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Staff experience of sound environment in operating rooms built with non-absorbing modules

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ABSTRACT

Modular solutions for operation rooms made of glass and metal adversely affect the sound environment as the absorption of sound is non-existent. The requirement for Reverberation Time (T20) in operating rooms is according to Swedish Standard 25268 < 0.6 seconds. Modules without additional acoustic supplement are calculated to around 2.0 seconds.

In our research the modular ceiling was replaced with an Absorption Class A ceiling according to ISO 11654. Both normal sized rooms (65m²) and the Hybrid room (105 m²) were treated with absorbents. To gain better understanding on the sound environment we also measured Speech Clarity (C50) in addition to reverberation time. All acoustic requirements were fulfilled and this paper aim to evaluate how the staff perceives the sound environment in these rooms. Information will be obtained by questionnaires sent to 78 staff at Sundsvall hospital. The hospital performs 11000 procedures a year in 15 operating rooms. Procedures contains of common surgical, gynecological and orthopedic operations, as well as hernias, cancer, ear-nose-throat and fractures. Operating times varies from short to long and staff alternates within all procedures, the unit is open during evening and night for emergencies. Questionnaire consists of both multiple-choice and open questions.

Keywords: Operating room, Staff, Sound environment

1. INTRODUCTION

Noise levels have steadily increased in hospital over the last >40 years, both day time and night time (1). The noise level in operating rooms can be particularly difficult and research shows that this may affect the ability of the staff to perceive proper oral instruction; it also affects their perceived stress and well-being. Sound peaks can reach 110dB when saw and drill are in use (2). Kracht, Busch-Vishniac and West showed, in a study from 2007 in Johns Hopkins Hospital, that orthopedic surgery was found to have the highest L_{eq} at approximately 66dB(A). Neurosurgery, urology, cardiology and gastrointestinal surgery followed closely ranging from 62-65dB(A). For neurosurgery and orthopedic surgery peak levels exceeded 100dB over 40% of the time (3).

Medical errors due to noise are a safety concern that needs to be prevented in all possible ways. Staff reports that they find it difficult to properly hear what is being said and misunderstandings, due to reduced intelligibility, is a common problem (4). Misunderstandings might not be of life threatening sort but seem to delay procedures such as that the wrong size of requested material is collected from outside the operating room (2).

It can also be difficult to determine the origin of alarm signals from the technical devises due to reflection of the soundwaves between walls, floor and ceiling. Assessment of distance and direction is very well developed for the human ear in a setting without disturbing reflexes but it will be negatively affected in a confined space with multiple sound sources.

What can be done to reduce noise? It requires a combination of actions; use of sound absorbing materials to deal with excess sound energy and unwanted reflections, functional and operational sounds from the medical technical devices as well as their alarm sounds and settings together with

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alteration of human behavior (5). Sound absorbing material can improve the sound environment as shown in several studies and the effect has impact on both staff work environment, wellbeing and stress as well as patient experience of received care (6, 7).

In this building project, the client had chosen a complete package solution for the operating rooms with a modular solution that enables great flexibility for future changes in the building. All the technology and displays available on the wall surface are integrated in the module unit. This gives maximum use of surface and is functional and hygienic. The visual impression of the room is beautiful and perceived as pure and aesthetic and building time is heavily reduced and often enable the ongoing work in other operating rooms to continue without much negative affect from the building area as with traditional building work. However, there is a disadvantage of modular solutions; floors, walls and ceilings adversely affect the sound environment as the absorption of sound is more or less non-existent. This is due to the module material properties of glass and metal, which instead of decreasing the reverberation time instead contribute to increase it. The requirement for reverberation time in operating rooms is according to Swedish Standard 25268 0.6seconds or lower (8). Verification that these requirements have been met can be achieved in one of two ways. Either an acoustical measurement according to SS 3382-2:2008 (9,10) or a calculation of the values in conjunction with an inspection of the building site.

With the building materials used and the shape of most room types we find that sound waves are being reflected back and forward with very little sound absorption and decrease of the sound energy. Hard, reflective materials affect sound in a non-desirable way and sound pressure level is far exceeding the World Health Organization limit of L_{eq} 35dB(A) (11). The metal ceiling included in the modular package (Hospitaltechnik, DE) was decided to be replaced by a sound absorbing ceiling instead. The same grids and original measurement for the ceiling tiles was used. The product chosen was a glass wool mineral absorbent *Ecophon Hygiene Performance*™ 40mm (Saint-Gobain Ecophon, SE) with Absorption Class A, α_w 1,0 (12,13). The absorbent fulfill all cleaning requirements for high specialist area (methods, cleaning agents and disinfection according to national practice). Absorption Class A is the highest class and has a very good ability to absorb sound energy. It was used as a comprehensive ceiling solution with the exception of the Laminar Air Flow (LAF) ventilation, pendants and lighting, giving coverage of approximately 80% of the total ceiling area. No absorbents were mounted on the wall. Reverberation time (T20) was measured to 0,6seconds after the ceiling had been installed

Sundsvall Hospital is a Regional hospital with approximately 11000 visits/year. It consists of 15 operating room of 65m^2 where all but one has advanced ventilation, laminar air flow (LAF). The Hybrid operating room of 105m^2 has been used as a normal operating room during the first year after installation and the hybrid usage started after the collection of answers in this survey. Procedures contains of common surgical, gynecological and orthopedic operations, as well as hernias, cancer, ear-nose-throat and fractures. Staff rotates in all rooms and work with all procedures mentioned. The majority of procedures are planned ahead but emergency procedures are a part of the weekly work and can also be done during late evening and during the night. Operating times varies from short to medium and long. Staff normal working hours are either 8,5 hours or 9,5 hours per shift, during the night shift another five hours of on call duty is added. A lunch break of 45min is mandatory and the staff can leave the operating department during that time. In the operating room all operating staff wears a full head coverage and mouth protection, anesthetic and assisting staff only have the hair covered.

The staff consists of 28 registered operating nurses, 32 registered anesthetic nurses, 18 assisting nurses and a fluctuating number of surgeons. Surgeons are not included in this survey. All 78 nursing staff have been employed more than two years meaning that they worked in the previous non-refurbished operating rooms and have experience of a different working environment. The survey consists of 13 multiple choice questions and one question with a possibility to add comments in free writing.

2. METHOD

The survey consists of three more general questions around the sound environment in the operating room with a four scale answer possibility (such as does the sound environment affect the patients wellbeing). Followed by eight question with a specific aim towards different issues (such as ability to hear the direction of a sound source) with a three scale answer possibility. Nest question is a multiple choice question that includes human speech, technical equipment and sounds from the room (such as

ventilation, opening of doors). The technical equipment question was presented as operating sounds (such as engine, fan), functional sounds (such as suction, sawing) and alarm sounds (such as blood pressure, heartbeat). The following question regarded their function and placement in the room where they stated if being part of the operating team or the anesthetic team. Next question asked if they had been employed at this department for more or less than two years. Last question was and open question where the respondents could express any comment in free text.

All 78 staff were invited to take the survey during a four-week period in February and Mars 2019. Surveys was distributed by the department manager to their individual post boxes with an introduction letter explaining the reason for the survey and the contact details to the author. Surveys were anonymous and respondent were to place it in a common envelop that was posted to the author at the finishing date. The collection of data could have been performed digitally but the department manager believed it would be less work for staff to fill in the paper as they had very limited time accessing a computer. In total we received 30 answers and they were processed in a digital tool for numerical presentation and graphs.

3. RESULT

30 answer were received and 15 came from the operating staff, abbreviated OR in the following text, and 15 from the anesthetic staff, abbreviated AN. All respondents have worked in the ward since before the reconstruction i.e. more than 2 years. Most staff have worked there for many years and the turnover on staff is low. In the free field to comment five comments where received, four out of those were from the AN staff.

Q1: Does the sound environment have an impact on your ability to do a good job? The sound environment seems to be of significance as 90% answered *very important* (43.3%) and *rather important* (46,7%) to this question but two respondents from the AN staff thought it had *very little* (6,7%) significance.

Q2: Does the sound environment affect how the patient feels? When turning the focus towards the significance of the sound environment for the patience wellbeing, the importance is expressed as *very important* (33,3%) and *rather important* (40%) with a total of 73,3%. Meaning that 1/3 of the staff didn´t think the sound environment had much importance for the patient during surgery. There was no difference between the answers from OR and AN staff.

Q3: How do you experience the sound environment in general in the operating room? The staff seemed very content with the sound environment in general in the operating room. *Very good* (17,2%) and *good* (65,5%) gives a total of 82,7% that is happy with the present environment. Five people answered *poor* (17,2%) but no one answered *very poor* (0%). There were more staff on the OR team answering that it was *poor* (24,1%) than on the AN team (13,3%). Only one of those (AN) left a comment in the free text box about the functional sound of gas extraction. Comparing to the previous enquire (14) with a total of 154 staff (mixed OR and AN) the overall perception of the sound environment scored more positively in this survey. The previous one scored *very good* 0%, *good* 16,7%, *poor* 71,3%, *very poor* 12%. Overall positive responses.

Q4: The sound environment affects my well-being? Only one person (3,3%) didn´t think that the sound environment affected their wellbeing at all. 63,3% thought it had an impact (*agree fully*) and 33,3% answered that it *partly* had an impact. The OR staff scored 80% on *agree fully* and 20% on *agree partly* as to compare with AN staff scoring 46,7% on both.

Q5: It is easy to perceive speech in the operating room. Roughly half of the respondents choose the middle alternative *agree partly* to this question. 11 out of 30 people thought it was easy to hear spoken communication, *fully agree* (36,7%), and 3 out of 30 did *not agree* at all (10%). The groups did not differ much on this question. Comparing to our previous enquire (14) the responses *agree fully* has risen from 11% to 36,7% and the do *not agree* has fallen from 22% to 10%!

Q6: The sound environment feels comfortable? The majority *agreed fully* that the sound environment felt comfortable (26,7%) or *agreed partly* (66,7%) with a total positive score of 93,3%. There was a slight overweight to the *fully agree* in the AN group. Two people did not agree at all and choose the do *not agree* option. The overall difference between the two groups may be connected to both work tasks and placement in the room as the possible disturbances differs somewhat as shown in Q11.

Q7: It is easy to hear where the sound is coming from. The majority of answers (67,7%) *agree partly*, 30% *agree fully* and one person (3,3%) does *not agree* at all. Comparing the two groups the AN staff were more positive on being able to determine the direction of the sound source as shown in Figure 1.

Figure 1 - Q7: It is easy to hear where the sound is coming from

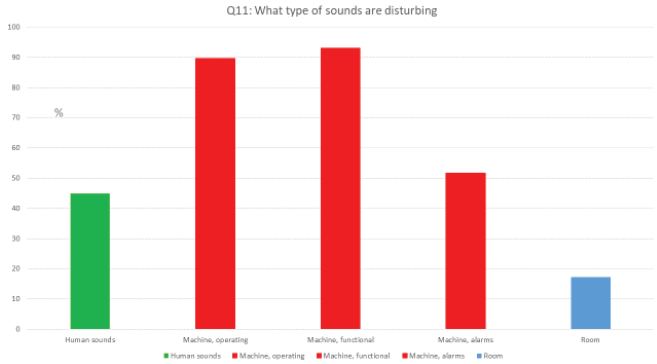
Could this be that they primarily have their focus on the sounds coming from the medical technical equipment located in their zone in the operating room? The direct sound reaches them with no obstacles interfering? Comparing with the previous enquire (14) the *fully agree* group has risen from 11% to 30% and the do *not agree* at all lowered from 21% to 3%!

Q8: The sound environment makes it easy to concentrate. Only 6,7% answers fully negatively with do *not agree* at all. 30% are positive (*agree fully*) and a large section of 63,3% says *agree partly*. There was very little difference between the two groups. There is however a striking difference to the previous enquire (14) with the *agree fully* rising from 10% to 30% and an even larger shift in the do *not agree* with a decrease from 52% to 6,7%. The staff in this survey found it considerable more easy to concentrate.

Q9: The sound environment sometimes causes us to misunderstand each other. 13,3% (four people) answers do *not agree*, but the majority of answers *agree partly* meaning that 67,7% relate the sound environment to the risk of misunderstandings occurring in the operating room. 20% agrees fully that such misunderstandings may be related to sound. There is no difference between the two groups. As a comparison to the previous enquire (14) the perceived risk of misunderstanding has fallen from 83% to 67,7%. The fully agree has halved from 41% to 20%.

Q10: The sound environment feels good even when we are many and have a stressful shift. The *agree fully* (20,7%) and do *not agree* (17,2%) shows two opposite answers very distinctly with the rest choosing the mid-alternative *agree partly*. Sub diving it shows that OR staff feel more affected when work conditions are more strained and more staff are present in the room. Their do *not agree* scores 26,7% as compared to the AN that only scores 7,1%. Understanding this may be explained by the nature of the work, if the stress level increases it might be more likely that it is on the OR side of the procedure there is a complication and need for more staff and quick decision and handling of more instruments?

Q11: What type of sounds are disturbing? *Human sounds* such as speech is seen as disturbing by 44,8% of the respondents, AN staff had a slightly higher score than OR. Machine made sounds are divided into three categories where the *operating sounds* (such as engine or fan) is seen as disturbing by 89,7% and *functional sounds* (such as suction, sawing) are seen as disturbing by 93,1% of the staff. *Alarm sounds* (such as for heartrate or blood pressure) scores lower with 51,7% as shown in Figure 2. *Other sounds* in the room (such as ventilation or closing doors) rate the lowest of 17,2%. In both total score and divide into the two groups, *functional sounds* by the machines are the most disturbing noise. 27 out of the 29 respondents ticked this option in the survey. OR staff were not as disturbed by *alarm sounds* and *other sounds* in the room as the AN staff. Possibly related to their placement in the room and distance to the technical equipment as well as often having their back against the room facing the surgical site?



Answer choices	%	Respondents
Human sounds (speech)	44,83	13
Machine operating sounds (engine, fan)	89,66	26
Machine functional sounds (suction, sawing)	93,10	27
Machine alarm sounds (heartrate, blood pressure)	51,72	15
Other sounds in the room (ventilation, closing doors)	17,24	5

Figure 2 - Q11: What type of sounds are disturbing?

Q12: Your professional role. 50% of the respondents was part of the *Operating* (OR) team and 50% of the *Anesthetic* (AN) team. The assisting nurses was part of the OR team.

Q13: How long have you been working at the operating ward in Sundsvall. All of the respondents had worked in Sundsvall for *more than* two years. All staff had experience working in the previous, older localities to compare with the newly built operating rooms.

4. DISCUSSION

The staff in this survey seem to share the same view as operating staff in general; that the sound environment affects both their ability to perform well at work and that it has an impact on the well-being of the patients. They show great contentment with the general sound environment in the newly built modular operating rooms and have expressed that they clearly both felt and heard a difference in sound manifestations. The sharpness of sounds is described to have been softened and the clatter less apparent.

The main findings in this survey would be that it seems easier to perceive speech in the newly built operating rooms compared to the country average in previous results (Q5). It also seems as if it is easier to determine the direction of the sound source (Q7) even though ears are fully covered during procedures, possibly affecting the ability to determine the direction and the distance to the sound source (15). In addition to this, the inner circle of staff in the sterile zone will by default have their backs toward most other staff in the room, thus affecting their ability to practice both lip-reading and visually overlook the whole room and the actions done by other staff. Speech Clarity (C50) in the operating rooms are measured to 5,6dB(A) which correlates well with the optimal values for good speech communication, normally considered 6-10dB(A). C50 are likely to rise as well when there are more people and equipment in the room during a procedure. The combination of a C50 of 5,6dB(A) and a reverberation time (T20) of <0,6 seconds was thought to be favorable values for the perception of a good sound environment and ability to interpret human speech. But interpretation of sound is individual and the perception of what is considered noise can vary as it is dependent on more factors then sheer combination of mathematical numbers.

Noise also affects our cognitive response and influences our ability to concentrate, our short term memory, level of fatigue and motivation to “go the extra mile”. These effects of sound are not always taken into proper consideration when designing the operating room even though it is known that misunderstanding in oral instructions is common (2,16) The positive results in Q7 implicates that the newly built modules with sound absorbers improved this acoustical challenge. Results from Q8 implicates that it is easier to concentrate in the newly built operating rooms compared to an average as the *agree fully* tripled and the do *not agree* fell from 52% to 6,7% (14).

Most disturbance comes from the technical equipment where the functional and operative sounds are considered the most annoying, followed by the alarm sounds and human speech. Manufacturers should be advised to pay close attention to these sounds and these sound parameters should be considered in tenders as well. Insulation, cooling, length of tubes and pipes may be altered for less disturbance. Alarm sounds can in some cases be replaced or combined with other ways of calling for

the anesthesiologist attention. Q9 brings attention to the cause of misunderstanding due to the sound environment and there is substantial lowering of the perceived risk compared to previous results. Additionally, staff also expressed that patients often comment on how quiet, calm and soft the sound environment is in the operating room and the adjacent corridor.

Highly specialized localities such as the operating room often have ventilation systems that generally add to the sound pressure level but also cause disturbances in ability to interpret speech and alarm signals due to unwanted sound wave reflections from hard surfaces (3). Sound disturbances from the advanced ventilation system are often mentioned as disturbing but this did not occur at all in this survey. The option of sounds generated by ventilation or other additional sounds like door closing scored low (CRC Medical, SE). However, we find that a large amount of unwanted sounds come from the technical equipment. This part of the problem needs to be addressed by the manufacturers of the devices and proper acoustic demand set in tenders so that the purchase of each device is put in context with the rest of the sound producing devices (Q11). Human behavior also contributes to which sound or noise level will be dominant in a situation. Most people agree that necessary verbal information is a natural part of the work environment but some people are more sensitive to other unnecessary conversations, some would like music to be played in the operating room whereas some see it as unwanted sounds e.g noise.

5. CONCLUSIONS

The results showed that the sound environment has importance for the nurse's possibility to conduct their work in a good manner in the operating room. There can be a challenge in interpreting where different sounds are coming from and considering that the support mechanism as lip reading are limited due clothing requirements, and the ears of the staff normally are covered, room condition needs to be optimally acoustically prepared. The risk of misunderstanding should not be neglected and an operating room with the required reverberation time (T20) of 0,6 seconds should be met. In conjunction with measured speech clarity it might be easier to determine how the sound environment will be perceived by the staff? It would be interesting to compare staff perception in operating rooms with higher and lower C50, it might be a good indicator for future building recommendations? These operating rooms were acoustically treated with 40 mm absorption class-A products, normally the modular concept consists of a metal ceiling with more or less no sound absorption. Comparing the results in this survey with the average of the previous enquire, implicates that improvement can be made from existing operating rooms and modular constructions, were the metal ceiling is replaced with sound absorbing tiles, and it may improve the sound environment as perceived by the staff.

REFERENCES

1. IJ. Busch-Vishniac, JE. West, C. Barnhill, T. Hunter, D. Orellana, R. Chivukula: Noise levels in Johns Hopkins Hospital. J Acoust Soc Am. 2005;118:3629–3645.
2. Sentinel Event Alert Issue 50: "Medical device alarm safety in hospitals" A complimentary publication of Issue 50.The Joint Commission, 2013.
3. JM. Kracht, IJ. Busch-Vishniac, JE. West: Noise in the operating rooms of Johns Hopkins Hospital. J Acoust Soc Am. 2007;121:2673–2680.
4. SC. Beyea: Noise: a distraction, interruption, and safety hazard. AORN J. 2007;86:281–285.
5. CR. Engelmann, JP. Neis, C. Kirschbaum, G. Grote, BM. Ure: A noise reduction program in a pediatric operation theatre is associated with surgeon's benefits and a reduced rate of complications: a prospective controlled clinical trial. Ann Surg. 2014;259:1025–1033.
6. M. MacLeod, J. Dunn, IJ. Busch-Vishniac, JE. West, A. Reedy: Quieting Weinberg 5C: a case study in hospital noise control. J Acoust Soc Am. 2007;121:3501–3508.
7. V. Blomkvist, CA. Eriksen, T. Theorell, R. Ulrich, G. Rasmanis: Acoustics and psychosocial environment in intensive coronary care. Occup Environ Med. 2005;62:e1.
8. Swedish Standard Institute: SS 25268:2007 Acoustics – Sound classification of spaces in buildings – Institutional premises, rooms for education, preschools and leisure-time centres, rooms for officework and hotels. 2007.
9. Swedish Standard Institute: SS EN ISO 3382-2:2008 Building acoustics - Measurement of reverberation time in rooms - Test methods, 1987, Swedish Standard Institute.
10. SS EN-ISO 3382-2:2008/AC:2009 Acoustics - Measurement of room acoustic parameters - Part 2:

Reverberation time in ordinary rooms (ISO 3382-2:2008)
11. Berglund et al.,"Guidelines for community noise", Technical Report 1999, World Health Organization.
12. Swedish Standard Institute: SS EN ISO 354:2003 Acoustics -- Measurement of sound absorption in a reverberation room. 2003.
13. Swedish Standard Institute: SS EN ISO 11654:1997 Acoustics – Sound absorbers for use in buildings – Rating of sound absorption.1997.
14. Quinn, M. Staff perception on sound environments in operating rooms. Poster at Baltic-Nordic Acoustics Meeting. Reykjavik, 2018.
15. Schwartz, J.-L., Berthommier, F., & Savariaux, C., "Seeing to hear better: Evidence for early audio-visual interactions in speech identification". Cognition, 2004, 93, 69-78.
16. EE. Ryherd, S. Okcu, J. Ackerman, C. Zimring, K. Persson Waye: "Noise pollution in hospitals: Impacts on staff", J. Clin. Out. Mgmt. 2012, vol 19, no 11, p491-500.