Can acoustic renovation of an orchestra stage lead to reduced sound exposure levels of the musicians?

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1 INTRODUCTION

In 2008, the EU directive 2003/10/EC – noise was enforced in the music industry, meaning that the sound exposure levels of the musicians must not exceed 87 dB. Still, to the author's knowledge, no symphony orchestra has yet been able to demonstrate compliance. In Odense, Denmark, the Work Environment Agency recently lost patience with the local symphony orchestra, which kept sending reports to the agency about musicians' hearing damage during work. Consequently, the author was hired to see if improvement of long criticized acoustic conditions on stage in their home hall, the Carl Nielsen Hall in Odense Koncerthus, could help the orchestra to reduce their sound levels. Our hypothesis was that if the hall could be modified so that the musicians would hear each other better, they might be able to play more chamber-music-like and thereby develop a playing practice which would focus more on details in the lower range of the dynamic scale instead of primarily playing between mf and fff. This hypothesis was tested during an extensive set of experimental rehearsals with different risers, reflectors and screens being applied.

When we have discussed these matters with musicians, they often agree that they tend to play louder, if they do not hear their colleagues clearly and in reasonable balance with their own sound. If much absorption has been installed and the room does not respond, they might also be tempted to play louder. If one musician starts playing louder, those around might start playing louder as well – equivalent to the Lombard effect known from restaurants[1] - and the result will be that the entire orchestra plays too loud and often with unpleasant timbre because the players are led to force their instruments.

When it comes to the exposure levels at the ears of the individual musician, research, Wenmaekers[2] has shown that the acoustics of the room has no or very little direct influence, <u>if</u> the source power is held constant. However, musicians are not constant sound sources, they adjust their playing according to what they hear. Consequently, when the aim is to reduce the levels, it is essential that the musicians are comfortable with what they hear so they are not tempted to increase their levels beyond what is justified by artistic reasons.

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2 THE CARL NIELSEN HALL, ODENSE

This rectangular "shoe box" hall opened in 1982 and was built to be the home of the Odense Symphony Orchestra (OSO). It has a volume of 14,000 m^3 and the seating capacity as of today is 1152. Originally, it had 150 more seats; but 5 rows on the flat floor have been removed to make room for a 4 m extension of the original stage, so that its area increased from 180 m^2 to 260 m^2. Later, 24 plexiglass reflectors, each measuring about 1 m x 2 m, were installed above the stage (but not covering the brass and percussion in the back nor the strings closest to the stage front). Above the reflectors, a number of mineral wool ceiling tiles have been glued on the concrete ceiling. All the remaining main floor seating is placed on a rather steep bleacher system. RT in the furnished but empty hall is now exactly 2.0 Sec. at mid-frequencies with a 10 % increase towards 125 Hz. Fig. 1 shows the hall as of 1983. The V shaped elements seen under the concrete ceiling are intended for sound diffusion and are distributed beneath the entire ceiling area.

Fig. 1: The Carl Nielsen Hall in Odense, Denmark as it looked in 1983 before the stage was extended and reflectors were mounted above the stage.

3 PRELIMINARY SURVEY

Before the tests began, a questionnaire was distributed to all members of the orchestra to get an impression of how many had problems with loud levels, which instruments they felt were too loud or too weak and whether they were preoccupied about different possible changes being favorable or not.

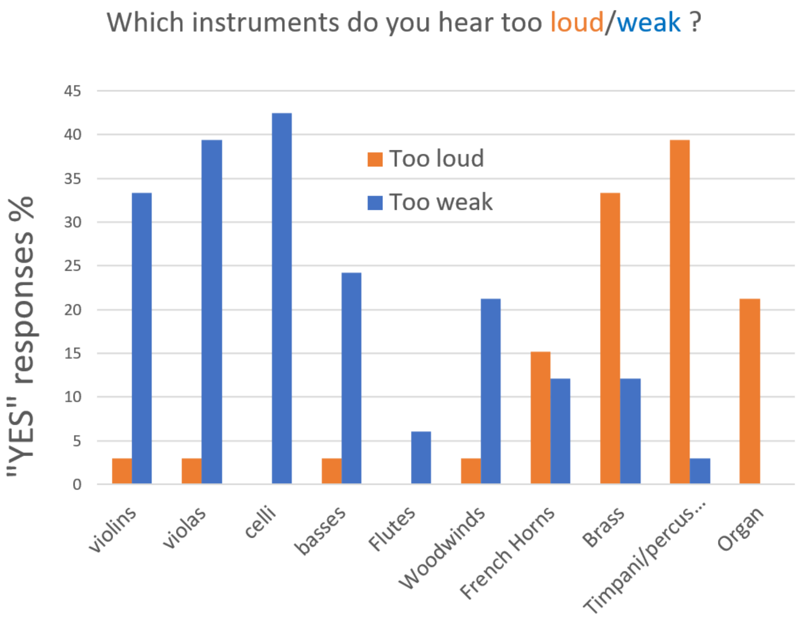

Fig. 2: Percentage of responses being positive regarding instruments being too loud or too weak

First of all, 80 % of the musicians responded that they felt the levels were too high, confirming that this orchestra faces a serious level problem.
To hear other parts of the orchestra well, it is important that each musician hears the different groups in proper mutual balance. The results regarding too weak or too loud instruments are shown in Figure 2 as the percentage of responses mentioning the different instrument groups. Not surprising, it is primarily the strings and woodwinds which cannot be heard and primarily brass and percussion, which are too loud.
The questionnaire also asked the musicians to tick “Yes” or “No” for whether they believed different measures could have a positive effect on reducing the levels. Our own hypothesis was that reduction of the general absorption around the stage and installation of more overhead reflectors would be useful. Other measures suggested in the questionnaire were more traditional ones like larger distances to loud instruments, use of hearing protection, placing of screens in front of loud instruments and installation of absorption. Also changes in the riser configuration or deliberate changes in playing style including playing softer (- if the others would reduce their levels too!) were listed for the musicians to evaluate. As shown in Figure 3, the responses indicated that a change in playing style and a willingness to reduce one’s own levels as well as improved hearing of weak instruments would help bring down the levels. Also modified risers were judged positive by more than 50% of the players.

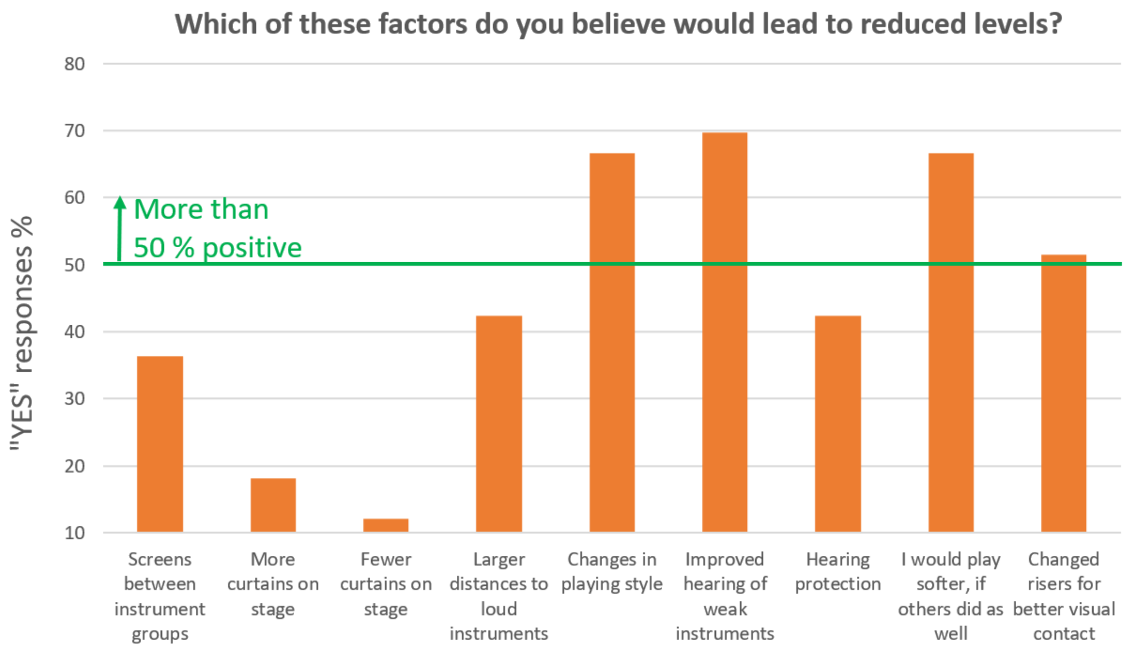

Fig. 3: Percentage of Musician responses which were positive towards the idea that different measures can lead to lower sound exposure levels

These promising results made us focus on improvement in transmission of the weaker instruments and modifying the risers in the actual experiments.
It should be mentioned that changing the playing style in an orchestra will probably take a long time – perhaps several years – and require a very focused and dedicated effort by everybody including the chief conductor and the management. Therefore, we did not expect to see the full effect of factors influencing mutual hearing during these experiments, which were carried out in the span of a few months.

4 THE MAIN EXPERIMENT

4.1 The experimental design

The experiments were carried out as orchestra rehearsal sessions on three different days: 8th and 17th November 2023 and 23rd February 2024. Each day the sessions lasted about 3 – 4 hours including breaks and musicians filling out questionnaires. A repertoire was chosen by the conductor which included excerpts from three works from the symphonic standard repertoire: Tjajkovskij's 5th symphony, first movement, Musorgski's pictures from an exhibition and Sjostakovitj 5th symphony, 2nd movement. The aim was to choose works with moderate to high – but not extreme - playing levels. The total playing time was 15 minutes. This programme was then played twice both in the beginning and end of each test day to allow for half an hour measurement of sound doses on the shoulders of ten of the musicians in the orchestra. The purpose of this was to monitor whether the levels developed during the courses of the tests. Altogether we then had six sets of level measurement data to analyze. In between these measurements, the allotted time each day was devoted to playing the same pieces according to the conductor's choice in different configurations of the hall. The configurations were selected so that either we expected, or the orchestra evaluated a positive development during the day. In other words, we were not able to carry out an experimental design fulfilling the rules of experimental design regarding blind testing, randomization and balancing of independent variables. Such considerations would have required far too much time and killed the musicians' motivation.

4.2 The chosen independent variables

The tests on 8th November started with the orchestra's standard configuration (see Fig. 4), linear risers for wood wind, brass and percussion and shallow boxes for the last rows of strings on each side. When the day was over, more of the strings had been elevated on risers and strings and woodwinds had been moved further back on the stage (closer to brass and percussion. Heavy curtains had been removed to expose more of the hard wall around the stage and in turn some absorbing pads had been placed on the floor in front brass and percussion.

Fig. 4 The Odense Symphony Orchestra in their standard configuration on the present extended stage (to be compared with Fig. 1) The blue absorbing curtains are also seen. The brass is placed in the stage left corner outside the picture to the right

The tests on the 2nd test day (17th November) started with higher risers arranged in a curve, so that some visual contact was obtained amongst the woodwinds and so that they were closer to the strings (but further away from the brass/percussion than on the end of the first day). Before the break some diffusion/absorption was also placed on the stage right wall behind the French Horns. At the end of the day, the heavily absorbing (blue) curtains had been exchanged with a less absorbing fabric (Molton) and again absorption was placed on the floor in front of brass and percussion.

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Fig. 5 The hall on November 17th (2nd day) with more and higher risers and reduced curtain area. Two of the three plexiglass reflector arrays are also visible

On the third and last test day (February 23rd), the same high and curved risers as used on the 2nd test day were installed (and had actually been used daily since the second test). The main new element was suspended tilted reflecting panels on each side of the stage and above/behind the brass section (stage left) as shown in Fig. 6. Before the break, high screens had also been installed between tympani and woodwinds. After the break, Molton was installed to cover about 400 m2 of the side and rear walls in the audience area to obtain a moderate reduction of the reverberation, and before the test ended absorption was again placed on the floor in front of tympani and brass.

Fig. 6 Tilted reflectors installed for the last day of testing, 23rd February

4.3 Results

After each day of testing, the musicians filled out questionnaires in which they indicated whether they liked the different measures presented (see Section 4.3.1) and in which direction and how much different aspects of the acoustic impression had changed between the start and the end of the test day (see section 4.3.2). Objective room acoustic measurements were carried out (without musicians on stage) in some of the many settings presented (see Section 4.3.3). Finally, the sound exposure measurements are presented in Section 4.3.4.

4.3.1 Musicians' opinions about the objective variations

Figure 7 shows the percentage of musicians appreciating the different variables tested, however, the leftmost column simply indicates the percentage evaluating the settings on the second day to be better than those on the first. This mainly relates to the higher risers arranged in a curved form being well liked, as also indicated directly in the second column.

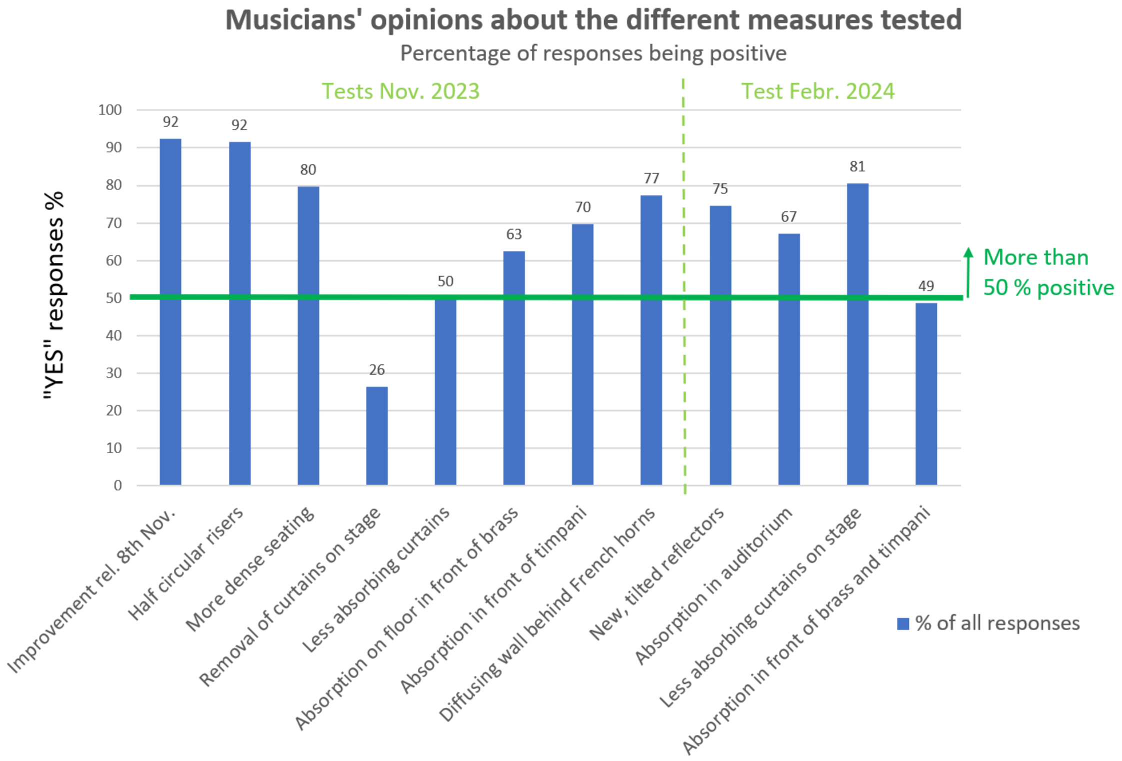

Fig. 7 The percentage of answers being positive for each of the different measures tested.

On the second day, more dense seating (with woodwinds closer to the strings), absorption on floor in front of brass and timpani and a diffusing wall behind horns were also appreciated (by those to whom it was relevant). However, reduction or removal of the curtains on stage was not preferred by most of the players. Still, on the third day, less absorption by the curtains was preferred by more than 80 % and the numbers of answers voting for absorption on the floor in front of brass and timpani were reduced as well. This might indicate that the other measures had already improved the conditions and reduced the need for absorption – or that by that time, they had already learned to play a little softer? It was also encouraging to see the very positive response to the added reflectors and to the slight reduction of RT (see section 4.3.3) in the auditorium.

4.3.2 Musicians' perception of changes in acoustic aspects

The questionnaire also allowed the musicians to scale their impressions of how much different subjective aspects changed. These were Sound level, Ease of ensemble, Ease of hearing own instrument, Ease of hearing own group, Ease of hearing other groups and finally an Overall evaluation. The individual responses were very scattered and pointing in different directions. Consequently, for all aspects except sound Level, the values averaged over all musicians did not vary more than about half a unit between the tests (see Fig. 8), while the standard deviations representing the differences in musicians' opinions were much larger (STD between 1 and 2 units). Therefore, except for the perceived level, none of the subjective aspects showed any significant variation.

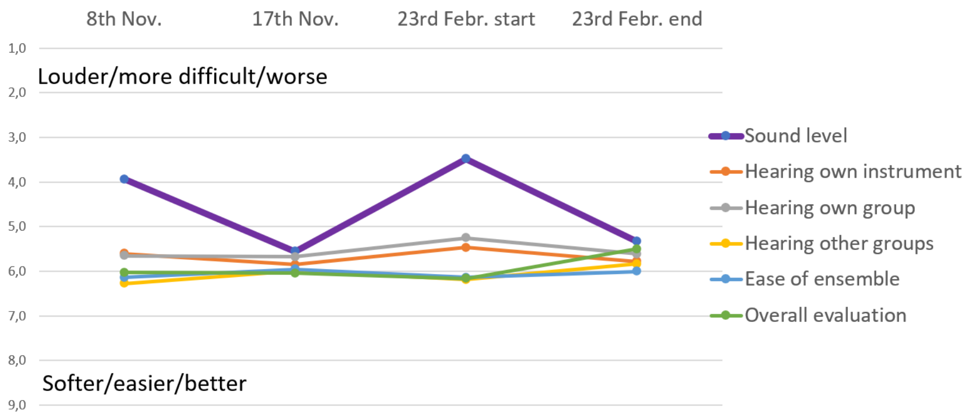

Figure 8: Development in musicians' evaluations (mean values) of different acoustic aspects over the course of the experiments

The clear trends in the averaged evaluation of level are shown by the purple curve. The left most data point indicates that musicians' felt an increase in level on the first test day when they were placed closer together and some of the curtains had been removed. The perceived level was less on the second test day, when steeper risers had been introduced and some of the curtain area had been reinstalled. The reactions to installation of the new reflectors (23rd Febr. Start) and the attempts to reduce RT in the auditorium (23rd Febr. End) should also be mentioned. Most of the musicians felt that the level increased with the reflectors installed (although the dose meter measurements indicated that not being the case!). The reason could be the dominating visual impact of the reflectors. The subsequent reduction of RT in the auditorium (from 2.0 to 1.8 Sec. at 1kHz, see Fig. 12) gave a strong subjective reaction towards the levels being reduced. Neither this result is supported by the dose measurements, as the averaged reduction in L_{Aeq} between start and end of the tests on that day is only about half a dB (see Fig. 13). As an example of the individual differences in opinion, a mapping of Ease of Ensemble after installation of the reflectors is shown in Fig. 9. Overall, the installation of the reflectors is judged positively, as most responses are green; but some are also negative, orange or red, and it is not obvious why even musicians sitting next to each other end up with opposite opinions.

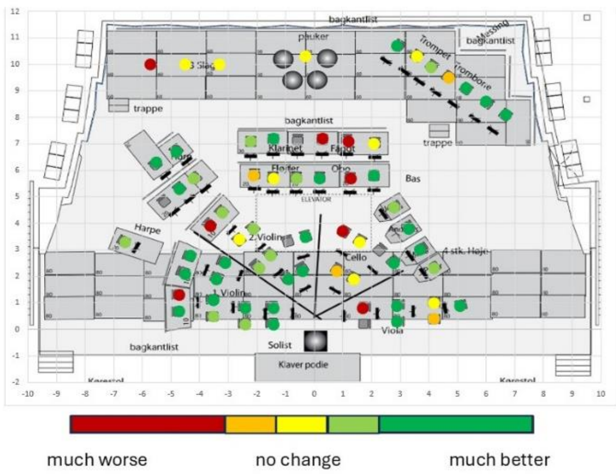

Figure 9: Mapping of the scaled perceived changes in Ease of Ensemble after introduction of the tilted reflectors

4.3.3 Objective room acoustic data

Two sets of objective room acoustic data from the stage, Support ST_{early} and EDT_p, were available representing the stage conditions before the tests started. One set from February 1983 dates to the conditions right after the opening of the hall (in 1882). The second set from February 2023 (measured under a different project) represents the conditions right before we started the experiments. Finally, we measured the same parameters twice on the last testing day (February 2024) with added, tilted reflectors around the stage and without or with the absorbing curtains in the auditorium respectively.

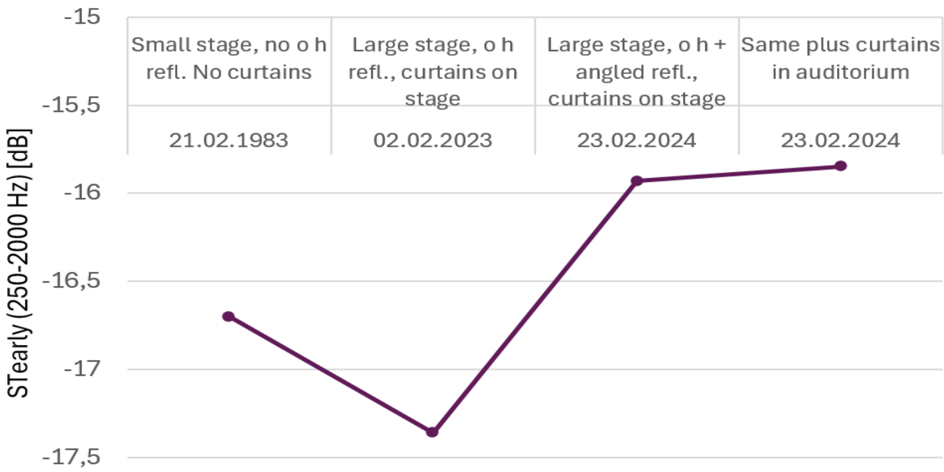

Fig. 10: Development in ST_{early} in the Carl Nielsen Hall, Odense

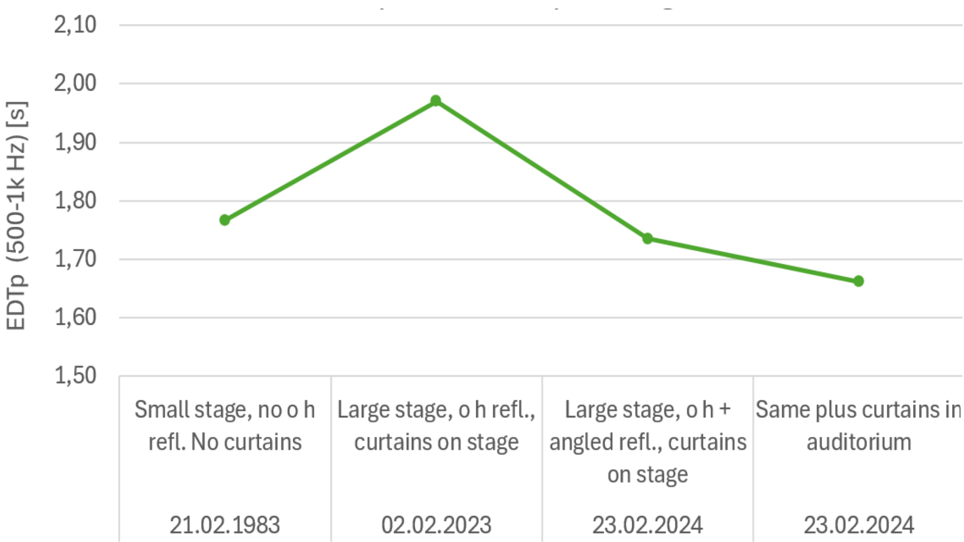

Fig. 11: Development in EDT measured on the stage (EDT_p) in the Carl Nielsen Hall, Odense

Comparison of the measurements of 21.02.1983 and 02.02.2023 indicates that the sum of the changes made in this period: installed plexi glass reflectors, removal of 5 seat rows and extending the stage, placing absorbing curtains on stage and gluing absorbing mineral wool batts on the concrete ceiling has resulted in an increase in EDT_p measured on stage and a decrease in ST_{early}. Both changes are believed to have worsened the stage conditions! However, with the reflectors added on the 3rd testing day, EDT is again reduced and ST_{early} is increased significantly. (The slight increase of 0.1 dB with absorption in the auditorium is probably just due to measurement uncertainty.)

It should be mentioned that neither ST_{early} nor EDT_p were expected to change significantly by most of the other variables introduced, such as placing diffusion behind the horn section, changing the risers and adding screens and a little absorption between different instrument groups.

The bottom line is that introducing tilted reflectors (and adding absorption in the auditorium) causing ST_{early} to increase and EDT_p to decrease were judged as improvements by the orchestra.

Fig. 12 shows the influence of the absorbing curtains installed in the audience area after the break on the last test day. Reverberation time versus frequency was measured in the audience area before (green curve) and after (blue curve) installation of Molton covering 400 m^2 of the wall surfaces. It is seen that the change is about 0.2 Sec. from 1000 Hz and up. The dotted brown curve shows that originally RT was much higher!

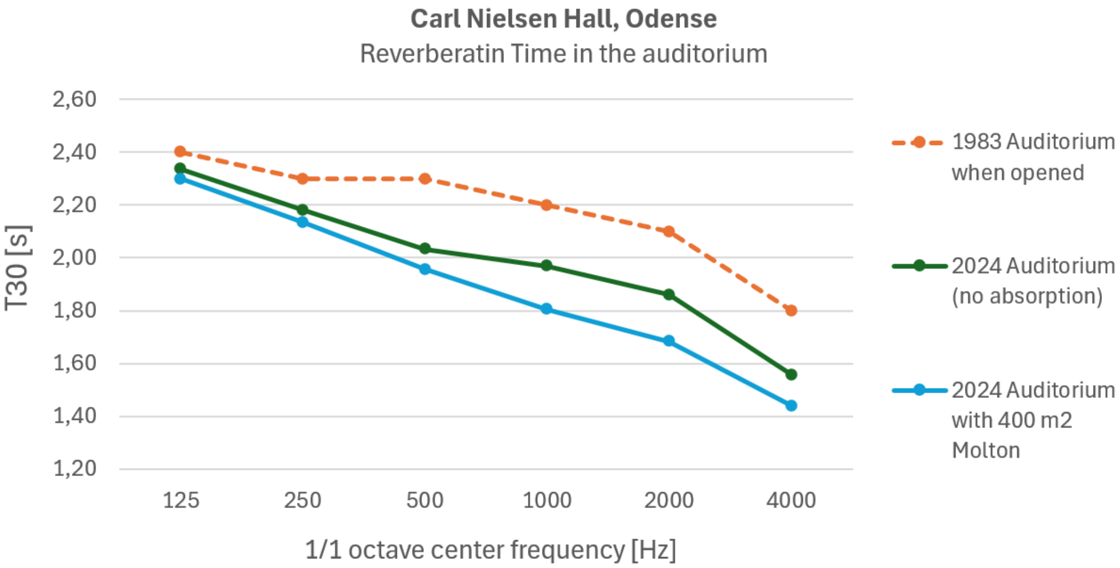

Figure 12: Reverberation Time (RT) measured in the Carl Nielsen Hall, Odense shortly after opening (1983) and during the experiments in February 2024

None of the variations introduced on the two first test days in November 2023 (changing risers and adding/removing absorption with areas less than 50 m^2 in total) had any significant influence on RT in the auditorium.

4.3.4 Objective changes in sound exposure levels

While the discussion above dealt with musicians' evaluations and the room acoustic measurements, we now focus on what the total exercise was all about: reducing the sound exposure levels of the musicians. Fig. 13, show the $_{LA,eq,\ 30\ min.}$ values measured on the shoulder of 10 selected musicians in the orchestra at the beginning and end of each of the three test days, that is six registrations for each musician. Exactly the same repertoire was played during all six occasions. The data are shown in chronological order from left to right, and the average for all ten (9 on the last day due to a failure of one dose meter) is shown as the thick, dark blue curve. As expected, the highest values were measured on the brass instrument and French horn players. Some 3 to 5 dB lower, we find the curves for the other instruments. More interesting, all but two of the curves finish at a level which is lower than that at the start. If the values were generated randomly, the probability that 8 or more out of the 10 curves would have a downward slope (the null hypothesis) is less than 5 %. Consequently, the null hypothesis of no effect is very unlikely. On average, the exposure levels were reduced by 2 dB!

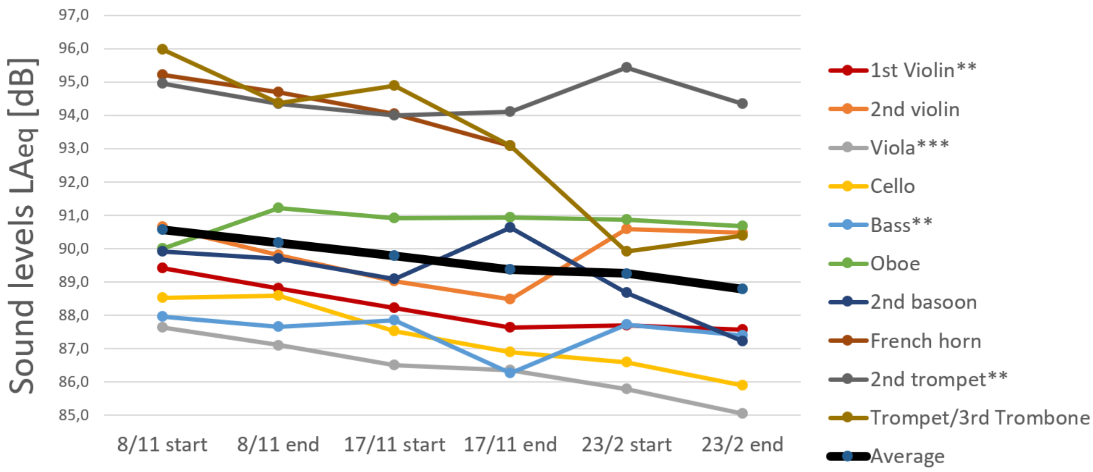

Figure 13: Sound levels, $L_{Aeq,30\ min.}$, measured with dose meters on 10 musicians during OSO tests in the Carl Nielsen Hall in November a2023 and February 2024.

5 DISCUSSION

The result regarding reductions of the exposure levels is very encouraging, indeed, but the question about what caused this result remains unanswered. Was it because we created better mutual hearing along the way or due to psychological factors such as a desire by the musicians to deliver a good result? – and would we get the same result if we measured again today, more than a year later? The conductor was well aware of the purpose of the tests; but did not encourage the orchestra to play less loud, he rightfully focused on the music. Besides, our experimental approach did not fulfill the rules of scientific experimental design. Therefore, skepticism towards the validity of the results is relevant.

The scatter in the scaling of subjective acoustic aspects by the musicians was large. This underlines how difficult it is to establish solid, statistically significant results when dealing with orchestra musicians. Still, both the musicians' evaluations of the different measures tested and the objective measurements on the stage indicated that ease of ensemble improved during the test period. The most important reasons for this result are believed to be:

1) placing most of the orchestra on semicircular risers (improving direct sound transmission)

and

2) installing tilted reflectors over the strings on each side of the stage and above the brass.

Even though the reflectors made ST_{early} increase, the values obtained were low compared to our experience and recommendations[3]. This was due to limited resources (time and money) available for the experiment. Still, the improvement might have been larger than indicated by the position averaged ST_{early} values since we attempted to design the reflectors only to increase the levels of weak instruments without amplifying sound from the loud brass - in line with the needs shown in Fig. 2.
The moderate reduction of the reverberation time in the hall caused EDT_p to decrease slightly and was judged favorable by most musicians (except the brass). Besides, smaller measures like small areas of absorption and screens near loud instruments and some diffusion behind the French horns were favorable for musicians sitting close by. Only after some practice, the musicians were ready to have some of the absorption on the stage walls removed.
Overall, the added reflectors in combination with the adjustment of absorption attempted to improve the balance between the different instruments with the purpose of improving the musicians' mutual hearing.

In this particular case, we found installation of absorption in the hall to be beneficial; but in “dry” halls it may be right to increase reverberation rather than introduce even more absorption, although this may be controversial to some and against the traditional ideas in “noise” abatement. Careless installation of sound absorbing materials near the stage may be counterproductive, if it reduces reflections useful for ensemble and clarity on stage or reduces reverberation to a degree, where musicians start forcing their instruments.
The musicians did not react specifically on the use of hearing protectors. However, after the test in which all orchestra members wore protection, the conductor, Henrik Vagn Christensen declared that session to be the least musical of all! Apparently, they had not been able to balance and nuance their playing.
The fact that the exposure levels were reduced parallel to the ensemble conditions being improved might indicate the hypothesis about such a relationship being true. This is in line with many musicians claiming that they would play less loud if they heard their colleagues better! The author has discussed this issue with Stefan Weinzierl, whose lab at TU Berlin has made several interesting experiments on musicians’ reaction to changes in their acoustic environment[4]; but no scientific proof for the hypothesis has yet been found.
Finally, an unexpected but positive outcome of the experiment should be mentioned. In the process, the musicians started showing interest in each other’s needs and problems concerning levels – instead of only thinking about their personal problems.

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Regarding the future for the Carl Nielsen Hall, permanent implementation of some of the measures are being considered at the time of writing. The first step is to design new orchestra risers. Hopefully, it will be possible to follow up with the design of new overhead reflectors.

6 REFERENCES

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