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Impact of acoustics on staff performance in operation rooms

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ABSTRACT
Of-site constructions in healthcare are getting more and more common and especially operation rooms and operation theatres that are known to be complex facilities are often being produced as modules. Hygiene demands often go before acoustic demands in hospitals and because of that a lot of operation rooms are traditionally constructed with hard non-absorbing surfaces despite the fact that hygienic acoustic absorption class A products for ceilings and walls are available. In this study at Hvidovre Hospital in Denmark - three operation rooms (one control room, two experimental rooms) were investigated in regards to 1) Room acoustics (reverberation time, speech clarity, speech transmission index and spatial decay) and 2) Staff performance. The two experimental rooms were refurbished acoustically – one room with a class A glass wool ceiling and the other room with class A glass wool ceiling and wall panels. The intervention was done as a blind study and together with room acoustic measurements before and after the room acoustic intervention, questionnaires were conducted with staff members after a period of three weeks. The results showed that even small changes in room acoustics had a high impact on staff performance and wellbeing.

Keywords: Acoustic descriptors, Healthcare, Performance
I-INCE Classification of Subject Number: 35

1. INTRODUCTION

When we are sick and feeling bad – just opening the door to a hospital makes us out of our comfort zone. Our system is already stressed and our senses therefor alert. We are more sensitive to sound and noise than normal – and in hospitals this can be a challenge.

Florence Nightingale said in 1859 that '*Unnecessary noise is the most cruel absence of care which can be inflicted upon either the sick or well!*', and a lot of research since then has been done around sound pressure levels and the impact of sound on patients.

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1.1 Patients

Patients are affected by sound levels in hospitals – and during the years the sound levels have been increasing dramatically both during daytime and night time (Busch-Vishniac et al 2005). The reason for this can be a combination of more people in the buildings, more equipment, more complex tasks – and in general more sound sources. The hospital buildings on the other hand have not changed much – and the lacking of room acoustic treatment becomes a problem.

High sound levels in healthcare facilities are known to: impair sleep, increase stress, delay post-illness rehabilitation, aggravate agitation, cause psychiatric symptoms, escalate restlessness, increase respiratory rates and increase heart rates (Wiese 2010) and the lacking of sufficient demands in regards to room acoustics descriptors in mandatory building regulations is a problem. But how important is room acoustic treatment really, if you are really sick?

It has been discussed whether a patient will be affected by room acoustic treatment and to what extend if he/ she is critically ill (or sedated) and in a study from Sweden some of the conclusions were that '*…being a patient in a sound-intensive environment were interpreted as never knowing what to expect next regarding noise, but also of being situated in the middle of an uncontrollable barrage of noise, unable to take cover or disappear*'– and '*We can no longer claim that the patients are too critically ill to reflect on the surrounding sounds and noises.*' (Johansson et al. 2012). It doesn't matter how sick you are – you will be affected by sound and noise can be very harmful to recovery. Sleep is fundamental to human health in general and critical to patient recovery. Alertness, mood, behaviour, coping abilities, respiratory muscle function, healing time and length of stay are just a few of the potential impacts of patient sleep disturbance or deprivation (Hsu et al. 2012).

Unfortunately, sound and noise in healthcare is therefore not 'just' uncomfortable for the patient, it is also known to affect the treatment and recovery itself. In a study of chest pain patients at the intensive coronary heart unit at Huddinge University Hospital, Sweden, researchers found that a good sound environment reduced patients' pulses, hospital readmissions and the need for extra medication. In comparison to this they saw the opposite trend in the bad sound environment (Hagerman et a. 2005).

1.2 Staff

Hospital staff goes to work every day – to the hospital, clinic or other healthcare facility. In comparison to the patients they are not sick and you would suppose that they feel a bit better when they open the door (!) – that they have maybe the opportunity to secure or react towards a healthy sound environment. Even though the working environment in a healthcare facility is highly affected by sound and acoustics, staff is unfortunately not often aware of it.

A recent study about theoretical knowledge about sound and noise amongst staff revealed that 1047 staff members answered in average 4 correct answers out of 10 on questions related to the impact of noise (in the questionnaire some of the themes were chronic physiological changes related to noise, maximum levels according to WHO, Acute physiological changes related to noise) (Johansson et al. 2016). This could tell us that even though staff members are 'just' at work (and not sick) they are not consciously aware of the impact of noise on patients and themselves. And why should they – their competences are about saving lives.

We know from performance studies with office workers that sound pressure levels and room acoustic conditions affect efficiency and wellbeing in general. A field study with a cross-over design by The Stress Research Institute and The Department of

Psychology, Stockholm University, recently revealed that improved sound environments were beneficial for health and performance together with less cognitive stress and less disturbances. Another interesting insight was that objective acoustic descriptors corresponded well with self-rated measures (Seddigh et al. 2015).

In hospitals communication errors can lead to fatal mistakes and in a cross-sectional survey with 84 nurses in four hospitals in the Pacific Northwest region of the United States it showed that several physical environmental factors were potentially problematic in the nursing station area and could lead to medication, documentation, and other types of nursing errors. The most problematic factor according to the survey was high noise levels (Mahmood et al. 2011).

In an advisory report based on healthcare staff reporting to the PAPSRS, Pennsylvania Patient Safety Reporting System (USA) the same trend was documented and several examples of real-life medical errors due to mishearing were published. Example: "*A physician called in an order for '15 mg' of hydralazine to be given IV every 2 hours. The nurse, thinking that he had said '50 mg' administered an overdose to the patient who developed tachycardia and had a significant drop in blood pressure*." (Pennsylvania patient safety authority 2006).

There is no doubt that hospital staff – like everyone else, is affected by sound, noise and acoustics when they try to do their tasks, and it is highly important that acoustic standards and guidelines for healthcare facilities are prioritized.

The World Health Organisation recommends that since patients have less ability to cope with stress, the average sound levels should not exceed 35 dB in most rooms in which patients are being treated or observed – and in ward rooms, the equivalent sound levels should be 30 dB (and the noise peaks during the night should not exceed 40 dB) (Berglund et al. 1999) – and even though this recommendation might be impossible to meet, it makes sense – for both patients and staff to aim for better sound environments in hospitals.

2. OBJECTIVE ACOUSTIC DESCRIPTORS

2.1 Standards and lacking of descriptors

Standards, guidelines and mandatory building regulations on room acoustics in healthcare facilities are often lacking – and if they do exist they often only include values for reverberation time (RT) despite the fact that a long tradition of research shows that multiple acoustic descriptors are necessary to secure good room acoustics in working environments (Bradley and Sato 2003, Bradley et al. 1998 + 1999).

As an example, Denmark has for many years had quite strong mandatory acoustic demands for buildings in the education sector. Since 2008 the building regulation (Bygningsreglementet 2008) for day care centres (and in group rooms in schools) has demanded RT≤ 0.4 sec., and in open learning environments the regulation points to a guideline (SBI anvisning 218) that set values for both RT, spatial decay (Dl_2) and STI. At the same time there has not been any mandatory demands for hospitals or healthcare facilities – and it is not until late 2018 that a new set of guidelines for hospitals were implemented in the mandatory building regulation. Up until then there was 'only' a vague guideline on RT.

For staff members the rooms in the healthcare facilities should support speech and communication, and acoustic descriptors such as RT, Clarity (C_{50}), Deutlichkeit/Definition (D_{50}) and Speech Transmission Index (STI) are known to support both low noise levels, good speech intelligibility and sufficient signal-to-noise ratios, but calculations and measurements of RT alone are still the preferred descriptor (Bradley and

Sato 2003, Bradley et al. 1998, Bradley et al. 1999). On top of that the ISO 3383-3 includes several other descriptors - that are also not generally implemented in larger open spaces in healthcare settings.

2.2 Reverberation time

RT was developed by W. Sabine in the 1890s and still remains the preferred descriptor even though most traditional healthcare facilities cannot be described as a diffused sound field since most of the absorption material (if any) is on one surface; the ceiling.

The diffuse field is only a theoretical condition almost impossible to obtain practically in reality. When we have absorption on one surface only the decay will not follow a straight line according to the theory but will be split in an early part correlating more or less to the theory and a late part with a longer RT (Nilsson 2004 Part I + II).

RT is defined in ISO 3382-1 as the time it takes for sound source to decrease in level by 60 dB after the source emission has stopped. RT is more commonly measured over a 20 or 30 dB range (T_{20} and T_{30}) starting 5 dB below the initial level and then extrapolated to the full 60 dB range.

In healthcare facilities in many countries in Europe T_{20} (and/or T_{30}) is the only acoustic descriptor that is evaluated – and sometimes only in the mid frequency range. In comparison to T_{20} and T_{30} the rate of the first 10 dB of the decay is more related to the perceived reverberance and this can be measured by the early decay time (EDT) (Barron et al. 1995) .

According to the standard the evaluation of a measurement of T_{20} and T_{30} starts 5 dB below the initial level which can be problematic since this part of the decay contains a lot of information – both direct sound and early reflections – important for the perception of sound and speech clarity. The human ear analyses so much more than the defined RT but the simplicity of the Sabine formula and the fact that only one single number is ‘enough’ to describe the acoustic quality of a room might be the reason why RT – calculated (and/or measured) – has been preferred for many years (Lochner and Burger 1964).

All this considered it is interesting to investigate how hospital staff is affected if not only reverberation time is changed in a field study – and to see if very little differences in RT together with differences in values on other descriptors will affect how hospital staff perceive the operation room (OR). In regards to critical areas, like an OR, we know that there will be a different cognitive workload for different type of staff during the surgery and that sound therefore will affect staff differently during the different stages of the operation (Keller et al. 2017). Knowing that hygiene demands in hospitals go before acoustic demands it is also very much interesting to learn if we with today’s disinfectable and cleanable acoustic ceilings and walls can make critical areas more sustainable for the people working in them.

3. METHOD

The study took place in Hvidovre Hospital, Denmark, and the main goal was to explore whether altered acoustics in operation rooms would affect the staff and if yes in what way. Three rooms were part of the study; one control room and two experimental rooms. The study had two aims and was therefore divided in two parts. The first aim was to see what would happen to room acoustic values if acoustics were altered in two operation rooms (OR) and compared to an OR without acoustic treatment (control room OR4 – original ceiling treatment, experimental room OR5 – modified ceiling, experimental room OR6. – modified ceiling and walls). The room acoustic descriptors RT (T_{20} and EDT), C_{50}, STI and Dl_2 were measured. The second aim was to see if the measured acoustic descriptors would correspond with staff self-rated measures in regards to well-being, communication, mistakes and impact of sound environment in general in the three rooms. The study was done as a blind study and 15 staff members answered questionnaires 4 weeks after the acoustic intervention of the two control rooms.

3.1 The rooms: OR 4, 5 and 6

At Hvidovre hospital the OR department is structured in a way to make it possible for surgeons and staff to attend operations in several rooms at the same time which means that the rooms are placed next to each other in a corridor. The ORs in the study were just next to each other and had the following dimensions:

- OR 4: 38.6 m2, 135 m3
- OR 5: 40.2 m2, 131 m3
- OR 6: 38.6 m2, 135 m3

The sound-absorbing ceilings in OR 5 and OR 6 were installed in the centre of the ceiling and covered 14 m2 (fig. 1. blue marking). The wall absorbers in OR 6 were installed as a frieze where the ceiling meets the walls – in total 21.6 m2 (fig. 1. red marking).

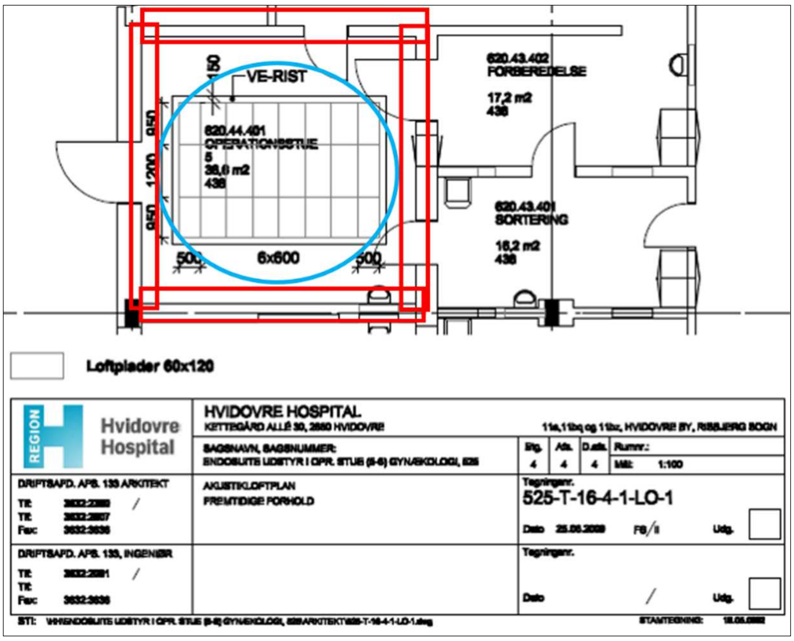

Figure 1.
Placement of acoustic ceiling (blue marking) and sound absorbing wall panels (red marking).

4. RESULTS

4.1 Measurements

Acoustic measurements were done by the engineering company COWI and according to ISO 3382-2 using the software programme DIRAC. The impulse response measurement was made with an exponential sweep and 2-3 source positions and a total of 12 source-microphone combinations were done in all the rooms. An overview of values can be seen in figure 2.

	OR 4	OR 5	OR 6
T_{20}/sec. (average 125-4,000 Hz)	0.7	0.6	0.5
STI (distance)	0.65 (1.3 m) 0.65 (1.9 m) 0.64 (2.6 m)	0.74 (1.8 m) 0.62 (2.4 m) 0.60 (2.4 m)	0.70 (1.8 m) 0.72 (2.2 m) 0.65 (3.1 m)
C_{50}/dB (average 125-4,000 Hz)	5.2	6.5	6.8
DI_2/dB	2	2.6	2.8

Figure 2.
Measured room acoustic descriptors – mean values 125-4000 Hz.

4.2 Danish guideline for hospitals

If we look into the measurements in regards to the Danish guidelines for room acoustics in hospitals, the only parameter is RT (T_{20}). At the time the guideline suggested 0.8 sec. (125 Hz can exceed with 20%) in all hospital rooms (with the new guideline the demand is 0.6 sec). See figure 3.

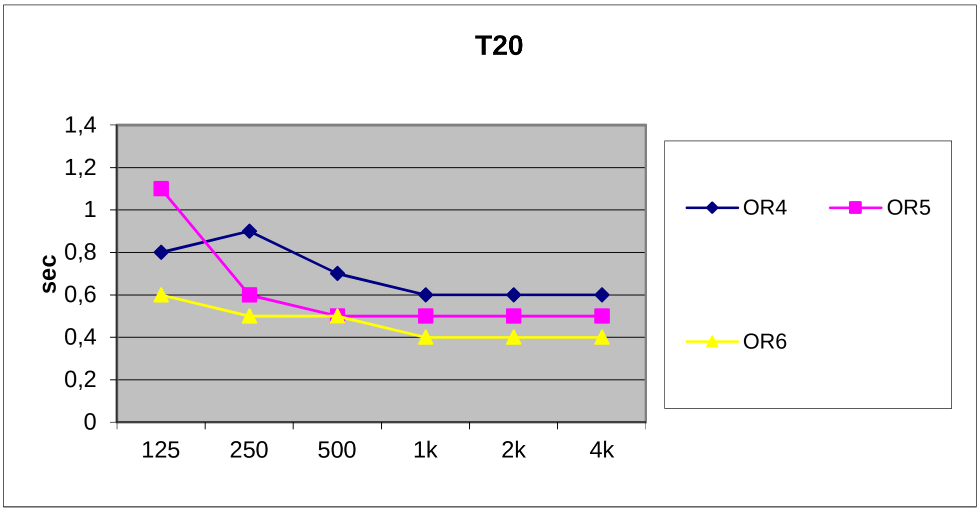

Figure 3. Values for T_{20}

4.3 Questionnaires

Questionnaires were handed out to the staff 4 weeks after the acoustic intervention and the questions asked were as follows:

- Does the sound environment affect the quality of your work?
- Does the sound environment affect the patients?
- Does the sound environment affect concentration?
- I can easily communicate with my colleagues without disruptions (of noise).
- The sound environment is stressful.

- The sound environment sometimes causes headache.
- The sound in the room makes me tired.
- The sound in the rooms feels dampened and calm.
- The sound environment causes mistakes.
- The sound environment causes the voices to get louder and louder.
- The sound environment feels calm even when we are many people working.
- The sound environment is calm and does not cause misunderstandings.

For every question the staff could tick off either totally agree, agree, neutral, somehow disagree or totally disagree. Questionnaires were completed for every one of the 3 ORs on different days (e.g. if one staff member was in OR4 a Monday and OR5 Wednesday, he/she would do the questionnaire the same day as he/she worked there). The tendency was clearly that the staff members felt better in the treated rooms and some of the results can be seen in figure 4, 5 and 6.

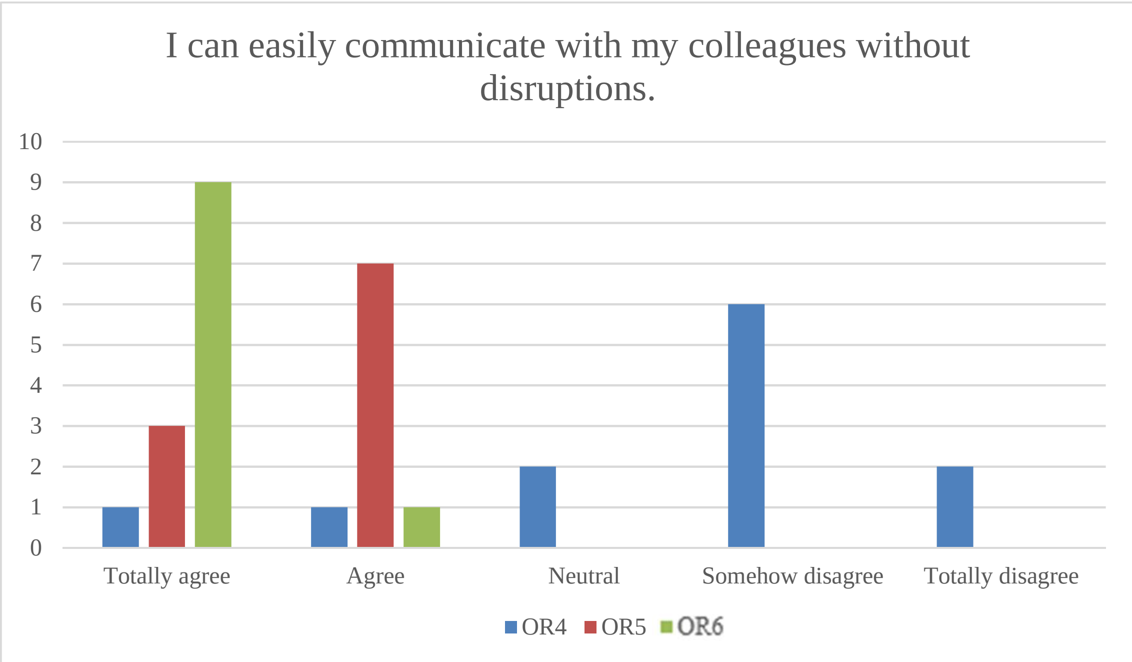

Figure 4.
Results for the question: I can easily communicate with my colleagues without disruptions.

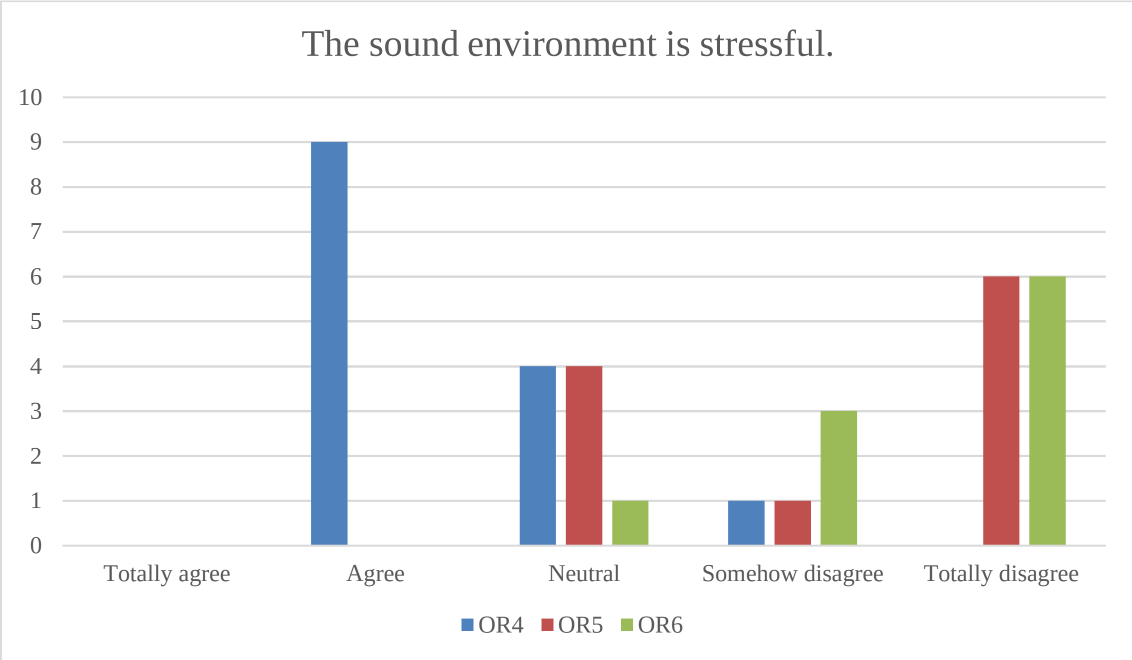

Figure 5.
Results for the question: The sound environment is stressful.

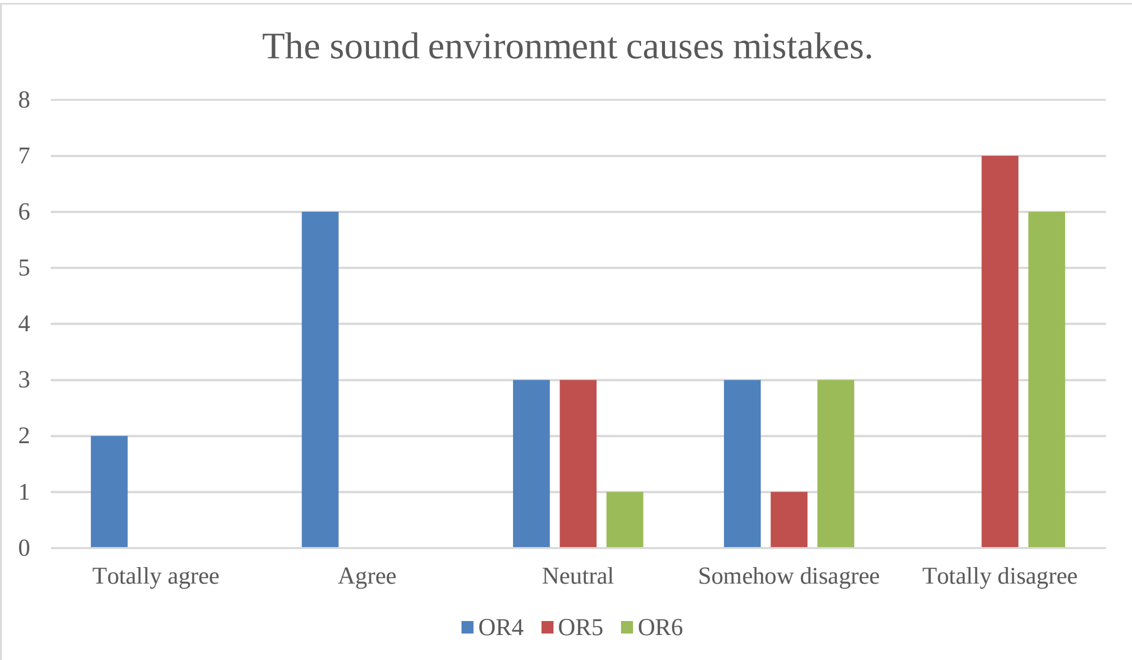

Figure 6.
Results for the question: The sound environment causes mistakes.

5. DISCUSSION

The aims of the study were to see what would happen to room acoustic values if acoustics were altered in two ORs and compared to an OR without acoustic treatment. The second aim was to see if the measured acoustic descriptors would correspond with staff self-rated measures in regards to well-being, communication, mistakes and impact of sound environment in general in the three rooms.

5.1 Room acoustic values

It is clear that when acoustics are altered in the two ORs room acoustic values change to the better. But how much actually? When looking at fig. 2 we see only small changes on the general average values in all evaluated acoustic descriptors. The reason why we did this 'average' table is that this is often what the project group often sees in a building process. You could most likely find people that would argument that the step from OR4 to OR5 in regards to RT has no consequences and that is isn't worth the money nor the time to go from OR5 to OR6 event though the just noticeable difference for RT is 5% (Seraphim 1958).

5.1.1 Reverberation time

If we take a look into RT based on the octave bands (fig. 3) we see a more detailed picture. We see that the curve changes from OR4 to OR5 especially on the low frequencies (and that OR5 actually has a strange 'hop' on 125 Hz). OR5 would, despite, the 'hop' live up to the new Danish hospital standard – where OR4 doesn't. It is interesting though to see that even when adding the frieze of wall panels, the curve gets more uniform and RT drops a bit more. Often, long RT on 125 Hz and 250 Hz are known to affect speech intelligibility negatively (Canning and James 2012) which could be a problem in OR 4 (maybe OR5) and a way of solving this could generally be to work in more dimensions than just the ceiling (which is actually making the room more diffuse).

OR6 must be considered a good room in regards to RT – just below 0.6 sec. on 125 Hz and decreasing on the higher frequencies. If we compare this actual room to a similar room in schools I Denmark – a group room meant for peer-to-peer work, group work or similar activities, the standard has a mandatory demand to reach 0.4 sec. (Bygningsreglementet 2008), which is exactly what this room does. We could compare the operation situation to a 'group work situation'/project based situation so even though the activities are very much different from a school situation to an operation event, it would make sense to discuss whether the new standard for hospitals is actually good enough or if the demands should follow the mandatory demands for education facilities.

5.1.2 C_{50} and STI

When we look at average values on C_{50} and STI we don't see a 'straight forward trend'. On STI the acoustician chose to not have exactly the same distances from room to room and it 'blurs' the picture a bit. If we look at distance OR4 1.9 m., OR5 1.8 m. and OR6 1.8 m. we see an expected improvement from OR4 to OR5 but then it drops from OR5 to OR6 – yet still we see an improvement from OR4 to OR6 on the numbers but they all fit in the 'good' level. On the longer distances OR4 2.6 m., OR5 2.4 m. and OR6 2.2 m. we see a negative drop from OR4 to OR5 – but a positive change from both OR4 and OR5 to OR6. Again all values are in the 'good' level and therefore wouldn't be considered to be really important changes. In comparison to STI C_{50} shows a clearer trend. In fig. 3 we see values for 1 m. distance and from OR4 to OR5 to OR6 we see an improvement every time we alter the room. On the distance 2.4 m. (not in the figure) we see an even bigger change since OR4 shows 2.4 dB, OR5 3.7 dB and OR6 5.7 dB. This does not follow the trend for STI (that had a negative drop from OR4 to OR5) but shows that we have – for C_{50} – an improvement on +3 dB from OR4 to OR6 that is quite remarkable. There is one common trend between STI and C_{50} though – and that is that there always is a positive change from OR4 to OR6.

5.1.3. Dl_2

The values for Dl_2 shows a step by step improvement in general from OR4 to OR5 to OR6. It can be discussed whether it is relevant to include Dl_2 in this study since the rooms are 38.6-40.2 m2 and that special decay then is less interesting. What we could say about Dl_2 in this study is that we do have hard surfaces in the room (the walls near the sound sources) and it would be difficult (and maybe not for the better) to have a higher value. You still need some feedback from the room to secure that communication is not 'lost' from one staff member to another across the room.

In general, the results for the measurements show that there is an expected correlation between especially T_{20} and C_{50} – but we have to look into the details to see the whole picture. The unexpected hops and drops on STI are hard to explain – but another round of measurements could maybe be relevant. Overall there is no doubt that the acoustic treatment makes the room acoustic quality from room to room better and when we discuss all the parameters together the trend is clear. If we only look isolated on one parameter, we could conclude that the changes are not really important – but the picture changes when all values are considered together.

5.2 Questionnaires

The three questions chosen for this discussion show that there is a correlation between room acoustic results and staff self-rated measures in regards to well-being, communication, mistakes and impact of sound environment in general. The trend is clear in regards to OR4, that this room is considered to be less popular. For all of the questions this room stands alone when negative evaluations are done (keep in mind that this room actually lived up to the old acoustic guideline). The trend for OR5 and OR6 is a bit more 'blurred'. The overall tendency is that OR6 is most popular if we collect the scores in total and regardless the question, but when we look at each column for each question sometimes the best score goes to OR5 (considering the best score is the column 'totally agree/disagree'). This can be seen in fig. 6. On the other hand, if we look closer at fig. 6 and focus on the more positive columns together we see that OR5 takes a drop from 'neutral' to 'somehow disagree' whereas OR6 takes the 'expected' hops from 'neutral' to 'somehow disagree' to 'totally disagree'. We need to keep in mind that the answers are not statically significant and that the questions could be leading so these result only shows a tendency. It would be really interesting in the future to integrate questionnaires in room acoustic studies to learn more about what improvements on numbers actually means for the end-users.

6. CONCLUSION

The overall goal of the study was to explore whether altered acoustics in operation rooms would affect the staff and if yes in what way. Also, it was important for the study to investigate if evaluating more acoustic descriptors would give a better picture of the room acoustic qualities than if RT alone was evaluated. The overall conclusion is that an acoustic ceiling alone will improve room acoustic results but if we want constant positive staff feedback/satisfaction we need also to add wall panels in the OR. When we include more descriptors than just RT we get a better picture of what the sound environment can 'support'. The activities in an OR are complex and besides keeping the sound pressure levels as low as possible, speech clarity need to be considered together with RT – and both STI (the subjective consideration) and C_{50} (the objective consideration) have to be part of the evaluation. Spatial decay might not be really important in smaller ORs – but should definitely be evaluated in e.g. bigger hybrid ORs. Finally, it can be concluded that staff self-rated measures in regards to well-being, communication, mistakes and impact of sound environment correlates with room acoustic improvements.

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