THE ACOUSTICS OF CHOIR REHEARSAL ROOMS

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Abstract
The study investigates choir rehearsal room physical and acoustical parameters. The reverberation time measurements (T30) were carried out in twenty choir rehearsal rooms. The measurements were provided according to ISO 3382-1:2009. Based on acquired T30 and room volume, the lower and upper limits of T30 and sound strength G were estimated (ISO 23591, 2021). Six out of 20 rehearsal rooms had T30 sufficient for requirements specified for quiet acoustic music. T30 and sound strength G values allowed us/me to model the optimal acoustical environment for choir rehearsals according to the number of singers and choir type.
Keywords: *choir, rehearsal rooms, reverberation time, sound strength G, choral acoustics*

Introduction

The study on choir room acoustics completes a series of articles written on the project *"An Investigation of Vocal Load in Choral Conductors in the Context of Voice Ergonomics"*. The first paper investigated voice ergonomic factors in choir conductors (Trinite, Blauzde, Paipare, Valce, Barute, Ivane & Sleze, 2021). In this research, data was obtained by surveying a representative sample of Latvian choir conductors. The second paper was written based on the interviews given by six choir conductors. Their answers reflected both individual and empirically approved approaches to singers' voice preservation in the voice ergonomic context (Valce, Blauzde, Paipare, Trinite, Barute, Sleze, Ivane & Kruza, 2022). In both research studies, whether in anonymous surveys or face-to-face interviews, the significance of room acoustics for choral singing became quite evident.

Research on the reverberation time measurements in rehearsal rooms is rare and the author of this research is not aware of any such research being conducted in Latvia. Although choir singing is one of the most frequent musical activities, studies about room acoustical influence on choir performances are rare. Moreover, there are few studies where the interaction between voice and room has been analyzed from the singers' perspective (Fischinger, Frieler & Louhivouri, 2015).

In 1637, the first ticket was sold for an opera performance in San Cassiano, Venice. This occasion changed the existing music culture in closed spaces. The opera house was open for everyone who could pay for a ticket. Previously, musician's and singer's performances were available only for a narrow circle of aristocrats – in kings' residences and houses of wealthy citizens, also held in the opera house, which was a favorite place of entertainment for rich people. Usually, music was performed in small rooms and for a small audience. When music became available to a broader audience, there was a necessity for larger halls. Consequently, instruments had to be played louder, and singers had to master other singing techniques appropriate for the bigger size of the performance rooms. At this historic crossroad, a singer's voice or musical composition performance was closely knitted together with the acoustic properties of space, i.e., unconsciously, the room's acoustics became an essential factor for performance quality.

Historical studies provide scholars with information that composers were acquainted with the acoustical features of the locations in which their music was performed. For instance, Renaissance polyphony was composed to avoid stylistically unsuitable dissonance that could occur due to long reverberation time in churches or cathedrals (Fischinger, Frieler & Louhivouri, 2015). In the late Renaissance and early Baroque periods, composers created compositions for several choirs (polyphonic school of Venice), where two or more choirs (It. *chori speccati*) performed Psalms singing in turns. The arrangement of choirs in different places allowed using spatial effects related to church acoustics (Jaunslaviete, 2021). Historical records tells us when W.A. Mozart, in writing a mass for the cathedral of Salzburg, envisaged not only a particular composition of the orchestra, but also the arrangement of musicians and singers (of soloists and choirs) at this cathedral. In *"The Technical Recommendations"* for the composition performance, the composer's father, Leopold Mozart indicated, which musicians should be in the cathedral's rear and which should stand at the altar, or on the balcony (Cassel, 1985).

Professor Sten Ternstrom of the Stockholm Music Acoustics Group introduced the term 'choir acoustics', which includes the acoustics of voice production, the acoustics of rooms, and psychoacoustic properties of the auditory system (Ternstrom, 1991). One of the parameters characterising the room acoustics is reverberation time (T). Reverberation time is defined as a measure of the time after the sound source ceases that it takes for the sound pressure level to reduce by 60 decibels (dB). The length of reverberation time depends on room volume, form, sound absorbing or reflecting properties of the surfaces, and how full the room is. Room reverberation time determines the sound of a composition. The choir's sound becomes unclear and muddy if the reverberation time is too long. However, too short reverberation time makes the sound 'dry', and the timbral nuances get lost (Rindel, 2014). As previously mentioned, reverberation time may impact the perception, transmission, and production of performance (voice). In this study, the author will focus on the interaction between reverberation time and voice production.

The changes in voice production, which take place in different acoustic environments with various reverberation times, have attracted the attention of several researchers

(Ternstrom, 1991; Fischinger, Frieler & Louhivouri, 2015; Bottalico, Lastowiecka, Glasner & Redman, 2022).

The purpose of this study is to investigate physical and acoustical parameters of choir rehearsal rooms.

Question of the study: *Do rehearsal rooms meet the acoustic requirements necessary for choir singing?*

Background

A. Reverberation time and merging of the singer's voice with the sounding of the choir

A steady, homogenous merging of voices characterises good choral singing. Not to stand out among others, choristers must constantly adjust their voices' loudness, pitch and timbre to those of other singers. This implies that choristers are supposed to hear their own (self) and other singers' voices simultaneously. Airborne and bone-conducted parts of the auditory system contribute to hearing the self-voice. The perception of other singers' voices is determined by the spacing between singers and the amount of reverberation in the room (Ternstrom, 2002). If the spacing between singers is larger, the voice of the singer next to you is less audible. In rooms with a long reverberation time, the loudness of other singers' voices suppresses your own voice, and to hear yourself, you sing louder. Such a way of singing involves the risk of voice overloading. Reverberation time can be corrected by extending the room's absorbing surface area (Ternstrom, 1991). For example, in singing within a hall the rehearsal may differ from singing at the concert because at concert, there are listeners in the hall who absorb the sound in the hall. For the choir sound at the concert to be the same as at the rehearsal, the reverberation time in the rehearsal rooms must be shorter than in concert halls of the same size (Rindel, 2014). Ternstrom (2002) maintains that the conductor can control the reference or choral sound by changing the spacing between singers and choosing a suitable room for rehearsals.

B. Reverberation time and choir rehearsals

A long reverberation time in the room promotes the merging of choir sounds, which makes it difficult to hear the contribution of each singer. This is why the conductors sometimes prefer rehearsal rooms which absorb sounds well because it makes hearing each singer's voice easier (Ternstrom, 1991). The same observation was heard from Latvian conductors during interviews. The conductors said that at rehearsals, they did not like to work in rooms with excellent acoustics because it is impossible to hear individual singer's voices (Valce, Blauzde, Paipare, Trinite, Barute, Sleze, Ivane & Kruza, 2022). Studies testify to the fact that singing in rooms absorbing sounds, choristers sing in higher voices (Ternstrom, 1991). The rise in the pitch of the voice is related to changes in the position of the larynx, e.i., the larynx is in a higher position and the vocal tract is shorter. Under such conditions, cervical muscles of a shoulder zone get additionally tensed. Singing long in acoustically inadequate rooms creates vocal effort.

C. Reverberation time and intonation, timing and rhythm of singing

Fischeringer, Frieler & Louhivouri (2015) had recorded voices of 23 mixed choir singers who performed the mass *Locus Iste* by Anton Bruckner (1824 – 1896) in three different acoustic environments. The aim of the research was to elucidate whether reverberation time makes impact on the intonation, timing and rhythm of singing. The research outcomes showed that it was the easiest for singers to sing in a room with 1.87 s long reverberation time. With regard to objective measurements, the research demonstrated that the tempo of singing increases slower in bigger rooms with a longer reverberation time. And on the contrary, reverberation time has almost no impact on the intonation of singing or expressiveness, which from an acoustic aspect is characterised as changes of a fundamental frequency (F_0). The increasing length of T did not make any impact on parameters of a vocal pitch (Fischinger, Frieler & Louhivouri, 2015). Similar results were obtained from research during which 18 conductors carried out vocal loading assignments in acoustically different spaces for choir rehearsals. Neither the size of rehearsal rooms nor the length of reverberation time impacted the vocal fundamental frequency as well as other acoustic parameters of the voice (*jitter, shimmer, CPPs, SD CPPs*) (Trinite, Barute, Blauzde, Ivane, Paipare, Sleze & Valce, 2022).

D. Interrelations between reverberation time, sound strength, volume and absorption

In this research concerning choir acoustics, attention should be paid not only to the reverberation time, but also to sound strength (G). Sound strength is a sound amplified by the space. The strength is the sound pressure level in the room relative to the sound pressure level in a free field in the distance 10m from the same source, which must be omni-directional (Rindel, 2014). For example, if the sound strength in the room is 0 dB, it implies that the sound strength created by the same sound source in a free field in 10 meters' distance from the source is the same as in the room, i.e., the specific room does not amplify the sound. If the sound strength is 20 dB, then in a free sound field, a sound of the same loudness will be heard in 1 meter's distance. Sound strength is related to room volume and reverberation time (ISO 23591, 2021).

Room volume and absorption coefficient are architectonic parameters of the room, but reverberation time and sound strength are acoustic parameters. The interaction between all four parameters determines the sound of the choir. Reverberation time influences the entire sound, while sound strength impacts the dynamics of the sound. If the sound strength is too large, the singing of the choir will be explicitly loud, but in case of a small strength, it will be too low. In turn, if reverberation time does not correspond to the physical parameters of the room, the sounding will be unclear or dry. As Rindel (2022) states, to find balance between reverberation time and sound strength in order to counterbalance sounding and dynamics of singing is a big challenge. In small rooms with a lasting reverberation, the sound is explicitly strong and may become unpleasant. In big rooms with a short reverberation time, choir sounding is too faint (Rindel, 2022). In both cases, singers will attempt to adapt themselves to the existing room conditions by singing softer or louder. However, it is possible to try to affect the quality of the choir sound by influencing the acoustic properties of the room. For example, by extending the area of absorbing surfaces by drawing curtains or blinds, and thus reducing reverberation time of the room in this way. In rooms with a larger volume and longer reverberation time, the sound strength is smaller.

E. Acoustic requirements for choir rehearsal rooms

Both soloists and choristers routinely adjust their vocal techniques and loudness of singing to differing acoustic environments to become acclimated to variations, and if need be, adjust their performance to their physical environment (Ternstrom, 1991; Bottalico, Lastowiecka, Glasner & Redman, 2022). Taking into consideration the significance of room acoustics for voice sounding, and the fact that such an acoustic parameter as the length of reverberation time may change if the area of absorbing surfaces is increased, it must be understood that the conditions between a rehearsal and a concert are quite different. Therefore, in working with choirs, rehearsal rooms should differ from performance avenues. For example, rehearsal rooms are smaller in size than concert halls and sometimes there are fewer musicians or singers in them (some vocal or instrumental groups) (Rindel, 2022).

In 2021, the ISO standard 23591 was published and it extensively outlined the physical and acoustic parameters of rooms used for music rehearsals. The previous standard was known as the Norway standard NS 8178 (2014), which was devised to improve the unsatisfactory acoustics of rehearsal rooms for learning music, and holding rehearsals of amateur groups (Rindel, 2014). The Norway standard emphasized that an artistic performance can be qualitatively achieved if the room acoustics is adequate for the performed music, type of ensemble, and size of the room. In turn, ISO 23591 (2021), refers to rehearsal rooms that differ according to their role. That is, what kind of music will be performed in them, their size and the correlating number of singers. This necessitates that room parameters must correspond to the music performed in them. For instance, when special requirements are used for rehearsal rooms where the performed music needs electro-acoustic tuning, or for rehearsal rooms that utilize instrumental music ensembles and symphonic orchestras. Further still is when choirs, vocal ensembles, and string ensembles perform quiet music, and hence, the requirements for rehearsal rooms need of these groups are different.

General requirements imposed on choir rehearsal rooms demand that their size must comply with the number of singers, and they must have a definitive ceiling height and the reverberation time must correspond to the size of the room. Sound reflection and dispersion must be controlled, and the level of background noises must be low. For the rehearsals of small groups or voice groups in choirs, small rooms are characterised by the following parameters: height of ceiling (h) ≥ 3.5 m and volume (V) up to 300 m, are sufficient. Rooms of average size are good for 13 – 30 singers (h > 4.5 m, V = 300 – 750 m). Large rooms are necessary for choirs consisting of more than 30 singers (up to 80 – 100) (h > 5 m, V = 750 m) (ISO 23591, 2021).

Research Methods

To carry out measurements, 20 rooms, where the choir rehearsals are held, were selected in Liepaja and in Liepaja region. In these rooms, measurements were made, and their volume was calculated, and acoustic measurements were carried out by professional acousticians. Reverberation time (T30) was measured in empty rooms using omnidirectional dodecahedron loudspeaker GSR as a sound source. Reverberation measurements were carried out in compliance with ISO standard 3382-1, 2009. A sound source was denoted as a 'pink' noise in the range of frequencies from 88 to 5657 hertz (Hz). The mean reverberation time was calculated in 500 and 1000 Hz frequency. Depending on the size, there were two or three locations of a sound source (S) and microphone (M) determined in the room: S1M1, S1M2, S1M3; S2M1, S2M2, S2M3; S3M1, S3M3. The location of a sound source and microphone corresponded to the location of the conductor and choristers during the rehearsal. Reverberation time was measured with a handheld acoustic analyser XL 2 (NTi AUDIO) and microphone M4261 (Class2/Type 2, sensitivity 15.2 mV/Pa).

The upper and lower limits of reverberation time T30 for rehearsal rooms were obtained through calculation (ISO 23591: 2021) by applying the formula:

$$T_{0.5\text{-}1kHz} = a \times \lg(V) - b \text{ (s)} \quad (1),$$

where V is a room volume; *a* is the constant of the lower limit of reverberation time for rooms where quiet acoustic music is performed; *b* is the constant of the upper limit of reverberation time where quiet acoustic music is performed. In rooms with the volume up to 3000 m^3 a = 0.55, b = 0.45. In rooms with the volume over 3000 m^3 a = 0.75, b = 0.65.

Sound strength (G) was obtained by calculations (Rindel, 2014, 2022), using the formula:

$$G = 31 + 10 \lg \left(\frac{4(1-\alpha_m)}{\alpha_m S}\right) \text{ (dB)} \quad (2),$$

where S is a mean area of room surfaces, α_m is a mean factor of sound absorption which characterises the factor describing the acoustic absorbing efficiency of a material (NS 8178).

The mean area of room surfaces was estimated by using the known room volume (Rindel, 2014, 2022):

$$S = 7.36 * \left(\frac{V}{1.28}\right)^{2/3} \text{ (m}^2\text{)} \quad (3).$$

The mean factor of sound absorption was estimated (Rindel, 2014, 2022):

$$\alpha_m = \frac{0.161 * V}{T * S} \quad (4).$$

Results

The acoustic measurements were carried out in ten small rooms (> 300m^3): one room of average size and in nine large rehearsal rooms (> 700 m^3). The characterisation of rehearsal rooms is given in Tables 1 and 2.

There were seven halls with stages. The area of the stage in one hall (No 20) was larger than 70 m^2. The small and average size rooms were predominantly classrooms, but there were larger rooms that had stages or platforms. Walls were decorated mainly with painted plaster, but the floors were primarily parquet in nature. The ceilings were also mostly painted plaster (n = 11), and the drop ceilings (n = 8). Only one room was completely empty with no furniture (No 6). In the remaining rooms there was sufficient furniture functional for the purposes of the room (chairs and benches for listeners), and in all of the rooms there were pianos.

Table 1. Characterisation of choir rehearsal rooms

Room No	Stage	Walls	Floor	Ceiling	Other
1	No	Wallpaper, one window with blinds	Parquet	Plaster	A classroom. There are a lot of books, notes, concert costumes in the room
2	No	Painted plaster, windows with blinds along one wall	Linoleum	Drop ceiling	Painting studio and music classroom. There are materials for painting (paper, easels, exposition vessels) in the room
3	No	Painted plaster, windows along one wall, a thin curtain, wooden door	Painted boards	Concrete	Music classroom. There are desks, chairs, musical instruments in the room
4	No	Painted plaster, windows along one wall, roller blinds, wooden door	Parquet	Drop ceiling, painted plaster	A meeting-room. A big wooden table in the middle, round it – chairs upholstered with leatherette
5	No	Painted plaster, windows along one wall, drawn roller blinds	Laminate	Drop ceiling	A classroom. There are wooden desks and chairs in the room, and built-in closets at the end wall
6	Is, without a curtain, height 0.6 m	Painted plaster, windows along one wall	Linoleum	Painted plaster	Music school hall. There is no furniture in the room
7	No	Painted plaster, windows along one wall, thin curtains	Parquet	Painted plaster	Choir rehearsal room. There are wooden closets, upholstered chairs in the room
8	No	Wallpaper, windows along one wall, fabric blinds	Linoleum	Painted plaster	A classroom. There are desks and chairs with soft upholstering in the room
9	No	Painted plaster, windows along one wall, fabric blinds, a textile décor at the back wall	Painted boards	Painted plaster	A classroom. Desks in the room are arranged on steps
10	Is, without a curtain, height 0.7 m	Painted plaster, windows along the side wall and wall opposite the stage covered with blinds, wooden door	Painted boards	Drop ceiling, painted plaster	A primary school hall. There are wooden tables and chairs with a soft upholstering in the room
11	No	Painted plaster, windows along one wall, with both fabric roller blinds and thin curtains. Wooden door	Parquet	Drop ceiling, painted plaster	A culture house hall. Upholstered metal chairs along the walls of the hall.

Room No	Stage	Walls	Floor	Ceiling	Other
12	No	Painted plaster, decorative fabric elements at one wall, windows along two walls, light curtains	Parquet	Painted plaster	A culture house hall. Two columns in the middle of the hall
13	Is, curtain, wings, thin fabric hangings along the back wall, the height 0.4m	Painted plaster, windows along one wall, covered with light curtains	Parquet	Painted ceiling with decorative wooden beams	A music school hall. A grand piano covered with a thick cloth in the middle of the stage
14	Platforms at the sides of the hall, no curtain	Painted plaster, sound muffling panels, opposite the stage big windows with blinds, glass doors at both ends	Parquet	Drop ceiling	A secondary school hall. There are desks and chairs in the room
15	No	Painted plaster, windows with thin curtains along two walls	Parquet	Drop ceiling painted plaster	A culture house hall. Three columns in the middle of the room
16	Is, curtain, the stage partly covered up with a screen. Stage height 0.9m	Painted plaster, windows along two walls, windows are partly covered with roller blinds and thin curtains	Laminate	Drop ceiling	A secondary school hall. Rows of sot chairs along the walls
17	Is, without a curtain	Painted plaster, big windows along two walls, without curtains	Parquet	Painted, slightly bent ceiling with decorative elements, several big chandeliers	A university hall. Soft chairs
18	Is, a curtain, stage height 1m	Plastered walls, plaster panels at a height of 2.57 m from the floor. Windows along two walls of a hall	Parquet	Painted plaster with decorative beams	A secondary school hall. A balcony opposite the stage
19	is	Painted plaster walls, big windows behind the stage and along one wall of the hall, a big wooden closed door opposite the stage which connects the hall with another room. Big paintings on the walls.	Parquet	Painted plaster with decorative elements, chandeliers	A secondary school hall. A balcony opposite the stage
20	Is, with a curtain, stage height 1m	Painted plaster, big windows along one wall, partly covered with blinds	Parquet	Wooden, with decorative elements, big chandeliers	A culture house hall. There are upholstered chairs in the room

Table 2 shows measurement data (*h*, V, T30), which are supplemented with data obtained by calculations (S, a_m. G). The data obtained in calculations comply with the criteria established by the ISO standard for choir rehearsal rooms with regard to the duration of reverberation time and sound strength (G).

Table 2. Choir rehearsal room height (h), volume (V), average reverberation time (T30), field of surfaces (S), average sound absorption factor (a_m), room strength (G) and upper and lower limits of reverberation time established by the standard ISO 23591 (2021)

Room No	*h* (m)	*V* (m^3)	$T30_{0.5\text{-}1kHz}$ (s)	*T30 (ISO 23591:2021)* (s)		*S* (m^2)	α_m	*G* (dB)
				Lower limit	*Upper limt*			
1.	3.5	70	0.53	0.56	0.73	106	0,20	23
2.	2.6	112	0.59	0.68	0.89	145	0,21	21
3.	3.0	127	0.8	0.71	0.93	158	0,16	22
4.	3.5	129	0.9	0.71	0.93	159	0,14	23
5.	2.8	158	0.44	0.76	1.00	182	0,32	17
6.	2.8	188	1.76	0.80	1.06	205	0,08	24
7.	3.4	189	0.84	0.80	1.06	206	0,18	21
8.	3.4	200	1.11	0.82	1.08	214	0,14	22
9.	3.9	214	1.53	0.83	1.10	223	0,10	23
10.	3.5	251	1.13	0.87	1.15	248	0,14	21
11.	3.4	437	1.66	1.00	1.33	360	0,12	20
Room No	*h* (m)	*V* (m^3)	$T30_{0.5\text{-}1kHz}$ (s)	*T30 (ISO 23591:2021)* (s)		*S* (m^2)	α_m	*G* (dB)
				Lower limit	*Upper limt*			
12.	3.9	742	1.88	1.13	1.50	512	0,12	18
13.	4.5	790	1.67	1.14	1.52	534	0,14	18
14.	5.2	1021	1.02	1.20	1.61	633	0,25	14
15.	3.7	1091	2.04	1.22	1.63	662	0,13	17
16.	4.7	1181	0.86	1.24	1.65	698	0,32	12
17.	5.3	1389	1.57	1.28	1.71	777	0,18	15
18.	6.6	1778	2.48	1.34	1.79	916	0,13	16
19.	8.2	2138	3.25	1.38	1.85	1036	0,10	16
20.	7.5	3299	1.96	1.61	2.19	1384	0,20	12

The average height of ceiling in the small rooms was 3.2 m (SD 0.4 m, range 2.6–3.9 m), in rooms of an average size – 3.4 m, in big rooms – 5.5 m (SD 1.6 m, range 3.7–8.2 m). The average room volume in the small rooms was 164 m^3 (SD 55 m^3, range 70–251 m^3), in the rooms of average size – 437 m^3 and in large halls – 1492 m^3 (SD 815 m^3, range 742–3299 m^3). The average reverberation time in small rooms was 0.96 s (SD 0.43 s), in rooms of average size – 1.66 s and in larger ones – 1.86 s (SD 0.72 s).

The upper and lower limits of room reverberation time were obtained by calculations. One rehearsal room (No 20) satisfied the criteria for concert halls established by ISO 23591 (2021). Therefore, the upper and lower limits of reverberation time for this room were calculated by using other coefficients. The average reverberation time $T30_{0.5\text{-}1\,kHz}$ of six rooms (No 3, 4, 7, 10, 17, 20) complied with the limits established by ISO standard 23591 (2021).

The average area of room surfaces and sound absorption were obtained by calculations, and then were used to estimate the strength of sound amplification of the room. The average area of surfaces increased with the increase in room volume and, respectively, in small rooms it was 185 m^2 but in larger ones 794 m^2. The coefficients of sound absorption in small and larger rooms were similar – 0.17 and 0.18, respectively. Smaller rooms amplified the sound stronger than the larger ones, 22 dB and 15 dB, respectively.

Discussion and Conclusions

This research characterises acoustic properties of choir rehearsal rooms in one city and region. Though the measurements were not carried out in all rooms where the rehearsals took place, the sample of rooms are sufficient to represent the locations normally allotted for choir rehearsals. This sampling is representative not only for previously described city and region, but also for Latvia in general because places chosen for choir rehearsals are the same over the country – halls and music classrooms of education institutions, as well as bigger and smaller halls of houses of culture. In some individualized cases such as room No. 2 that was used as an example, the choir rehearsal rooms were shared with other interconnected educational activities.

Within the framework of this research, the physical parameters and reverberation time of rooms were measured, while the rest of the data examined sound strength, area of surfaces, coefficients, and the matter of absorption obtained by calculations. It is essential to emphasise that sound strength (G) obtained in calculations complied with G values established in ISO standard 23591 (2021_ with regard to room volume and reverberation time.

Usually, a choir or ensemble chooses rehearsal rooms according to the number of singers it is comprised of. Larger choirs rehearse in bigger rooms and smaller choirs, or voice groups hold their rehearsals in a smaller space. More than likely, for the conductors the height of ceiling does not serve as an important criterion in selecting rooms. Our research indicated that the height of ceiling in the rehearsal rooms under study did not correspond to the height indicated in the [ISO] standard. Thus, in small rooms, the height of the ceiling must be above 3.5 meters. However, only four rehearsal rooms (No 1, 4, 9, 10) satisfied this criterion. Similarly, in larger rehearsal rooms, only in 5 out of 9 rehearsal rooms the height of the ceiling reached the height established in the standard (≥ 5 m).

Our research shows that halls or rooms, where the height of ceiling is sufficient, are situated in buildings that were built during the pre-war or post-war period of WWII. It should be mentioned that rooms No 7 and 11 are also located at the Liepaja Latvian Society building that was built in 1934. However, it is surmised that the architect of this building did not plan to have choir rehearsals in them. This observation leads us to the conclusion that many other rehearsal rooms have not been selected by purposely taking into consideration the specific requirements of choir rehearsals, but have been used and adjusted to the needs of choirs. The height of rehearsal room ceiling influences sound quality, a balanced coloratura, by reflecting from the surface (Rindel, 2014).

Knowing the acoustical parameters of rooms, we may try to model different situations for choirs of different compositions. For instance, we will want to find out how large, and with what reverberation time rehearsal room will be necessary for a women's choir with 32 singers (sopranos and altos), so that the loudness of singing at singing *forte* would be with 85–90 dB intensity. The sound in this space should be neither too diffused nor dry (this is determined by the optimal reverberation time), and the singing should be neither too loud nor too quiet (this is determined by the amplification of room or sound strength). According to Rindel (2022), choir singing will be the best under conditions where reverberation time is in balance with sound amplification of the room.

To meet these requirements, it is necessary to know the loudness of the specific women's choir sounding or sound power level (L_w) at singing *forte.* L_w characterises the sound strength produced by the choir, taking into consideration the environmental factors. For this purpose, the applied formula (Rindel, 2014) will be:

$$L_w(f) = 90 + 10 \log \# n_s k_s + n_a k_a \text{ (dB)} \qquad (5),$$

where n_s is the number of sopranos (n = 16), n_a is the number of altos, k_s is the sound power level for sopranos (constant value 5.0), k_a is the strength factor for altos (2.0) (ISO 23591, 2021).

The calculations show that the sound produced by a choir singing loudly corresponds to 110 dB. Further, it is necessary to elucidate what conditions, and which hall are the best for this choir to have their rehearsals so that its sound would correspond to 85–90 dB of intensity – diapason. If the limits of sound pressure level (L_p) and L_w value are known, the necessary sound amplification of the room can be calculated by applying the formula (Rindel, 2014):

$$L_p (f) = L_w (f) + G - 31 \text{ (dB)} \qquad (6).$$

The final result of this research shows that in singing loudly, this women's choir will reach the sound pressure level of 85–90 dB, if they have rehearsals in halls where the sound is amplified within the limits of 6 to 11 dB. Such optimal dynamic sounds can be achieved by choosing rooms for rehearsals which are no smaller than 3000 m^3 and have at least 2 s long reverberation time. Of all the halls included in our research, the most adequate for this choir would be hall No 20 whose size is 3299 m^3 and T30 – 1.96 s. Singing in this hall, the choir sounding at singing *forte* would be close to 90 dB. Singing in larger halls, sound pressure level perceived by the listeners would reduce to 85 dB.

If the above choir rehearsed in hall No 17, whose volume is 1389 m^3, T30 is 1.57 m and sound strength is 15 dB, the sound pressure level L_p (f) produced by the choir would be 95 dB. If the sound level at singing *forte* is higher than 90 dB, this implies that at singing *fortissimo,* the sound level will reach beyond 100 dB, which might involve risks of auditory impairments. The dynamic range of choir singing (from *pp* to *ff*), the sound level at singing *fortissimo* including, depends on chorister's professional preparedness, the number of singers and room acoustics (Ternstrom, 1991). One of the ways how to reduce loudness of singing in hall No 17 might be the enlargement of the area of absorbing surfaces, thereby decreasing reverberation time and sound strength G (Rindel, 2014). However, the duration of reverberation time should not be shorter than the lowest limit indicated in standard ISO 23591 (2021), since this study concludes that if a singer sings in space with an explicit absorption, the position of the larynx and technique of singing changes, which might cause damage to the singer's vocal health (Ternstrom, 1991). If the conductor chooses to reduce the number of singers in the choir, this would not produce essential changes in the joint sounding of the choir, since a double reduction of the number of singers will decrease the sound level only by 3 dB (Ternstorm, 1991). The third variant is to improve choristers' ability to manage the loudness of their voices by using various vocal techniques. In this case as to avoid strenuous vocal efforts, ergonomics of voice should be taken into consideration.

In conclusion, the author of this study wants to emphasise that space is an essential factor where the sound created by the choir lives and meets its listeners. The life of the song performed is short. It lives until the last note, until the singer's voice dies away, and it disappears with the last vibration in space. What remains is elusive sensations and emotional experience left upon the listeners by the compositions, which later transform into memories about what has been heard. Space with its acoustic properties, is a song's way to a listener. Hence, conductors should pay attention not only to the choice of compositions and the professional preparedness of singers, but also to the essential, and crucial, factor of the choice of adequate rehearsal and concert rooms, the arrangement of choristers in the room, and length of reverberation time.

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