Soundscape challenges in surgery and interventional medicine: Squaring the circle?

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ABSTRACT
The operating theater (along with other intervention areas such as cath labs, intensive care units, etc.) occupies a special position in a hospital in many respects. It represents a scene of most challenging teamwork with little fault tolerance and at the same time one of the most fear-laden places for patients. In sum, anxiety and stress seem to be inextricably linked with medical interventions – both for patients and staff. This has considerable consequences, not only on situational well-being but also on healing processes and long-term outcome, as well as on healthcare costs. In this melange, acoustic aspects stand centrally. Soundscape can function as a major stress factor as well as a source of stress mitigation. Yet, requirements for adequate soundscape standards in this field are extraordinarily complex and demand sophisticated concepts due to widely different – and sometimes even contradictory – acoustic needs and interests of the persons concerned. Regarding individual sound perception in connection with other sensory stimuli is the key approach to this issue. Intelligent and differentiated soundscape design, using latest technological achievements, can help to reduce stress for all persons concerned and enhance procedural safety and efficacy.

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1. INTRODUCTION: STRESS IN SURGERY AND INTERVENTIONAL MEDICINE

Stress is a physiologic reaction on a large number of challenges and impacts, aiming to preserve the individual’s integrity when being (or feeling to be) threatened (1). The nature of these challenges can be physical, chemical, biological, or psychological. In the latter case stress is the result of a feeling of threat which the person tries to overcome or avoid and flee from respectively (“fight or flight”).

Independently from the reason, stress always causes a complex yet rather uniform biochemical and nervous reaction which i. a. leads to an activation of the sympathetic nervous system. At the same time the individual is alerted in order to take quick decisions.

Doubtlessly, this kind of reaction can help the individual to ascertain his/her integrity in many situations. However, the addressed biochemical and nervous response elicits inevitable side effects which in the long run are potentially life-shortening.

There are differences between acute and chronic stress. However, even in the short run stress may have a negative impact on work performance and concentration (2,3). When becoming chronic, stress could be revealed as a risk factor for recreation inability, exhaustion, cardiovascular diseases, and even depressive disorders (4).

Workplaces with the following features could be identified as especially stress-laden (5):
- Pressure to perform
- Ambitious time frames
- Multitasking
- Unpredictable disruptions/disturbances of work processes

This list is, of course, far from being complete. Anyway, regarding these aspects, it becomes obvious that an operating theater (OT) – as well as other locations of interventional medicine – can, in general, be considered as an epitome of an area with a high stress potential, yet, on two accounts: personnel and patients. In the following, the different reasons and sources of stress in the two groups shall be exposed more thoroughly, and it will be shown that there are remarkable overlaps.

Patients undergoing operations or other medical interventions are usually in an exceptional situation. Typically, there is an existential threat which potentially creates anxiety, inextricably linked

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with unavoidable lack of control, lack of intimate space, uncertainty according to the results, unknown environment, etc. etc. According to recent research results, patients’ situational stress connected with invasive medical treatment has been underestimated in the past – both concerning the situational amount and the devastating consequences. Findings from the past decade revealed pre-operative anxiety as an independent risk factor for mortality after heart operations (6,7,8,9)! Taking into account that also drugs intended for stress mitigation and anxiolysis as well as general anesthesia (!) may have a direct negative impact on the patients’ health (10,11), an urgent need is revealed to minimize all avoidable “extrinsic” stress factors, and moreover, if possible, render an environmental contribution to de-stressing.

On the – literally – other side, OT personnel have to face tough challenges with regard to alertness, responsibility, and, not least, frustration by failure. Besides these intrinsic psychological reasons there are several extrinsic ones, such as narrowness, time pressure, hygienic requirements, organizational and logistical demands, surprising obstacles and disruptions (e.g. due to individual peculiarities of the patients or emergency cases), and many others (12). Not least, working invasively in human beings is in itself a stress factor due to the – not always reversible – consequences of any failure or mischief. All these findings are supported by several studies (13,14,15,16,17).

If stress on workplaces becomes chronic, it is a risk factor for recreation inability, exhaustion, cardiovascular diseases, and even depressive disorders (18). In fact, the amount and quality of work performance is highly influenced by stress factors – virtually a truism. By implication, it is obvious that avoidable stress factors both for patients and employees should be abolished as extensively as possible – not only for the sake of health, but also for the sake of quality of processes and results, and, all in all, for economic reasons.

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**Figure 1 – The possible influence of environment on patients’ stress**

2. **PARAMETERS OF SOUNDSCAPE IN THE OPERATING THEATER**

There is virtually no field in the OT which has such a large overlap concerning stress for employees and patients as acoustics. It could be clearly revealed that noise in the OT has a negative impact on work performance and quality of processes and results (19). However, a main characteristic of noise in this context is that its assessment is largely varying concerning the persons concerned as well as the moments. The main sources of noise (or, what is considered as noise) are listed in the table below. However, some of the mentioned items need to be commented.
It is evident that technical as well as non-technical work sounds are widely considered as noise by all protagonists. Yet, even this aspect has a different significance concerning the respective persons due to the individual preconditions. Whereas tearing up a peel package will not attract noteworthy attention by most employees there are patients who associate the corresponding sound with hellfire (20). The situation-related emotional lability and suggestibility often provides a kind of acute neurosis in many patients which prompts such sort of perception. Therefore, consideration of psychological factors (perception) is crucial when assessing sounds: Soundscape rather than loudness alone!

Similarly, human communication can also be considered ambivalently. Whereas it could be shown that prohibiting all unnecessary talking of the staff rendered better operation results (19), it is also clear that banning small talk completely will itself be a stress factor for the persons concerned.

In any case, one has to consider the fact that an OT functions by intense interdependent teamwork, with widely different tasks, work experience, and, not least, personality types. This means, by implication, that widely different, sometimes diverging “soundscape interests” are present on a narrow space. Considering the table above, the definition of noise must necessarily have an interindividual and even situational variation. Therefore, the mélange of soundscape demands is rather complex.

| Technical equipment (inherent) | • Air conditioning  
| | • Aspirators  
| | • Anesthesia machines  
| | • Surgical devices  
| Non-technical work noise | • Tearing of peel packages  
| | • Rattling of containers  
| | • Floor noise  
| Human communication | • Small talk, but also:  
| | • Work related talking  
| Note sounds | • Phone bells and pagers  
| Monitoring sounds | • ECG  
| | • Pulse oximetry  
| Alarm sounds |  
| Music |  

Table 1 – Sources of noise in the operating theater

![Image](image.png)

Figure 2 – Major parameters concerning soundscape in an OT (from [20], modified)
This applies also to a much debated item, music in the OT. Already in 1914, Evan Kane, a Pennsylvanian surgeon, emphasized the value of music in the operating room with respect to the patients’ situational horror (21). He also mentioned the necessary adjustment of music to the individual taste. Today there is no serious doubt that music may have a considerable positive impact on the patients’ emotional status.

But also the staff may profit from music; in principle, music can influence surgical work results positively (22, 23). In this context, the effect of music on work performance depends not only on individual properties (e.g. professional expertise) but also on the phase of the operation as well as on the music style – loud rhythms are not necessarily useful in this connection (24). Moreover, one has to realize that the individual music taste differs in a wide range. Comparable to the protagonists’ different assessment of sounds in general, music interests are highly distinct: One participant’s music may be considered as awful noise by another one, and vice versa. A specific aspect in this connection applies to the anesthesiologist who usually estimates the patients’ vital condition by the pitch of the pulse oximeter. For this reason, every kind of music must be noise in his ears, since the patient’s heart rhythm will necessarily be different.

Therefore, future soundscape design has to take into account a differentiation – an individualized tailoring according to personal and situational demands. We will revert to this aspect below.

Figure 3 – Left: Dr. Kane operating himself on an inguinal hernia
Right: Kane’s original article from 1914 (emphasis added)

3. SOUNDSCAPE IN THE OPERATING THEATER:
MEASUREMENTS AND MEASURES IN KLINIKUM WESTFALEN

3.1 Holding area

With the intention of developing and implementing suitable stress-countering measures in the operating theater, the AFRO project (“anxiety-free operation theater”) was started at Klinikum Westfalen, in 2010. From the beginning on, it has been conceptualized as a multimodal, technology-supported approach, aiming at positive stimulation of the human senses. It is based on a number of components which, at least in part, originally were not intended for usage in this connection, less

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2 Kane knew what he was speaking about since he performed surgery on himself several times (see also figure 2).
than ever for being part of a whole stress-reducing “orchestra”. One of the key components is designing stress damping environments for the patients which, at the same time, fulfill all the requirements for usage in an operating theater (e.g. hygiene aspects) and, at the same time do not disturb the ongoing work processes. It is not on the dice that soundscape plays a key role in this concern; yet, it has to be embedded into a consistent environment design.

And also with respect to the pre-operative procedures, a holistic view is necessary in order to be credible and successful. This means including the whole pre-operative process into the efforts. The waiting area where the patients stay immediately before the being transferred into the very operating room (OR)\(^3\) could be identified as crucial: the so-called holding area. The time which patients spent here is up to an hour. Therefore, a modular cocooning prototype, called NEST\(^4\), was constructed, including a screen combined with loudspeakers and easy-to-remove curtains.

![Cocooning device “NEST”\(^5\) (first prototype, by Philips Research; from [20])](image)

This design proved to be successful for the intended use from the beginning on. In an in-practice investigation, skin conductance (SC) of 68 patients undergoing ear or nose surgery in general anesthesia was measured.\(^6\) Skin conductance can – within some limitations – be regarded as an indicator of the activity of the sympathetic nervous system, and therefore – again within some limitations – as a parameter of stress (25). Assessing the measured results, it is important to notice that there does not exist a “normal” SC value due to huge interindividual and situational differences, not least because of environmental factors like temperature etc. Therefore it is not useful to compare the absolute values but rather to normalize the data and compare the time-dependent changes.

When regarding the mean curve in the described way (see below) one immediately sees that the patients have already a considerable, steadily increasing stress level prior to arriving in the OT. However, there is a remarkable “dip” in the curve after they have come into the cocooning device – prompting the conclusion that the device really is effective in the intended way. When the patients leave it, there is a marked peak of SC, indicating that there is still some work to be done in order damp stress during the transfer phase satisfyingly.

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\(^3\) The term “operating room” (OR) should not be confused with “operating theater” (OT); the latter being the whole area with the several operating rooms and the related locations, including the holding area, the wakeup unit, supply corridors etc.

\(^4\) Acronym derived from German: “Neurozeptives Entspannungs- und Stressreduktionsmodul” (neuroceptive relaxation and stress reduction module)

\(^5\) The first prototype was designed by Hans Schaper (Philips Research).

\(^6\) Skin conductance measurements were mainly performed by Jürgen Vogt, and the data processing and evaluation was done by Hans Weda (both Philips Research).
Anyway, the dip could be revealed as significant: When comparing the period 30-150 seconds after the start of the cocooning with the period 150-30 seconds before the transfer into the operating room one finds for the normalized SC difference during cocooning: $t(25) = 2.57, p= 0.0165$. This means that the normalized skin conductance levels decrease significantly during the cocooning period.

Remarkably, though treating the patients in the NEST means an additional workload for the staff members, their reactions are consistently positive. This is not only due to the convincingly positive effect on the patients. In fact, the particular soundscape created by the NEST is expressively described as soothing and stress-damping by the staff members concerning themselves.

Thus, the first results of environment and soundscape design are encouraging; at this time, there is ongoing work on an optimized prototype with improved immersion, including even better noise shielding.

### 3.2 Soundscapes inside the operating room

Soundscapes deal – by definition – not only with objective, measurable parameters but also with perception. As persons in an operating room have quite different tasks, attitudes, and – therefore – acoustic interests, it seems insofar problematic to speak of “the” soundscape. This means that one has to take a differentiated standpoint in order to meet the respective requirements.

In order to learn more about the soundscape conditions in our OR, an investigation was conducted in order to measure sound levels in different operations. As could be expected, junction replacement operations were among the most loud ones, being characterized by sudden bangs exceeding 90 dB(A) (see diagram below). Now, bangs which are expected have a much less stressful impact than unexpected ones. And the latter is, unfortunately, basically the case in wake patients. As indicated above, Memtsoudis et al. could reveal that in these operations it is particularly desirable to avoid general anesthesia. So, even more, one should make efforts to shield the patients from the bangs or – even better – counteract by soothing sounds.

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7 The investigation was responsibly performed by G. Notbohm and S. Siegmann, Institut für Arbeitsmedizin und Sozialmedizin, Heinrich-Heine-Universität Düsseldorf.
Offering soothing sounds is, of course, not only actual for potentially noisy operations. Instead, this may generally serve as a countermeasure against stress, as described above. Yet, in the OT, it is, of course, required that the work flow must in no way be disturbed. Therefore, one has to create an individual (virtual) environment including a “micro-soundscape”. Up to now, there are two kinds of devices which are being used within the frame of the AFRO project: Patients are either offered goggles with ear phones which can be used as screens (e.g. for watching films) or so-called visualization glasses are offered which render suggestive audiovisual contents. Thus, the patients are uncoupled from the “threatening” surrounding and, instead, immersed in another, affirmative (virtual) environment (fig. 7 and 8).

Figure 7 – Creating a “micro-soundscape” for a wake patient undergoing surgery

Figure 8 – “Micro-soundscaping” during surgery in prone position

In contrast to the holding area, usage of goggles proved to be advantageous in the operating room when compared with “macro-soundscape” designs like NEST (see table 2). Both components are able to complement each other when being used successively.
<table>
<thead>
<tr>
<th>Micro-soundscape (googles)</th>
<th>Macro-soundscape (environment)</th>
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<tbody>
<tr>
<td>- Easier uncoupling from surroundings</td>
<td></td>
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<tr>
<td>- Easy body repositioning</td>
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<tr>
<td>- No additional noise in the operating room</td>
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<tr>
<td>- Mobility</td>
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<tr>
<td>- No touch (hygiene, intimate space)</td>
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<tr>
<td>- Eased communication</td>
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<td>- Positive side-effects on staff outside the OR</td>
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Anyway, there may be several reasons why patients don’t wish or are not suitable for wearable devices. Therefore – and also for the sake of the employees –, it is also reasonable to think about additional “macro” soundscape design in the OR. Not least, measurements in our OT revealed reverberation levels exceeding the recommended limits. Therefore, ongoing research is conducted in order to mitigate sound stress in the OR – both for the sake of the patients and of the staff. This includes, of course, usage of sound absorbing materials, but maybe, also other approaches like active noise cancellation will not necessarily remain a taboo.

![Figure 9 – Employee testing the effects of sound absorbing materials](image)

4. **FINAL REMARKS**

Several questionnaires concerning the introduced stress-damping measures have been conducted, some of them by ourselves, some by third parties (26); the persons concerned were on the one hand those who had undergone surgery accompanied in the described way, and on the other hand healthy passers-by. The results were uniformly encouraging, revealing a large majority of all persons demanding to be treated according to the principles of the AFRO concept. All in all, tackling stress and anxiety by actively designing the audiovisual environment – with soundscape as a key parameter – does not only appear to be a matter of humanity but also an issue of high relevance concerning the protagonist’s working ability, health and quality of life, yet also – in the long run – a matter of economics. Soundscape in the OT appears to be like squaring the circle – due to the many diverging yet eligible sound interests on a narrow space. However, modern research can help creating differentiated sounds. Thus, though a lot of development and research work is still to be done, there is a realistic chance for a significant improvement in health care procedures – for the sake of the patients as well as the staff.

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