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Absorption area matters in symphony orchestra rehearsal rooms

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ABSTRACT

Reverberation time and room volume data from 37 rehearsal rooms for symphony orchestras have been collected and plotted in the *T-V* diagram of the work draft for recommendations in a new ISO standard. Reverberation times vary quite randomly between 0.7 and 1.9s in room volumes smaller than 7000m3 and do not provide an obvious explanation as to why some rooms had acoustical issues and others not. However, absorption area *A* from Sabine's Formula turned out be a critical metric in the data. No issues were found for rooms with *A* greater than 560m2Sa, except for one room. A criterion of *D-R*=0dB applied to a model of orchestra and rehearsal room simulated in Odeon turned out to produce limits in the *T-V* diagram that were quite like the *A*=560 limit. Either of these limits seem to be a good candidate for recommendations. This paper presents results and analysis, and discusses implications and perceptual aspects of *A*, such as reverberation distance and its impact on transparency and the balance between direct and reverberant sound. By taking the perspective of a receiver, such as conductor and the individual musician, reverberation distance provides a different insight than the source-oriented one.

Keywords: Room acoustics, symphony orchestra, rehearsal rooms, reverberation time, absorption area, reverberation distance, direct-reverberant ratio balance, acoustical transparency

1. INTRODUCTION

Dedicated rehearsal spaces for symphony orchestras may be required for a variety of reasons. An obvious requirement would be that the acoustical conditions are not too different from those in a good performance space, i.e. on stage in a concert hall with good acoustics. However, due to restricted room volume, according to Revised Theory, the rehearsal room cannot at the same time have both the reverberation time T and the reverberation sound level G_r of the concert hall:

$$Gr= 45+10*lg(T/V)-0.176r/T \tag{1}$$

For the average inter-orchestral distances r in a typical rehearsal room, the latter term will be approximately 1dB, so a good estimate would be

$$Gr= 44dB+10*log(T/V), \tag{2}$$

demonstrating the dependence on V/T. To maintain unchanged reverberant level in a smaller room, reverberation time needs to be shorter. Some musicians, orchestras and conductors prefer T=1.8-2.0s like in the concert hall, others prefer G_r = *4*-6dB like in the concert hall, while yet others go for a compromise with shorter T and higher G.

The work group ISO-TC43-SC2-WG33 is currently working on a new standard for acoustics in rehearsal rooms, the work draft being the Norwegian Standard NS8178. The latter has requirements for combinations of V and T in rehearsal rooms with volume up to 3000m3. Many rehearsal rooms for symphony orchestras are bigger than 3000m3. It is therefore natural to investigate if the limits in NS8178 can be extrapolated or not, if existing NS-limits needs to be revised, or if a different approach

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is needed for the wide range of volumes. In this paper, combinations of *V* and *T* will frequently be referred to as *T-V* data for short. Figure 1 shows the NS 8178 limits for combinations of *V* and *T* in rehearsal rooms for ensembles with unreinforced instruments.

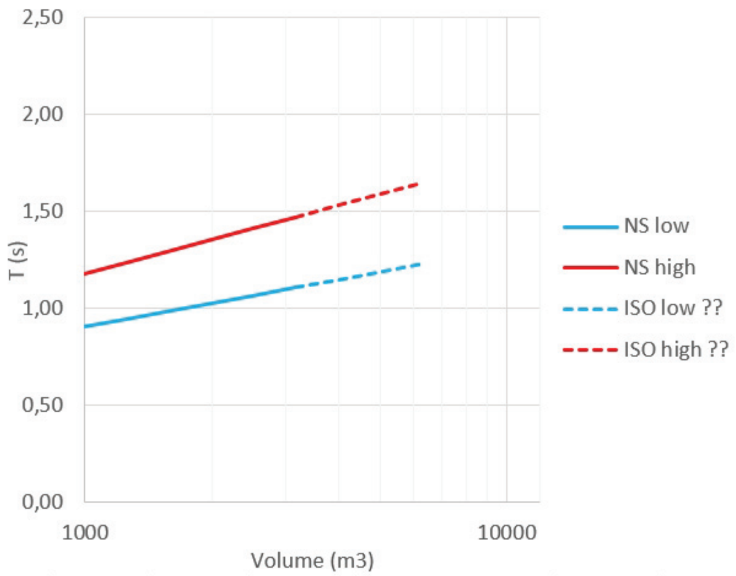

Figure 1 – NS 8178 limits for combinations of *V* and *T* in rehearsal rooms for unreinforced ensembles

2. RESEARCH IN EXISTING REHEARSAL ROOMS

2.1 *T-V* Data

In an ongoing research in *T-V* data from existing rehearsal rooms by this author, previously published as well as unpublished data is being compilated in a single data base. This includes *T-V* data in papers with various topics on rehearsal rooms, by several authors[1] [2] [3] [4] between 1995 and 2018. In addition, consultants and researchers are being invited directly via email and an online dedicated page [6] on the Akutek site. For updated results, source references, and other information, readers are referred to the online site. As of 2019-07-01, the size of the database was N=37. Data is plotted in Figure 2.

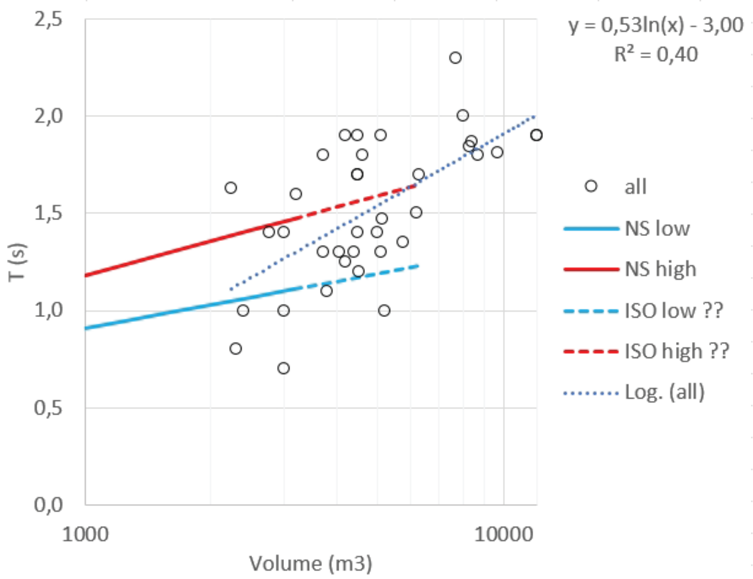

Figure 2 – *T-V* data (N=37) plotted into the diagram in Figure 1

2.2 Data trend

An immediate impression from Figure 2, is a cloud formation of the plot with a steeper trend than the slopes in the ISO work draft. An abrupt change is seen at 7000m3, below which *T* varies between 0.7s and 1.9s, while in the bigger rooms, *T* is 1.8s or larger, very similar to *T* in concert halls.

2.3 Statistics

Statistics are given in Table 1, in categories All rooms, Small, Medium and Big rooms, in metrics *V, N, T, A* and *Gr*. *A* and G_r are calculated values from Sabine's Formula and Revised Theory, respectively. Average *T* in the room categories increase with their average *V*, confirming the impression from Figure 2.

At N=37, the rehearsal rooms have an average volume of 5288m3±48% and a reverberation time of T=1.52s±24%, where ±% denotes the relative standard deviation. The "normal" room is in the range of 3600 and 7800m3 with reverberation time between 1.23s and 1.78s.

A medium group with volume V=4877m3±14% has reverberation time T=1.50s±18%. The average room would be just within the extrapolated limits of NS, close to the upper limit of T. Reverberant sound level ranges from 7dB to 10dB, from the largest to the smallest group.

Table 1 – Statistics. All rooms, small, medium and big rooms, in metrics *V, N, T, A* and *Gr*.

	V range (m3)	*N* count	*N* %	*V* avr. (m3)	*V* sd %	*T* avr. (s)	*T* sd %	*A* avr. m2Sa	*A* sd %	G_r (BRT) avr. (dB)	G_r (BRT) sd (dB)
all	2230-12000	37	100 %	5288	47 %	1,52	24 %	553	34 %	8,9	1,5
small	< 4000	11	30 %	3007	19 %	1,25	29 %	413	32 %	10,1	1,4
medium	4000-6300	18	49 %	4877	14 %	1,50	18 %	536	23 %	8,9	1,0
big	>6300	8	22 %	9350	19 %	1,93	8 %	783	22 %	7,2	0,9

2.4 Issues or not

With the *T-V* data, a rough assessment was assigned. In more detail, frequent issues were described as "too dry" "too reverberant", "too loud", "too muddy" or "poor ensemble". These could eventually form categories that could be analyzed for common features. However, at present, there is too little data to make such analysis statistically significant. In this paper, the rooms are assessed binaurally in terms of "issues" and "no issues", as plotted in Figure 3.

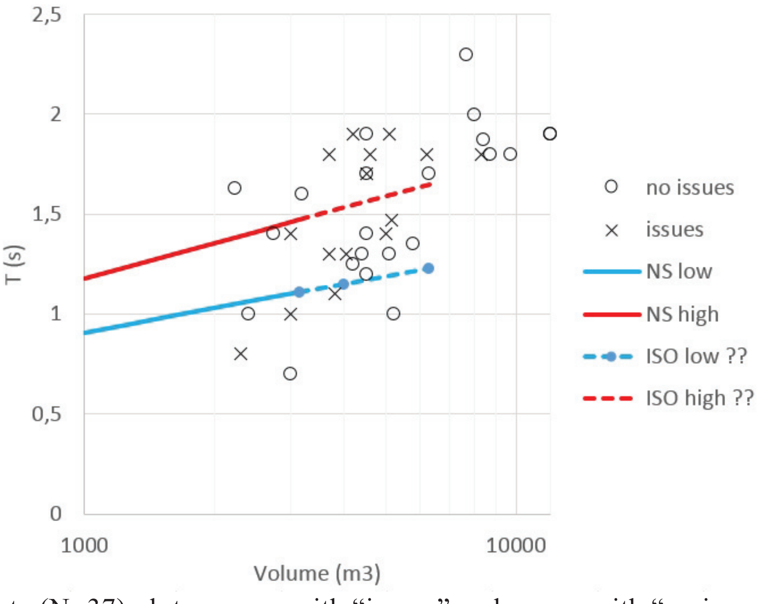

Figure 3 – *T-V* data (N=37) plot as room with "issues" and rooms with "no issues"

In 15 "issues" rooms conditions led to physical changes, either corrections or abandoned rooms. In the 22 "no issues rooms", conditions are accepted, or at least they have not led to drastic measures.

2.5 Absorption Area (A)

The *T-V* diagram in Figure 3 did not reveal any simple explanations as to why there are issues in some of the rooms, while in others not. Only 12 of the rooms are within the extrapolated limits in NS, and only 7 are without any known issues. This motivates for a search for other explanations than those found in unprocessed *T-V* data. The significance of the Sabine absorption area A=0.16·V/T have previously [3][5] been suggested as a possible critical property in rehearsal rooms. In Figure 4, absorption area *A* is plotted against reverberation times *T*.

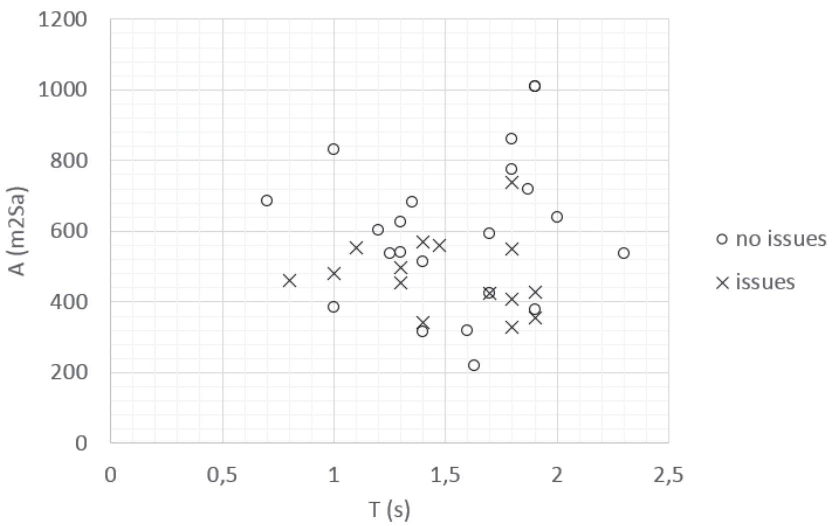

Figure 4 – Absorption area versus Reverberation time

Figure 4 reveals that, except for the isolated sample "x" at 1.8s and 837m2Sa (BBC studio 7), there are no issues above 560m2Sa. To be precise, the highest value of *A* associated with an issue is 571m2Sa at 1.4s (Frichs). Both cases are data from [3], and among the issues reported were loud levels and poor ensemble. In Frichs there was a low ceiling. Indeed, too strong early energy, e.g. from a low, sound reflective ceiling are often linked to too high levels and poor ensemble. Since the portion of early energy is not described by A, a room can have issues with too loud reverberant sound even with a sufficient value of *A*. Gade [3] proposed 8m2Sa per musician[3]. In the case of a symphony orchestra, depending on repertoire, at least 70 musicians and 560m2Sa would be required. This corresponds well with the limit that best fits the current database, Figure 5.

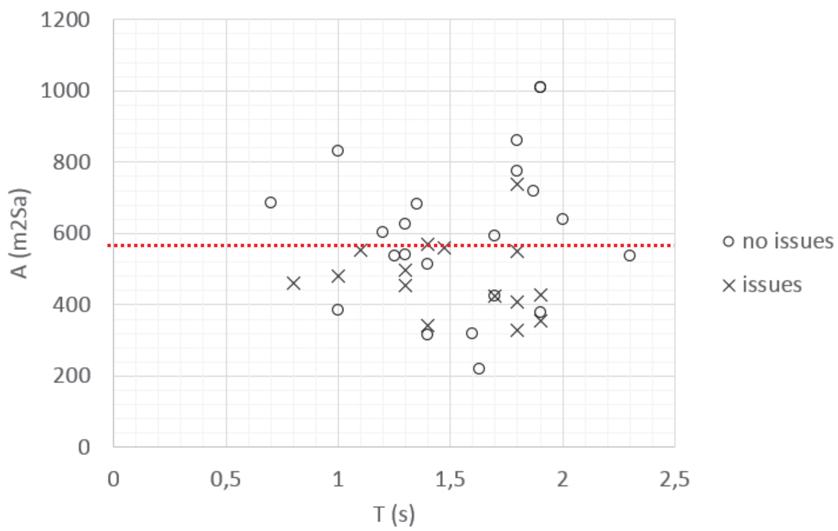

Figure 5 – Absorption area limit A=560m2Sa, independent of T

[3] 8m2Sa per musician is equivalent to *V/T>50*N* or T< V/(50*N) for *N* musicians

2.6 T-test

Given the feature in Figures 4 and 5 that few issues, if any, are found in rooms with rooms with absorption area A=560 or more, a valid question would be: What is the uncertainty related to the limited size of data? In science, a careful assumption is that all observations are members of the same population having the same distribution, and any variation found in a sub-set of data is purely a random outcome of the selection. Student's T-test offer a simple test of the probability of the default assumption being valid. In our case, we would use the T-test to ask the question:

- (Rand of all T?) Are the T (reverberation time) values in the "issues" rooms a random selection from the population of T values of all rehearsal rooms?
- (Same pop of T?) Are the T values in the "issues" rooms and the T values in the "no issues" rooms two random selections from one and the same population of T values of all rehearsal rooms?
- (Rand of all A?) Are the A values in the "issues" rooms a random selection from the population of A values of all rehearsal rooms?
- (Same pop of A?) Are the A values in the "issues" rooms and the A values in the "no issues" rooms two random selections from the population of A values of all rehearsal rooms?

In the output of the T-test, 100% would mean yes, 0% would mean no, and values 1-99% would express the probabilities in-between. Values close to 0% would indicate that the metric is critical and would be able to discriminate rooms with issues from rooms with no issues. Answers are given in Table 2.

Table 2 – T-test of the rooms with "issues"

	Rand of all T?	Same pop of T?	Rand of all A?	Same pop of A?
Probability	86 %	74 %	13 %	4 %

From Table 2 we interpret that A can discriminate rooms with issues from rooms with no issues with 4% risk of error. Moreover, A can discriminate rooms with issues from all rooms with 13% risk of error. Another interpretation would be to substitute risk of error with overlap between distributions.

3. IMPLICATIONS AND PERCEPTUAL ASPECTS OF *A*

Several acoustical properties and perceptual features are linked to the Sabine Absorption Area A, as elaborated in [3] and [5]. Some of them will be briefly repeated in the following, offering explanations as to why A appears to be a critical metric in our database.

3.1 Reverberation distance d_r and transparency

The reverberation distance from an omni-directional receiver is $d_r = 0.14*A^{0.5}$. At this distance, the direct-to-reverberant ratio will be d/r=1 and the direct to reverberant sound level balance will be zero, D-R=0(dB). At this distance a source would be received as an equal mix of direct and reverberant sound. At closer distances, direct sound from the source would tend to dominate, and at longer distances reflected sound from the source would dominate. In an orchestra, ears of conductor and musicians are receivers and instruments are sources.

Transparency is the perceptual aspect of d_r. When d_r is shorter than optimal, reverberant sound dominates, transparency is poor, and musicians will often complain about muddy sound or a dense sound field with poor ensemble. Opposite, if d_r is longer than optimal, direct sound dominates, only the farthest instruments has a reverberant part, sound becomes too dry and weak, blend is poor. Both extremes could result in musicians playing stronger than optimal[4]. A conductor working in optimal transparency, i.e. with optimal d_r, would not like the d_r to change. Each instrument is perceived with its unique D-R. Instruments at first desks with high D-R and instruments at the rear with lower D-R.

d_r determines the overall balance between direct and reverberant sound perceived in the orchestra. An optimum d_r ensures an optimum fraction of reverberant sound in the total orchestral sound. It is in the reverberant sound the violin group and other instrument groups can form a unison sound and actually hear it, an exercise involving hours of repetition and listening in the group rehearsal room.

For a given orchestra and layout, transparency in inter-orchestral hearing is governed by d_r, and thereby by A. If an orchestra moves to a different space they need to keep A unchanged, if they want

[4] Bad hearing conditions tend to be met with a demand for more power, as elaborated in [5]

to keep their individual *D-R* balances unchanged.

If the ensemble moves to a room with different critical distance, their mutual hearing would be different. A common saying is that conductors like to hear details during the rehearsal phase, while in performance a more blended sound is preferred. This would imply a longer critical distance in the rehearsal room than in the performance room. This rarely is the case. However, some orchestras prefer to rehearse in far dryer rehearsal rooms than recommended by the standard NS8178.

To be precise, A determine how wide d_r can be and how transparent the orchestra sound can potentially be. On the other hand, it can be reduced by too much early energy and too strong support, e.g. from a low ceiling. This means that sufficient A is necessary, but not a guarantee.

3.2 Noise exposure

For a given musical source with power W the reverberant sound level would depend on $10*log(W/A)$ or the balance $L_w - 10*log(A)$. From this we can tell that parts with equal L_w, loudness level will be unchanged if A is unchanged, higher as A decrease, and lower as A decrease. However, in live orchestral music, L_w can vary dynamically over a range of more than 60 dB is property of the music, while $10*log(A)$ varies less than 5dB from the loudest to the quietest rehearsal room in our data set. This implies that A is responsible for a much, much smaller part of noise exposure than the power W. Still it could mean that noise exposure levels are 90dB instead of 85dB and vice versa. Note also that, independent of A, excessive early energy can add a couple of dB more to noise exposure.

3.3 Entangled features

While perceived sound level depends mostly on L_w , A has its most perceivable impact on the direct-reverberant balance. The biggest impact of A on sound quality and noise level in a symphony orchestra, may be the indirect or long-term effect it has on playing style and consequently, noise exposure. If A is far from optimal, transparency, mutual hearing and ensemble will be far from optimal. Masking of sound will almost inevitably lead to someone having to play stronger. A more forced style of playing, will inevitably lead to more high frequency content, leading to even more masking, driving a vicious circle. This self-reinforcing mechanism is not unlike the one often encountered in cocktail-parties, canteens, foyers and other mingling places with many competing sources. The escalating levels will be inevitable whenever d_r is small compared to the distances between the members of a group conversation, not dissimilar to what sometimes happens in an orchestra. We have described the entanglement of transparency, mutual hearing, ensemble, sound quality and excess loudness. If transparency is far from optimal, the other features will be affected in a chain-reaction. What ties them together and control them is A, d_r, and their size related to the layout size of the orchestra.

3.4 Optimal *D-R* balance

In [5] an average *D-R* balance equal to zero over the orchestra, with a source or receiver in Concert Master position, or conductor position for that matter. In order to see what such a criterion would imply in a *T-V* diagram or an A-T diagram, a standard orchestra has been modeled and placed in rehearsal rooms of different volumes and with various absorption factors. *D-R* (dB) over orchestra in a 5000m3 room, simulated in Odeon 14, is seen in Figure 6.

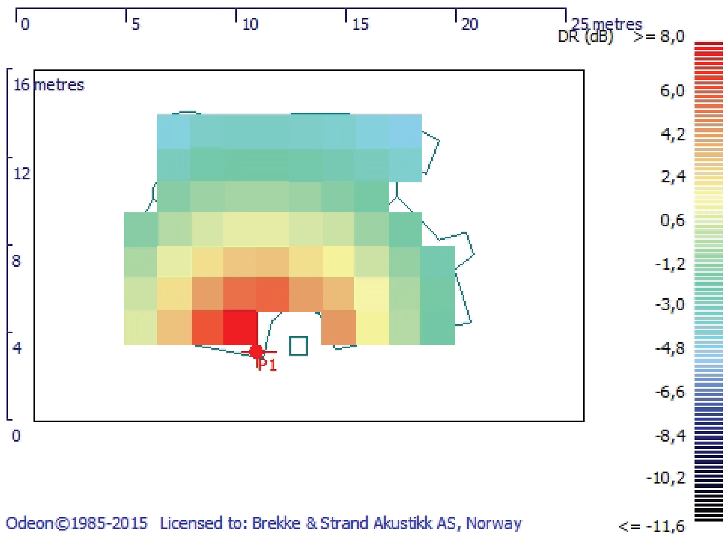

Figure 6 – *D-R* (dB) over orchestra in a 5000m3 room, simulated in Odeon 14

In Figure 7, combinations of *A* and *T* corresponding to the criterion *D-R*=0dB is plotted into the diagram in Figure 4. Strikingly, with an average close to the criterion A=560 above, but slightly increasing towards higher T, the trend of A=455+84*T (m2Sa) offers a slightly more refined version of the "issues"-limit in Figure 4.

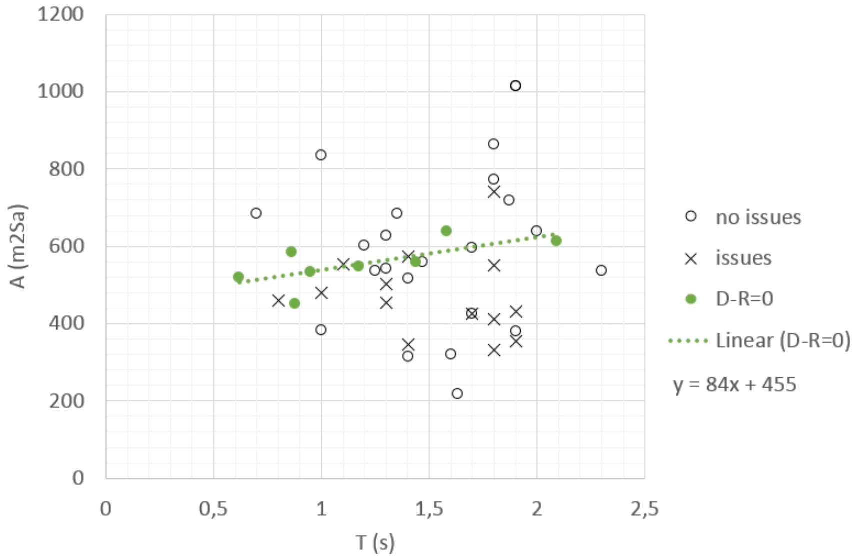

Figure 7 – combinations of *T* and *A* corresponding to *D-R*=0dB

A practical and perceivable consequence of more absorption area is that the difference in reverberation time from the empty floor condition to the occupied floor condition becomes smaller. Figure 8 shows that when the *D-R*=0dB condition in Figure 7 is fulfilled, $T_{occ}=0.63*T_{empty}+0.19$ (s). E.g. when *T* is 2.0s with empty floor, *T* is merely 1.5s with the orchestra present. For the rooms below the limit in Figure 7, the difference would be even bigger. The smaller the *A*, the bigger the difference $T_{occ} – T_{empty}$.

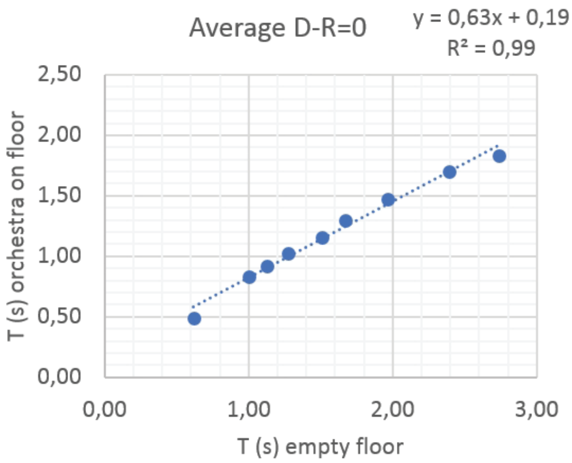

Figure 8 – *T* with orchestra on floor vs *T* with empty floor, when average D-R=0dB

Another advantage with the *D-R*=0dB requirement is that reverberant sound level, and thus the total level at musicians' ears, would be related to the direct sound from co-players, and not to the usual theoretical reference of G, i.e. direct sound in anechoic conditions at 10m distance. Reverberant sound would on average be equal to direct sound and thus the total sound level would automatically be 3dB above direct sound level.

Finally, to the present task of developing recommended *T-V* limits in the new ISO work draft, the criterion of *D-R*=0dB is inserted in the *T-V* diagram, plotted at N=37, as presented in Figure 9.

4. CONCLUSIONS, RECOMMENDATIONS AND FURTHER WORK

Collected data from 37 rehearsal rooms for symphony orchestras have been plotted in the *T-V* diagram of the work draft for recommendations in a new ISO standard. A wide variation of *T* is seen in rooms of volume less than 7000m3, interpreted as a variety in how different orchestras prioritize between reverberance versus transparency and noise control. A demand for more transparency can be an explanation for some orchestras preferring shorter reverberation times in rehearsal rooms. Sabine absorption area *A* turned out be critical metric in the data. No issues were found for rooms with *A* greater than 560m2Sa, except for one room. A criterion of *D-R*=0dB applied to a model of orchestra and rehearsal room simulated in Odeon 14 turned out to produce limits in the *T-V* diagram that were close the A=560 limit. Either of these limits seem to be a good candidate for recommendations, and the latter would be equivalent to Gade's recommendation for 70 musicians or more. Transparency is a perceptual aspect of *A* due to its implications on reverberation distance and direct-to-reverberant balance in inter-orchestral hearing and should be considered in acoustical research and design of orchestra rehearsal rooms. The *D-R*=0dB criterion would work also for ensembles with smaller layout.

Excessive early energy, e.g. from a low reflective ceiling, appears to be detrimental and can cause problem even if the criteria presented here are satisfied. This means that any limits in a *T-V* diagram can serve as a necessary requirement but not a guarantee. In simulations it is observed that reverberation times are very much reduced by the presence of the orchestra, but less so if *A* large enough.

In planning of rooms, it is recommended to use the A>560m2Sa course start criterion, and develop the design assisted with simulations of orchestra and room in a 3D-model, aiming for an average *D-R*=0dB in the inter-orchestral sound transmission.

In future work, the data collection will be extended, and so will the work with simulations in orchestra models, introducing the detrimental effects of early energy in the study. Researchers and consultants are invited to take part in the research program by submitting data online [6].

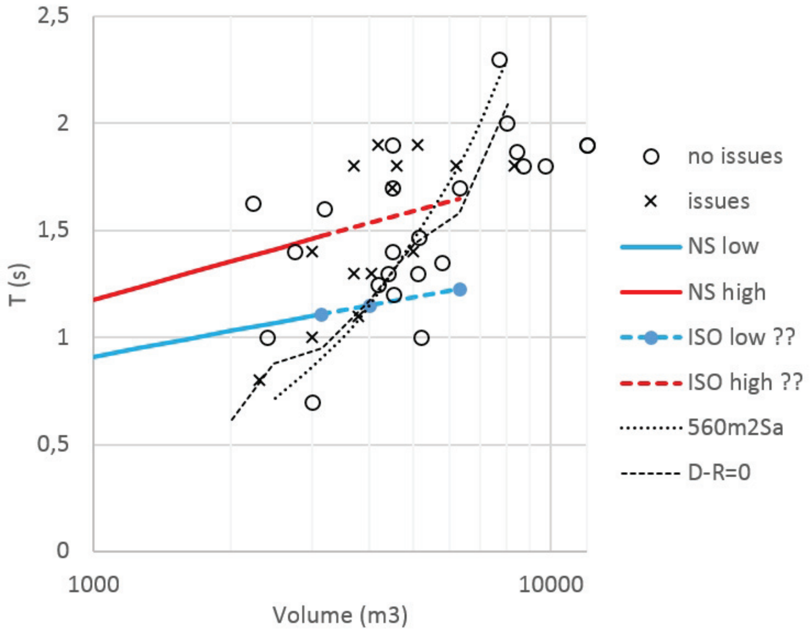

Figure 9 – plot of the data set N=37, NS-limits, possible extrapolations, "issues limit" (A=560m2Sa) and the limit corresponding to the criterion *D-R*=0dB.

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