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Sound levels in rehearsal and medium sized concert halls; are they too loud for the musicians ?

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Since the EU directive 2003/10/EC "on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (noise)" became enforced for the music industry in February 2008, managers of symphony and opera orchestras in Europe must pay serious attention to the sound levels to which their musicians are exposed. In this context, it is often discussed whether some halls are simply too small to accommodate the large sound power output of a symphony orchestra. Based on measurements of sound exposure levels of musicians according to ISO 9612 in both performance and smaller rehearsal halls, as well as room acoustic data from a number of small sized halls that we have designed or worked in, it is discussed whether this is likely to be true. To avoid too loud levels, a simple rule of thumb is suggested which can be used for the acoustic design of practice rooms, small concert and rehearsal halls as well as studios for recording and broadcasting.

1 Introduction

During several decades of research and consultancy, we have come across numerous halls which were considered too loud and/or too reverberant. In other cases we have had to judge whether the available space for a new hall was adequate or not. The rooms in question have ranged from small practice/teaching rooms, over rehearsal and recording halls to small concert halls with a modest size audience.

Literature on this topic is sparse. Apart from a section in Meyer's famous book [1] and a paper by Tennhardt and Winkler from 1995 [2], most papers are from the 1950'es, when concern about exposure levels was less developed and the performance practice was quite different from that of today.

In order to find out whether a hall is too small or not, we could be tempting to take a physical approach: a) to find sound power levels of instruments as reported by Meyer [3], b) to calculate the levels caused by the instruments in the halls determined by source receiver distances, hall volume and reverberation time, and c) to compare these with the levels allowed according to the EU Directive 2003/10/EC. This directive defines an "upper exposure action value" of LEX,8h = 85dB(A), which has been adopted as the upper limit in most EU countries.

However, we do not know, how the Leq integrated over the work day of a musician relate to the values listed in [3], as this differs widely with music score, ensemble size and playing style and the number of hours the musician plays per day or per week. Besides, the levels at each musician's ears might depend on the propagation of direct sound from nearby musicians (determined by mutual distances and instrument directivity) as well as on the level of reflected sound from the room surfaces. Therefore, a more promising approach may be to organize one's experiences regarding measured exposure levels and which halls had level problems and which did not.

2 L_{Aeq} levels measured at the ears of performers in different halls

Recently we participated in carrying out sound exposure level measurements on members of the Royal Danish Opera orchestra playing the same pieces in different halls [4]. The rooms were the old and the new opera theaters in

Copenhagen and two rehearsal halls in the new opera. Each of four pieces were played in one of the rehearsal halls and subsequently performed in the pit in the opera. LAeq values - averaged over the duration of the rehearsal session or performance - were measured with noise dose meters close to the most exposed ear of 2 to 4 members of four different instrument groups: strings, woodwind, brass and percussion. The values averaged over the musicians in each group as well as the average over all 8 - 10 musicians have been listed in Table 1 below.

Table 1 – Measured L_{Aeq} at musicians' ears in different halls

Work	Romeo & Juliet		Il Nozze di Figaro		The happy Widow		The Physician's visit	
Hall volume	Cph 1 4,400m^3	Old Op. 6,500m^3	Cph 1 4,400m^3	Old Op. 6,500m^3	Cph 2 2,300m^3	New Op. 10,300m^3	Cph. 1 4,400m^3	New Op. 10,300m^3
Hall RT	1.3 Sec.	1.1 Sec.	1.3 Sec.	1.1 Sec.	0,8 Sec.	1.4 Sec.	1.3 Sec.	1.4 Sec.
Strings	86	89	84	85	87	87	84	88
Woodwind	86	89	88	86	85	88	87	89
Brass	87	94			88	92	89	94
Percussion	81	92			85	92	88	90
Average	85	91	86	85	86	90	87	90

As can be seen, the measured LAeq were on average 3 dB lower in the small rehearsal halls than in the opera pits. Many possible explanations for these differences can be imagined. It is likely that musicians play with less energy and passion in rehearsals than during a performance. During the rehearsal the playing may also be interrupted, e.g. by sequences of speech. It is also likely that in smaller rooms with higher acoustic support, musicians feel that they need not play very loud to create the sound they want resulting in the total level at their neighbor's ears being lower than in larger or less reverberant rooms, where they might feel a need to force their playing. On the other hand, if they play with constant level regardless of the room, the levels will be higher in small or more reverberant rooms.

Like most other reports on level measurements among orchestra musicians, we found that musicians subject to the highest levels are those closest to the loud brass and percussion - including the players of these instruments themselves. This is in line with Meyer's results, [3] indicating that brass instruments are about 10dB more powerful than strings and woodwinds. Consequently, the average levels are more determined by the size of the brass (and percussion) sections than by the overall size of the orchestra.

So far we can conclude that there is no simple relationship between room acoustics and levels. Our measurements of levels at the musician's ears can't tell us much about the influence of the hall design, since the possible effect is confounded with other factors. But still, there are many testimonies about some halls generate too loud sound levels while others do not. Therefore, we will give it another try.

3 The influence of room acoustics according to diffuse field theory

The results in the previous section indicated that musicians further away from the loud instruments receive lower levels. This implies that primarily these high levels must be transmitted as direct sound; but the question remains: How much of the sound is direct and how much is reflected from room surfaces? In other words: how important is the orchestra layout and furnishing compared to the room acoustic design of the hall itself? This balance is determined by the critical distance or reverberation radius.

3.1 The direct sound energy

In halls ranging in volume and reverberation time between say 2000m3/RT=1 Sec. to 20000m3/RT=2 Sec., the critical distance typically varies between 3 and 5 metres for an omni directional source. (The loudest instruments, typically brass, are highly directive; but if a screen is used to block propagation in the direction of most efficient radiation, an assumption about omni directionality might not be completely wrong.) A circle with radius equal to the critical distance between 3 and 5 meters has an area between 28 and 78 m2. With each musician typically occupying an area of 1.5m2, a musician in the middle of the orchestra would receive primarily direct sound from between 20 and 50 other musicians in the orchestra. But we also have to consider the barrier effect of the musicians themselves, their music stands and the regular use of “noise” screens, which will attenuate the direct level beyond the barrier. Hereby the reflected/reverberant energy may still be of importance.

3.2 The reverberant energy

According to classical diffuse field theory, reverberation time is proportional to volume, V, divided by the absorption area, A: T = (0,161*V)/A. The level of the diffuse field is proportional to N/A with N being the number of musicians: $L_p = L_w + 10 \cdot LOG(4N/A)$. (Here, for reasons of simplicity, we assume all musicians to emit the same sound power, L_w, per musician). In other words, increasing A reduces both RT and the level; but with a generous volume, we can still obtain a certain amount of reverberation, which is desirable in most cases.

If we wish to accommodate a larger orchestra, we can maintain the same (reverberant) level by increasing A proportionally to the increase in N. Therefore, the absorption area per musician A/N could be a parameter worth a closer look.

4 Absorption area per musician in different halls

In the following, we will investigate whether a specific value of A/N can be found, which will create a situation without too loud reverberant levels in moderate sized rehearsal and concert halls.

Our approach will be to dig in our experience with different rooms and halls in which we have worked on the acoustics. While many more relevant design variables exist, see e.g. [5], in the following we will concentrate on A/N only.

In Figure 1 we have plotted the absorption area of the room per musician, A/N, versus volume for different halls in which we have worked. The absorption per musician has been calculated from the measured reverberation time in the hall (without musicians present) and assuming that the hall is to be used for a full symphony orchestra with 90 musicians. However, a few halls used only for smaller ensembles have been included as well. In these cases the relevant number of musicians used to calculate A/N has been added in parenthesis.

Also lines representing the relationship between A per musician and volume for different values of RT between 1.0 and 2.0 seconds are shown. Also when calculating these, a 90 piece orchestra was assumed.

4.1 Orchestra rehearsal halls

Nine dedicated rehearsal halls have been included in the graph. Among these, Tennhardt [2] comments on the two marked with yellow labels. The level was found to be too high in the $4200m^3$, 1.9 Sec. rehearsal hall in Neues Gewandhaus, Leipzig, while a much smaller $2400m^3$, 1.0 Sec hall in Concerthaus Berlin worked much better. Both of these halls had a fairly low ceiling height of about 8m, so it is likely that the ceiling in Leipzig gave too strong reflections while the one in Berlin may be highly absorbing.

The seven halls marked with black labels represent halls from Denmark plus a well liked rehearsal hall in the Oslo Opera.

The larger of the halls in the new Danish Opera, “Cph Opera 1”, is also well liked. For heavy orchestration, RT in this hall can be reduced to 1.0 Sec. whereby A/mus increases to $7.8m^2$. The smaller Cph Opera 2 is not highly ranked and used only when Cph Opera 1 is not available.

Frichs is a 5000 m^3 orchestra rehearsal hall with low ceiling, and RT= 1.4s. It is no longer used and the sound was considered too loud for the resident symphony orchestra.

Lumbye is a 4600 m^3 rehearsal hall which had an RT of 1.8 Sec. when we were called in to suggest changes because it was too loud (and muddy) for the resident Tivoli Symphony Orchestra.

Haderslev is a fairly small hall with RT = 1 Sec. which works well for a military music band of 36 players. For this hall, A/N was calculated for RT=1s and N=36; but RT can be reduced to 0,6s if needed.

The Queens hall is intended for chamber music concerts and conferences. RT is variable between 1.1 and 1.9 Sec. The stage was planned to be usable for a symphony orchestra rehearsals; but A/N is calculated for N=40 (Sinfonietta) and RT=1.9 Sec., which works fine.

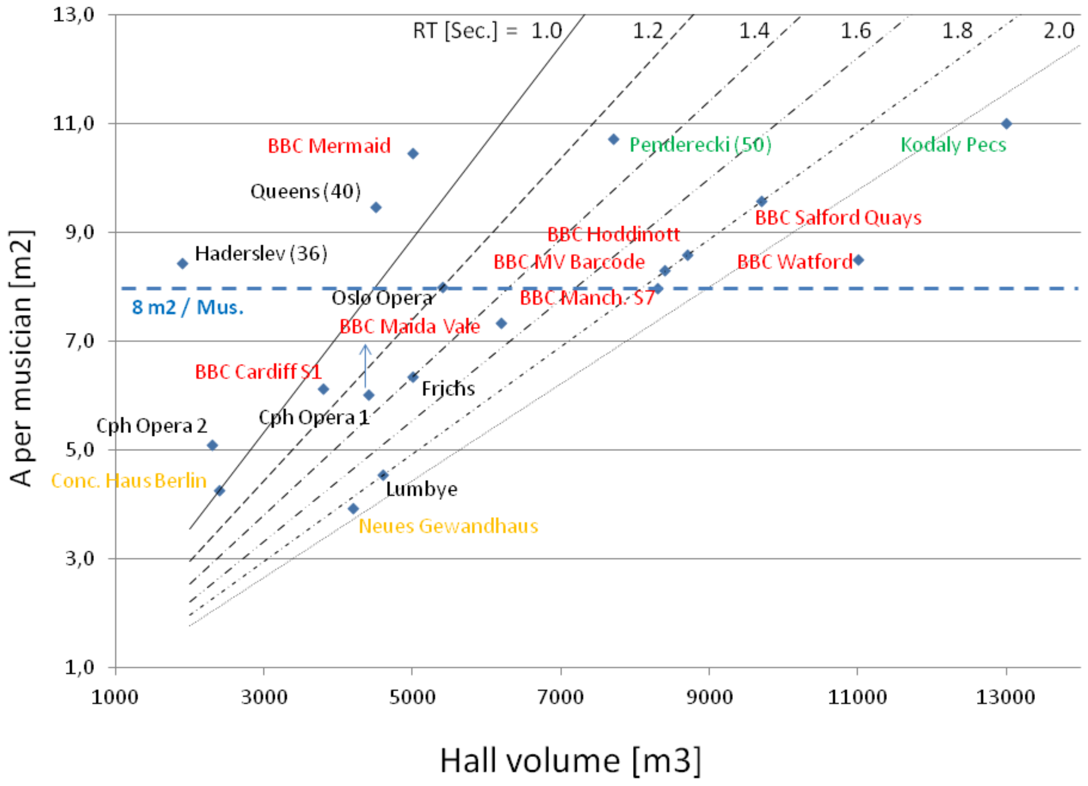

Figure 1 – Absorption per musician versus volume in small/medium halls for classical music; see text

4.2 BBC concert studios

As client advisors for the BBC, we have been involved in establishing new concert studios for the regional BBC orchestras in Wales and Manchester. We have also participated in renovation plans for the BBC Maida Vale studio in London and analyzed the conditions in two halls in London used by the BBC Concert Orchestra. The relevant halls have been given red labels in Figure 1.

In Cardiff, the BBC National Orchestra of Wales used the Studio 1 in Cardiff until 2009, when they moved to the new Hoddinott studio designed by Arup Acoustics [6]. They hereby experienced an increase in A/N from 6.1 to 8.6 m^2 along with RT increasing from 1.1 to 1.8 Sec. thanks to the volume being more than doubled. Needless to say, previous problems regarding loudness no longer exist.

In Manchester, the conditions in Studio 7 used until May 2011 suffered from too high levels and poor ensemble. Both aspects have been much improved in the new studio at Salford Quays.

The BBC Symphony has long been fighting with less than optimal conditions including loudness problems in the Maida Vale facility. We recently participated in a renovation plan suggesting increasing the low ceiling height and the A/N from 7.3 to 8.3 m^2 along with an increase in RT from 1.5 to 1.8 Sec. Variable acoustics should be included to increase A/N even further if needed.

Finally we have analyzed the acoustics in the Watford and Mermaid halls because the BBC needed suggestions for improvements. The Mermaid is much too loud (with a low ceiling) and dry while Watford causes poor ensemble and has too long reverberation for the rhythmic repertoire, but loudness is much less of a problem here than in the Mermaid.

4.3 Small and medium sized concert halls (500 – 1000 seats)

Recently we have assisted with the design of two medium sized concert halls: the Penderecki hall in Radom, Poland [7] and the Kodaly Concert hall in Pecs, Hungary [8]. For a 50 piece orchestra, the hall in Radom causes no problem with loudness even though RT is about 2.3 Sec. The hall in Pecs capable of accommodating a full symphony orchestra has no problem with level either.

5 A suggestion for a rule of thumb

If we draw a horizontal line corresponding to $8m^2$ absorption area per musician in Figure 1, we see that most of the satisfactory halls are above and the ones with level problems fall below this line. In many of the halls shown, RT can be reduced further, which is often used with heavily orchestrated music.

We know that the requirement for absorption differs depending on instrument played and the percentage of loud instruments in the orchestra; but the 8m2 seems valid for all orchestras with ambitions to play the standard symphonic repertoire – regardless of their sizes, since these differs mainly by the number of strings, which are not responsible for the highest levels anyway.

Figure 1 can also be used to find the necessary volume, if the wish is to achieve a certain reverberation time without compromising an A/N of at least $8m^2$. This can be found from the crossings between the oblique lines and the dotted, horizontal line.

It is of interest to see the consequences of applying this recommendation in more extreme cases. A room for individual practice with 12 m^2 floor area and a generous 3m ceiling height should then have a recommended (maximum) reverberation time of 0,7s. From our experience in music schools and conservatories, this seems about right. In the other end of the spectrum, $8m^2$ per musician implies that a concert hall for 90 musicians and a target reverberation time of 2 Sec. must have a volume of at least 9.000 m^3 – and so it could seat an audience of 900 people if we aim for the usual 10 m^3 volume per seat.

From the above, it looks as if the minimum A/N of $8m^2$ is fairly robust as a general recommendation for rooms in which classical music is played. For loud instruments like brass and percussion and for amplified instruments for rhythmic music, it is wise to allow for larger values through additional (variable) absorption.

Table 2 – Volume in m^3 for classical music rooms depending on number of musicians, N and RT

RT Sec.	2.0	1.8	1.6	1.4	1.2	1.0	0.8	0.6
N=1	100	90	80	70	60	50	40	30
N=2	200	180	160	140	120	100	80	60
N=4	400	360	320	280	240	200	160	120
N=8	800	720	640	560	480	400	320	240
N=16	1600	1440	1280	1120	960	800	640	480
N=32	3200	2880	2560	2240	1920	1600	1280	960
N=64	6400	5760	5120	4480	3840	3200	2560	1920

For ensembles with less than 90 musicians, Table 2 shows the required volume for different values of RT and number of musicians – assuming that the goal is $A/N = 8m^2$.

A recommendation similar to the above has been derived by Rindel [9] for limiting noise levels in restaurants. Also here we have many independent evenly distributed sources emitting sound in the same room. Rindel has shown that in restaurants a certain amount of absorption per person is needed to avoid the Lombard effect, according to which the level increases about 6dB per doubling of the number of sources rather than 3dB, if the absorption per source is so low that the individual voices start to “compete” in attempt to be heard over the noise generated by all the other persons talking in the room. The analogy should not be taken too far of course, since the mechanisms influencing the levels generated in orchestras are different from those which govern the speech power levels in restaurants. It is puzzling however, that Rindel also reached values around 8 m^2 per person for achieving acceptable conditions in restaurants.

6 Concluding remarks

We can conclude that besides sufficient stage floor area per musician, preferably $2m^2$ per musician, a sufficient high ceiling and an absorption area per musician of about $8m^2$ is needed to avoid too high levels. If the volume is adequate, it is possible to achieve this and still allow for some reverberation. We have also seen that this rule of thumb might work not only for rehearsal halls but even for concert halls and small practice rooms as well. Ceiling height also matters. Even with large volume, a low ceiling is problematic.

Of course other factors than the absorption are per musician and volume are of importance. Through the choice of room geometry, rises, reflectors and the distribution of absorption, the balance between early and late arriving sound components can be influenced, which determines both levels, ease of hearing each other and support of own instrument and the ability to balance with the rest of the orchestra. Neither have we discussed the possible influence of support and mutual hearing in the levels played; but it is likely that strong support and good mutual hearing will result in a softer - and more musical! – playing style.

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