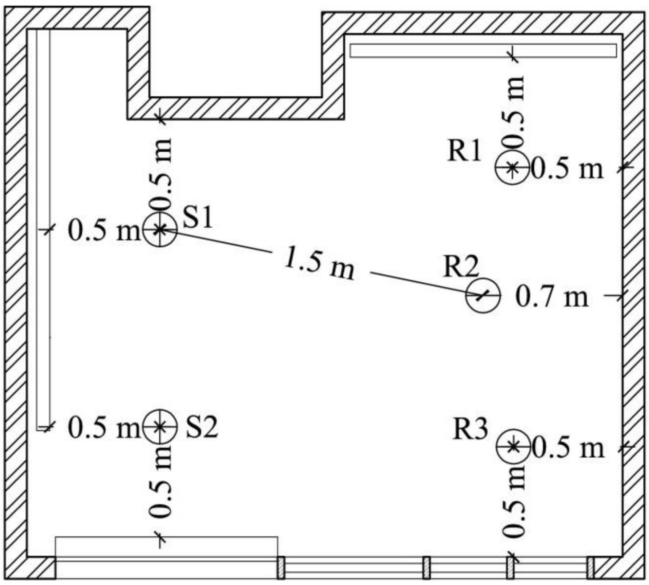

Figure D. 4 Source-Receiver Points in LG room

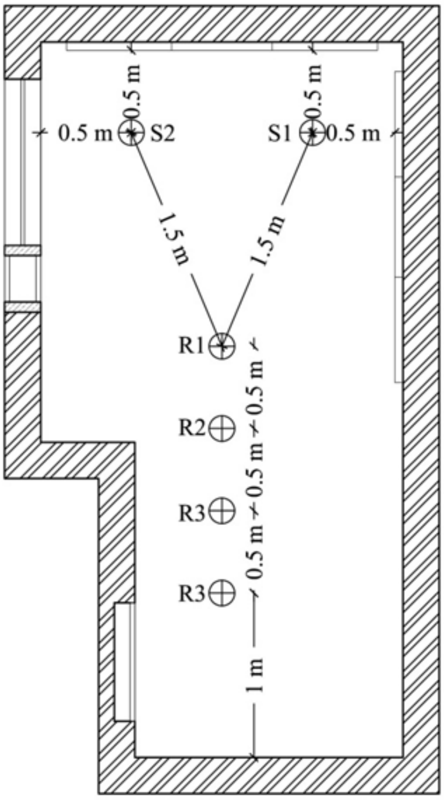

Figure D. 5 Source-Receiver Points in DR room

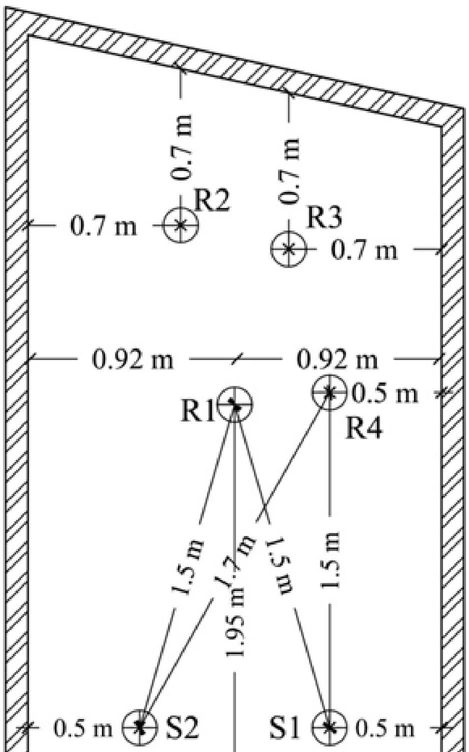

Figure D. 6 Source-Receiver Points in T room

APPENDIX E

“About You” Questionnaire

AN INVESTIGATION INTO THE SINGING ENVIRONMENT AND THE SINGING VOICE

About this questionnaire:

This study forms part of a PhD research project being carried out at London South Bank University.

Any information gathered in this study will be treated anonymously and will be used for research purposes only. Thank you very much for your participation.

Gizem Okten

ABOUT YOU		
Please circle the appropriate responses		
1	What is your gender?	Male Female
2	What is your age?	18-24 25-29 30-34 35-39
3	What is your voice type?	Bass Baritone Tenor Counter-Tenor Mezzo Soprano
4	How many years have you been singing?	0-5 5-10 10-20 20-30
5	For how many years have you been taking singing lessons?	No Yes: 0-5 5-10 10-20 20-30
6	Are you still taking singing lessons?	No Yes
7	Do you have any vocal problems? If yes, please explain the problem and the cause of it. (e.g. vocal cord lesions as nodules, polyps arising from smoking, speaking loudly, wrong singing techniques, bad singing environment etc.)	No Yes :

APPENDIX F

Room Questionnaire

AN INVESTIGATION INTO THE SINGING ENVIRONMENT AND THE SINGING VOICE

Room:

Please circle the appropriate answer for the room you've sung in.

Thank you for completing this questionnaire.

1	**Loudness (how do you perceive your sound level in this room?)**						
	1	2	3	4	5	6	7
	extremely weak	very weak	weak	sufficient	loud	very loud	extremely loud
2	**Clarity (how would you rate the degree to which notes are distinctly separated in time and clearly heard?)**						
	1	2	3	4	5	6	7
	extremely unclear	very little clear	a little clear	sufficient	clear	very clear	extremely clear
3	**Reverberance (how would you rate the persistence of sound in this room?)**						
	1	2	3	4	5	6	7
	extremely dry	very dry	dry	balanced	reverberant	very reverberant	extremely reverberant
4	**Background noise (how would you rate the background noise levels in this room?)**						
	1	2	3	4	5	6	7
	not audible	very weak	weak	acceptable	loud	very loud	extremely loud
5	**Size of the room (how would you rate the size of this room?)**						
	1	2	3	4	5	6	7
	extremely small	very small	small	sufficient	large	very large	extremely large
6	**Pleasure of singing in this room (how would you rate your pleasure of singing in this room?)**						
	1	2	3	4	5	6	7
	extremely bad	very bad	bad	sufficient	good	very good	extremely good
7	**Voice feeling (how would you rate your voice feeling in this room in terms of vocal support?)**						
	1	2	3	4	5	6	7
	extremely weak	very weak	weak	as usual	strong	very strong	extremely strong
8	**Singing effort (how would you rate your effort singing in this room?)**						
	1	2	3	4	5	6	7
	extremely less than usual	quite less than usual	less than usual	as usual	more than usual	quite more than usual	extremely more than usual
9	**Overall Impression (how would you rate the acoustical quality of this room?)**						
	1	2	3	4	5	6	7
	extremely bad	very bad	bad	sufficient	good	very good	extremely good

APPENDIX G

Source – Receiver Points for Singers' Measurements in LSBU Chambers

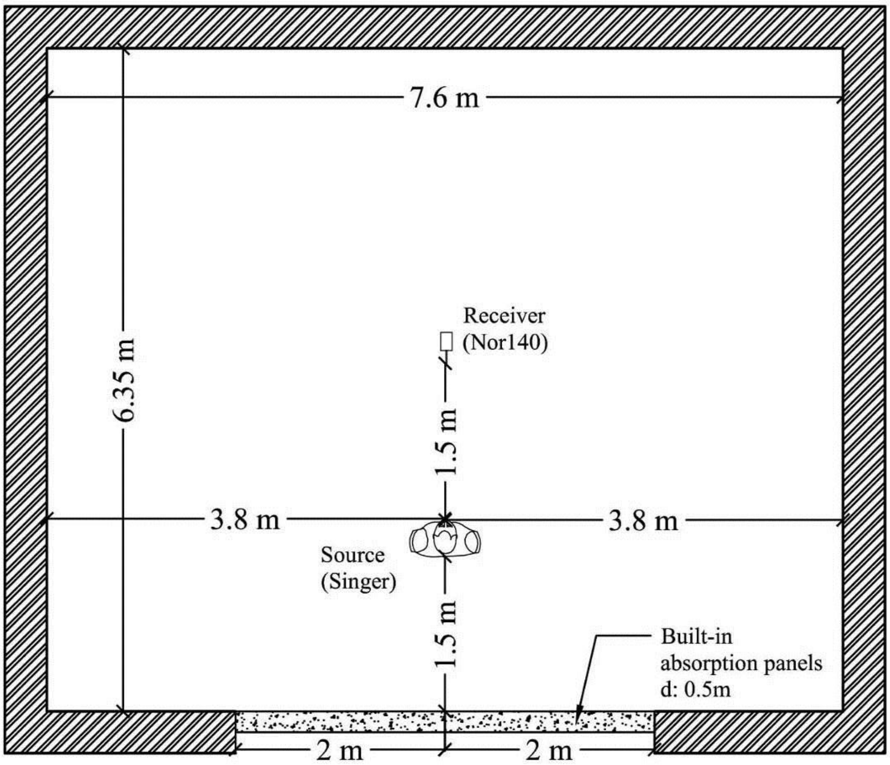

Figure G. 1 Reverberant and Semi-Reverberant chamber source-receiver points

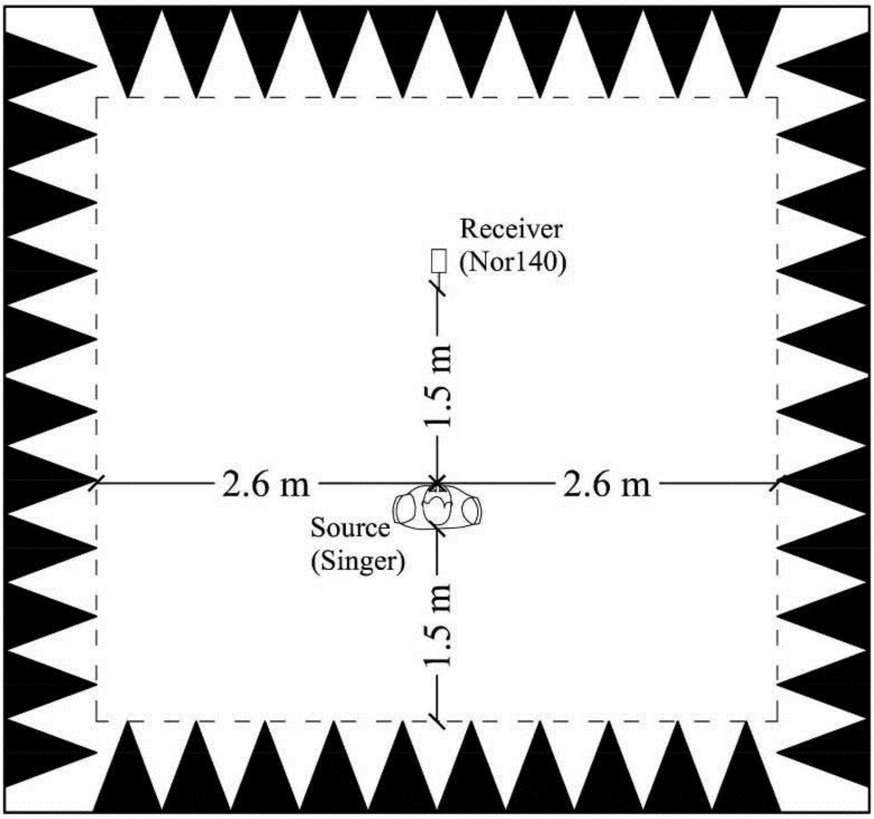

Figure G. 2 Anechoic chamber source-receiver points

APPENDIX H

Source – Receiver Points for Singers' Measurements in RAM Practice Rooms

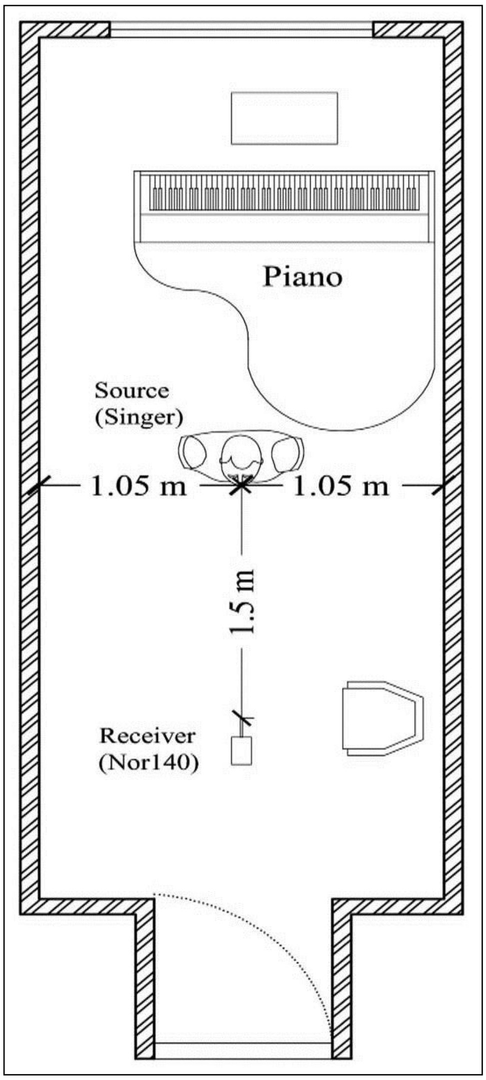

Figure H. 1 YG room source-receiver points

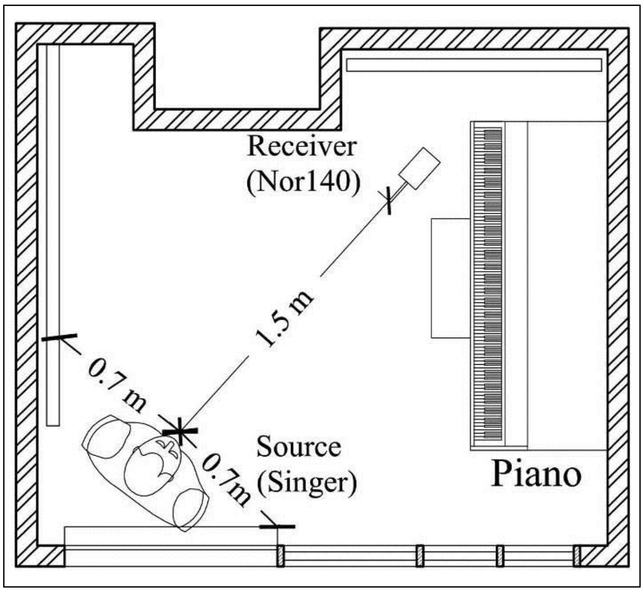

Figure H. 2 LG room source-receiver points

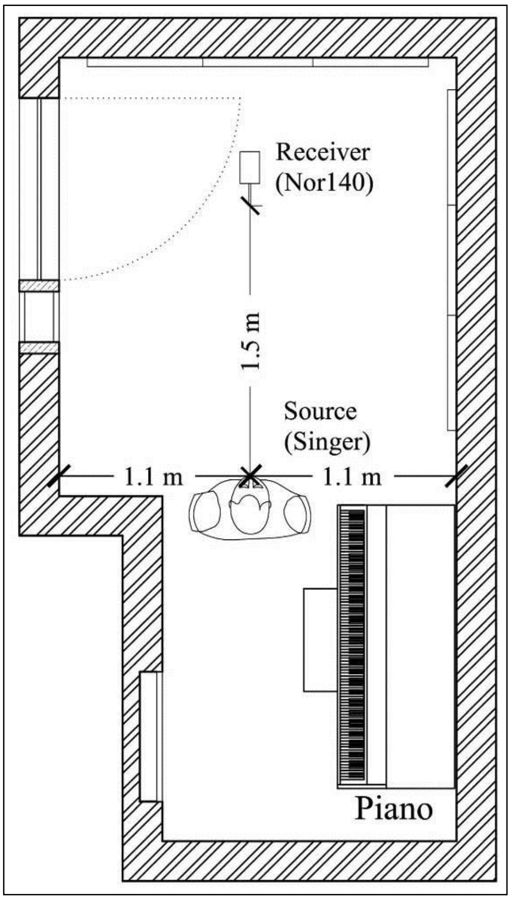

Figure H. 3 Dr room source-receiver points

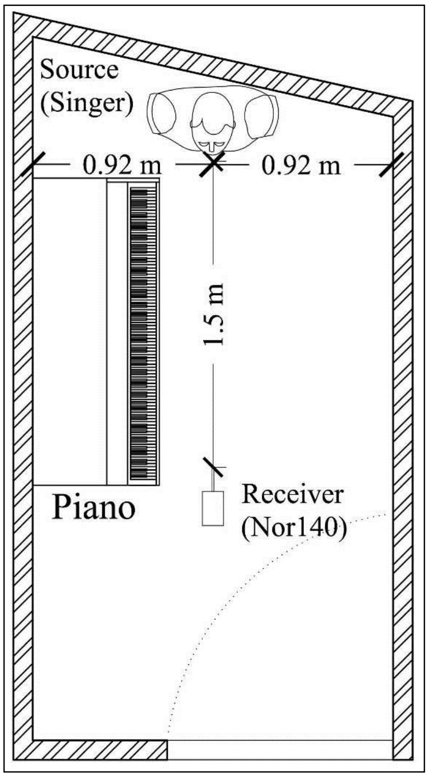

Figure H. 4 T room source-receiver points

APPENDIX I

Measured Representative Background Noise Levels

Table I. 1 Representative background noise levels measured in the YG room

Measurement #	LAeq,2min	Octave band Centre Frequency						
		63 Hz	125 Hz	250 Hz	500 Hz	1 k	2 k	4 k
1	33.3	39.0	34.9	28.9	28.4	28.9	26.3	23.4
2	36.7	45.9	34.1	36.8	31.9	30.3	29.7	28.5
3	44.6	42.7	35.5	33.0	35.2	35.6	38.0	40.8
4	36.8	41.2	37.5	39.8	30.0	32.4	26.7	26.7
5	44.6	40.8	35.5	39.8	35.4	35.5	37.9	40.7
6	32.2	48.8	38.5	34.7	28.2	22.8	23.3	20.4
7	46.4	49.2	36.9	42.2	39.3	38.8	40.0	41.2
8	44.2	41.9	34.2	31.9	33.1	35.3	37.7	40.5
9	45.6	42.5	44.7	40.8	38.8	37.7	38.8	40.8
10	38.9	51.4	40.9	41.4	36.7	32.3	29.3	22.6
11	44.3	35.9	32.1	32.2	33.7	36.2	37.8	40.4
12	44.0	44.5	39.1	34.4	33.1	35.0	37.5	40.3
13	45.6	40.4	37.2	37.1	34.4	40.4	38.2	40.6
14	44.7	43.9	35.6	34.4	33.8	35.7	38.2	40.9
15	30.9	42.6	39.0	32.3	27.4	21.6	21.1	21.5
16	45.7	46.1	40.0	40.3	40.0	37.7	38.8	40.7
17	39.7	43.5	41.5	43.9	37.2	31.9	28.7	27.1
18	37.0	39.6	34.3	30.7	28.5	33.2	31.7	25.4
19	38.9	37.7	34.2	32.1	31.5	33.7	34.1	29.6
20	42.1	41.6	32.5	32.9	33.3	36.4	37.7	33.8
21	41.8	53.6	45.3	39.9	37.4	37.7	33.2	29.4
22	32.7	34.5	31.1	28.1	25.7	29.2	27.3	17.3
23	47.5	48.6	46.0	44.7	43.9	41.5	42.9	28.0
24	35.7	41.5	33.8	38.6	33.0	30.4	25.8	20.9
25	38.5	36.5	32.7	32.2	33.4	33.3	33.8	25.9
26	31.9	44.4	38.4	28.2	24.7	25.4	25.6	23.1
27	44.4	40.0	33.8	32.4	33.7	35.8	38.0	40.6
28	38.3	49.0	42.7	38.7	34.4	30.4	31.5	28.5
29	31.5	39.6	35.2	32.8	27.2	26.0	23.6	20.2
30	48.6	44.0	42.0	46.4	40.8	42.4	43.0	41.4
31	32.0	37.6	29.7	31.4	29.5	26.0	24.2	22.1
32	42.4	44.3	42.3	44.1	40.9	35.7	34.0	26.8
33	44.6	37.8	36.1	36.6	35.2	36.5	38.0	40.5
34	44.4	49.2	47.7	42.7	36.3	41.2	38.1	23.0
35	28.4	34.3	28.8	28.3	26.3	21.5	19.3	19.6
36	45.0	39.8	34.4	33.7	35.4	37.4	38.8	40.5
37	39.6	42.1	43.7	44.1	35.5	33.2	30.0	22.4
38	30.6	39.6	32.6	26.4	24.3	27.0	23.2	19.8
39	43.4	42.9	39.1	40.0	40.2	39.3	36.1	30.6
40	40.8	38.8	32.2	32.8	36.5	35.8	35.6	29.1
41	37.1	41.6	33.5	35.6	35.0	32.7	27.9	24.8
42	34.1	39.5	39.9	31.7	30.0	29.0	25.8	24.0
43	26.0	37.7	35.1	25.4	18.6	18.3	17.2	18.6
44	45.6	40.2	34.5	34.8	35.3	37.4	39.8	41.1
45	44.3	42.2	38.2	36.5	35.0	35.5	37.7	40.4
46	45.9	40.0	39.6	39.8	45.6	39.5	38.4	30.8
47	29.6	47.1	30.4	26.3	28.1	22.5	19.4	18.8
48	25.9	39.5	34.9	25.5	17.9	17.2	17.2	18.6
49	34.8	52.3	35.2	33.0	32.5	29.2	25.1	20.7
50	40.3	41.0	33.6	35.6	36.8	36.3	32.9	29.0
51	33.2	43.6	33.8	29.8	29.4	27.1	26.4	24.7
52	44.5	42.6	38.7	34.9	33.5	35.5	38.0	40.7
53	38.3	42.4	39.0	38.8	35.5	33.6	29.8	24.5
54	37.0	39.1	34.1	31.8	29.4	30.4	30.6	31.5
55	44.8	47.8	49.7	39.0	33.2	35.3	37.9	40.7

Table I. 2 Representative background noise levels measured in the LG room

Measurement #	LAeq,2min	Octave band Centre Frequency						
		63 Hz	125 Hz	250 Hz	500 Hz	1 k	2 k	4 k
1	34.6	52.6	34.9	34.2	31.5	28.3	24.2	23.9
2	31.5	37.3	33.1	30.3	30.0	24.2	22.8	22.2
3	34.2	45.2	42.1	34.4	31.8	26.3	25.4	21.5
4	40.9	47.9	48.4	48.1	29.8	28.1	29.0	22.3
5	44.2	50.1	37.3	37.6	33.6	35.0	37.6	40.3
6	33.2	50.8	32.0	34.2	27.3	26.1	25.2	24.2
7	45.7	42.9	35.2	36.2	36.3	37.9	39.7	41.2
8	44.6	42.4	35.3	34.1	35.2	36.5	38.1	40.6
9	44.2	37.7	34.0	31.7	33.2	35.1	37.7	40.5
10	34.5	44.5	39.9	42.2	24.2	18.1	19.0	19.5
11	44.7	42.8	44.4	40.1	33.8	35.2	37.7	40.9
12	30.4	42.8	36.9	32.6	24.7	23.0	21.4	21.2
13	33.6	51.4	34.6	36.5	30.4	25.1	24.4	19.4
14	45.8	43.7	42.9	39.0	35.1	36.5	40.7	40.9
15	32.6	42.9	36.6	33.3	28.9	26.2	24.5	22.7
16	32.3	50.1	38.0	36.1	25.5	17.4	25.0	20.1
17	32.4	45.6	39.5	32.8	30.6	24.2	21.9	20.8
18	38.1	50.6	48.6	42.6	30.0	25.3	28.8	23.2
19	39.0	38.0	41.9	34.1	31.2	32.9	33.9	31.0
20	39.9	38.7	32.8	37.7	33.4	34.2	34.6	31.1
21	41.4	40.7	39.7	37.2	33.8	35.9	36.1	33.1
22	30.2	42.0	32.3	31.1	28.2	22.7	21.6	19.1
23	37.0	42.6	37.4	37.8	34.8	31.4	28.1	24.8
24	37.5	37.6	32.7	32.1	33.4	30.9	30.2	31.4
25	33.6	39.9	33.6	30.1	31.2	27.8	26.1	23.6
26	28.0	36.4	32.4	30.5	23.4	22.2	17.3	18.3
27	34.1	42.0	42.8	32.9	32.4	26.0	24.9	20.7
28	44.6	49.1	35.6	34.6	33.6	35.4	38.1	40.9
29	41.6	45.9	45.4	44.4	39.7	32.9	32.6	29.0
30	45.9	49.5	52.3	46.4	34.8	36.0	38.4	40.7
31	32.5	42.6	35.0	30.2	26.5	27.6	25.2	24.0
32	38.9	44.2	52.6	41.2	28.8	27.1	25.8	21.1
33	48.2	37.6	35.2	33.0	37.9	40.6	43.6	42.6
34	41.1	47.1	52.5	45.1	34.9	32.3	28.2	23.3
35	30.8	46.8	30.6	29.2	28.6	21.6	21.4	23.3
36	45.3	46.3	46.7	40.7	38.4	36.2	38.7	40.6
37	40.5	49.1	52.6	43.6	34.5	30.3	27.4	24.3
38	36.5	44.1	37.0	33.3	30.7	32.9	29.4	25.2
39	34.1	45.6	36.6	33.5	29.1	26.6	25.5	27.7
40	31.3	39.4	36.3	31.4	27.6	24.8	24.2	19.4
41	33.1	39.1	36.3	36.6	27.5	25.3	25.0	24.2
42	38.6	50.6	45.8	40.1	35.0	33.4	27.2	23.0
43	31.4	53.6	34.8	34.4	24.9	16.9	18.1	18.9
44	47.8	48.8	40.0	39.8	38.7	40.9	41.7	42.7
45	27.7	44.5	36.1	27.7	21.6	17.0	18.9	19.6
46	37.3	47.7	40.6	36.8	35.4	28.8	29.6	27.7
47	31.2	40.4	41.2	29.9	27.8	23.8	21.7	19.5
48	44.3	53.7	39.5	34.1	34.3	35.2	37.7	40.3
49	32.4	37.3	32.0	30.9	29.2	27.0	26.0	19.5
50	29.5	47.1	36.2	33.8	26.0	18.9	15.2	14.1
51	41.7	47.8	41.4	40.0	40.4	36.0	33.9	26.9
52	33.7	55.4	36.8	36.9	28.8	20.0	20.4	19.5
53	34.5	42.7	42.5	39.1	28.1	27.2	23.3	21.7
54	31.5	40.0	40.5	32.8	25.2	23.3	23.0	22.5
55	46.7	49.7	51.0	45.8	40.2	39.7	38.8	40.7

Table I. 3 Representative background noise levels measured in the DR room

Measurement #	LAeq,2min	Octave band Centre Frequency						
		63 Hz	125 Hz	250 Hz	500 Hz	1 k	2 k	4 k
1	48.8	65.9	54.6	51.3	46.5	41.4	36.4	28.6
2	47.3	48.6	45.5	43.8	45.0	43.3	39.7	29.3
3	40.8	52.5	44.0	38.6	40.8	33.9	30.5	21.4
4	39.1	56.3	49.1	41.6	35.1	30.0	25.5	20.8
5	46.6	56.5	52.1	43.8	40.3	39.1	38.8	40.5
6	41.4	52.9	52.1	44.9	36.0	33.9	28.0	19.6
7	46.7	55.0	48.0	40.6	40.5	38.8	40.2	41.2
8	46.9	60.2	51.7	44.0	39.7	39.3	39.6	40.6
9	43.2	53.8	49.8	47.5	41.1	35.5	27.9	20.8
10	38.5	57.3	48.3	39.6	32.7	30.4	27.1	22.4
11	47.7	53.5	49.6	43.6	38.7	44.4	37.9	40.3
12	46.0	54.4	50.5	43.0	35.2	39.9	38.5	40.4
13	39.1	56.3	45.5	40.6	35.6	32.4	29.4	20.7
14	45.7	49.8	46.0	42.2	39.2	37.7	38.5	40.7
15	42.0	54.0	48.7	45.2	40.0	35.2	27.4	21.0
16	42.0	55.2	49.2	46.4	38.5	34.5	28.4	21.6
17	46.1	46.5	45.1	43.3	40.9	42.9	39.3	24.8
18	37.0	52.5	48.2	39.6	31.8	27.8	23.4	19.6
19	43.2	51.1	46.2	43.7	42.2	37.6	32.1	22.8
20	49.6	50.7	52.5	51.8	48.9	42.7	38.7	29.6
21	43.7	59.3	50.0	45.2	41.9	36.2	31.7	26.8
22	42.7	52.4	46.6	41.2	41.8	37.9	30.4	19.3
23	35.5	38.5	34.1	31.8	32.1	30.2	29.5	24.2
24	43.7	55.7	50.5	44.0	40.3	39.2	33.2	25.7
25	46.8	63.5	48.5	45.1	41.5	43.9	34.3	29.3
26	37.0	45.0	36.2	32.9	33.1	28.9	31.3	29.5
27	45.5	47.0	39.8	35.8	36.3	39.6	38.2	40.7
28	39.1	56.3	45.5	40.6	35.6	32.4	29.4	20.7
29	39.1	56.3	45.5	40.6	35.6	32.4	29.4	20.7
30	45.2	54.7	45.2	42.7	37.3	36.4	37.9	40.5
31	45.6	54.8	49.9	45.7	43.7	39.9	37.0	25.1
32	39.3	52.6	45.8	42.1	37.5	31.3	27.7	21.6
33	46.7	53.7	47.8	47.9	40.4	38.5	39.0	40.7
34	42.7	54.0	51.3	47.4	39.7	33.7	26.6	19.7
35	42.2	55.5	48.2	47.0	39.9	32.3	28.8	22.8
36	45.2	57.6	48.8	41.0	35.8	36.3	38.1	40.4
37	42.9	51.3	47.5	43.0	38.0	36.4	35.8	33.8
38	43.0	52.4	53.8	46.7	38.8	33.8	30.2	22.4
39	46.1	54.0	51.6	47.4	45.8	39.4	32.1	22.1
40	48.4	57.7	50.0	45.5	47.4	43.7	39.0	24.3
41	43.3	51.5	42.7	46.9	41.7	36.4	32.3	23.2
42	29.7	41.7	33.0	25.4	24.9	25.7	21.0	19.9
43	42.6	53.8	49.3	46.8	38.7	36.1	29.9	22.2
44	46.0	58.3	48.3	41.0	38.6	39.5	38.5	40.4
45	46.6	53.8	52.2	44.5	40.7	38.7	38.9	40.5
46	42.7	54.8	47.8	42.6	39.3	37.5	34.1	27.8
47	45.9	54.1	47.6	47.5	44.1	39.6	37.1	30.2
48	46.0	53.9	47.5	42.0	40.4	38.2	38.7	40.5
49	43.8	59.1	48.1	42.9	41.2	38.6	34.9	22.8
50	47.2	56.7	47.2	45.4	47.1	41.5	36.6	25.5
51	42.1	60.3	48.5	43.0	39.4	34.5	31.5	25.4
52	47.8	55.6	50.5	45.9	41.9	39.6	40.8	41.8
53	45.0	53.4	51.7	50.5	42.6	34.2	29.1	23.8
54	40.8	53.4	43.9	40.1	36.5	32.9	33.1	33.4
55	47.2	55.5	49.1	47.7	42.1	39.1	39.6	40.7

Table I. 4 Representative background noise levels measured in the T room

Measurement #	LAeq,2min	Octave band Centre Frequency						
		63 Hz	125 Hz	250 Hz	500 Hz	1 k	2 k	4 k
1	30.4	47.3	43.0	31.3	21.3	20.4	18.1	14.1
2	26.0	35.8	34.1	28.9	20.1	15.2	16.5	18.4
3	44.5	45.4	40.8	35.1	33.0	36.1	38.1	40.6
4	27.5	40.1	29.5	25.9	17.7	19.0	22.5	20.0
5	25.3	38.0	33.8	26.0	19.6	14.6	16.1	18.2
6	22.8	35.6	24.0	18.6	14.5	13.6	15.9	18.1
7	45.5	48.4	38.9	37.4	35.9	38.3	39.0	40.9
8	44.5	51.9	40.5	34.7	33.4	36.6	37.9	40.4
9	34.7	37.3	32.6	27.5	29.0	24.5	28.6	29.8
10	31.3	51.9	34.7	32.6	29.6	17.0	17.1	18.1
11	44.6	47.4	49.0	37.4	33.0	35.2	37.7	40.5
12	29.4	50.1	31.2	33.5	21.4	17.1	18.7	18.4
13	35.7	50.4	43.3	33.9	30.8	29.0	25.6	27.5
14	44.6	43.8	39.6	33.1	33.8	35.8	38.1	40.8
15	30.9	47.9	36.2	32.2	20.3	27.3	18.5	18.6
16	44.6	41.6	37.0	37.1	34.0	35.8	38.2	40.7
17	24.5	41.4	27.0	19.6	20.5	14.6	16.2	18.3
18	34.0	36.8	34.6	31.9	30.3	26.7	28.0	25.3
19	35.0	42.8	32.8	34.3	29.9	30.9	27.8	23.5
20	36.4	52.2	43.1	33.1	32.7	29.5	28.8	24.8
21	37.1	47.8	33.2	30.6	29.9	31.5	31.9	28.6
22	28.9	47.9	38.1	32.5	20.6	17.1	17.6	16.3
23	40.5	44.6	42.3	43.7	41.4	26.8	22.6	19.8
24	37.5	45.7	46.2	41.5	34.8	27.3	26.4	19.7
25	35.5	45.8	38.7	29.8	25.9	29.1	30.4	27.7
26	43.4	55.2	51.9	44.8	41.8	35.5	31.7	25.2
27	30.1	51.8	31.8	31.6	24.2	17.8	20.2	19.2
28	30.4	47.3	43.0	31.3	21.3	20.4	18.1	14.1
29	30.4	47.3	43.0	31.3	21.3	20.4	18.1	14.1
30	44.5	41.5	34.1	33.9	33.4	35.6	38.0	40.7
31	32.2	44.2	44.8	28.3	26.4	22.8	21.9	20.8
32	38.0	43.7	40.9	35.5	32.4	35.3	29.3	20.5
33	44.4	46.5	37.5	33.3	32.9	35.3	37.9	40.7
34	43.9	45.5	42.4	33.3	33.0	34.7	37.3	40.1
35	27.1	43.5	29.5	30.0	18.1	19.1	18.2	19.3
36	28.1	39.5	33.4	27.5	23.2	23.4	17.7	19.1
37	24.7	36.6	27.3	24.3	20.3	15.6	16.6	18.4
38	29.1	50.6	38.9	29.7	18.5	16.1	16.0	18.3
39	35.2	43.8	42.2	37.0	26.3	22.0	25.5	30.4
40	36.0	41.8	39.6	40.2	35.6	26.2	19.3	16.2
41	41.2	53.8	42.1	37.2	29.5	30.6	37.3	33.9
42	29.8	36.0	31.4	26.9	25.8	23.9	22.2	22.0
43	44.6	53.3	42.7	35.3	33.7	35.9	38.0	40.6
44	44.4	44.4	44.3	38.2	32.9	35.2	37.8	40.5
45	44.4	49.0	39.7	33.6	32.8	35.3	37.9	40.6
46	36.0	44.0	40.0	36.4	33.7	30.9	26.6	21.4
47	37.2	45.1	42.8	32.7	29.5	30.4	32.1	28.6
48	44.5	51.7	48.4	37.2	33.1	35.1	37.7	40.3
49	34.6	54.8	41.8	37.4	28.2	26.0	22.7	18.4
50	36.3	54.7	46.3	34.8	30.7	29.2	26.5	19.8
51	35.3	50.5	39.8	34.4	30.9	31.5	24.2	19.9
52	27.9	49.6	28.5	31.2	15.9	15.3	16.6	18.4
53	31.5	42.1	38.7	36.3	27.7	21.7	19.3	19.5
54	38.4	42.2	36.1	35.9	32.0	34.6	31.1	29.2
55	44.6	43.5	37.6	33.4	33.8	36.0	38.1	40.8

APPENDIX J

Results of Pearson Correlation Analysis between Room Parameters and Singers' Subjective Data in RAM Practice Rooms

Table J. 1 Results of Pearson Correlation analysis between subjective data (questionnaire) and objective T30 parameter in octave-bands.

Parameters		T30 (63Hz)	T30 (125Hz)	T30 (250Hz)	T30 (500Hz)	T30 (1k)	T30 (2k)	T30 (4k)
Reverberance	Pearson Corr.	.840	.401	.883	.843	.822	.813	.955*
	Sig. 2-tailed	.160	.599	.117	.157	.178	.187	.045
Loudness	Pearson Corr.	.503	.044	.808	.508	.488	.495	.708
	Sig. 2-tailed	.497	.956	.192	.492	.512	.505	.292
Background noise	Pearson Corr.	.824	.442	.516	.823	.795	.755	.839
	Sig. 2-tailed	.176	.558	.484	.177	.205	.245	.161
Size of the room	Pearson Corr.	.902	.880	.539	.900	.904	.890	.766
	Sig. 2-tailed	.098	.120	.461	.100	.096	.110	.234
Pleasure	Pearson Corr.	.961*	.663	.925	.963*	.955*	.952*	.998***
	Sig. 2-tailed	.039	.337	.075	.037	.045	.048	.002
Voice feeling	Pearson Corr.	.842	.420	.910	.844	.826	.821	.955*
	Sig. 2-tailed	.158	.580	.090	.156	.174	.179	.045
Singing effort	Pearson Corr.	-.855	-.439	-.909	-.857	-.840	-.834	-.963*
	Sig. 2-tailed	.145	.561	.091	.143	.160	.166	.037
Overall impression	Pearson Corr.	.960*	.658	.924	.962*	.953*	.950*	.998***
	Sig. 2-tailed	.040	.342	.076	.038	.047	.050	.002

*: p<0,05 **: p<0,01 ***: p<0,001

Table J. 2 Results of Pearson Correlation analysis between subjective data (questionnaire) and objective EDT parameter in octave-bands.

Parameters		EDT (63Hz)	EDT (125Hz)	EDT (250Hz)	EDT (500Hz)	EDT (1k)	EDT (2k)	EDT (4k)
Reverberance	Pearson Corr.	.872	.726	.788	.876	.933	.787	.946
	Sig. 2-tailed	.128	.274	.212	.124	.067	.213	.054
Loudness	Pearson Corr.	.706	.333	.414	.554	.741	.467	.683
	Sig. 2-tailed	.294	.667	.586	.446	.259	.533	.317
Background noise	Pearson Corr.	.601	.798	.835	.847	.713	.726	.850
	Sig. 2-tailed	.399	.202	.165	.153	.287	.274	.150
Size of the room	Pearson Corr.	.686	.964*	.942	.878	.711	.892	.787
	Sig. 2-tailed	.314	.036	.058	.122	.289	.108	.213
Pleasure	Pearson Corr.	.958*	.893	.929	.975*	.991***	.938	.996***
	Sig. 2-tailed	.042	.107	.071	.025	.009	.062	.004
Voice feeling	Pearson Corr.	.894	.726	.787	.876	.945	.797	.945
	Sig. 2-tailed	.106	.274	.213	.124	.055	.203	.055
Singing effort	Pearson Corr.	-.898	-.743	-.802	-.888	-.950*	-.810	-.953*
	Sig. 2-tailed	.102	.257	.198	.112	.050	.190	.047
Overall impression	Pearson Corr.	.956*	.891	.927	.975*	.990***	.936	.996***
	Sig. 2-tailed	.044	.109	.073	.025	.010	.064	.004

*: p<0,05 **: p<0,01 ***: p<0,001

Table J. 3 Results of Pearson Correlation analysis between subjective data (questionnaire) and objective C80 parameter in octave-bands.

Parameters		C80 (63Hz)	C80 (125Hz)	C80 (250Hz)	C80 (500Hz)	C80 (1k)	C80 (2k)	C80 (4k)
Reverberance	Pearson Corr.	-.817	-.911	-.945	.-.986**	.-.988**	.-.957*	.-.996***
	Sig. 2-tailed	.183	.089	.055	.014	.012	.043	.004
Loudness	Pearson Corr.	-.712	-.589	-.663	-.775	-.794	-.717	-.830
	Sig. 2-tailed	.288	.411	.337	.225	.206	.283	.170
Background noise	Pearson Corr.	-.471	-.939	-.937	-.865	-.826	-.829	-.842
	Sig. 2-tailed	.529	.061	.063	.135	.174	.171	.158
Size of the room	Pearson Corr.	-.593	-.833	-.764	-.682	-.671	-.758	-.595
	Sig. 2-tailed	.407	.167	.236	.318	.329	.242	.405
Pleasure	Pearson Corr.	-.904	.-.956*	.-.955*	.-.977*	.-.986**	.-.999***	.-.951*
	Sig. 2-tailed	.096	.044	.045	.023	.014	.001	.049
Voice feeling	Pearson Corr.	-.848	-.898	-.930	.-.980**	.-.987**	.-.958*	.-.989**
	Sig. 2-tailed	.152	.102	.070	.020	.013	.042	.011
Singing effort	Pearson Corr.	.849	.909	.939	.984**	.991***	.965*	.991***
	Sig. 2-tailed	.151	.091	.061	.016	.009	.035	.009
Overall impression	Pearson Corr.	-.901	.-.957*	.-.956*	.-.978*	.-.987**	.-.999***	.-.953*
	Sig. 2-tailed	.099	.043	.044	.022	.013	.001	.047

*: p<0,05 **: p<0,01 ***: p<0,001

Table J. 4 Results of Pearson Correlation analysis between subjective data (questionnaire) and objective G parameter in octave-bands.

Parameters		G (63Hz)	G (125Hz)	G (250Hz)	G (500Hz)	G (1k)	G (2k)	G (4k)
Reverberance	Pearson Corr.	.935	-.611	.577	.881	.574	.643	.633
	Sig. 2-tailed	.065	.389	.423	.119	.426	.357	.367
Loudness	Pearson Corr.	.945	-.591	.903	.952*	.876	.933	.885
	Sig. 2-tailed	.055	.409	.097	.048	.124	.067	.115
Background noise	Pearson Corr.	.667	-.654	-.001	.579	.136	.136	.250
	Sig. 2-tailed	.333	.346	.999	.421	.864	.864	.750
Size of the room	Pearson Corr.	.247	-.049	-.308	.116	-.363	-.274	-.282
	Sig. 2-tailed	.753	.951	.692	.884	.637	.726	.718
Pleasure	Pearson Corr.	.781	-.384	.392	.695	.318	.426	.375
	Sig. 2-tailed	.219	.616	.608	.305	.682	.574	.625
Voice feeling	Pearson Corr.	.927	-.570	.603	.874	.578	.657	.630
	Sig. 2-tailed	.073	.430	.397	.126	.422	.343	.370
Singing effort	Pearson Corr.	-.920	.565	-.582	-.864	-.557	-.637	-.611
	Sig. 2-tailed	.080	.435	.418	.136	.443	.363	.389
Overall impression	Pearson Corr.	.784	-.391	.393	.699	.322	.429	.380
	Sig. 2-tailed	.216	.609	.607	.301	.678	.571	.620

*: p<0,05 **: p<0,01 ***: p<0,001

Table J. 5 Results of Pearson Correlation analysis between subjective data (questionnaire) and objective T30 parameter in octave-band combinations.

Parameters		T30 (125-250Hz)	T30 (250-500Hz)	T30 (500Hz-1k)	T30 (1k-2k)	T30 (mid)	T30 (low)	T30 (125-500Hz)	T30 (250Hz-1k)	T30 (125Hz-1k)
Reverberance	Pearson Corr.	.641	.902	.837	.821	.833	.729	.689	.887	.713
	Sig. 2-tailed	.359	.098	.163	.179	.167	.271	.311	.113	.287
Loudness	Pearson Corr.	.363	.716	.503	.499	.506	.427	.399	.670	.413
	Sig. 2-tailed	.637	.284	.497	.501	.494	.573	.601	.330	.587
Background noise	Pearson Corr.	.520	.662	.814	.770	.795	.637	.582	.686	.620
	Sig. 2-tailed	.480	.338	.186	.230	.205	.363	.418	.314	.380
Size of the room	Pearson Corr.	.833	.710	.901	.892	.896	.871	.854	.757	.869
	Sig. 2-tailed	.167	.290	.099	.108	.104	.129	.146	.243	.131
Pleasure	Pearson Corr.	.840	.978*	.961*	.956*	.961*	.903	.875	.979*	.893
	Sig. 2-tailed	.160	.022	.039	.044	.039	.097	.125	.021	.107
Voice feeling	Pearson Corr.	.666	.919	.839	.828	.837	.746	.710	.903	.732
	Sig. 2-tailed	.334	.081	.161	.172	.163	.254	.290	.097	.268
Singing effort	Pearson Corr.	-.678	-.924	-.853	-.841	-.850	-.758	-.723	-.909	-.744
	Sig. 2-tailed	.322	.076	.147	.159	.150	.242	.277	.091	.256
Overall impression	Pearson Corr.	.836	.976*	.960*	.954*	.959*	.900	.872	.978*	.889
	Sig. 2-tailed	.164	.024	.040	.046	.041	.100	.128	.022	.111

*: p<0,05 **: p<0,01 ***: p<0,001

Table J. 6 Results of Pearson Correlation analysis between subjective data (questionnaire) and objective EDT parameter in octave-band combinations.

Parameters		EDT (125-250Hz)	EDT (250-500Hz)	EDT (500Hz-1k)	EDT (1k-2k)	EDT (mid)	EDT (low)	EDT (125-500Hz)	EDT (250Hz-1k)	EDT (125Hz-1k)
Reverberance	PearsonCorr.	.750	.824	.910	.882	.878	.809	.777	.862	.807
	Sig.2-tailed	.250	.176	.090	.118	.122	.191	.223	.138	.193
Loudness	PearsonCorr.	.365	.467	.636	.629	.594	.477	.401	.540	.458
	Sig.2-tailed	.635	.533	.364	.371	.406	.523	.599	.460	.542
Background noise	PearsonCorr.	.810	.844	.805	.733	.777	.774	.823	.826	.806
	Sig.2-tailed	.190	.156	.195	.267	.223	.226	.177	.174	.194
Size of the room	PearsonCorr.	.956*	.921	.820	.805	.842	.904	.945	.883	.920
	Sig.2-tailed	.044	.079	.180	.195	.158	.096	.055	.117	.080
Pleasure	PearsonCorr.	.908	.949	.993***	.983**	.982**	.949	.924	.972*	.945
	Sig.2-tailed	.092	.051	.007	.017	.018	.051	.076	.028	.055
Voice feeling	PearsonCorr.	.750	.822	.914	.894	.885	.815	.776	.864	.810
	Sig.2-tailed	.250	.178	.086	.106	.115	.185	.224	.136	.190
Singing effort	PearsonCorr.	-.766	-.837	-.924	-.902	-.895	-.828	-.792	-.876	-.824
	PearsonCorr.	.234	.163	.076	.098	.105	.172	.208	.124	.176
Overall impression	Sig.2-tailed	.906	.948	.992***	.982**	.981**	.947	.922	.971*	.944
	PearsonCorr.	.094	.052	.008	.018	.019	.053	.078	.029	.056

*: p<0,05 **: p<0,01 ***: p<0,001

Table J. 7 Results of Pearson Correlation analysis between subjective data (questionnaire) and objective C80 parameter in octave-band combinations.

Parameters		C80 (125-250Hz)	C80 (250-500Hz)	C80 (500Hz-1k)	C80 (1k-2k)	C80 (mid)	C80 (low)	C80 (125-500Hz)	C80 (250Hz-1k)	C80 (125Hz-1k)
Reverberance	Pearson Corr.	-.929	-.978*	-.988*	-.969*	-.984*	-.943	-.960*	-.984*	-.974*
	Sig. 2-tailed	.071	.022	.012	.031	.016	.057	.040	.016	.026
Loudness	Pearson Corr.	-.626	-.748	-.787	-.744	-.771	-.667	-.698	-.771	-.736
	Sig. 2-tailed	.374	.252	.213	.256	.229	.333	.302	.229	.264
Background noise	Pearson Corr.	-.890	-.836	-.786	-.756	-.803	-.800	-.858	-.803	-.825
	Sig. 2-tailed	.110	.164	.214	.244	.197	.200	.142	.197	.175
Size of the room	Pearson Corr.	-.796	-.704	-.676	-.731	-.691	-.798	-.749	-.691	-.725
	Sig. 2-tailed	.204	.296	.324	.269	.309	.202	.251	.309	.275
Pleasure	Pearson Corr.	-.954*	-.973*	-.983*	-.997**	-.982*	-.990**	-.970*	-.982*	-.981*
	Sig. 2-tailed	.046	.027	.017	.003	.018	.010	.030	.018	.019
Voice feeling	Pearson Corr.	-.915	-.970*	-.985*	-.970*	-.980*	-.939	-.950	-.980*	-.967*
	Sig. 2-tailed	.085	.030	.015	.030	.020	.061	.050	.020	.033
Singing effort	Pearson Corr.	.924	.975*	.989*	.976*	.984*	.948	.957*	.984*	.973*
	Sig. 2-tailed	.076	.025	.011	.024	.016	.052	.043	.016	.027
Overall impression	Pearson Corr.	-.955*	-.975*	-.984*	-.997**	-.983*	-.991**	-.972*	-.983*	-.982*
	Sig. 2-tailed	.045	.025	.016	.003	.017	.009	.028	.017	.018

*: p<0,05 **: p<0,01 ***: p<0,001

Table J. 8 Results of Pearson Correlation analysis between subjective data (questionnaire) and objective G parameter in octave-band combinations.

Parameters		G (125-250Hz)	G (250-500Hz)	G (500Hz-1k)	G (1k-2k)	G (mid)	G (low)	G (125-500Hz)	G (250Hz-1k)	G (125Hz-1k)
Reverberance	Pearson Corr.	-.019	.677	.792	.613	.657	.477	.217	.657	.282
	Sig. 2-tailed	.981	.323	.208	.387	.343	.523	.783	.343	.718
Loudness	Pearson Corr.	.355	.953*	.952*	.909	.942	.801	.594	.942	.669
	Sig. 2-tailed	.645	.047	.048	.091	.058	.199	.406	.058	.331
Background noise	Pearson Corr.	-.677	.165	.473	.190	.156	-.201	-.473	.156	-.397
	Sig. 2-tailed	.323	.835	.527	.810	.844	.799	.527	.844	.603
Size of the room	Pearson Corr.	-.445	-.215	-.061	-.318	-.248	-.260	-.400	-.248	-.418
	Sig. 2-tailed	.555	.785	.939	.682	.752	.740	.600	.752	.582
Pleasure	Pearson Corr.	-.035	.482	.574	.375	.452	.374	.148	.452	.180
	Sig. 2-tailed	.965	.518	.426	.625	.548	.626	.852	.548	.820
Voice feeling	Pearson Corr.	.039	.695	.788	.622	.673	.520	.270	.673	.330
	Sig. 2-tailed	.961	.305	.212	.378	.327	.480	.730	.327	.670
Singing effort	Pearson Corr.	-.020	-.676	-.774	-.601	-.653	-.501	-.249	-.653	-.308
	Sig. 2-tailed	.980	.324	.226	.399	.347	.499	.751	.347	.692
Overall impression	Pearson Corr.	-.038	.485	.578	.378	.454	.373	.146	.454	.179
	Sig. 2-tailed	.962	.515	.422	.622	.546	.627	.854	.546	.821

*: p<0,05 **: p<0,01 ***: p<0,001

Table J. 9 Results of Pearson Correlation analysis between subjective data (questionnaire) and objective room parameters: height, length, width, area, volume and background noise level LAeq.

Parameters		Room height	Room length	Room width	Room area	Room volume	LAeq
Reverberance	Pearson Corr.	.744	.490	.818	.621	.641	.596
	Sig. 2-tailed	.256	.510	.182	.379	.359	.404
Loudness	Pearson Corr.	.564	.004	.756	.194	.246	.324
	Sig. 2-tailed	.436	.996	.244	.806	.754	.676
Background noise	Pearson Corr.	.483	.791	.428	.761	.713	.956*
	Sig. 2-tailed	.517	.209	.572	.239	.287	.044
Size of the room	Pearson Corr.	.706	.993***	.523	.988**	.965*	.469
	Sig. 2-tailed	.294	.007	.477	.012	.035	.531
Pleasure	Pearson Corr.	.887	.687	.885	.818	.841	.498
	Sig. 2-tailed	.113	.313	.115	.182	.159	.502
Voice feeling	Pearson Corr.	.774	.474	.851	.620	.646	.545
	Sig. 2-tailed	.226	.526	.149	.380	.354	.455
Singing effort	Pearson Corr.	-.780	-.498	-.850	-.640	-.664	-.554
	Sig. 2-tailed	.220	.502	.150	.360	.336	.446
Overall impression	Pearson Corr.	.883	.686	.882	.816	.839	.503
	Sig. 2-tailed	.117	.314	.118	.184	.161	.497

*: p<0,05 **: p<0,01 ***: p<0,001

APPENDIX K

Regression Models for Loudness, Background Noise and Size of the Room Subjective Parameters and Room Parameters that Show Correlation

Table K. 1 Regression model for Loudness subjective parameter and $G_{(250Hz-500Hz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	-5.119	2.248	.951	-2.278	.150
$G_{(250Hz-500Hz)}$	.330	.075		4.368	.049

a. Dependent Variable: Loudness

Table K. 2 Regression model for Loudness subjective parameter and $G_{(500Hz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	-8.634	2.981	.953	-2.897	.101
$G_{(500Hz)}$	.469	.105		4.472	.047

a. Dependent Variable: Loudness

Table K. 3 Regression model for Loudness subjective parameter and $G_{(500Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	-12.166	3.836	.952	-3.171	.087
$G_{(500Hz-1kHz)}$	.597	.136		4.395	.048

a. Dependent Variable: Loudness

Table K. 4 Regression model for Background noise subjective parameter and $L_{Aeq,2min}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	-8.123	2.484	.960	-3.270	.082
$L_{Aeq,2min}$	.287	.059		4.846	.040

a. Dependent Variable: Subjective Background noise parameter

Table K. 5 Regression model for Size of the room subjective parameter and objective Room length parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	.703	.193	.993	3.644	.068
Room length	.571	.047		12.253	.007

a. Dependent Variable: Size of the room subjective parameter

Table K. 6 Regression model for Size of the room subjective parameter and objective Room floor-area parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.191	.206	.988	5.783	.029
Room floor area	.211	.023		9.205	.012

a. Dependent Variable: Size of the room subjective parameter

Table K. 7 Regression model for Size of the room subjective parameter and objective Room volume parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.552	.296	.965	5.237	.035
Room volume	.069	.013		5.239	.035

a. Dependent Variable: Size of the room subjective parameter

APPENDIX L

Regression Models for Reverberance Subjective Parameter and Room Parameters that Show Correlation

Table L. 8 Regression model for Reverberance subjective parameter and $C80_{(4kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.956	.158	-.996	37.680	.001
$C80_{(4kHz)}$	-.118	.008		-15.552	.004

a. Dependent Variable: Reverberance

Table L. 9 Regression model for Reverberance subjective parameter and $C80_{(1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	6.071	.284	-.988	21.387	.002
$C80_{(1kHz)}$	-.169	.019		-9.024	.012

a. Dependent Variable: Reverberance

Table L .10 Regression model for Reverberance subjective parameter and $C80_{(500Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.844	.262	-.988	22.304	.002
$C80_{(500Hz-1kHz)}$	-.160	.018		-8.979	.012

a. Dependent Variable: Reverberance

Table L. 11 Regression model for Reverberance subjective parameter and $C80_{(500Hz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.582	.255	-.986	21.864	.002
$C80_{(500Hz)}$	-.149	.018		-8.287	.014

Table L. 12 Regression model for Reverberance subjective parameter and $C80_{(250Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.712	.283	-.984	20.184	.002
$C80_{(250Hz-1kHz)}$	-.162	.021		-7.886	.016

a. Dependent Variable: Reverberance

Table L. 13 Regression model for Reverberance subjective parameter and $C80_{(mid)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	6.075	.418	-.974	14.518	.005
$C80_{(mid)}$	-.159	.026		-6.119	.026

a. Dependent Variable: Reverberance

Table L. 14 Regression model for Reverberance subjective parameter and $C80_{(250Hz-500Hz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.442	.300	-.978	18.128	.003
$C80_{(250Hz-500Hz)}$	-.156	.023		-6.624	.022

a. Dependent Variable: Reverberance

Table L. 15 Regression model for Reverberance subjective parameter and $C80_{(125Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.540	.342	-.974	16.215	.004
$C80_{(125Hz-1kHz)}$	-.154	.025		-6.068	.026

Table L. 9 Regression model for Reverberance subjective parameter and $C80_{(1kHz-2kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	6.236	.485	-.969	12.863	.006
$C80_{(1kHz-2kHz)}$	-.161	.029		-5.588	.031

a. Dependent Variable: Reverberance

Table L. 10 Regression model for Reverberance subjective parameter and $C80_{(2kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	6.338	.601	-.957	10.548	.009
$C80_{(2kHz)}$	-.155	.033		-4.661	.043

a. Dependent Variable: Reverberance

Table L. 11 Regression model for Reverberance subjective parameter and $T30_{(4kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.144	.596	.955	1.919	.195
$T30_{(4kHz)}$	7.679	1.685		4.558	.045

a. Dependent Variable: Reverberance

Table L. 12 Predicted values of room parameters corresponding to the singers' preferred Reverberance ratings: "balanced" (4) and "reverberant" (5)

Room parameters	Regression Equation	Questionnaire	Room parameter	Questionnaire	Room parameter
		y (balanced)	x (predicted)	y (reverberant)	x (predicted)
$C80_{(4k)}$	y = -0.1183x +5.9555	4	16.53 dB	5	8.08 dB
$C80_{(1k)}$	y = -0.1688x + 6.0706	4	12.27 dB	5	6.34 dB
$C80_{(500Hz\text{-}1k)}$	y = -0.1598x + 5.8445	4	11.54 dB	5	5.28 dB
$C80_{(500Hz)}$	y = -0.149x + 5.5824	4	10.62 dB	5	3.91 dB
$C80_{(250Hz\text{-}1kHz)}$	y = -0.1624x + 5.7116	4	10.54 dB	5	4.38 dB
$C80_{(mid)}$	y = -0.1586x + 6.0751	4	13.08 dB	5	6.78 dB
$C80_{(250Hz\text{-}500Hz)}$	y = -0.1556x + 5.4428	4	9.27 dB	5	2.85 dB
$C80_{(125Hz\text{-}1kHz)}$	y = -0.1543x + 5.5401	4	9.98 dB	5	3.50 dB
$C80_{(1kHz\text{-}2kHz)}$	y = -0.1609x + 6.2372	4	13.90 dB	5	7.69 dB
$C80_{(2kHz)}$	y = -0.1554x + 6.3378	4	15.04 dB	5	8.61 dB
$T30_{(4kHz)}$	y = 7.6794x + 1.1441	4	0.37 sec	5	0.50 sec

APPENDIX M

Regression Models for Pleasure of Singing Subjective Parameter and Room Parameters that Show Correlation

Table M. 1 Regression model for Pleasure of singing subjective parameter and $C80_{(2kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.967	.085	-.999	70.158	.000
$C80_{(2kHz)}$	-.130	.005		-27.494	.001

a. Dependent Variable: Pleasure of singing

Table M. 2 Regression model for Pleasure of singing subjective parameter and $T30_{(4kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.628	.111	.998	14.674	.005
$T30_{(4kHz)}$	6.418	.314		20.471	.002

a. Dependent Variable: Pleasure of singing

Table M. 3 Regression model for Pleasure of singing subjective parameter and $EDT_{(4kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.356	.165	.996	8.228	.014
$EDT_{(4kHz)}$	8.372	.545		15.352	.004

a. Dependent Variable: Pleasure of singing

Table M. 4 Regression model for Pleasure of singing subjective parameter and $C80_{(1kHz-2kHz)}$room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.851	.129	-.997	45.220	.000
$C80_{(1kHz-2kHz)}$	-.132	.008		-17.224	.003

a. Dependent Variable: Pleasure of singing

Table M. 5 Regression model for Pleasure of singing subjective parameter and $EDT_{(500Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.674	.190	.993	8.826	.013
$EDT_{(500Hz-1kHz)}$	4.858	.413		11.748	.007

a. Dependent Variable: Pleasure of singing

Table M. 6 Regression model for Pleasure of singing subjective parameter and $EDT_{(1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.502	.229	.991	6.574	.022
$EDT_{(1kHz)}$	5.722	.547		10.452	.009

a. Dependent Variable: Pleasure of singing

Table M. 7 Regression model for Pleasure of singing subjective parameter and $C80_{(low)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	4.935	.141	-.990	34.929	.001
$C80_{(low)}$	-.129	.013		-9.939	.010

a. Dependent Variable: Pleasure of singing

Table M. 8 Regression model for Pleasure of singing subjective parameter and $C80_{(1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.658	.242	-.986	23.385	.002
$C80_{(1kHz)}$	-.135	.016		-8.456	.014

a. Dependent Variable: Pleasure of singing

Table M. 9 Regression model for Pleasure of singing subjective parameter and $C80_{(mid)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.704	.161	-.994	35.330	.001
$C80_{(mid)}$	-.129	.010		-12.948	.006

a. Dependent Variable: Pleasure of singing

Table M. 10 Regression model for Pleasure of singing subjective parameter and $C80_{(500Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.471	.249	-.983	21.959	.002
$C80_{(500Hz-1kHz)}$	-.127	.017		-7.517	.017

a. Dependent Variable: Pleasure of singing

Table M. 11 Regression model for Pleasure of singing subjective parameter and $EDT_{(1kHz-2kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.619	.301	.983	5.372	.033
$EDT_{(1kHz-2kHz)}$	5.997	.794		7.556	.017

a. Dependent Variable: Pleasure of singing

Table M. 12 Regression model for Pleasure of singing subjective parameter and $EDT_{(mid)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.635	.304	.982	5.385	.033
$EDT_{(mid)}$	5.385	.723		7.447	.018

a. Dependent Variable: Pleasure of singing

Table M. 13 Regression model for Pleasure of singing subjective parameter and $C80_{(250Hz\text{-}1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.370	.245	-.982	21.906	.002
$C80_{(250Hz\text{-}1kHz)}$	-.130	.018		-7.264	.018

a. Dependent Variable: Pleasure of singing

Table M. 14 Regression model for Pleasure of singing subjective parameter and $C80_{(125Hz\text{-}1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.247	.235	-.981	22.327	.002
$C80_{(125Hz\text{-}1kHz)}$	-.124	.017		-7.108	.019

a. Dependent Variable: Pleasure of singing

Table M. 15 Regression model for Pleasure of singing subjective parameter and $C80_{(4kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.488	.431	-.951	12.742	.006
$C80_{(4kHz)}$	-.090	.021		-4.362	.049

a. Dependent Variable: Pleasure of singing

Table M. 16 Predicted values of room parameters corresponding to the singers' preferred Pleasure of singing ratings: "good" (4) and "very good" (5)

Room parameters	Regression Equation	Questionnaire	Room parameter	Questionnaire	Room parameter
		y (good)	x (predicted)	y (very good)	x (predicted)
$C80_{(2kHz)}$	y = -0.1298x + 5.9673	4	15.2 dB	5	7.45 dB
$T30_{(4kHz)}$	y = 6.4183x + 1.6284	4	0.37	5	0.53
$EDT_{(4kHz)}$	y = 8.372x + 1.3555	4	0.32	5	0.44
$C80_{(1kHz-2kHz)}$	y = -0.1323x + 5.8519	4	14.00	5	6.44
$EDT_{(500Hz-1kHz)}$	y = 4.8576x + 1.6737	4	0.48	5	0.68
$EDT_{(1kHz)}$	y = 5.7216x + 1.5025	4	0.44	5	0.61
$C80_{(low)}$	y = -0.1288x + 4.9353	4	7.26	5	-0.50
$C80_{(1kHz)}$	y = -0.1349x + 5.6582	4	12.3	5	4.88
$C80_{(mid)}$	y = -0.1295x + 5.7034	4	13.15	5	5.43
$C80_{(500Hz-1kHz)}$	y = -0.1272x + 5.4715	4	11.57	5	3.71
$EDT_{(1kHz-2kHz)}$	y = 5.9966x + 1.6187	4	0.40	5	0.56
$EDT_{(mid)}$	y = 5.3853x + 1.6353	4	0.44	5	0.62
$C80_{(250Hz-1kHz)}$	y = -0.1296x + 5.3697	4	10.57	5	2.85
$C80_{(125Hz-1kHz)}$	y = -0.1243x + 5.2472	4	10.03	5	1.99
$T30_{(250-1kHz)}$	y = 3.3475x + 1.8795	4	0.63	5	0.93
$T30_{(250-500Hz)}$	y = 2.841x + 1.9514	4	0.72	5	1.07
$C80_{(500Hz)}$	y = -0.1181x + 5.2566	4	10.6 dB	5	2.17 dB
$C80_{(4kHz)}$	y = -0.0904x + 5.4882	4	16.5 dB	5	5.40 dB

APPENDIX N

Regression Models for Voice Feeling Subjective Parameter and Room Parameters that Show Correlation

Table N. 1 Regression model for Voice feeling subjective parameter and $C80_{(4kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.333	.164	-.989	32.568	.001
$C80_{(4kHz)}$	-.074	.008		-9.391	.011

a. Dependent Variable: Voice feeling

Table N. 2 Regression model for Voice feeling subjective parameter and $C80_{(1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.414	.186	-.987	29.050	.001
$C80_{(1kHz)}$	-.106	.012		-8.650	.013

a. Dependent Variable: Voice feeling

Table N. 3 Regression model for Voice feeling subjective parameter and $C80_{(500Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.268	.185	-.985	28.431	.001
$C80_{(500Hz-1kHz)}$	-.100	.013		-7.974	.015

a. Dependent Variable: Voice feeling

Table N. 4 Regression model for Voice feeling subjective parameter and $C80_{(500Hz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.100	.191	-.980	26.647	.001
$C80_{(500Hz)}$	-.093	.013		-6.923	.020

a. Dependent Variable: Voice feeling

Table N. 5 Regression model for Voice feeling subjective parameter and $C80_{(mid)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.417	.268	-.974	20.239	.002
$C80_{(mid)}$	-.100	.017		-6.023	.026

a. Dependent Variable: Voice feeling

Table N. 6 Regression model for Voice feeling subjective parameter and $C80_{(250Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.183	.203	-.980	25.489	.002
$C80_{(250Hz-1kHz)}$	-.102	.015		-6.881	.020

a. Dependent Variable: Voice feeling

Table N. 7 Regression model for Voice feeling subjective parameter and $C80_{(1kHz-2kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.520	.303	-.970	18.199	.003
$C80_{(1kHz-2kHz)}$	-.101	.018		-5.630	.030

a. Dependent Variable: Voice feeling

Table N. 8 Regression model for Voice feeling subjective parameter and $C80_{(250Hz-500Hz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.010	.222	-.970	22.618	.002
$C80_{(250Hz-500Hz)}$	-.097	.017		-5.608	.030

a. Dependent Variable: Voice feeling

Table N. 9 Regression model for Voice feeling subjective parameter and $C80_{(125Hz\text{-}1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.073	.241	-.967	21.032	.002
$C80_{(125Hz\text{-}1kHz)}$	-.097	.018		-5.378	.033

a. Dependent Variable: Voice feeling

Table N. 10 Regression model for Voice feeling subjective parameter and $C80_{(2kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.586	.373	-.958	14.977	.004
$C80_{(2kHz)}$	-.098	.021		-4.737	.042

a. Dependent Variable: Voice feeling

Table N. 11 Regression model for Voice feeling subjective parameter and $T30_{(4k)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	2.311	.375	.955	6.163	.025
$T30_{(4kHz)}$	4.839	1.059		4.568	.045

a. Dependent Variable: Voice feeling

Table N. 12 Predicted values of room parameters corresponding to the singers' preferred Voice feeling ratings: "as usual" (4) and "strong" (5)

Room parameters	Regression Equation	Questionnaire	Room parameter	Questionnaire	Room parameter
		y (as usual)	x (predicted)	y (strong)	x (predicted)
$C80_{(4k)}$	y = -0.074x + 5.3325	4	18.01 dB	5	4.49 dB
$C80_{(1k)}$	y = -0.1062x + 5.4135	4	13.31 dB	5	3.89 dB
$C80_{(500Hz\text{-}1k)}$	y = -0.1004x + 5.2683	4	12.63 dB	5	2.67 dB
$C80_{(500Hz)}$	y = -0.0933x + 5.1003	4	11.79 dB	5	1.08 dB
$C80_{(mid)}$	y = -0.0999x + 5.4167	4	14.18 dB	5	4.17 dB
$C80_{(250Hz\text{-}1kHz)}$	y = -0.1018x + 5.1828	4	11.62 dB	5	1.80 dB
$C80_{(1k\text{-}2k)}$	y = -0.1014x + 5.5208	4	15.00 dB	5	5.14 dB
$C80_{(250Hz\text{-}500Hz)}$	y = -0.0972x + 5.0102	4	10.39 dB	5	0.10 dB
$C80_{(125Hz\text{-}1kHz)}$	y = -0.0965x + 5.0728	4	11.12 dB	5	0.75 dB
$C80_{(2k)}$	y = -0.098x + 5.5857	4	16.18 dB	5	5.98 dB
$T30_{(4k)}$	y = 4.8391x + 2.311	4	0.35 sec	5	0.56 sec

APPENDIX O

Regression Models for Singing Effort Subjective Parameter and Room Parameters that Show Correlation

Table O. 1 Regression model for Singing effort subjective parameter and $C80_{(4kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	3.241	.110	.991	29.519	.001
$C80_{(4kHz)}$	.055	.005		10.398	.009

a. Dependent Variable: Singing effort

Table O. 2 Regression model for Singing effort subjective parameter and $C80_{(1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	3.179	.115	.991	27.525	.001
$C80_{(1kHz)}$	.079	.008		10.383	.009

a. Dependent Variable: Singing effort

Table O. 3 Regression model for Singing effort subjective parameter and $C80_{(500Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	3.287	.117	.989	28.162	.001
$C80_{(500Hz-1kHz)}$	.075	.008		9.420	.011

a. Dependent Variable: Singing effort

Table O. 4 Regression model for Singing effort subjective parameter and $C80_{(500Hz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	3.411	.124	.984	27.450	.001
$C80_{(500Hz)}$	.069	.009		7.938	.016

a. Dependent Variable: Singing effort

Table O. 5 Regression model for Singing effort subjective parameter and $C80_{(mid)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	3.175	.176	.979	18.035	.003
$C80_{(mid)}$	.074	.011		6.824	.021

a. Dependent Variable: Singing effort

Table O. 6 Regression model for Singing effort subjective parameter and $C80_{(250Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	3.349	.131	.984	25.484	.002
$C80_{(250Hz-1kHz)}$	.076	.010		7.928	.016

a. Dependent Variable: Singing effort

Table O. 7 Regression model for Singing effort subjective parameter and $C80_{(1kHz-2kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	3.097	.202	.976	15.357	.004
$C80_{(1kHz-2kHz)}$	.076	.012		6.312	.024

a. Dependent Variable: Singing effort

Table O. 8 Regression model for Singing effort subjective parameter and $C80_{(250Hz-500Hz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	3.478	.148	.975	23.507	.002
$C80_{(250Hz-500Hz)}$	.072	.012		6.258	.025

a. Dependent Variable: Singing effort

Table O. 9 Regression model for Singing effort subjective parameter and $C80_{(125Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	3.430	.161	.973	21.316	.002
$C80_{(125Hz-1kHz)}$	.072	.012		6.011	.027

a. Dependent Variable: Singing effort

Table O. 10 Regression model for Singing effort subjective parameter and $C80_{(2kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	3.047	.253	.965	12.045	.007
$C80_{(2kHz)}$	.073	.014		5.212	.035

a. Dependent Variable: Singing effort

Table O. 11 Regression model for Singing effort subjective parameter and $T30_{(4kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.491	.255	-.963	21.560	.002
$T30_{(4kHz)}$	-3.613	.720		-5.021	.037

a. Dependent Variable: Singing effort

Table O. 12 Regression model for Singing effort subjective parameter and $EDT_{(4kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.634	.316	-.953	17.804	.003
$EDT_{(4kHz)}$	-4.676	1.047		-4.464	.047

a. Dependent Variable: Singing effort

Table O. 13 Regression model for Singing effort subjective parameter and $EDT_{(1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.554	.309	-.950	17.947	.003
$EDT_{(1kHz)}$	-3.201	.741		-4.318	.050

a. Dependent Variable: Singing effort

Table O. 14 Predicted values of room parameters corresponding to the singers' preferred Singing effort rating: "as usual" (4)

Room parameters	**Regression Equation**	**Questionnaire**	**Room parameter**
		y	**x**
$C80_{(4kHz)}$	y = 0.055x + 3.2413	4	13.79
$C80_{(1kHz)}$	y = 0.079x + 3.1789	4	10.39
$C80_{(500Hz-1kHz)}$	y = 0.0747x + 3.2867	4	9.55
$C80_{(500Hz)}$	y = 0.0695x + 3.4113	4	8.47
$C80_{(mid)}$	y = 0.0744x + 3.1746	4	11.09
$C80_{(250Hz-1kHz)}$	y = 0.0758x + 3.3497	4	8.58
$C80_{(1kHz-2kHz)}$	y = 0.0756x + 3.0966	4	11.95
$C80_{(250Hz-500Hz)}$	y = 0.0725x + 3.4775	4	7.21
$C80_{(125Hz-1kHz)}$	y = 0.072x + 3.4303	4	7.91
$C80_{(2kHz)}$	y = 0.0732x + 3.047	4	13.02
$T30_{(4kHz)}$	y = -3.6127x + 5.4912	4	0.41
$EDT_{(4kHz)}$	y = -4.6759x + 5.6343	4	0.35
$EDT_{(1kHz)}$	y = -3.2011x + 5.5544	4	0.49

APPENDIX P

Regression Models for Overall Impression Subjective Parameter and Room Parameters that Show Correlation

Table P. 1 Regression model for Overall impression subjective parameter and $C80_{(2kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	6.057	.078	-.999	77.813	.000
$C80_{(2kHz)}$	-.135	.004		-31.163	.001

a. Dependent Variable: Overall Impression

Table P. 2 Regression model for Overall impression subjective parameter and $T30_{(4kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.556	.106	.998	14.657	.005
$T30_{(4kHz)}$	6.658	.300		22.196	.002

a. Dependent Variable: Overall Impression

Table P. 3 Regression model for Overall impression subjective parameter and $C80_{(1kHz-2kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.937	.122	-.997	48.604	.000
$C80_{(1kHz-2kHz)}$	-.137	.007		-18.930	.003

a. Dependent Variable: Overall Impression

Table P. 4 Regression model for Overall impression subjective parameter and $C80_{(low)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	4.986	.142	-.991	35.022	.001
$C80_{(low)}$	-.134	.013		-10.233	.009

a. Dependent Variable: Overall Impression

Table P. 5 Regression model for Overall impression subjective parameter and $EDT_{(500Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.605	.205	.992	7.849	.016
$EDT_{(500Hz-1kHz)}$	5.034	.446		11.291	.008

a. Dependent Variable: Overall Impression

Table P. 6 Regression model for Overall impression subjective parameter and $EDT_{(1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.428	.247	.990	5.790	.029
$EDT_{(1kHz)}$	5.929	.591		10.035	.010

a. Dependent Variable: Overall Impression

Table P. 7 Regression model for Overall impression subjective parameter and $C80_{(1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.738	.241	-.987	23.853	.002
$C80_{(1kHz)}$	-.140	.016		-8.830	.013

a. Dependent Variable: Overall Impression

Table P. 8 Regression model for Overall impression subjective parameter and $C80_{(500Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.544	.248	-.984	22.316	.002
$C80_{(500Hz-1kHz)}$	-.132	.017		-7.828	.016

a. Dependent Variable: Overall Impression

Table P. 9 Regression model for Overall impression subjective parameter and $C80_{(250Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.439	.245	-.983	22.238	.002
$C80_{(250Hz-1kHz)}$	-.135	.018		-7.560	.017

a. Dependent Variable: Overall Impression

Table P. 10 Regression model for Overall impression subjective parameter and $C80_{(mid)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.784	.156	-.995	37.048	.001
$C80_{(mid)}$	-.134	.010		-13.895	.005

a. Dependent Variable: Overall Impression

Table P. 11 Regression model for Overall impression subjective parameter and $C80_{(125Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.312	.235	-.982	22.604	.002
$C80_{(125Hz-1kHz)}$	-.129	.017		-7.382	.018

a. Dependent Variable: Overall Impression

Table P. 12 Regression model for Overall impression subjective parameter and $EDT_{(1kHz-2kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.550	.324	.982	4.777	.041
$EDT_{(1kHz-2kHz)}$	6.210	.854		7.268	.018

a. Dependent Variable: Overall Impression

Table P. 13 Regression model for Overall impression subjective parameter and $EDT_{(mid)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.567	.325	.981	4.825	.040
$EDT_{(mid)}$	5.578	.773		7.214	.019

a. Dependent Variable: Overall Impression

Table P. 14 Regression model for Overall impression subjective parameter and $C80_{(500Hz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.322	.262	-.978	20.311	.002
$C80_{(500Hz)}$	-.123	.018		-6.649	.022

a. Dependent Variable: Overall Impression

Table P. 15 Regression model for Overall impression subjective parameter and $T30_{(250Hz-1kHz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.820	.320	.978	5.685	.030
$T30_{(250Hz-1kHz)}$	3.466	.527		6.572	.022

a. Dependent Variable: Overall Impression

Table P. 16 Regression model for Overall impression subjective parameter and $T30_{(250Hz-500Hz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	1.894	.318	.976	5.960	.027
$T30_{(250Hz-500Hz)}$	2.942	.460		6.403	.024

a. Dependent Variable: Overall Impression

Table P. 17 Regression model for Overall impression subjective parameter and $C80_{(250Hz\text{-}500Hz)}$ room parameter

Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	5.213	.266	-.975	19.589	.003
$C80_{(250Hz\text{-}500Hz)}$	-.129	.021		-6.180	.025

a. Dependent Variable: Overall Impression

Table P. 18 Predicted values of room parameters corresponding to the singers' preferred Overall impression ratings: "good" (4) and "very good" (5)

Room parameters	Regression Equation	Questionnaire	Room	Questionnaire	Room
		y	x	y	x
$C80_{(2kHz)}$	y = -0.1346x + 6.0571	4	15.28 dB	5	7.85 dB
$T30_{(4kHz)}$	y = 6.6582x + 1.5562	4	0.37 sec	5	0.52 sec
$EDT_{(4kHz)}$	y = 8.6846x + 1.2732	4	0.31 sec	5	0.43 sec
$C80_{(1kHz\text{-}2kHz)}$	y = -0.1373x + 5.938	4	14.12 dB	5	6.83 dB
$C80_{(low)}$	y = -0.1337x + 4.9869	4	7.38 dB	5	-0.10 dB
$EDT_{(500Hz\text{-}1kHz)}$	y = 5.0344x + 1.6052	4	0.48 sec	5	0.67 sec
$EDT_{(1kHz)}$	y = 5.9289x + 1.4281	4	0.43 sec	5	0.60 sec
$C80_{(1kHz)}$	y = -0.14x + 5.7381	4	12.42 dB	5	5.27 dB
$C80_{(500Hz\text{-}1kHz)}$	y = -0.1321x + 5.5446	4	11.69 dB	5	4.12 dB
$C80_{(250Hz\text{-}1kHz)}$	y = -0.1346x + 5.439	4	10.69 dB	5	3.26 dB
$C80_{(mid)}$	y = -0.1344x + 5.7843	4	13.28 dB	5	5.84 dB
$C80_{(125Hz\text{-}1kHz)}$	y = -0.1291x + 5.3118	4	10.16 dB	5	2.42 dB
$EDT_{(1kHz\text{-}2kHz)}$	y = 6.21x + 1.5499	4	0.39 sec	5	0.56 sec
$EDT_{(mid)}$	y = 5.5783x + 1.5666	4	0.44 sec	5	0.62 sec
$C80_{(500Hz)}$	y = -0.1227x + 5.3219	4	10.77 dB	5	2.62 dB
$T30_{(250Hz\text{-}1kHz)}$	y = 3.4661x + 1.8203	4	0.63 sec	5	0.92 sec
$T30_{(250Hz\text{-}500Hz)}$	y = 2.9421x + 1.8944	4	0.72 sec	5	1.06 sec
$C80_{(250Hz\text{-}500Hz)}$	y = -0.1287x + 5.2134	4	9.43 dB	5	1.66 dB
$C80_{(4kHz)}$	y = -0.094x + 5.5637	4	16.64 dB	5	6.00 dB

APPENDIX Q

Voice Production

Voice is produced by the voice organ which consists of the lungs, the larynx, the pharynx, the nose, and the mouth [74]. The functions of these organs in voice production, can be grouped into three subsystems: air pressure system, vibratory system, the resonating and modifying system [75]. The subsystems that take part in sound generation of speech and singing voice is shown schematically in Figure P.3. [75]

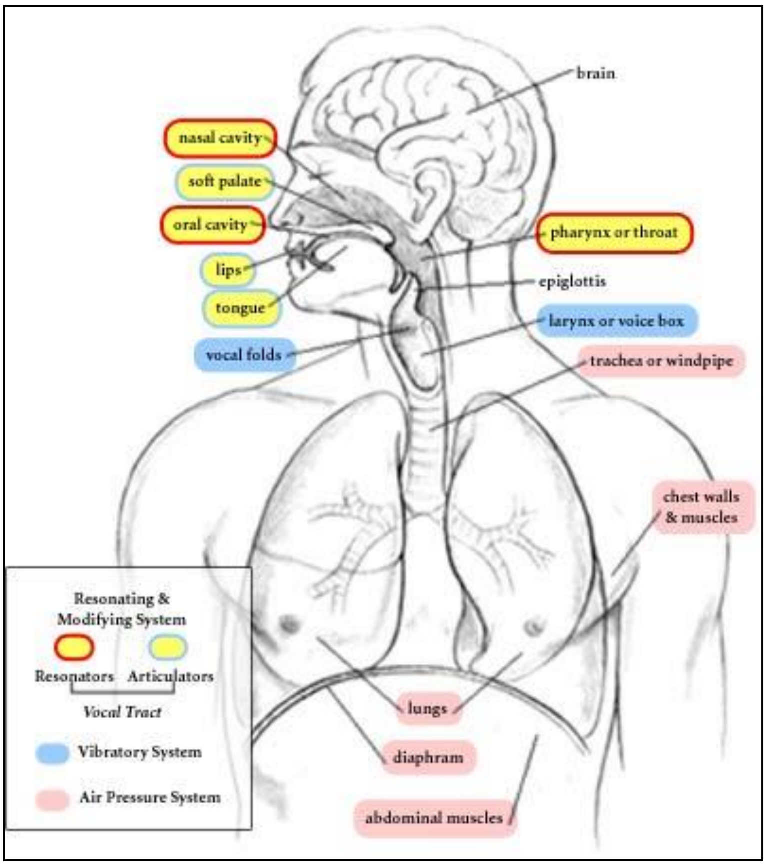

Figure P. 1. The Voice Subsystems [75]

The air pressure system consists of diaphragm, chest muscles, ribs, abdominal muscles, and lungs and the main function is to generate an adequate air pressure and an air flow. The vibratory system consists of the larynx (the voice box) and the vocal folds. This is where the pressure difference and the air flow generated by the lungs forces the vocal folds to open and close rapidly creating a vocal fold vibration. The process of opening and closing of the vocal folds is shown in Figure P.2. [76]

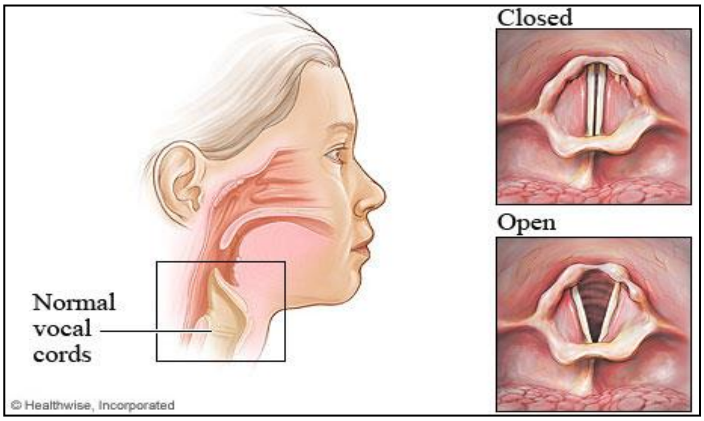

Figure P. 2. The process of opening and closing of the vocal folds [76]

The air pressure changes into audible sound waves when it meets with the oscillating vocal folds. The vibration pattern and the air flow between the vocal folds are shown in Figure P.3. [77] The audible sound waves which also can be described as the "voice source" are then changed into person's recognisable voice in the resonating and the modifying system by the resonators (throat (pharynx), mouth cavity, nasal passages) and by the articulators (tongue, soft palate and lips) located in the vocal tract [74, 75].

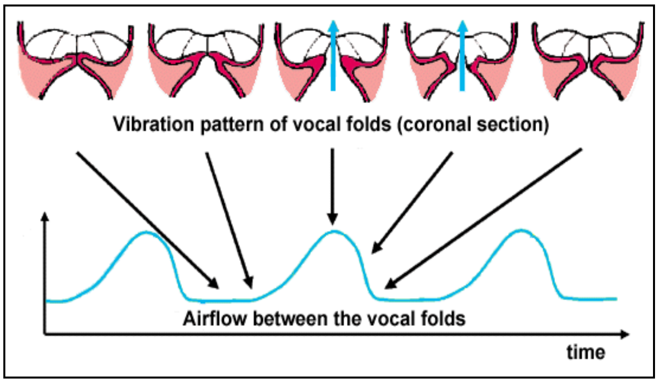

Figure P. 3. The vibration pattern of the vocal folds [77]