On the importance of sound strength in music rehearsal rooms

Jens Holger Rindel[1]

[1] *Odeon A/S, DK-2800 Kgs. Lyngby, E-mail: jhr@odeon.dk*

Introduction

The standard ISO 23591 [1] on the acoustics of music rehearsal rooms was published in 2021. It gives upper and lower limits for the reverberation time as function of volume and type of music. The standard also contains an annex in which a method is outlined for estimating the sound pressure level (SPL) in the room. If the sound powers of the sources are known, the connection between SPL and sound power is the sound strength of the room G as defined in ISO 3382-1 [2]. Music rehearsal rooms deviate from concert halls in several ways. Since there is no need for an audience, the volume is normally significantly smaller. The number of musicians playing in the room can be the same as in the concert hall in case of an orchestra rehearsal room, but often the room is meant for considerably fewer musicians, and the smallest case is a practice room for a single musician. The volume of a room is one of the most important parameters for the acoustics. When the volume is reduced, it is necessary to find a balance between increase of SPL and decrease of reverberation time.

Loudness of music in a room

Although W.C. Sabine is best known for the introduction of reverberation time around 1900, he also pointed at loudness as very important for the quality of a music room [3, p. 68]. Later, Nagata [4], Wu *et al.* [5], and many others have found that loudness is one of the most essential parameters for a hall, be it large or small.

Musical instruments have a wide dynamic range and for an orchestra the difference between pianissimo (*pp*) and fortissimo (*ff*) may exceed 40 dB. Thus, it has become a generally accepted practice to consider the mean forte (*f*) sound pressure level of *tutti* sound as the criterion for the loudness, as first applied by Meyer [6]. He suggested that the optimum SPL at forte should be 90 dB. Other researchers have found that the level should be within a range of 85 to 91 dB [5]. A basis for ISO 23591 [1] has been that the SPL at forte should preferably be between 85 and 90 dB. However, for ensembles with only loud instruments (music bands) this may not be realistic, and one can expect levels up to 97 dB for realistic room sizes of rehearsal rooms.

The sound power level at *forte* for musical instruments

The sound power from musical instruments has been studied in detail by Meyer [7, 8] and Burghauser & Spelda [9]. Measured data are obtained for musical instruments playing at *ff* and *pp*. To handle the difficulties related to the various ways of playing and the great dynamic range, four equal steps from *pp* to *ff* are assumed, and thus the sound power level at forte is calculated:

$$L_W(f) = L_W(ff) - \frac{D}{4} \ \text{(dB)} \tag{1}$$

where $L_W(ff)$ is the sound power level at fortissimo and D is the dynamic range, *i.e.* the level difference between *ff* and *pp*.

The total sound power level for a number n_i of instruments playing *tutti* at forte is then estimated from:

$$L_W = 90 + 10 \log \sum_i n_i P_i \ \text{(dB)} \tag{2}$$

where P_i is the sound power in mW of instrument type i.

Burghauser & Spelda [9] have published detailed data of sound emission for the most common instruments in the classical symphony orchestra, measured in the 1960'ies in Czechoslovakia. Their data were also applied by Meyer [8]. To ISO 23591, the list of instruments has been extended to 39 instruments, including examples of singers [1, Table A.1].

The room acoustic parameter sound strength *G*

The sound strength was first suggested as a room acoustic parameter by Lehman [11]. It is defined in ISO 3382-1 [2, eq. (A.7)] as the SPL in the room relative to the SPL in a free field in the distance r_0 = 10 m from the same source, which must be omni-directional.

The sound pressure level in a room can be calculated under the usual assumptions of a combined direct and reverberant sound field, see *e.g.*, Maekawa *et al.* [10, eq. (3.43)]:

$$L_p = L_W + 10 \lg\left(\frac{1}{4\,\pi\, r^2} + \frac{4(1-\alpha_m)}{\alpha_m S}\right) \ \text{(dB)} \tag{3}$$

where L_W is the sound power level of an omidirectional sound source, S is the total surface area (in m^2) and α_m is the mean absorption coefficient of all surfaces in the room. The influence of the direct sound is negligible when the distance r from the source is sufficiently large. The sound strength of the reverberant field (without direct sound) is estimated from:

$$G = 10 \lg\left(\frac{4(1-\alpha_m)}{\alpha_m S}\right) - 10 \lg\left(\frac{1}{4\pi\, r_0^2}\right)$$
$$\cong 31 + 10 \lg\left(\frac{4(1-\alpha_m)}{\alpha_m S}\right) \ \text{(dB)} \tag{4}$$

The surface area of the room is normally not known, but it can be estimated from the volume with sufficient accuracy. For this purpose, the room is assumed to be of box shape with the ratio between length, width and height (1.6 : 1 : 0.8). If V is the volume, the surface area is

$$S = 7.36 \cdot \left(\frac{V}{1.28}\right)^{2/3} \cong 6.243161 \cdot (V)^{2/3} \ (\text{m}^2) \tag{5}$$

and the mean absorption coefficient is calculated from:

$$\alpha_m = \frac{0.161 \cdot V}{T \cdot S} \cong \frac{0.0258}{T} \cdot \sqrt[3]{V} \tag{6}$$

where T is the reverberation time and V is the volume (m^3).

Evaluation of the sound strength

To understand the meaning of various *G*-values, it is useful to compare with the loudness in a free field (outdoors). If a room has the sound strength 0 dB it means that the sound from a single source (*e.g.*, a trumpet) has the same loudness as in the distance of 10 m outdoors. This might be OK for a loud instrument like the trumpet, but for a quiet instrument the sound may bee too weak. If a room has the sound strength 20 dB it means that the loudness is like that only 1 m from the source, see Table 1. The sound strength 25 dB corresponds to the distance 0.6 m in a free field, and this may be too loud for comfortable listening to a musical instrument.

In a room with the sound strength *G*, the SPL at forte can be estimated using the number n_i of instruments of type *i* and the sound power P_i (in mW) for the instruments by the equation:

$$L_p = G + 59 + 10\log \sum_i n_i P_i \quad \text{(dB)} \qquad (7)$$

Some examples are shown in Table 1. A classical symphony orchestra with 77 musicians can be expected to generate a sound power at forte around 272 mW using the instrument data from [1, Table A1]. It is seen that a hall with *G* around 5 dB will provide a SPL at forte around 88 dB, which is in the middle of the optimum range as discussed above.

A wind quintet (flute, oboe, clarinet, horn, bassoon) can be expected to generate a sound power at forte around 23 mW, and a hall with *G* around 15 dB should be ideal. Finally, a string quartet generates 3.1 mW at forte, and a small room with *G* around 20 – 25 dB will give optimum loudness.

Table 1: The relation between *G* and the free-field distance *d* with same SPL. Three examples of ensembles and SPL at forte as function of *G*.

		Symphony orchestra (77)	Wind quintet (5)	String quartet (4)
Sound power at forte (mW)		272	23	3.1
G (dB)	*d* (m)	L_p (dB)	L_p (dB)	L_p (dB)
0	10,0	83	73	64
5	5,6	88	78	69
10	3,2	93	83	74
15	1,8	98	88	79
20	1,0	103	93	84
25	0,6	108	98	89
30	0,3	113	103	94

The *G* – *T* space

While the important parameters in the **architectural space** of a hall could be said to be volume and materials represented by absorption coefficients, the **acoustical space** expands between sound strength and reverberation time. These two spaces are inter-related as shown in the diagram Figure 1, first suggested by Nijs & de Vries [12]. They mention (with reference to Leo Beranek) that the ideal European concert hall for a symphony orchestra should have a reverberation time between 2.0 and 2.3 s, and the sound strength should be between 4.0 and 5.5 dB. This is shown as a blue area in Figure 1, and it is seen to agree with a volume around 20 000 m³ and mean absorption coefficient around 0.3. It is remarkable that the optimum range is so narrow, only 1.5 dB in *G*.

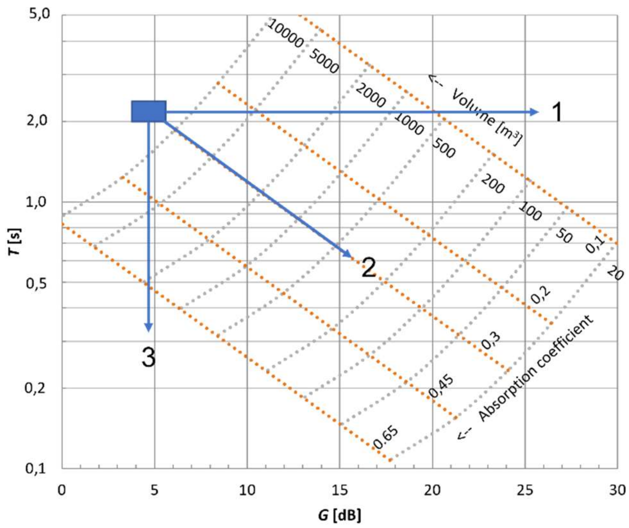

Figure 1: The *G* – *T* space and three principles for reducing the volume of a hall. The blue area marks Beranek's ideal for a European concert hall.

Figure 1 shows three different principles for how to reduce the volume of a hall. Option one is to stick to the optimum reverberation of the concert hall, which means that the materials must have much lower absorption coefficients. A volume of 500 m³ would require mean absorption coefficient around 0.10 and the sound strength will be around 20 dB. The room would appear as very reverberant and too loud for most kinds of music.

Option two is to keep the materials with same mean absorption coefficient. Then a 500 m³ room would get a reverberation time of 0.7 s and the sound strength will be around 15 dB. This room will be quite loud, but also very dry; too dry for singing and many musical instruments.

The third option is to keep the sound strength around 5 dB in a hall with reduced volume. The materials must be changed to much higher absorption coefficient and the reverberation time would be around 0.3 s in a 500 m³ room. Obviously, this is not a usable solution for a music rehearsal room.

How to balance reverberation time versus sound strength

In ISO 23591 the solution to the problem is none of the three options discussed above. Instead, the solution is to have the rehearsal rooms as reverberant as possible without excessive loudness. In the smallest rooms (50 m³ or less), *G* should not exceed a value around 25 dB (26 dB for quiet music). It was found that a good compromise could be achieved, using a relationship between volume and reverberation time of this form, as suggested by Valk *et al.* [13]:

$$T = a \cdot \lg(V) - b \quad \text{(s)} \qquad (9)$$

The constants *a* and *b* have been selected for the minimum and maximum reverberation time for each of the three groups, quiet, loud, and amplified music. The details and values of the constants are found in [1, Table 5].

ISO 23591 distinguishes between rehearsal rooms and recital rooms used for rehearsal up to a size of 6 500 m³. Recital rooms have areas for an audience and in general the volume is larger than in a dedicated rehearsal room. The reverberation times in such halls are referring to the empty state (without audience), and consequently the reverberation time should be longer in recital rooms than in rehearsal rooms.

Figure 2 shows the upper and lower limits of reverberation time in recital rooms used for rehearsal for three types of music. Whereas there is an overlap between the limits for quiet music and loud music, the curves for amplified music indicate much shorter reverberation times.

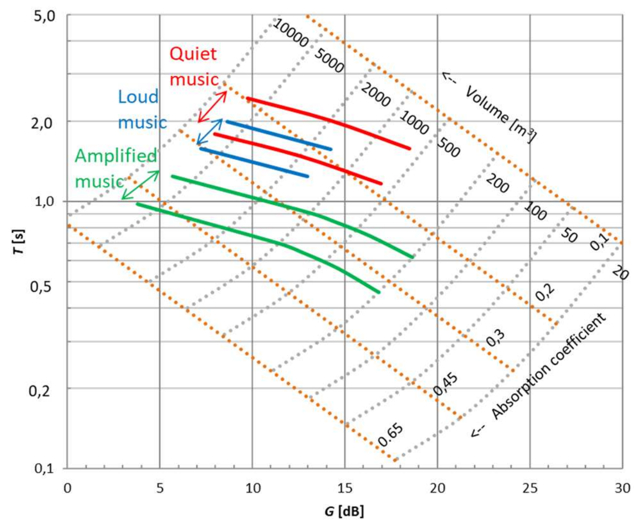

Figure 2: The $G - T$ space and upper and lower limits of the mid-frequency reverberation time in recital rooms as function of volume. The three categories of music are quiet, loud, and amplified music.

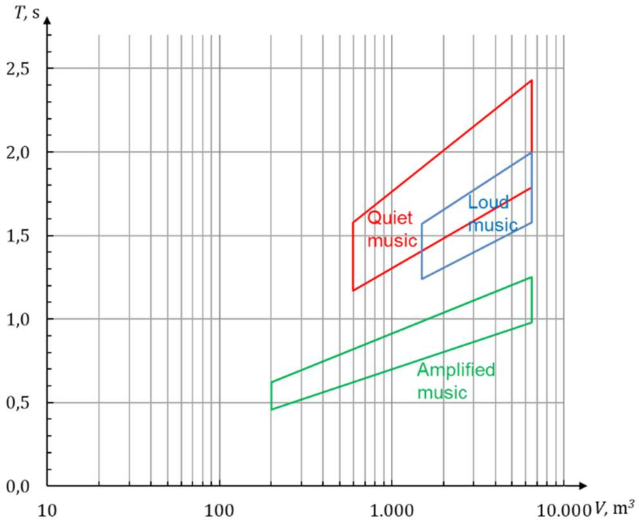

Figure 3: The upper and lower limits of the mid-frequency reverberation time in recital rooms as function of volume. The three categories of music are quiet, loud, and amplified music.

For recital rooms, smaller volumes lead to increased sound strength and slightly decreased reverberation times. The curves follow a course which is a balance between options 1 and 2 in Figure 1. The same curves as in Figure 2 are displayed in Figure 3, but in the V-T space, which makes it clear that the curves follow Eq. (9).

Figure 4 and 5 show the upper and lower limits of reverberation time in dedicated rehearsal rooms (without space for an audience). For quiet music and loud music, the reverberation times are shorter than in recital rooms.

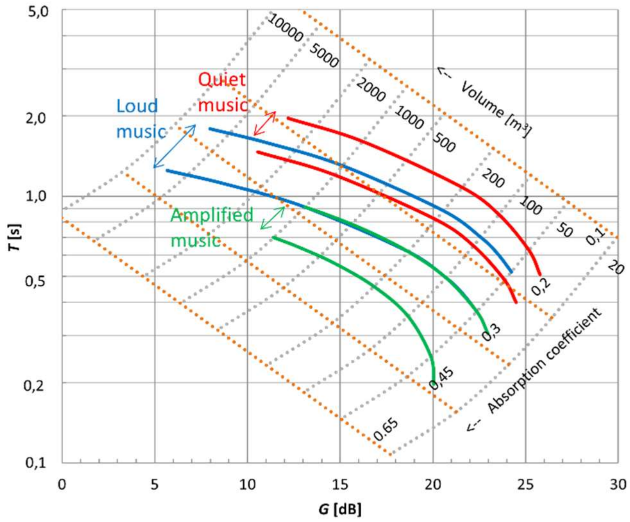

Figure 4: The $G - T$ space and upper and lower limits of the mid-frequency reverberation time in rehearsal rooms as function of volume. The three categories of music are quiet, loud, and amplified music.

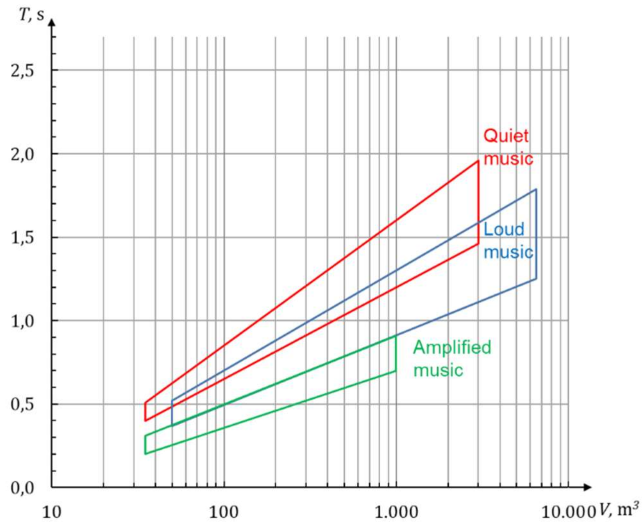

Figure 5: The upper and lower limits of the mid-frequency reverberation time in rehearsal rooms as function of volume. The three categories of music are quiet, loud, and amplified music.

The upper and lower limits of reverberation time should not be taken too rigidly. Such limits can only be approximate. Also, the division into the groups of quiet and loud music cannot be perfectly strict. So, it is noted that there is some overlap between these two groups. The important difference is, that loud music requires larger volumes and lower sound strength than quiet music.

For amplified music the requirements for volume and sound strength in the rehearsal rooms are also important, although they cannot be related to the emitted sound power of the instruments in the same way as for acoustic music.

The reverberation time is here presented as the mid-frequency average (500 and 1000 Hz octave bands). ISO 23591 also specifies limits for variation in octave bands from 63 Hz to 4000 Hz [1, Figure 2 and Table 6].

Discussion

Musical instruments have been developed and improved over centuries, and to-day's instruments are more powerful than instruments from the past centuries. Some music ensembles like symphony orchestras are meant to perform in relatively large concert halls, and other ensembles like marching bands are meant to perform outdoors. When such music groups are rehearsing, the volume and the acoustics of the rehearsal room are very important. Often, the rehearsal rooms are too small and/or have too high sound strength resulting in very high loudness, some times with a risk of hearing damage for the performers. Another consequence of a room with too high sound strength is that the musicians may try to change their way of playing, avoiding the upper part of the instrument's dynamic range [14]. Clearly, the quality of the music suffers in such cases.

The opposite situation is when the rehearsal room is very big and with high acoustic damping. Then the sound strength is low and especially some types of quiet music will suffer from insufficient loudness. Again, the musicians may try to compensate for the inadequate acoustics, this time by forcing the instrument and avoiding the soft part of the instrument's dynamic range [14]. The sound from instruments that are forced to high sound levels can be harsh and shrill, and once again the quality of the music suffers.

Conclusion

Traditionally, the reverberation time has been considered the most important acoustical parameter in a music hall. However, when it comes to music rehearsal rooms with significantly lower volume than concert halls, the sound strength may be more important than reverberation time.

The biggest acoustical challenge in music rehearsal rooms is to balance the reverberation time and the sound strength. In small rooms the sound strength should not exceed a value around 25 dB, even if this means that the reverberation time is very short.

For the design of new rehearsal rooms, it is of decisive importance that the volume is sufficiently large and adapted to the music type and ensemble size that the room is meant for. The ISO 23591 may help to find good solutions, leading to acoustically better rehearsal rooms in the future.

References

[1] ISO 23591:2021, *Acoustics – Acoustic quality criteria for music rehearsal rooms and spaces.* International Standardization Organization, Geneva, 2021.

[2] ISO 3382-1:2009, *Acoustics - Measurement of room acoustic parameters - Part 1: Performance spaces.* International Standardization Organization, Geneva, 2009.

[3] W.C. Sabine. Reverberation. *The American Architect* and *The Engineering Record*, 1900. Paper No. 1 in Collected Papers on Acoustics (Harvard University Press. Cambridge. MA. 1923).

[4] M. Nagata. Design problems of concert hall acoustics. *J. Acoust. Soc. Jpn*. (E) **10.2**, 1989, 59-72.

[5] S. Wu, Q. Li, E. Kittinger. A New Criterion of Concert Hall Loudness Evaluation. *Acta Acustica – Acustica* **87**, 2001, 286-289.

[6] J. Meyer. Raumakustik und Orchesterklang in den Konzertsälen Joseph Haydns. *Acustica* **41**, 1978, 145-162.

[7] J. Meyer. Zur Dynamik und Schalleistung von Orchesterinstrumenten. *Acustica* **71**, 1990, 277-286.

[8] J. Meyer. *Acoustics and the performance of music*, Springer, 2009.

[9] J. Burghauser & A. Spelda. *Akustische Grundlagen des Orchestrierens*, Gustav Bosse Verlag, Regensburg, 1971.

[10] Z. Maekawa, J.H. Rindel, P. Lord. *Environmental and Architectural Acoustics,* 2nd Edition, Spon Press, London, 2011.

[11] P. Lehmann. *Über die Ermittlung raumakustischer Kriterien und deren Zu´sammenhang mit subjektiven Beurteilungen der Hörsamkeit*. Dissertation, Berlin, 1976.

[12] L. Nijs & D. de Vries. The young architect's guide to room acoustics. *Acoust. Sci. & Tech.* **26**, 2, 2005, 229-232.

[13] M. Valk, L. Nijs, P. Heringa. Optimising the room acoustics for lesson and study rooms of the Conservatorium van Amsterdam (In Dutch*). NAG-Journaal*, **178**, 2006.

[14] Z. Schärer Kalkandjiev. *The influence of room acoustics on solo music performances*. Thesis, Berlin, 2015.