

# Care for Sound

*Sound Environment, Healing & Health-Care*

PATRIK GRAHN | JOHANNES VAN DER BERG | KERSTIN PERSSON WAYE  
TÖRES THEORELL | PER THORGAARD | MARIA QUINN

SOUND ENVIRONMENT CENTER AT LUND UNIVERSITY  
LJUDMILJÖCENTRUM VID LUNDS UNIVERSITET

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# Preface

**I**ntensive care environments are often characterised by a heavy work load for the staff in combination with undersized premises, insufficient staff and funding. This leads to stress and tension affecting the well-being and recovery of patients. The experience of an intensive care unit has more than once been likened to ending up in the middle of a central railway station.

An important aim in traditional health care has been for patients to recover in a healing environment regarding light, sound and treatment. In reality, this aim is often disappointingly distant, due to conventional strategies and financial restraints.

This edition intends to focus on the handling of sound environments in health care. The large EU-financed COST project, COST Action TD0804, Soundscape of European cities and landscapes has recently stressed the importance of conscious handling of the sound environment, including perspectives other than the negative aspects of noise as a waste, but also as a resource for health, enjoyment and well-being. This is a view that could very well be embraced as a task for health care design and government today.

The Sound Environment Centre, here in collaboration with Ecophon, Sweden, gathered an interdisciplinary group of renowned researchers, doctors and medical staff to share and discuss knowledge, experiences and thoughts on how sound affects us when we are at our most vulnerable and in need of care and recovery, whether we're newborn infants, patients inside an ambulance or in intensive care, chronically ill or psychologically burnt out. With this report from the symposium Care for Sound held in Lund on 17th October 2013, we want to make it clear that attention to sound in health care is currently becoming an active component in a rethinking of healing and recovery.

***Kerstin Persson Waye*** is a professor at the Department of Occupational and Environmental Medicine at Gothenburg University and a well known and appreciated researcher in the noise research field. She gives a summary of what is known today, specifically focusing on the outcomes from intervention

studies of the physical environment, and points out the most important areas for further improvements in research.

Many kinds of sound make up the sound environment in hospitals: human sounds, voices, steps, doors slamming, machines, alarms and beeps to name a few. It is well known that noise has not always been milder in the past, but Persson Waye points out that the total noise levels are reported to have risen considerably in recent times, by about one decibel a year over twenty years, which adds up to around twenty decibels in about as many years.

In her overview, she reports on studies of cardiovascular and sleep effects. However, It is not until recently that acoustic properties appear to have been studied in detail, although the characteristics of noise are unmistakably linked to the acoustic environment. Findings from her own studies include that level ratios between peaks and background are more important than sound levels per se, and that the most disturbing sounds seem to remain disturbing even at reduced levels.

She concludes that the complexity of the matter requires interdisciplinary, collaborative studies on the effects of acoustic environments in hospitals and intensive care units. Further studies are needed, incorporating advanced acoustic measuring and health parameters. Persson Waye advocates the importance of developing “supportive sound environments” with capacities for supporting communication, surveillance and recuperation.

The sound environment in hospitals affects us from the moment we are born and seemingly sometimes even before that. It is still unknown how this may affect people later in life. *Johannes van der Berg* is a PhD graduate and a critical care nurse. He has rich experience of handling new born infants that for some reason have to be transported from one place to another for special treatment and care. These transfers are made by specially trained teams and with highly specialised equipment. Van der Berg is the director of transport at Norrland University Hospital in Umeå, Sweden with responsibility for transport of infants in the northern part of Sweden. In his report Neonatal Intensive Care Sound Environments: Impact on the infant and preventative strategies he describes the realities of neonatal intensive care units and the infant’s vulnerability to sound and noise.

Critically ill infants in neonatal intensive care environments are often constantly exposed to ambient sound levels that exceed recommended levels, and high sound levels may have negative effects on the cardiovascular, respiratory and behavioural systems of the infant. This report describes different neonatal intensive care environments, their sound levels, as well as strategies to reduce them and protect the infant.

Professor emeritus *Töres Theorell* at The Stress Research Institute at Stockholm University has conducted research on stress levels and acoustic environments in coronary care units in a number of studies together with colleagues. Results and experiences from two studies are presented in this collection. In the experiments, the sound environment in a patient's room has been acoustically modified and redesigned in terms of reverberance through the mounting of sound-absorbing materials. The result showed to be dramatic. Theorell writes "the findings indicate that the improved acoustics had affected the psychosocial environment in such a way that during the afternoon the staff experienced reduced demands, and less pressure/strain. Such changes open up for an increased capacity to care for the patients".

The second study focuses on noise sensitivity after acute stress situations and shows interesting differences between men and women. It also shows that exhausted patients have more difficulties handling disturbing sounds when they are combined with stressful conditions, which as Theorell notes "is the reality for most of our patients".

In a second contribution to this book, he shares some of his observations of physiological effects of music looking closely at the processing of sound in the brain and how it affects stress responses. Theorell notes that information from sound stimuli reaches the brain in two routes that operate in different ways and speeds: one is slower and connected to the cognitive apparatus, while the other is connected to the primitive reactive nervous system. The physical effects of music on us in terms of arousal and relaxation show rich complexity in how subjects react to music that differs in parameters like tempo, timbre and character. The clearest effects seem to rise from rhythmic and intensive music while the perception of slow, relaxing types of music shows larger variability within subjects in terms of heart rate and tempo of breathing, etc.

Theorell also shows that research today continuously develops new frontiers in the knowledge of effects of music on hitherto unexpected bodily domains, from physical rest and recovery to gastrointestinal aspects.

Chief physician *Per Thorgaard* at Aalborg hospital in Denmark reports on a rather unique experiment in modifying sound environments in acute ambulance transports in emergency response, with the help of music intervention, playing calming and soothing music through speakers inside the ambulance.

The typical patient inside an ambulance in an emergency transport is often in a state of stress, pain and fear, he writes. These can be further reinforced by the sounds of the ambulance, the noise, the sirens and the movements of the car while the needs of the patient are quite the opposite, being peace and stillness for recovery.

The experiments turned out to be a very successful project showing a large percentage of patients experiencing the music intervention as a rather a positive and soothing ingredient in the ambulance environment. Thorgaard points out the importance of delicacy and sensitivity with which the music intervention has to be managed to answer for all the different needs in the ambulance, such as communication, medical treatment and machinery as well as the comfort of the patient.

To conceptualise a healthy environment in terms of green spaces and parks, *Patrik Grahn* and *Matilda van der Bosch* at the Swedish University of Agricultural Sciences in Alnarp outside Lund use a model consisting of eight characteristics within a landscape, that in one form or the other are required for an environment to be experienced as restorative. By using this model, they found for instance that physical health in residential areas could be directly linked to the presence of certain restorative qualities.

To further develop the scientific knowledge of the restorative qualities of the environment, a therapeutic garden has been developed at Alnarp under Grahn's supervision. The garden is aimed at treatment of patients with various degrees of stress-induced mental illness of one kind or another. To further explore the relationships between environment and stress reduction, the research group reports on a study making use of a virtual reality system in a VR lab to measure the effects of visual input with and without sound stimuli on stress reduction.

The experiences of Grahn and his colleagues at Alnarp clearly show the importance of sound in health-promoting environments.

The Coronary Care Nurse and Concept Developer at Ecophon Sweden, *Maria Quinn*, finally brings it all down to the hands-on experiences of a nurse in a coronary care unit, and the daily realities of the demands and stress she has to work under. When a nurse starts her working career, she writes, she has 30 or 40 years of career ahead, but her question arises early: will she last? The sounds of colleagues, patients and beeping and flashing alarms are important in this environment, and to be attentive to the sounds in the ward, to filter out the important ones is sometimes as important as it is difficult. Quinn writes “awareness is the key”, both for the individual nurse and for authorities and planners, and pleads for consideration of all the senses together in the development and construction of healing environments in hospitals.

Finally with this report in your hands, we hope and are convinced that the discussion will continue. Be sure to watch the interviews and video presentations by the speakers on the website [www.careforsound.com](http://www.careforsound.com) for reference.

Frans Mossberg, editor & director  
Sound Environment Centre at Lund University



# A caring sound environment in hospitals?

Kerstin Persson Waye

*Occupational and Environmental Medicine, the Sahlgrenska Academy,  
Gothenburg University, Sweden*

kerstin.persson.waye@amm.gu.se

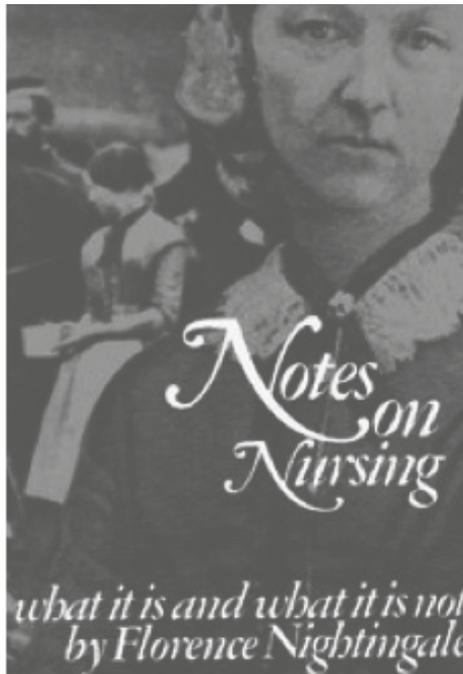
## Summary

A large number of studies show that hospitals are unacceptably noisy. Up to date no study has measured noise levels in intensive care units or neonatal wards that comply with the WHO recommended noise levels. Furthermore, sound levels in hospitals have risen since the 1960s. The noise origins mainly from: operational activities generated by the staff in their care giving activities and communication, medical equipment and alarms and structural sounds from the building such as ventilation and closing doors. While some sounds are unavoidable, many are totally or partially unnecessary. Noise in hospitals has been suggested to increase the risk for cardiovascular response, pain, intensive care delirium, fragmented sleep and reduced recuperation. For patients, the cause of these outcomes is multi-factorial, however the impact of the sound environment can, as opposed to most other factors, be abated. For the personnel, noise may cause annoyance, stress, tiredness and lead to more errors however these outcomes are less well investigated. The paper will give a summary of what is known today, specifically focusing on the outcomes from intervention studies of the physical environment and point to the most important areas for further improvements in research.

**Keywords:** hospital, noise, patients, personnel

## Intoduction

As early as 1859, Florence Nightingale declared the importance of a good sound quality in nursing and in her “Notes on Nursing” can be read “Unnecessary noise is the most cruel abuse of care which can be inflicted on either the sick or the well [1].



**Figure 1.** “Notes of Nursing- what it is and what it is not” by Florence Nightingale 1859, who raised the importance of a good sound environment in caregiving.

In spite of this early insight the importance of sound environment in modern hospitals has hitherto largely been neglected. The results of this neglect on the sound environment was clearly indicated in a meta analyses of available noise measurements in hospitals done between 1960 and 2005 made by Busch-Vishniac et al [2]. The A-weighted sound levels had on average increased by 0.38dB per year during the day and by 0.42dB per year during the night. In

other words, the perceived loudness has nearly doubled over a 20 year period. Particularly high sound pressure levels can be found in intensive care units (ICU), neonatal units and during certain processes in the orthopedic clinics.

One reason for the increased sound levels is the high technology density of health care today. The development and use of medical technology in health care is vital in treatment, care and for diagnostics. However the side-effects with many of the equipment producing high sound levels and constant lights, have at least until now been overseen. The high-tech equipment also puts great demand on the care giving personnel and in combination with stress in general and noise may lead to an increased risk for medical and care giving errors, threatening patients' safety. Most of the sounds from hospital equipment are tonal and intermittent and are experienced by the patients and their next-of-kin as unfamiliar, maybe frightening and would be without their control [3]. All these elements are known ingredients for noise being annoying and stressful.

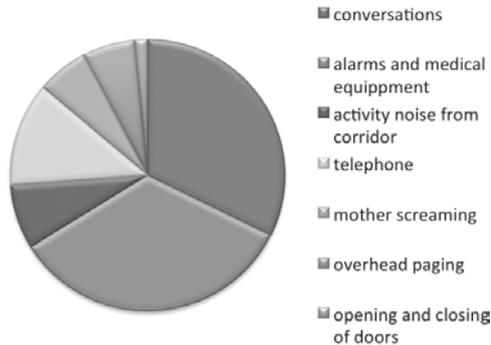
In addition to sounds and signals from medical devices, the sound environment at the ward comprise a mixture of sounds from other patients, care giving activities, communication between staff, signals from overhead paging systems, sounds from respiratory, heating, ventilation and air condition of the building and external sounds.

This paper will give a summary of what is known today of the links between noise exposure and health outcomes for personnel and patients and point to the most important areas for improvements within this field of research. As most studies are carried out within the ICU, this will also be reflected in this paper.

# The sound environment

## Most disturbing noise sources

The most annoying or intrusive noise sources have been defined by patients and staff in a few papers. In a large study comprising a variety of patient care units in two hospitals, voices were perceived as most bothersome by both patients and personnel followed by carts in the hall, footsteps in the hall and cardiac monitor alarms, overhead pages and pulse oximeter alarms [4]. The relative annoyance by these sources did not change after an intervention program. Staff in an ICU rated sounds from medical equipment, followed by conversation between personnel, and activity noise from the corridor to be most annoying [5]. In an operation theatre the most frequent noise sources of distraction or interruption were conversation, work environment problems, telephone calls and equipment [6]. These sounds were also rated as most distracting by an observer. The observer also noted a high number of movements through the operating theatre, with a total of 1543 door-openings during the observation period or a mean rate of 1.08/minute. Midwives and nurses in a obstetric ward rated screams from mothers giving birth as most disturbing, followed by alarms, equipment, talking, and phones [7]. Sound induced fatigue and noise annoyance was furthermore highly significantly correlated with screams. For sleep, ringing phones, sounds from alarms, overhead paging and opening and closing of doors was found to lead to most sleep arousals among healthy individuals [8]. Patients also frequently report staff talking as particularly disturbing source for sleep disturbance e.g. [9]. Figure 2 gives an overview of the relation between the most disturbing sources described in these studies.



**Figure 2.**

A relative distribution of the most disturbing noise sources given in hospital studies

## Sound levels at the hospital wards

A recent meta-analysis [2] indicated that noise levels had increased during the last 45 year with A-weighted daytime levels of about 57dB 1960 to 72dB 2005 and night time levels of 42dB to 60dB over the same period. The noise levels seem to be highest at the neonatal intensive care units (NICU) where the levels in an open bay ward ranged from 49.5 - 89.5dBA<sub>s</sub> and with a mean peak level of 134dBC [10] and in intensive care units where averaged levels over several days ranged from 53-58 dBLpAeq and with peak levels of 85dBC (daytime) and 78dBC (night time) exceeded more than 50% of the time [11]. Even higher sound levels were found in a burn intensive care unit in UK, where the A-weighted equivalent levels on average was 66dB day time and 61dB night time and A-weighted maximum levels being on average 88dB daytime and 84dB night time. This is comparable to a study of [12], who found average levels of 55 to 70dBLpAeq and peak levels from 100 to 120dBC. Most studies find in accordance with the meta-analysis [2] that night time levels are somewhat lower, although the exact difference varies. Also most studies find that there is little variation between days e.g. [11, 13]. A common problem when evaluating sound levels in hospital studies is the rudimental description of the measurement method and that details of for example integration time (slow or fast) and time reference for equivalent levels are not mentioned. These omissions make evaluation of levels very problematic.

In one of our previous study, analyses were made of the statistical distribution of maximal and peak levels during the day and night and the occurrence and lengths of restorative periods, defined as periods lasting longer than 5 minutes and being less than 55dB<sub>LpAFmax</sub>. It showed that periods possible for restoration lasted on average for 8 minutes during the day and 10 minutes during the night, with a maximum length of 9 to 15 minutes during the day and 10 to 26 minutes during the night. It is not difficult to grasp that such an environment pose a risk for sleep disturbance, reduced recuperation and staff annoyance.

Future studies should aim to better describe the sound environmental properties, so relevant associations between health outcomes and sound environment can be made.

## Effects on Patients and personnel

### Effects on patients

In a recent review of the impacts of hospital noise on patients it was found that the large number of papers dealt with sleep disturbance (17 papers), and cardiovascular effects (9 papers) while there were few papers on other outcomes, such as pain, hospital stay and wound healing [14]. The review did though not include papers on intensive care delirium. One very important conclusion from the review was that there were very few papers or less than five that included a pattern of mechanism linking an acoustic parameter to a studied health outcome.

Fragmented sleep or sleep disturbance has been reported since the 1970's mainly among ICU patients. More than 60% of patients treated in the ICU report insomnia or lack of sleep [15, 16]. An uninterrupted sleep is important for recovery and good health [17, 18] and experimental studies in animals and healthy volunteers show that sleep deprivation affects several physiological parameters that may adversely affect recovery of patients under care. For example, glucose intolerance, increased insulin resistance, activation of HPA axis and inflammatory cytokines have been demonstrated after nights of sleep deprivation [19, 20].

The cause of the sleep disturbance is multifactorial and in addition to the patient's medical condition, medication, respiratory care, treatments, care giving procedures and light and noise affect sleep quantity and quality. It is though important to remember that as opposed to factors related to the patient condition, noise as a source of sleep disturbance can in many cases be avoided. The exact contribution of noise for sleep disturbance varies between studies. In a review of current knowledge about sleep in the ICU Hardin [20] summarizes that noise is a major factor for sleep disorders and is estimated to account for as much as 40% of sleep disturbance. Specific data was provided by Freedman et al [21] who report that about 11 to 17% of the arousals respective awakenings were caused by noise, giving a total of 28%.

A large proportion of all ICU patients have illusory or hallucinatory memories from the intensive care [22, 23]. The environment in the ICU may be a contributing factor, where according to the patients' statements sudden and loud noises can initiate visual and auditory hallucinations. One study in USA, adopted several strategies to promote night time sleep and decrease day time napping [24]. Apart from behavioural changes also non-pharmacological sleep aids such as earplugs, eye masks and soothing music were offered. Sleep medication known to alter sleep and precipitate delirium were also discouraged. Noise was subjectively rated lower after the interventions, while improvement of sleep was not statistically significant. However, more importantly, there was a reduction of incidence of delirium coma and the number of daily delirium/coma free status was increased. Further studies are clearly warranted of the link between ICU delirium and the acoustic environment. A developed ICU delirium prolongs hospital stay and increases the risk of complications and impaired quality of life [22, 23].



**Figure 3.**  
Sleep and recuperation may be affected by the intermittent sound characteristics in intensive care units, giving little time for restoration.

A few studies have experimentally investigated the impacts of hospital sound environments on sleep. The arousal probability for a variety of sounds was investigated by [8] The polysomnogram of 12 healthy participants who slept in a sleep laboratory was recorded during one control night and two exposure nights with 14 normally occurring hospital sounds. Once the subject entered a steady sleep stage of 90 seconds, the probability of an arousal was obtained by increasing the sound level in 5 dB steps until an arousal occurred or until

the sound level reached 70 dBLpAeq (10s). The study was able to nicely show that sounds like phone ringing, intravenous alarm, and overhead paging had a very high probability of over 75% to cause arousal in sleep stage N2 starting already at 45 dBA. Interestingly also door opening and closing caused a high probability of arousal also in deep sleep (stage N3) at these rather modest sound levels.

With the aim of evaluating the effects of a global and realistic change of the sound environment sleep quantity and quality was evaluated in another experimental study comprising 17 healthy participants [25]. Recordings of a typical night at an intensive care unit comprising sequences of (i) sounds from a respirator in use, (ii) a variety of alarms, door closing and (iii) human voices and rustling. The sounds were played back in two conditions; one with the original sound quality aspects however reduced with LpAeq 7dB (ICU) and one with modified sound quality (ICU\_reduced) were also the levels of the loudest alarms were reduced and the closing and opening of the doors were made more quiet i.e. simulating a door stopper. Hence all alarms exceeding LpAFmax 55dB and the sounds of the doors closing were reduced, while voices and rustling were the same in both modes. During both ICU exposure nights, sleep was more fragmented with less slow wave sleep, more arousals and more time awake. The effects of reducing the maximal A-weighted levels from alarms and door closing from 64dB to 56dB was not enough to have a clear improved effect on objective or subjective sleep quality, The study by Persson Wayne et al hence support the finding of [8] where the most disturbing sounds caused arousals already at very low sound levels. Additional information was given in [26] who in a small study with five subjects found that disturbance of sleep was not only related to the actual sound pressure levels of the peaks but also to the relation between the peaks and the background sound level.

## **Effects on personnel**

Hospitals are inherently stressful work environments and health care personnel are reported to suffer from stress often linked to high expectations, insufficient time and skills [27]. Noise should therefore be considered as contributing to this mental load. Considering the nature of the sound environment - a high prevalence of intermittent sounds, speech and sometimes human screams, with little possibility to control- it is reasonable to expect a high degree of annoyance, mental distraction, fatigue and maybe medical errors. Noise

annoyance (rather, very or extremely annoyed) to noise was in [5] reported by 43% of the ICU nurses, which was clearly higher than office workers or primary health care personnel.

The risk for hearing damaged may be prevalent at the orthopedic surgery [28, 29] and is also the focus of an ongoing investigation in obstetrics care [7]. Few studies have however investigating the effects of noise among hospital personnel and as stated in a recent review [30] “hospital noise can potentially have serious negative effects on staff stress, satisfaction, psychosocial environment, job performance and health though the limited number of studies, often with a small sample size and lack of detailed acoustic methodological description makes conclusions difficult to draw.”

One study of 133 ICU nurses found that noise induced occupational stress was associated to burnout and emotional exhaustion [31]. Nurses sensitive to noise were particularly at risk for burnout. A study in the ICU comprising 47 nurses, found that they generally perceived noise to contribute to stress, and that 91% found that noise negatively affected them in their daily work [11]. Among nurses in a pediatric ICU Morrison et al [32] were not able to find an association between saliva amylase, subjective stress, annoyance and noise levels. They did however find an association with heart rate and noise levels. Less nursing experience, higher caffeine intake and work shift were found to influence the relationship.

Several studies report that personnel commonly ignore, silence or disable alarms. In [11] 49% of the 47 nurses reported that they sometimes adjust alarm levels so they would not hear them. This is corroborated by partly unpublished data in ongoing studies [5] where about 50 nurses in an ICU answered this question both at 2007 and 2010. As many as 57.1 and 60% answered that they partly agree or completely agree to that statement.

## Ongoing studies

An ongoing intervention study in a hospital in Sweden, focused on the visual and auditory stimuli in an ICU [33]. In one room a visual intervention was made by limiting the number of cables seen by the patient, changing the

colours of the room and by introducing artificial daylight to resemble the diurnal pattern of the day and night. The auditory sound environment was changed by mounting high quality absorbents in the ceiling. Room acoustic measurements point to a reduced reverberation time (T20) in the frequency range of 125 to 500Hz, in the intervention room as compared to the control room and an improved clarity (C50) especially in the frequency range below 1kHz but also above (2kHz-4kHz). The effect of the interventions will be evaluated by sound pressure level measurements and sound recordings and by personnel ratings and recordings of patient health outcomes and compared to the control room where no alterations have been done.

## Conclusion

A large number of studies have been carried out within hospital settings, however few have linked acoustic metrics to health outcomes. There is also a problem evaluating the sound levels in many of the articles as the description of the measurement method is rudimentary and important detailing of the description of sound metrics are missing. The complexity of the sound environment at hospitals may also require more advanced analyses with regard to temporal and frequency characteristics and periods of restoration in order to make relevant associations between health outcomes and sound environment. Further studies should try and address these matters more seriously.

Further studies are needed in order to study the effects of the acoustic environment on patients, especially with regard to factors affecting sleep, pain, recuperation and the development of ICU delirium. These types of studies are clearly very complex and require collaboration between disciplines.

Few studies have addressed the health and work performance among personnel, further studies should ideally comprise larger populations and include a wider context of measures of the psycho-social environment.

Future work should also more specifically identify and try in collaboration with hospital management and personnel try to integrate the following three aspects: 1) a supportive sound environment by which we mean a sound environment that support communication and surveillance and allows

integrity and rest. 2) an avoidance of unnecessary and disturbing sounds that impair sleep and recuperation and increase the risk for negative impact health impacts and medical errors. 3) a pleasant sound environment, that would enhance a positive experience for the patient and give their next-of-kin a feeling of belonging and security.

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# Neonatal Intensive Care Sound Environments: Impact on the infant and preventative strategies

Johannes van der Berg

## Introduction

The primary goal of neonatal intensive care is to increase the critical ill infant's chances to a life with a minimum of morbidity but it also to promote the bonding process between the infant and the parents. The care of the critical ill premature infants usually starts at the delivery unit or in the conjunction to an operation room and continues in a neonatal intensive care unit until the infant can be discharged. The basic medical principals are to ensure the infant oxygenation, ventilation, circulation, body temperature and nutrition but also reduce stress, pain and to provide comfort (1, 2).

Studies over the years have shown that the survival of extremely prematurely born infants have improved due to better collaboration between obstetric and neonatal professions, specialist neonatal transport team, technical advances and increased regionalization of the care of premature infants to a special neonatal intensive care unit (NICU) (3-10). Nursing care models such as kangaroo mother care (KMC), family centered care (FCC) and developmental supportive care, have also shown to promote the infant s health and the bounding process between the infant and the parents (11-17).

In the initial stage of neonatal intensive care, the physical NICU was designed to facilitate life-saving treatment. This environment could hardly be considered to be nurturing for the infant and was quite different from the premature infant's environment in the womb (18). Despite an increasing interest for

the effects of the physical environment on the infant, many NICU's can still be considered as an extraordinary health care environment characterized by advanced technical equipment, high staff - patient ratio, high activity and high sound levels. It is in this environment the infant's brain growth and development progress is at a rate without comparison to any other point in life (18, 19). Exposure to stressors in a NICU has been shown connect to alterations in the brain structure and function (20). Therefore interventions that reduce the infant's exposure to stressors in the neonatal intensive care unit are necessary. Sound in the NICU was one of the first stressors that was reported to have effect on the infant (21)



**Figure 1.** NEONATAL TRANSPORT INCUBATOR. The transport incubator used by the Neonatal Transport team in Umeå for transport of infants to the hospital with the right level of care. The number of different sound sources on the transport incubator varies from 3 to 12 depending on the level of care. On top of this there are the sounds from the ambulance flight, viewed in the background.

## Neonatal sound environments

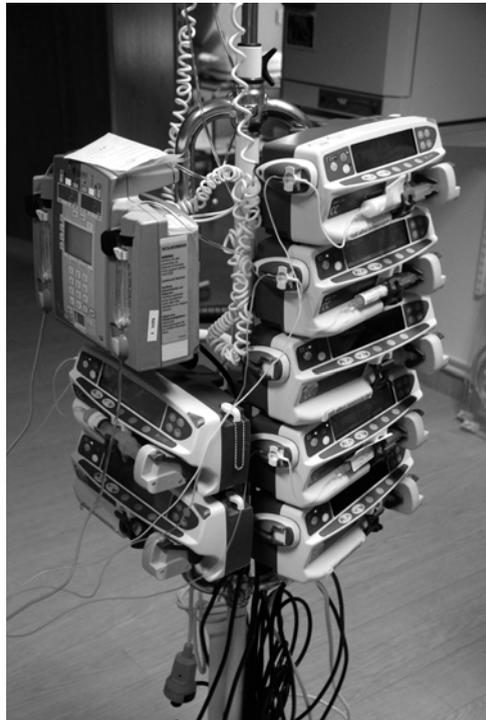
American Academy of Pediatrics has recommended that the sound level should be lower than 45 dBA (22). But numerous studies from NICU's report average sound levels ranging from around 55 dBA to 89 dBA (23-28). Sound levels have also been reported to be higher during daytime and weekdays compared to night and weekends (27, 29), but others have reported no differences between day and nighttime (28). Sound spectral analysis in NICU's have shown that the sounds mostly are in the high-frequency (1-8kHz) bands and exist close to infant's care area (30, 31) but there also exist sounds in the low-frequency band, for instance the incubator (32). As pointed out in a review there exist great methodological variability between studies (33), making it more difficult to compare them. But still, the most evident fact is that the sound levels in NICU are still above recommended levels, and efforts to reduce sound levels are essential. Common sound sources in a NICU are technical apparatus such respiratory support devices, incubators, syringes pumps and monitors, but also conversation between staff members, parents or staff - parents. Depending on the infants medical status, the number of technical apparatus that surrounds the infant varies. Each apparatus can have one or more different continuous sounds or intermittent alarms. A typical standard set up in the NICU at Umeå University Hospital in Sweden consist of eleven pieces of equipment with sixteen different sounds or alarms.

Average sound levels from these apparatus varies depending how modern they are and the combination of apparatus around the infant. For instance older incubators can have higher sound levels than more modern incubators (24). Inside the incubator the sound level can be lower than outside (34). Infants cared for in an incubator and mechanically ventilated can be exposed to lower sound levels, compared to infant care for in an open bed and mechanically ventilated (24) but with other respiratory support devices, such as continuous positive airway pressure (CPAP) support, the sound level can be high for infants cared for in the incubator, compared to infants cared for in an open bed (24, 25).

Regionalization of neonatal intensive care to university hospitals (level III-IV hospitals) demands special transport teams to improve the chances for infants born outside level III hospitals (3, 9, 10). This means that infants needs to be transported between university hospitals and community hospitals by air ambulances (fixed or rotor wing) and or ground ambulances. In these

environments the infant is exposed to extreme sound levels, 60 - 120 dBA with a tendency for higher levels in air ambulances (35-37). However, other circumstances such as snow, mud, bad roads, high speed and snow tyres, can lead to higher sound levels in the ground ambulances than in air ambulances and also higher sound levels inside the transport incubator than outside (38). Nevertheless, these sound levels exceeds the International Electrotechnical Commission (IEC) standard recommendation for maximum sound levels (<60 dBA) inside the transport incubator (39).

Magnetic resonance imaging (MRI) is a diagnostic tool for high-quality examination and images of physiological, chemical functions or structures of the infants brain. MRI's are associated with extreme high sound levels and depending on the on device and procedures the sound levels can reach 132 dBA (40-42).



**Figure. 2.**  
A RACK OF INFUSION PUMPS for the care of severely ill newborns.

# Effects of sound in neonatal environments

## Effect on the infant physiological and behavioral variables

The effect of sound can be viewed as changes in physiological and behavioral signs. High sound level (70 - 80 dBA) have been reported to increase the infants heart rate and respirator rate (34, 43) and but also lower the infants oxygenation (34). Increased blood pressure was found when infants were exposed to intermittent sounds 79-88 dBA (44), but not when exposed to continuous sound of 50-60 dBA (45). Change in the cerebral oxygenation have been investigated, but no significant changes could be observed when sound peaked 5 dB above mean ambient sound level (46).

When using EMG recordings and behavior assessment to study infants exposed to sound levels ranging from 70 - 90 dBA, a significant reaction in both these measures was shown, that prevented the infants from return to baseline (47). Sleep also is important for neurodevelopment and there are studies indicating that high sound affects preterm infants negatively, changed sleep states or behavioral states (48, 49).

The effects of high sound levels during neonatal transportation is poorly investigated, one study could show that the infants heart rate increases with high sound levels, and that infants wearing ear muffs during transport had lower heart rate (37).

Term infant undergoing MR examination showed increased heart rate, but also periods of bradycardia and low blood pressure (50) however sound levels were not recorded in this study.

## Hearing impairment

A review regarding hearing loss among very low birth weight (VLBW) infants report that hearing impairment in infants and young children are 0.1% to 0.2% while the hearing loss among infants discharged from a NICU are 0.7–1.5%, i.e around seven times higher (51). More importantly, the review points out a shift from defining VLBW as a risk factor for hearing impairment to a high lighting of the surrounding environment around the infant. Among

several risk factors, neonatal intensive care with ventilator support for more than five days is listed. Noise in combination with aminoglycoside is suspected to increase the risk for hearing impairment (52). The etiology of hearing in extremely preterm infants still not fully understood.

### **Effects on the parents**

The NICU environment differs from other hospital environments in many ways. One such aspect is that neonatal care, besides taking care of the extremely born infant, also need to care for the parents and siblings. At the NICU it may be the first time the parents meet their newborn infant, a baby that was abruptly taken away from them after the delivery in order to start resuscitation. Instead of having a full term healthy baby on the mothers chest the parents find themselves in a high tech intensive care unit up to 18 weeks before estimated time of birth. This means a major cries for the family and the natural bonding process is at risk (53). The nurses are important to facilitate the bonding process (54, 55) for instance by increasing the parents presence at the NICU and activities involving them in the care of their infant. However high sound levels have shown to be a barriers for parents' presence (56).

### **On the staff**

High sound levels and noise in hospital environment its effects are well described in studies (57-59) but less well specified for NICU environments. In a pediatric intensive care unit a study showed an association between noise and stress signals such as tachycardia and increased annoyance among the staff (60). NICU sounds may interfere with communication among caregivers and their job performance and have also been reported to negatively affect patient care quality (61, 62). It is reasonable to assume that the staff in a NICU are equally sensitive and equally affected by noise, compared to those working in intensive care units for adults, however the margins for staff errors are much smaller in a NICU.

# Strategies to reduce sound and sound levels

## Hearing protection

Research concerning the benefits of earmuffs on infants is poorly investigated. The few studies that exist have different populations and designs and are relatively small. Earmuffs that can reduce the sound levels by 7 to 12 dB were studied on infants in a NICU. The results showed that when earmuffs were used the infant had higher mean oxygen saturation, less variation in oxygen saturation, fewer behavioral state changes, and spent more time in the quiet sleep state (63). Another study of 20 stable infants < 1500 g with or without earmuffs also showed better sleep efficiency in terms of more time quiet in sleep (64). Results from a recent study found that preterm infants (28 - 32 gestational age) had higher heart rate (HR) and heart rate variability (HRV) while wearing eye goggles and earmuffs, and therefore concluded that these were not recommended for the clinical use (65). However, in the later study the intervention consisted of both wearing earmuffs and covering the eyes, making it more difficult to distinguish which of these two things contributed to changes in HR and HRV. A Swedish study found that by placing an acoustic hood in a MR-camera the peak sound levels are reduced with 16–22 dBA depending on the pulse sequence (66). This study adequately pointed out the need for careful placing the hearing protection with proper fixation to the head for optimal effect. They also used a dental putty (two-component material that is formed to fit into the ear canal) before placing the earmuffs, but the effect on the infants of these combination was not highlighted. In a study of 34 very low birth weight (VLBW) infants who were randomized to either earplugs or no earplugs, until they reached the age of 35 weeks or were discharged, could show that the infants wearing earplugs had better weight gain and scored better on the Bayley Mental Development Index (67). An important remark in the study was that the nurses were rewarded if they had shaped and properly positioned the earplugs in the infants concha. From this and also from the other studies mentioned in this section, one can conclude that there is a lack of specially made hearing protection for critical ill premature infants in NICU's, and that the home-made protections being used are difficult to position properly.

## Care protocol

The common aim of these type of studies are to lower the sound level by different forms of interventions, such as education or change a behavior. Implementation of a quiet hour is an old strategy to reduce environmental stimuli in order to enhance the sleep/wake stated and physiologic stability (48) has proven to reduce the sound level. However, no study have been able to show a long term effect of this implementation.

A study with positive and negative reinforcement to condition the staff to modify sound generating activities, showed reduced sound levels that lasted for 18 months (68) but not for 24 months. A simple educational program about sound and sound levels connected to care activities by nurses on surgical ward for newborns could show a reduction in sound levels (69). Another noise awareness educational program (NAEP) created for a NICU and it's staff included what noise is, effects and practical tips to prevent noise. Despite methodological issues the study could show an increased awareness regarding noise as well as a decrease in sound levels (70). A similar approach, using education to increase staff awareness and change their behavior, was also combined with minor changes in the NICU environment (for instance rubber shoes on furniture). The result was a reduction of sound levels by 2.1 to 9.6 dBA depending type nursing room (71). A French study also concluded that hospital staff can control the extent and frequency of sound sources, but that it demands awareness of the problem (72). Even if these studies can be questioned, when it comes to design or sample size they clearly point out two important aspects, awareness of sound and it's consequences as fundamental starting points for reducing noise. Small inexpensive intervention can be of major importance to reduce sound levels in neonatal units.



**Figure 3.**  
INTENSIVE CARE PLACE at the neonatal intensive care unit in Umeå. Incubator to the right, respirator and the monitors at left. Behind the incubator, hidden, is the infusion pumps placed (see fig. 2). In this case, there are a total of 16 different sound sources, with a total of 23 different alarm sounds.

## NICU design

The first planning guidelines for NICUs was published in 1976 (73). Since then several editions of recommended standard for NICU design have been developed and published by a north American committee of multi-disciplinary professionals (i.e. administrators, healthcare professionals, architects, and interior designers). The latest eighth edition (74) consist of 27 standards of witch acoustic environment is standard number 27. The standard 27, first sets the sound limits of the combined continuous background sound and operational sound in different conditions, and the continues with aspects more related to the building mechanical systems or permanent equipment. Acoustically absorptive surfaces are highlighted, as well as care rooms with incompatible adjacencies rooms.

In general, NICU often have an open-bay or multi-bed design, but during the last decade interest for NICU's with single-room design has increased. A report with a focus on the design of a quiet NICU, claim that open-bed NICUs is the most important factor in designs that produce noisy nurseries (75) but few studies have actually compared the two designs. A NICU with eight-bed open design was compared with a private room design and showed a decrease in the mean sound level (76). The effect of increasing a open-bay NICU from 650 m<sup>2</sup> to a 45 single rooms NICU of 2508 m<sup>2</sup> resulted in a significant reduction the sound level to less than half of the levels in the open-bay NICU exclusive ventilator support (77). Similar results (i.e lower sound level) was also found by others when comparing open-bay design with single-room care, however the results depended on which type of ventilation support the infants had. No differences was found if the infant was ventilated with high frequency ventilation (78). The drawbacks of a single room design that can be discussed are increased staffing, higher cost per bed, increased incidents reports and increased walking per shift. However, this is not properly studied.

To build a new NICU or to rebuild an existing NICU is usually a costly process, and most likely rarely done. The design of a NICU is of great importance for the sound environment and a current trend for single-room NICU seems to be beneficial for the infant, but other aspects also needs to be taken into account. Therefore carefully planning is mandatory and the knowledge from several experts needed.

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# The impact of sound in health promoting environments

Patrik Grahn & Matilda van den Bosch

*Institutionen för arbetsvetenskap, ekonomi och miljöpsykologi,  
SLU Alnarp*

## Essential qualities in a recreational outdoor setting

**D**uring the million programme - the ambitious housing programme in Sweden in the 1960s and 1970s - urban areas grew significantly. This was because housing areas in general were built outside the old city limits. In the 1980s, a backlash grew strong against this type of city planning, which meant increasing distances between people living in monotonous, dreary outskirts to livelier city centres. Criticism covered many aspects, such as a waste of good farmland; that people became addicted to cars; that the cities became more socially segregated; and that this way of planning and building was not at all about creating real, vital cities. One way of turning back and creating “real cities” again was to densify, saving cities from “urban sprawl” (Grahn, 2012).

However, to build in areas that had earlier been saved, e.g. urban parks, created much criticism as well, not at least from people living close to these areas. In addition, to have less access to urban parks together with increasing stress and more sedentary everyday situations could have negative impact on people’s mental health (Grahn & Stigsdotter, 2003). The question came to a head: what kind of recreational areas do people need? Which qualities are more needed than others? Several research projects started in the late 1970s and early 1980s, in order to find out which qualities people really do need in urban parks. A summary of the research that had been carried out was conducted,

and all the qualities that had been identified as of special importance were listed in an extensive questionnaire survey (Grahm & Sorte, 1985). The result was treated factor analytically, and a number of characteristics stood out clearly. Similar studies were conducted later, in Sweden, in the UK, USA, Germany, and other countries. Usually, eight characteristics emerge (Grahm & Stigsdotter, 2010; Adevi & Grahm, 2012).

In their most distinct forms, these eight characteristics can be described as follows (Grahm & Stigsdotter, 2010; Grahm et al 2010):

1. Serene: Peace, silence and signs of care, safe and secure. Sounds of wind, water, birds and insects. No rubbish, no weeds, no other people or just a few.
2. Nature: Fascination with wild nature. Plants seem self-sown. Lichen- and moss-grown rocks, old paths. Something created not by humans, but by the power of something mightier.
3. Rich in Species: An outdoor area offering a variety of species of animals and plants.
4. Space: An outdoor area offering a restful feeling of “entering another world”. A coherent whole, like a beech forest.
5. Prospect: A green, open place with room for vistas, and a place that invites you to stay.
6. Refuge: A sanctuary, an enclosed, safe, secret and secluded place, where you can relax and be yourself and also experiment and play.
7. Social: A meeting place for festivity and pleasure. A social arena or meeting place.
8. Culture: A place offering fascination through evidence of people’s values, beliefs, efforts and toils, and perhaps with the passage of time.

All these characteristics seem to include more than one sense; sight, hearing and some characteristic could also include other senses (Hedfors & Grahm, 1998).

## A health-promoting everyday environment

From above mentioned studies we got some knowledge about which qualities in urban parks and natural areas people seek to find because they are perceived as recreational. We assumed that e.g. architects and other planners in a near future could use this knowledge in planning and design. However, to develop tools for planners and architects, we had to know more about the characteristics (Grahn et al 2005): Which green areas correspond to people's expectations on e.g. the characteristic Space? In addition, we wanted to know more about recreational and health promoting effects.

We focused on the county of Scania. With available data from regional GIS-databases from the County Administrative Board, we could hypothetically stipulate the presence or not for five of the eight characteristics: Serene, Nature, Rich in Species, Space and Culture (Björk et al 2008). Data regarding these five characteristics were put in a large dataset, comprising an extensive public health survey (n=27 963 persons in Scania). Associations between access to different characteristics and health were analysed using ordinary epidemiological statistical methods. Could it be, that access or not to these presumed restorative characteristics in everyday life could affect people's health? Results showed that the number of recreational values near people's residence were strongly associated with satisfaction of their own neighbourhood, and moreover their amount of physical activity. There was an evident positive correlation between the number of recreational values present within 300 metres distance from the residence and time spent on moderate physical activities every week ( $p < 0.001$ ). The effect on satisfaction was especially marked among tenants: presence of recreational values was associated with low or normal BMI in this group (Björk et al 2008). One characteristic seemed more than others to be associated with different aspects of well-being – Serene.

The hypothetical "objective" ratings of the various characteristics proved to work quite well, but we wanted to make them more sharp and distinct. Hence, we included people's assessments of their neighbourhood with the "objective" criteria, and finally could merge these assessments to make a Scania Green Score (SGS) (de Jong et al 2011). This balanced SGS showed to have a positive influence on people's health. Again, Serene showed to be the most important characteristic (Annerstedt et al 2012; de Jong et al 2012).

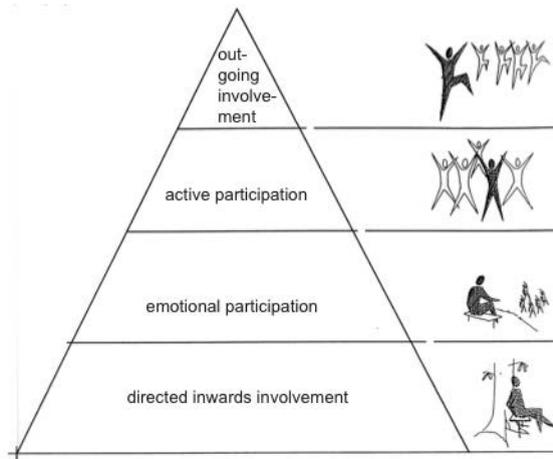
Several studies show that the characteristic Serene in urban parks and natural areas might be a specific factor, affecting people's mental health in a positive way. It could be that above all access to Serene in everyday life would render more people a positive development in public health. This is important information in an urbanizing society where any nature at hand should contain as much value as possible. The results may influence urban planning as well as health policies. Since the characteristic Serene could be of such great importance, it is of great value to further understand it.

## A salutogenic rehabilitation garden

Stress-induced sicknesses have become a huge global problem. According to the World Health Organization (WHO), mental health disorders and heart diseases – both of which are clearly affected by stress – are expected to be the two major contributors to sicknesses in all parts of the world, with mental health disorders calculated for all age groups and both sexes, by the year 2020 (WHO, 2008). In Sweden, mental health disorders are already the main cause of long-term sicknesses. The amount, especially in the younger age-groups 20-35, is still growing (Försäkringskassan, 2013). Rehabilitation is often prolonged, and return to work rate is low. It is recognized that individuals with stress-related mental sicknesses are in great need of rest and mental recovery (Perski 2004). There is increasing scientific evidence that nature can be a positive resource for relieving symptoms of stress and improving mental recovery (Nilsson, et al 2011). Since at least the 1930s, there also exist therapies, e.g. in the US, based on gardening (Stigsdotter et al 2011).

In order to scientifically establish rehabilitation based on activities and rest in nature, a Nature Based Rehabilitation (NBR) program was developed at the Swedish University of Agricultural Sciences, Alnarp campus. It consists of a specially designed garden, a selected treatment team and a special developed activity program for stress-related mental sickness (Stigsdotter & Grahn, 2003; Grahn et al 2010). The garden has been constructed and laid out on the basis of a theory, that people who suffer from stress-related mental sickness can best regain health in a natural setting (Grahn, 1999). The theory argues that people affected by stress-related mental sickness get a changed understanding of their activities as well as their surrounding environment, and how they

can work in and manage that change in their lives: their "Scope of meaning" and "Scope of action" (Grahn, 1991; Grahn et al 2010). Their function in everyday life has become seriously weak, and they need a lot of support from the environment. The theory asserts that people in the beginning of a process of rehabilitation from this illness has a great need of support, especially from natural environments (Grahn, 1991; Grahn et al 2010). Gradually, as they get better, the large and immediate need of support will diminish and will also change in character. Now, a need of support from people starts growing. This theory is summarized in a diagram (Fig. 1).



**Figure 1.**  
 “The pyramid of supporting environments summarizing the “Scope of meaning/scope of action” theory.”

When the Alnarp Rehabilitation Garden was laid out, the design mainly followed the above theory (Stigsdotter & Grahn, 2003). The garden had to be functioning in all phases of treatment; so according to the theory it consists of a range of different types of nature and garden environments. These garden rooms are designed to include the eight characteristics. Garden rooms which are designed to be used in the beginning of rehabilitation, include Serene, Refuge and Nature. Earlier research shows that these characteristics are of utmost value for those who are most vulnerable (Grahn & Stigsdotter, 2010). Other garden rooms include characteristics of value later in the rehabilitation program, like

Culture and Social (Grahn et al 2010). Moreover, the environment (social) consists of a small group of people (patients or participants) in the same situation as well as by a team who are experts in managing a rehabilitation garden (landscape engineer and landscape architect) and experts on human health (occupational therapist, physical therapist, and psychotherapist). The rehabilitation garden started in 2002.

Since then, several projects and dissertations have been made during the years (e.g. Stigsdotter, 2005; Tenngart Ivarsson, 2011 and Adevi, 2012). In essence, the program seems to work well, both when it comes to improving health and reducing health care consumption (Pálsdóttir et al 2013; Währborg et al 2014), as well as in terms of how the garden as a whole is perceived and used (Tenngart Ivarsson & Grahn, 2010; Grahn & Stigsdotter, 2010; Adevi 2012).

It has not been easy to establish how the different characteristics are perceived. It is clear that many senses are involved. As for “Rich in species”; in addition to vision, hearing is used (birdsong, insects) and olfactory perception (fungi, flowers). For the characteristic “Space”, many senses must be used to assess the size and coherence: using vision, hearing, locomotion, and a spatiotemporal perception together, can lead you to judge this quality.

The scope of meaning/scope of action theory we are now developing in Alnarp (Grahn et al, 2010) suggests that the surrounding environment and its characteristics communicate with the visitor on many levels: that an environment presents so called affordances of different intrinsic and perceived worth. These values can sometimes be of huge importance to their Self. An affordance of an environment offers the visitors possibilities for different kinds of activities (including rest) and experiences. These possibilities are considered as properties of person-environment interaction: not merely properties of the physical environment.

New research shows that especially at the beginning of the rehabilitation, Serene is important. All separate components of the characteristic are thus of importance: the absence of traffic sounds and noise; the presence of natural sounds such as birdsong and the sound of the wind in the leaves; and perhaps most important - the absence of people (Pálsdóttir et al 2014).

So, to be able to hear the sounds of serenity - calming sounds from nature - there must be absence of noise from traffic, and even absence of people. Why? Affordances from a rehabilitating environment is about sensitive

communication between a person and his surrounding world – what does the environment tell him, about how to react and behave. Johan Ottosson wrote an introspective study about his rehabilitation after a traffic accident. He had to use the natural environment outside the hospital to feel that he could have a chance to rehabilitate.

*He preferred to be alone when out in the wild. The feeling of communion, calm and harmony was too subtle, too delicate to compete with the company of other people. For him, the experience of being “alone with nature” was different from when he shared the experience with others. (...)*

*When he had company, nature assumed a different and more passive role, and the landscape was transformed into a backdrop.*

(Ottosson, 2001, page 170).

## Experimental investigation of relation between sound, environment, and human physiological reactions

### Background

From the above it has been shown that sounds are important for creating health promoting environments. This has been studied in epidemiological studies, and further been demonstrated in a rehabilitating garden. It has been found that the acoustic environment can be interpreted in varied ways and thus give rise to varied emotional or psychological reactions. However, it has not been clear what the bio-physiological reactions are behind those variations in psychological reactions. By understanding the physiological processes that mediate the associations between health and sound, a wider implication of the relationship might be expected. In addition, it may contribute to a better comprehension of how to optimally continue the research and exploration of the complex relationship between natural environments and human health in general.

The impact of nature experience on human health is often attributed to nature's inherent stress reducing effects (Lottrup et al. 2013, Grahn and Stigsdotter 2003). Stress, and especially chronic stress, has a well-known detrimental effect on health, directly or indirectly contributing to the epidemic of non-communicable diseases (NCDs), such as diabetes, cardiovascular and mental disorders (McEwen 1993, McEwen 2012).

Several studies have been performed using images of nature to investigate the impact on stress reactions. This has revealed a certain positive effect by visual exposure to nature (Balling and Falk 1982, Staats et al. 2003).

### **Purpose, method, and material**

In order to explore the specific impact of natural sounds and the interaction between visual and auditory exposure we planned and accomplished an experimental pilot-study in the virtual reality (VR) laboratory of Lund University.

Compared to static simulations (e.g. photos), virtual environments (VEs) provide a more dynamic alternative with greater ecological validity, that is, approximating the real-life situation (de Kort et al. 2003).

The VE in the study was presented using a CAVE™ system with three rear-projected walls (4 m × 3 m) and a floor projection (EON Development Inc.). Passive stereoscopy was used to achieve three-dimensional vision. The system also included an InterSense head tracking system that creates a motion parallax effect to further increase the sense of realism.

The test participants (n=30) were first exposed to a VR stress test, where after they were randomised to recover in three different conditions (10 persons in each condition).

The stress test was based on one of the most validated and reliable stress provoking tests that exist for research purposes – the Trier Social Stress Test (TSST). It has consistently been proven to activate the hypothalamus–pituitary–adrenal (HPA) axis and the sympatho–adrenal–medullary (SAM) system (Kudielka et al. 2004, Kelly et al. 2008), along with the corresponding endocrine and cardiovascular responses.

In this study we used a recently developed virtual form of TSST to induce

acute stress (Jönsson et al. 2010, Jönsson et al. 2008), which has demonstrated resembling reactions as the ordinary TSST.

Autonomic and endocrine stress reactivity was assessed by heart rate, T-wave amplitude (TWA), heart rate variability (HRV) parameters, and saliva cortisol, together with subjective ratings of stress (Annerstedt et al 2013). Heart rate (HR), TWA, and HRV were recorded with electrocardiogram (ECG) and a strain gauge for breathing registration. Both HE and TWA are markers of the sympathetic nervous system and increase with stress. HRV is a parasympathetic marker and decreases with stress (Dickerson and Kemeny 2004, Kline et al. 1998, Berntson 1997).

Saliva cortisol was collected in sampling tubes with cotton swabs. Cortisol is an indicator of sympathetic activity, and increases with stress. Baseline testing and subsequent testing throughout and after the experiment were carried out.

Subjective stress was assessed with the Spielberger state and trait inventory (STAI-S) (Spielberger et al. 1983).

The stress provoking part of the study, the TSST, was identical for all test participants and lasted about 15 minutes. After the stress test we changed the VE around the participant and they recovered in the new environment for about 40 minutes. The stress recovery took place in three different settings; i) VR-nature without any sound, ii) VR-nature and sounds of nature, and iii) an ordinary indoor control condition. After the recovery session was completed a few post-experiment tests were run and the purpose of the study was explained to the participant.

The virtual natural environment consisted of trees in a forest, surrounding a path leading to a stream of water, reminiscent of a natural setting in Scandinavia (see Fig. 2).



**Figure 2.**  
Photo of the virtual reality nature used in the recovery phase of the study

Regarding the sounds of nature we decided to use sounds of birdsong and water, since this has previously been related to feelings of relaxation and positive reactions (Brown and Muhar 2004, Nilsson and Berglund 2006). Such natural sounds have been used in stressful situations like surgical procedures, and have demonstrated stress-relieving effect via the autonomic nervous system (Alvarsson et al. 2010, Diette et al. 2003). The sounds were also in concordance with the virtual green environment we used.

### **Statistical analysis**

Repeated measures ANOVA were used in all analyses for the physiological measures ( $p < 0.05$ ), with experimental CONDITION as within-subject repeated factor and GROUP as the between-subject factor. Significant effects were reported with Greenhouse–Geisser adjustments to correct for violation of the assumption of sphericity, together with unadjusted degrees of freedom, adjusted p-values, and<sup>2</sup>.

## Results

No significant differences (independent samples Mann Whitney test) were found for the participants at baseline in terms of former experiences, or perception of stress and general health.

All the physiological measurements as well as the STAI-S ratings demonstrated that the stress induction was successful.

During the stress recovery phase there was a GROUP effect for the HRV-parameter, but nor for cortisol, TWA, or HR, which demonstrated a main effect of CONDITION only. The analysis of HRV showed that group recovering in VR-nature + sound responded with increased HRV-magnitude during recovery. The groups recovering in VR-nature without sound and the control group responded with decreased HRV of about the same magnitude (see Figure 2)

There was no significant difference in state anxiety during exposure to the green environment between the group that also received the auditory stimuli and the group that did not.

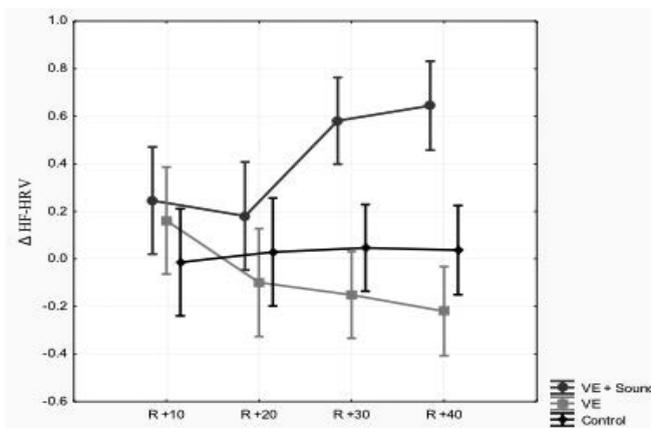


Figure 2.

Different changes in HRV depending on condition. R= Recovery, where numbers indicate time after stress provocation, e.g. +10 is 10 minute after ended stress test

## Discussion

We found that stress recovery can be facilitated by the addition of sounds of nature to a virtual green environment in a laboratory setting. Concerning recovery, HRV increased (indicating parasympathetic, stress relieving activity) for the group that after TSST were exposed to a virtual forest with congruent nature sounds. The control group showed about the same HRV magnitude as during TSST, and neither did we detect any significant effect on stress recovery in the silent green environment.

Thus, our hypothesis was partly confirmed. Stress recovery seemed to be facilitated for the group that recovered in the setting with both visual and auditory nature stimuli as indicated by increasing parasympathetic activity. However, in contrast to our intention the silent forest may have created a component of uncertainty or un-pleasantness. That is, the very quiet and silent VE was not Serene, safe and secure – on the contrary. Some of the participants, who recovered in the silent forest, mentioned that they had experienced some kind of anticipation fear, expecting something threatening or dangerous to appear from the surrounding VR nature. The incongruent situation of a high visual realism with no other modality exposure might produce an almost surrealistic experience that may be perceived as some-what frightening.

The lack of effect on cortisol response may reflect the inertness of this system. The reaction of cortisol is generally slow and difficult to affect in any measurable way by adjustment of the recovery environment.

Besides from the small sample size this study has several other limitations. An additional control group with only auditory recovery would have increased the interpretational value, and should be explored through further developed study protocols in response to this initial pilot study. Although inclusion of only men helps standardising the results it also restricts generalizability.

To summarize, the findings of this pilot study give preliminary but positive support for the potential of nature VE in research. There seems to be a significant interactive effect between sound modality and visual input in the virtual nature setting, contributing to increased parasympathetic activity and more efficient recovery after virtually-induced stress. Consequently, this

discovery of an activation mechanism operative in the case of stress recovery suggests novel interpretations of how health effects in nature are achieved. The findings offer prospects for a new research strategy in the field of interactions between humans and nature. By standardising natural settings, applying different modalities, and using varied measurement techniques and variables within the laboratory, a more fundamental understanding of the mechanisms and pathways for this interaction may be achieved, with an eventual importance for creating healthy environments.

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# Two studies of relevance to perceived noise in health care

Töres Theorell

## Introduction

Both studies in the present chapter concern the sound environment but they do so from two different perspectives – 1.) the acoustics in care and 2.) the perception of disturbing sounds in an emotionally exhausted group of people exposed to a combination acute stress and distressing sound, a group that is prevalent among patients in care.

The first study that I will refer to (Blomkvist et al 2005, Hagerman et al 2005) was published several years ago. When the main author Vanja Blomkvist performed interviews with the staff who had participated in the study they described how amazed they were at the striking difference between two sound environments (one sound reflecting and one sound absorbing) in their own work place. The intensive coronary care unit management had decided to allow a real experiment remodelling the ceilings of the patient rooms as well as the alarm station with all the monitoring equipment and the commanding central. The staff described how much easier their work became when they had a sound absorbing environment compared to when the environment was sound reflecting. This strong subjective staff impression was confirmed by scientific data.

In the second study (Hasson et al 2013, briefly referred here) we were able to observe how two groups of subjects recruited from a study of the general population, one with high scores on a scale measuring emotional exhaustion (corresponding symptoms of burnout) and one with low such scores. Subjects

in both groups were exposed to an acute stress situation in the laboratory and several aspects of hearing were assessed in both groups both before and after the acute stress. The results showed that subjects with emotional exhaustion showed hyperacusis (lower tolerance threshold for noise disturbance) after the acute stress situation. In the healthy group the noise tolerance improved after the acute stress. These findings were highly significant for women and similar but not significant for men. Many patients, regardless of diagnosis, suffer from emotional exhaustion at the hospital and there are many distressing factors in their environment. Our study shows that these patients are unable to activate mechanisms protecting themselves against hyperacusis.

## Study 1 (Blomkvist et al 2005, Hagerman et al 2005) The sound environment in coronary care – a practical experiment

The coronary care unit (CCU) at Huddinge Hospital which is part of the Karolinska Hospital in Stockholm has eight beds. This is where the study took place (see fig 1). The comparatively small number of beds enhances the turnover of patients in the unit; every day 6–7 patients with acute symptoms are admitted to the unit and the average observation time is 17 hours. The units are equipped with continuous ECG monitoring, all of which is controlled on screens in the CCU. All patients are monitored with a computerised system for ECG and/or haemodynamics, with different automatic alarms for critical values. Patients are continuously, when needed, transported to the laboratories for angiography, electrophysiology, or CT scanning. Laboratory testing is partly performed in a setting in a corner of the central area. This and other logistics, such as regular cleaning of the patient rooms, exchange of beds and laundry among other things, give the unit a noisy and somewhat turbulent atmosphere.

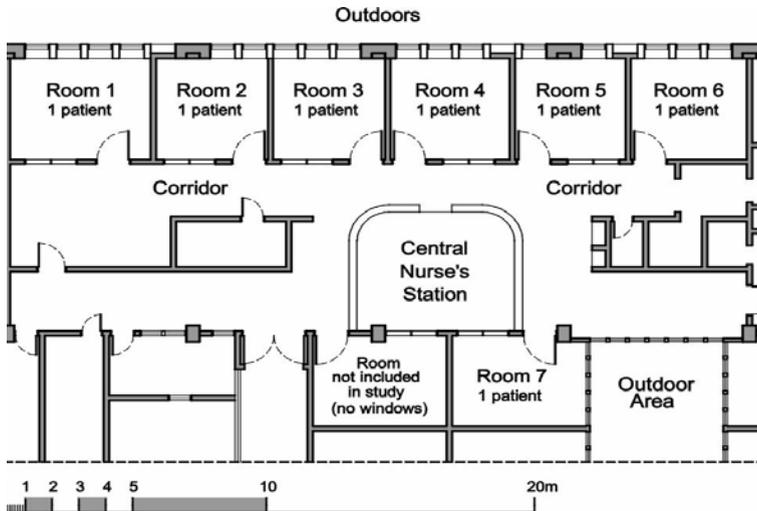


Figure 1.  
Plan of the intensive coronary care unit

The 36 nurses working regularly at the ward were asked to participate in the investigation of the psychosocial environment and emotional states at the start and end of each individual work shift.

After an initial baseline period the acoustics were changed in two steps in the patient rooms and the main work area of the unit where most decisions are made and monitoring of the patients takes place. In the first step, remodelling of the ceiling took place, creating a sound reflective ceiling surface in the entire ward. In the second step, sound absorbing ceilings were installed throughout the ward.

The baseline period lasted for three weeks. This period should be regarded as a “feasibility period” during which procedures and questionnaires were tested. The first part of the main study (sound reflecting period) was carried out during 20 weekdays—from the beginning of February until the beginning of March 2001. The second part (sound absorbing period) lasted from March during 22 weekdays until the middle of April 2001. Data for the project were collected during regular weekdays and corresponding nights, but not during weekends since there were changes in staffing and conditions during such periods.

## Measures

Questionnaires with psychosocial items were distributed and filled out on two occasions during the shift—at the beginning of the work shift and at the very end. The questions describing work situation were pace of work (high or low tempo), quantity of work (great or small), decision latitude (high or low), own competence (high or low), own hard decisions (seldom or often), self-determination (a lot or a little), information/education (a lot or a little), atmosphere at work (calm or unsettling), quality of care (easy to prioritise or hard to prioritise), and social support at work (good or poor). These questions correspond roughly to a condensed visual analogue version of the demand-control-support model, Swedish version.<sup>30</sup> The questions describing mood states were hastiness, calmness, irritation, anxiety, tension, happiness, sadness, anger, depression, stress, and fatigue. A longer version of this selection of adjectives has been used in previous research (Shimomitsu and Theorell 1996, Gillberg et al 1994). Analyses were performed with the difference between “end” and “start” score (“delta” values). The rationale behind the analysis of the delta values was that the accumulated effect of the exposure of working conditions would be particularly visible in the comparison between the start and the end levels. Another way of expressing this is that the delta value shows the “netto” effect. A negative delta score indicates a lower score at the end of the shift than at the beginning.

All psychosocial questions were measured with visual analogue scales. In the statistical analysis the measures were used as scores from 0 to 10. Statistically, the results obtained with the visual analogue scales were comparable to those obtained with the original questionnaires which were constructed with ordinal scales (Karasek 1997).

Acoustic measurements were done in the main work area and in three patient rooms (ISO 1997, Gillberg et al 1994). The reverberation time was the major acoustic variable defined as the time needed for the sound pressure level to decrease by 60 dB after the sound source has been switched off. A change in reverberation time was expected to influence sound pressure level, sound propagation, and speech intelligibility of the premises. The reverberation time was measured for the two different conditions<sup>36</sup> in the main work area and in Room 4. Patient rooms 1–7 were judged as similar in terms of room acoustic character (size, height, and positioning of furniture and equipment, etc) which meant that measurements were limited to Room 4. The equivalent

sound pressure level (LAeq) was measured for one week during each study period in Rooms 1, 4, and 7 (see fig 1) and in the main work area of the ward. Sound propagation was determined by measuring the attenuation of a reference sound of 88 db(A) pink noise (positioned in the lower corner of the left corridor), which was louder than the background noise level at all measured positions. Measurements were done at predetermined intervals from the source along the outer wall of the main ward. The sound pressure level of the reference sound was also measured in two patient rooms situated along the outer wall. Speech intelligibility was measured according to the RASTI (Rapid Speech Transmission Index) method, and intended to measure the effects on speech caused by background noise (mechanical installations and equipment) and reverberant sound. Measurements were done in Room 4 (the speaker next to the bed and the receiver at the patient's head) as well as at two positions in the main work area. The speaker was positioned at the lower left corner of the central nursing station and the receiver was positioned either at the upper right corner of the station or at the entrance to Room 5. The RASTI method allows the user to transform the numeric values to a qualitative interpretation, ranging from "bad", "poor", "fair", "good", to "excellent".

Reverberation time was manipulated during the two study periods through the use of sound reflective and sound absorbing ceilings. A sound reflective suspended ceiling (13 mm solid painted plaster board tiles) was mounted in the main work area. The original ceiling tiles (25 mm thick resin bonded glass wool with a painted surface) in the main work area were judged to correspond to absorption class A.<sup>41,42</sup> The patient rooms already contained a reflective ceiling surface (solid painted plaster). During the fifth week the plaster ceiling tiles in the main work area were substituted by visually identical sound absorbing ceiling tiles. Additionally the eight patient rooms were fitted with the same type of sound absorbing ceiling tiles. The sound absorbing Ecophon ceiling tile is made from a 40 mm thick high density resin bonded glass wool with a painted surface. The ceiling tiles have high sound absorption, absorption class A.

## **Statistical methods**

A principal component analysis (varimax, roots >1) highlighted a demand factor (high pace of work, high quantity of work, bad atmosphere at work, high demand on quality of care) as well as a control/support factor (autonomy,

self-determination, own competence, social support at work), which corresponds roughly to a combined decision latitude and social support factor in the demand-control-support model. The mood scales were also submitted to principal component analysis. Three distinct factors were found, namely distress (anxiety, sadness, depression), pressure (stress, calmness (reversed), hastiness), and strain (irritation, anger, tension). Five indices were computed by means of the summation of item scores within each dimension (demand, control/support, distress, pressure, strain). For each individual work shift the “delta” score (sum score at end minus sum score at start of shift) was computed, indicating the accumulated effect of working conditions. Means and 95% confidence intervals of these means were calculated for all the five sum delta scores during baseline, sound reflecting, and sound absorbing conditions. The calculations were made separately for the morning, afternoon, and night shifts.

Finally, five two-way analyses of variance (MANOVA) were performed using shift and acoustic condition (sound reflecting versus sound absorbing) as explanatory and each one of the five delta sum scores as dependent variables.

This study was approved by the local research ethics committee of Huddinge University Hospital, Stockholm, Sweden.

## **Results**

In order to avoid measurement instability, we only asked permanently employed working staff to fill out the questionnaires.

The sound reflecting period lasted for 20 days which corresponded to a maximum of 300 possible shifts. Two hundred of these shifts (67%) were covered by start and end questionnaires. Accordingly the total percentage of lost shifts was 33%. Sixteen per cent of the lost shifts were due to planned education, 8% to vacation, and 8% to sick leave due to own or child's illness. Only three (1%) were “true” drop-outs in the sense that there was no satisfactory explanation of the loss.

During the sound absorbing observation period that lasted for 22 days the maximum possible number of shifts was 330. One hundred and forty two (43%) were covered by start and end questionnaires. Accordingly the total percentage of lost shifts was 57%. Thirty seven per cent of these were due to

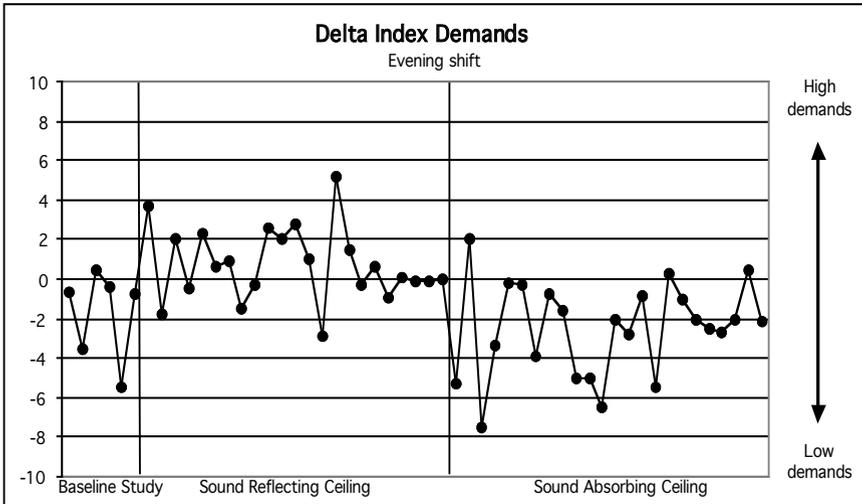
planned education, vacation, and sick leave due to own or child's illness (with relative proportions as in the previous period). The higher percentage of such drop-outs was mainly due to a vacation week (Easter). In addition, along the same lines as in the previous period, 20% were "true" drop-outs.

For the baseline period no corresponding calculations could be performed since the data collection was not continuous.

Prominent differences with regard to the delta (=difference from start to end of individual work shift) values were found in the afternoon shift when comparing the sound reflecting and the sound absorbing condition. There was a highly significant improvement (decrease) in demand ("delta") ( $p=0.0001$ ). Separate item analyses showed that improvements in pace of work, quantity of work, atmosphere at work, and demands on quality of work all contributed to this. There were also significant improvements with regard to "pressure" ("delta") ( $p=0.0003$ ) and "strain" ("delta") ( $p=0.029$ ) during the afternoon shift. Separate item analyses showed that changes in "lack of calmness", "hastiness", and "stress" ("delta") all contributed to the improvement in "pressure" ("delta") and that changes in "tension" and "irritation" ("delta") contributed to the improvement in "strain".

Two-way analyses of variance showed significant main effects of acoustic conditions for delta demand, delta pressure, and delta strain. There were significant two-way interactions (shift and acoustics) for delta demand and delta pressure. This means that the effects of the acoustics were significantly different in the three shifts for these variables. No interaction, however, was found for delta strain. This means that the effects of the acoustics on delta strain were similar in the three shifts.

The delta index demand was chosen to illustrate the changes over time for the afternoon shifts (see fig 2).



**Figure 2.** Mean change in demand score (10 cm Visual Analogue Scale, Delta Index Demands) from end to start of evening shift during baseline, "bad" acoustics (sound reflecting) and "good" acoustics period. Each dot represents one day. Plus change indicates worsened (increased demands and vice versa).

The figure shows changes over time in delta demands from the baseline study, period of sound reflecting ceilings, and the period of sound absorbing ceilings. More ratings were collected during the sound reflecting and sound absorbing periods. However, the figure clearly illustrates differences over time between the three different study periods. Acoustic environment was measured according to standards (IEC 1998,ISO 1985, 1996 a,b,c, 1997)

The acoustic measurements (equivalent sound pressure level) were continuous for one week during each study period. Reverberation time improved from 0.8 to 0.4 seconds after the instalment of the sound absorbing ceiling in the main working area, and from 0.9 to 0.4 seconds in one of the patient rooms. The sound pressure level measured directly over the main work area did not vary greatly during the two weeks (57 v 56 db(A)). As the microphone was positioned directly over the work area, mainly direct sound was measured, and under such circumstances changes in reverberation time have little impact on sound pressure level.

The measurements confirm that the central area was the noisiest area in the ward. The two patient rooms (4 and 7) showed a drop in sound level of 5–6 dB, where ca 3 dB is due to the shorter reverberation time in the actual room and 2–3 dB is due to a lower sound pressure level in the ward. This is also confirmed by the sound propagation measurements (see table 4).

The effect of the reference sound in the two rooms, Rooms 1 and 4 respectively, was 75 and 64 db(A) during the first period and 69 and 59 db(A) during the second period. For the two periods, speech intelligibility (RASTI value), improved from “good” to “excellent” in both measured areas.

In addition studies were made on the patients (Hagerman et al 2005). A total of 94 patients admitted to the intensive coronary heart unit for evaluation of chest pain were included in the study. Patient groups were recruited during bad and good acoustics, respectively. Patients were monitored with regard to blood pressure including pulse amplitude, heart rate and heart rate variability. The patients were asked to fill in a questionnaire about the quality of the care, and a follow-up of rehospitalization and mortality was made at 1 and 3 months, respectively. There were significant differences between good and bad acoustics with regard to pulse amplitude in the acute myocardial infarction and unstable angina pectoris groups, with lower values during the good acoustics period during the night. The incidence of rehospitalization during follow-up was higher for the bad acoustics group. Patient ratings of the care showed that patients treated during the good acoustics period considered the staff attitude to have been much better than during the bad acoustics period.

## Discussion

The findings indicate that the improved acoustics had affected the psychosocial environment in such a way that during the afternoon the staff experienced reduced demands, and less pressure/strain. Such changes open up for an increased capacity to care for the patients.

It seems likely that improved acoustic conditions in the healthcare environment reduce risks of conflicts and errors. During the study period with the sound absorbing acoustics the staff reported that they also felt more relaxed and irritability decreased. Although there were fewer patients during the period

with poor acoustics (longer reverberation time), the staff experienced more strain, demands and pressure at work. These negative effects occurred despite the fact that the nurses were highly educated, well trained in acute situations, and accustomed to coping with high demands and making critical decisions.

The staff members were surprised by the improved speech intelligibility after the installation of the new ceiling as well as the perceived noise level. During the period of long reverberation time speech intelligibility was thought to be below what is needed in the CCU. It is possible that alternative wording should be developed to better reflect the demands on speech intelligibility in this type of work environment. Although long term measurements have been unable to fully confirm this, the findings together suggest that the staff experienced a reduced noise load during the working day when sound absorbing ceiling tiles were in place. The most prominent positive effects of improved acoustics on the psychosocial work environment were found for the afternoon shift. Most of the effects were observed during the afternoon shift. This was also the shift that was subjected to the most noise due to family visits. In addition, the morning shift overlapped with, or worked parallel to, the afternoon shift during the initial part of the afternoon.

There was a significant worsening of delta demand between the baseline period and the period with the sound absorbing acoustics, perhaps partly due to some disarray still present during the first weeks of installation of the sound absorbing ceiling.

It is important to raise the question of a possible Hawthorne effect. Almost any change or extra attention, or the knowledge that a study is being conducted, can be enough to cause subjects to change. In this study design, however, the extra attention experienced by the staff was constant throughout the periods of sound reflecting and sound absorbing acoustics. Further, the patterns of improvement and deterioration observed were stable throughout the two periods. A Hawthorne effect would have resulted in an attenuation of the beneficial effect of sound absorption (shorter reverberation time) during the studied one month period, and perhaps in a progressive worsening of the perceived work environment during the sound reflective period (longer reverberation time). Control/support and distress were not affected by the acoustic condition at all. It is unlikely that the physical change and disarray associated with modification of the CCU ceiling at the start could explain the difference..

The study clearly raises the possibility that important gains in the psychosocial work environment of healthcare can be achieved by improving environmental acoustics. The findings imply that an approach for improving healthcare acoustics will be inadequate, however, if it focuses narrowly on reducing sound pressure levels.

A particularly interesting finding was that the patients treated during the good acoustics period rated the staff attitude to have been significantly better during the good acoustics period and also that the patients with the most severe conditions (myocardial infarction and unstable angina pectoris) had less psychophysiological activation (lower pulse amplitude) at night. This could have been of clinical significance for the healing process in these patients, which may have been mirrored by the fact that the incidence of re-hospitalisation was lower in the patients who had been cared for during the "good" acoustics period than patients in the "bad" period.

The findings point at the importance of environmental design interventions that shorten reverberation time. The importance of improved environmental acoustics for influencing speech intelligibility and perceived work demands, point to the need for further research to examine the possible role of acoustics in medical errors and other aspects of patient safety.

## Study 2 (Hasson et al 2013, briefly referred here) Sensitivity to a disturbing sound after acute stress in exhausted subjects

The aim of this study was to examine if an acute stress situation will increase auditory sensitivity in individuals with high levels of emotional exhaustion.

While there is increasing evidence for a relationship between stress and hearing problems its causality is not well-established. In experimental animals, acute stress has been shown to protect the auditory system from a subsequent noise trauma (Tahera et al 2006). However, direct evidence for the effects of stress, whether acute or chronic, on human hearing has not yet been directly tested. Recently, it was shown that emotional exhaustion is the variable that is the most strongly associated with tinnitus prevalence, more strongly associated

than traditional risk factors such as hearing loss, noise-exposure, smoking and hypertension (Hebert et al 2012). It is not known whether stress induces the hearing problems or if stress is a consequence of them. It is plausible that the association is bi-directional, i.e. that hearing problems are stressful and that stress causes increased vulnerability to hearing problems. The hypothesis being tested in the study was that an acute stress exposure will increase auditory sensitivity in individuals with high levels of emotional exhaustion. This would be in line with previous studies showing maladaptive reactions in the direction of increased hypersensitivity (Mc Ewen 1998, Ursin and Eriksen 2001, Eriksen and Ursin 2004). In contrast, the adaptive reaction would result in an increased tolerance or resilience after an acute stress (Mc Ewen 1998a,b, 2000, 2002) Over-sensitivity is a common feature in many stress-related disorders. A common symptom in individuals with hearing problems is hyperacusis, which is over-sensitivity and discomfort to normal environmental sounds that are easily tolerated by individuals without hyperacusis (Khalfa et al 2002). At present, there is no mechanistic explanation for this type of vulnerability.

Accordingly, the purpose of the present study was to directly determine the effects of acute stress on auditory sensitivity in a sample with different levels of EE. To achieve this goal, a combination of direct (uncomfortable loudness levels, ULL) and indirect (questionnaire) measures of hyperacusis was studied before and after an acute stress exposure. A common audiology test to assess hyperacusis is to determine uncomfortable loudness levels (ULL).

## **Population and Design**

The study was cross-sectional and included subjective and objective measures of hearing, as well as subjective ratings of emotional exhaustion. The sample was drawn from the Swedish Longitudinal Occupational Survey of Health (SLOSH) (Magnusson Hanson et al 2008), a cohort study of the Swedish working population which was initiated by the Stress Research Institute at Stockholm University in 2006. The present cohort was established through the second data collection, which was conducted in April 2008 by Statistics Sweden. The sample of the present study was based on the degree of emotional exhaustion - based on scorings on the exhaustion dimension of the Maslach Burnout Inventory, General survey (MBI-GS). The strategy was to select contrasting groups including the 200 women and men (100 each) with the highest emotional exhaustion scores, 200 with medium emotional scores

and 200 with the lowest scores. After plotting those scores for women and men separately, the cutoff was set around the highest quartile, the median and around the lowest quartile. The selection procedures yielded a sample of 687 individuals consisting of 143 women and 127 men with low scores, 118 women and 110 men with medium scores and 119 women and 103 men with high emotional exhaustion scores. 16 participants were excluded due to address problems. The final cohort size was thus 671. After two reminders, 348 (52%) individuals enrolled in the study.

### **Hearing assessment.**

Hearing status was assessed in the laboratory using a pure tone audiogram (PTA, 500–8,000 Hz by octave steps) following the standard Hughson-Westlake procedure in both ears using circumaural headphones (TDH39). After that, a hearing-in-noise-test (HINT) (Hagerman 1982 and 1995) was conducted in the left and right ears separately. Uncomfortable loudness levels (ULLs) were determined according to the SAME-method (see below for a further description). Each participant was instructed to let the examiner know when the pure tone became uncomfortably loud, by speaking into a microphone. The testing started at 1 kHz with a signal intensity of 70 dB. If this level was perceived as uncomfortably loud, the intensity was decreased by 10 dB and the starting level on the following frequencies was decreased to 60 dB. The sound intensity was increased in 5 dB steps until the participant gave a response that the sound was uncomfortably loud. The tested frequencies were 0.5, 1, 2 and 4 kHz. The left and right ears were tested separately. Hyperacusis was also assessed using the Hyperacusis Questionnaire (HQ) (Khalifa et al 2002).

### **Assessment of emotional exhaustion (EE)**

Emotional exhaustion was assessed with a Swedish version of the Maslach Burnout Inventory general survey (MBI-GS) using the emotional exhaustion subscale (Magnusson Hanson et al 2008). Scorings reach from 1 (every day) to 6 (a few times a year or less/never). The items included to assess the construct are: “I feel emotionally drained by my work”, “I feel completely exhausted when the working day is over”, “I feel tired when I get up in the morning to face a new working day”, “To work during a whole day is really stressful for me”, “I feel burned out of my work”.

## Acute stress task

In order to maximize the likelihood of eliciting stress, the study participants were exposed to three stress-inducing tasks simultaneously. The first task consisted of an emotional Stroop-test (Algom et al 2004, McLeod 1991, Williams et al 1996) where participants were asked to identify the colors of rapidly alternating words on a computer screen. At the bottom of the screen were boxes with the words: blue, brown, grey, green, yellow, pink, red, black, and white, and the task was to click on the box corresponding to the color of the letters of the word currently displayed. In contrast to the traditional Stroop-test, emotionally charged and neutral words were used to elicit a greater stress response. The charged and neutral words were distributed equally and presented in random order. Examples of charged words were: death, hate, and enemy. Examples of non-charged words were rose, senior, and bread. Different interfering colors were blinking on the background of the screen, and random colors were concurrently presented by a speaker voice via headphones. The pace of the visual and auditory presentation was 30 words per minute, while the background color shifted 80 times per minute.

The second task, performed simultaneously, was a cold pressor exposure, i.e. hand in ice water (about 4°C), which may be more or less painful for different individuals. The non-dominant hand was inserted wrist-deep into a bowl of water and ice for the entire the Stroop-test, i.e. four minutes. The cold-pressor test has been extensively used in laboratory settings to elicit a stress response (Fasano et al 1996, Streff et al 2010, Hines and Brown 1936). It has been demonstrated that adding a social evaluative task further enhances the stress response. Therefore, a social evaluation element was also included, i.e. video recording of the respondent and being observed by the researcher holding the camera. The video camera was stationed approximately 40 cm behind the computer screen, and participants were told that their facial expressions would be recorded for evaluation by a professional. The participants were instructed that they were allowed to remove their hand from the ice-water if the pain was unbearable. The recording started as soon as the headphones were properly equipped and one hand had been fully inserted the bowl of water.

## Statistical analyses.

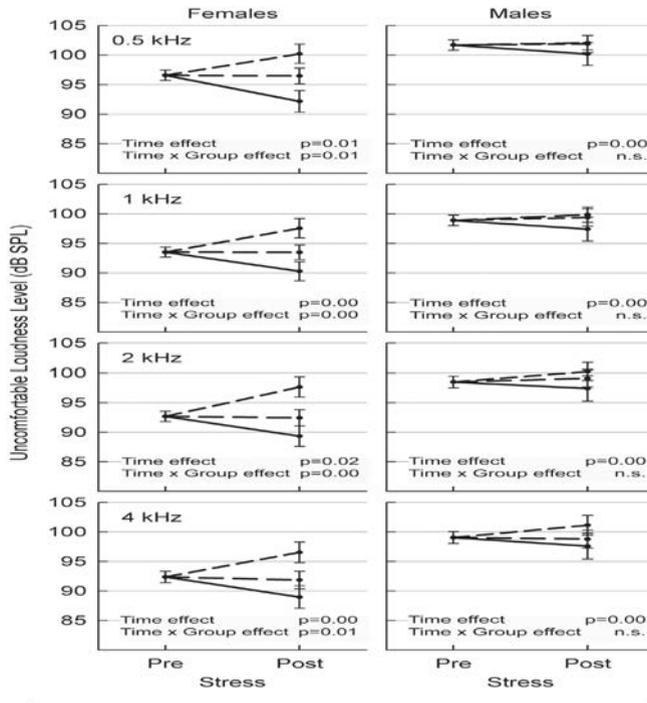
A one-way ANOVA with Bonferroni post-hoc tests was conducted in order to assess possible baseline differences in mean values of ULL. A 2-way ANCOVA was used to assess possible differences in mean ULLs over time (pre to post the acute stress task) between the EE-groups. Since there was a ceiling effect in the ULL assessment a new variable was created. If a person had a “>” symbol next to a 110 dB score, the value was set to 115 dB. This is a cautious approach to create at least a minor reduction in the ceiling effect. All the parametric analyses were conducted with this variable.

Multivariate analyses, proportional odds model (also called ordered logistic regression), were used to calculate possible odds ratios, including interacting or confounding effects of age, gender, ear wax and hearing loss (only PTA). All logistic regression analyses were adjusted for hearing loss and ear wax. For the logistic regression, ULLs were trichotomized. ULL values  $\leq 85$  dB HL were considered to be a sign of severe hyperacusis; 86–95 dB moderate hyperacusis and  $\geq 96$  normal values. EE was also divided by tertile split so that values between  $<1.2$  was considered to be low levels of EE; 1.21 to 2.99 medium EE and  $\geq 3$  high EE. All p-values were 2-sided and significance was set at 0.05. Data analysis was performed using SPSS Statistics version 20 and SAS.

## Results

There were no baseline differences in mean ULL levels between the three EE (emotional exhaustion) groups, except for the left ear 4 kHz where there was a mean difference of 6 dB between the low and high EE-groups ( $p = 0.035$ , one-way ANOVA with Bonferroni post-hoc test). However, after the acute stress exposure there were significant differences in mean levels of ULL (2 kHz right  $F = 5.78_{df=2}$   $p = 0.003$ ; left  $F = 4.54_{df=2}$   $p = 0.011$ ; 4 kHz right  $F = 5.25_{df=2}$   $p = 0.006$ , left  $F = 5.39_{df=2}$   $p = 0.005$ ) between the EE-groups. Bonferroni post-hoc analyses showed that the differences in mean ULLs were between those with high vs. low EE. Mean differences between the lowest and highest EE quartile were on average 6.0 dB. Similar results were found for frequencies 0.5 and 1 kHz. In order to illustrate these findings a two-way ANCOVA was performed yielding significant differences between groups over time. Figure 3 (see attachment hyperacusis figure) illustrates how women with high EE become more sensitive to pure tones at all frequencies tested after acute stress. In contrast, those with low levels of EE became more tolerant to higher levels

of stimulation after acute stress. Due to ceiling effects (maximum sound level was 115 dB SPL) mean values do not give a perfectly correct picture of true dB differences. Still, differences between the EE groups post-stress are apparent. These differences would probably be even larger without the ceiling effect.



**Figure 3.** Mean uncomfortable loudness level before and after acute stress in subjects with high burnout (emotional exhaustion, EE) score, medium burnout score and low burnout score. Female subjects to the left and male subjects to the right. Vertical bars indicate standard errors of means.

When the analyses were stratified for sex there were no differences in mean ULLs for men in different EE-groups, neither pre- nor post-stress. Women, however, only displayed a post-stress difference in mean ULLs and not a pre-stress difference, i.e. the exact same pattern as when analyzing the whole group consisting of both women and men. Thus, the differences that were found in the whole group are mostly influenced by the responses of the women. An

independent samples t-test showed that there was a statistically significant sex-related difference in baseline ULLs for all frequencies ( $p < 0.0001$ ) where men had consistently higher thresholds than women. When analyses were stratified for EE, the sex-related difference remained for those with medium and high EE levels. For those with low EE, the differences were found on 1, 2 and 4 kHz for the right ear and 4 kHz for the left ear ( $p < 0.05$ ). Thus, it is clear that there are sex-related differences in ULLs, independent of EE status.

## Effects of Acute Stress

The results demonstrate that women, but not men, who showed symptoms of long-term stress displayed hyperacusis after the acute stress task. The odds of having hyperacusis were 2.5 (2 kHz, right ear; left ns) and 2.2 (4 kHz, right ear; left ns) times higher among those with high EE compared to those with low levels. When comparing those having high EE-levels with those displaying intermediate levels, the odds of having hyperacusis decreased to 1.8 (2 kHz, right ear; left ns) and 1.6 (4 kHz, right ear; left ns) times respectively. For both women and men, higher HQ-scores increased the odds of having hyperacusis in both ears (2 and 4 kHz; OR = 1.1,  $p < 0.05$ ). Among women (left ear 2 kHz), age (<45 years) significantly increased the odds of having hyperacusis (OR = 1.9,  $p < 0.05$ ). Men exhibited a similar pattern for the right ear 4 kHz (OR = 2.9,  $p < 0.05$ ). All these results are adjusted for age, hearing loss and ear wax.

There was a systematic time\*group effect for the different EE-levels on the right, but not left, ear for women (2 kHz  $F = 10.07$ ,  $df = 2$ ,  $p < 0.01$  and 4 kHz  $F = 7.00$ ,  $df = 2$ ,  $p < 0.05$ ). This demonstrates that the different EE groups develop differently over time with regard to ULL. There were no significant differences for the men at any frequency.

## Discussion

Women with high levels of emotional exhaustion had reduced thresholds to loudness (i.e. more sensitive) after the acute stress task. It is important to note that basal levels of ULLs did not differ between the EE groups and differences were only detected after the acute stress challenge. This means that

the ULL test, when given to individuals with high levels of EE who are acutely stressed, will result in lower thresholds compared to individuals who are not emotionally exhausted. This also means that the ULL test will not detect signs of hyperacusis in women with high levels of EE if they are not acutely stressed during the testing. It cannot be expected that an acute stress task is performed in the clinics before and after ULL assessments and therefore other means of detecting hyperacusis in women with EE is needed. One way could be to question the patient about the circumstances that induce their hyperacusis.

## General conclusions

The two studies illustrate different aspects of the sound environment in care. The first study shows that both staff and patients are strongly affected by the acoustics in intensive coronary care. The second study shows that exhausted patients have much more difficulty in handling disturbing sounds when they are combined with acute stress situations. This is a reality for a large proportion of our patients.

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# Physiological effects of listening to music

Töres Theorell

The American neurobiologist Joseph Le Doux (1995) made the discovery with his co-workers some years ago that emotionally charged sound stimuli are transmitted to the brain via two different routes which he labelled the "upper" and the "lower". The same routes could also be labelled the "slower" and the "faster" route. The sound impulse first reaches a relay station in the thalamus located in the midbrain. A musical tune may be associated with anxiety. If this is the case, the faster lower route transmits the impulse to the amygdala which has an important role in stress and anxiety reactions. The amygdala, which is part of the emotional brain, rapidly triggers a stress response in the brain and the rest of the body. The emotional brain is a primitive part of our brain which can also be found in most animals.

The impulse is also transmitted via the higher route up to the brain cortex which processes the cognitive interpretation. (Which piece? Where did I hear this before? Does it mean danger?) If the cognitive analysis leads to the conclusion that the situation associated with the music is dangerous, an impulse is sent to the amygdala from the cortex as well. Since this transmittal is much slower, the amygdala has already reacted but the cortex reaction can now modify the primitive stress reaction. If the sound impulse lasts for a very short moment (for instance a dissonant chord disappearing rapidly) the cognitive cortex may never become aware of the phenomenon and may therefore not be able to process the information. In such a case it is only the lower route that has been activated, and the brain may never become aware

of the source of the anxiety reaction. This has been clearly shown in brain research on picture perception. If simplified pictures of neutral, sad, happy and angry faces are shown in random order very rapidly, the person will not be able to know cognitively which faces he or she has seen. But functional magnetic brain imaging (a method for studying activation of different parts of the brain during simulation) shows that the amygdala is activated every time the angry face is shown but not when the other faces are shown – despite the fact that the person cannot say when it is the angry face that turns up.

Is there any specific part of the brain that corresponds to musical experiences? No it is not that simple. But there are regions in the brain that are activated and which collaborate when musical processes are ongoing. And when certain parts of the brain are injured our ability to experience music may be affected. The parts that are important for musical experiences are partly overlapping with those processing speech, for instance. There is one region in the brain, the planum temporale in the left hemisphere, that is associated with absolute pitch, the ability to know exactly which tone is played or sung.



Photo Johan Person /LU bildbank

That people are strongly affected by music has been noticed by many. The music psychology professor Alf Gabrielsson (2005 and 2011) recruited more than 900 subjects for an interesting study. He asked people to describe in their own words the most profound musical experience that they had had in their lives. He also tried to categorise these experiences with regard to contents, context, consequences etc. Gabrielsson stated that it is very difficult to do such a categorisation since the experiences cover a very large area. Music seems to comprise the "whole psychological reality". Many of these situations have meant turning points in the subjects' lives. There are examples of subjects in deep depression who "discovered" a kind of music that they had never been interested in before but in this situation they became passionately engaged in listening to this kind of music, which helped them out of the depression. The enormous variation of themes in these stories may not be so surprising in view of the fact that music could amplify the emotional state that we happen to be in for the moment. Music can act both as a stimulating and as a relaxing agent. There is extensive published research showing that the body is reacting that way when one listens to music. Music which is "right" (right for the person and the situation) can "vitalise". This could correspond to increased heart rate and concentration of stress hormones (such as cortisol). It can also activate secretion of the body's own morphine (endorphins), raise blood pressure, increase the tendency for the body to form clots (coagulation) and furthermore increase the activity in some parts of the immune system (for instance immune-globulins). And, as I just pointed out, the reversed pattern has been observed when relaxing music is being played, lowered heart rate, lowered blood pressure etc.

Many have experienced chills while listening to music. A recently published study of one person who unexpectedly reacted with chills listening to improvised piano music - when the improvisation went from calming and harmonic sequences to more irregular rhythm and disharmonic chords (Vickhoff et al 2012). It so happened that several physiological functions were recorded "on line" in the subject while this happened. The recordings showed that the physiological reactions to the change in the music started with a slight increase in heart rate as well as diminished variation in heart rate. After this, sweating (recorded in the finger) increased. Finally the finger skin temperature started to decrease. Within 40 seconds, a 0.7 degrees Celsius decrease in skin temperature was observed.

To weep is also a common reaction while listening to sad music. Weeping also has a phylogenetic meaning: Few affective expressions are as effective in making surrounding people offer help and support! But the circumstances are also important. If I am irritated and aroused I could become even more irritated if somebody plays quiet and soft music. To conclude, music is a powerful tool but bodily effects are sometimes hard to predict. One example from our own research may serve as an illustration.

My student, Joseph Lingham, had other students and employees at the Karolinska Institute select two of their own favourite music pieces. One of them should be stimulating and the other one relaxing according to what the participants thought themselves. Having made their choices they were placed comfortably in a chair with a listening device. Psychophysiological equipment was applied so that among other things heart rate and breathing frequency could be recorded. They first sat quietly without music and then a random half of them listened to the stimulating piece. Then silence again and subsequently the relaxing piece. The other randomised half of the participants started with the relaxing piece – we did not want the order in which the pieces were being played to have any influence on the findings. Movements were not allowed during the experiment. The change in heart rate were very different in the 37 individuals. Two of them had a very pronounced increase in heart rate from silence, 20 beats per minute, when they listened to the stimulating music. One of these two participants also had a very pronounced lowering of heart rate, 20 beats per minute, during listening to the music that she thought would be relaxing. Accordingly there was a difference of 40 beats per minute between the two listening experiences in this individual.

On the whole the stimulating music was associated with a clear and statistically significant acceleration of heart rate. The average increase was seven beats per minute compared to the quiet condition when the heart rate was between 50 and 70 beats per minute. The “relaxing” music, on the other hand, did not produce the expected deceleration of heart rate in some individuals. Quite to the contrary, in eleven cases it was even associated with an increased heart rate. There were similar observations with regard to breathing. During the stimulating music the breathing frequency increased significantly and the average increase was four breathing cycles per minute. During “relaxing” music there was no significant change. Emotional self recordings verified this in the psychological domain, whereas the stimulating music quite clearly induced arousal feelings, the “relaxing” piece triggered both relaxed and aroused

feelings. The conclusion to be drawn from this seems to be that these highly educated people were skilful in selecting their own stimulating music but they were not as successful with regard to “relaxing” music – it frequently did not have the expected calming effect on heart rate and breathing. If breathing increases without proportion to physical needs a number of physical symptoms may arise. Most people know that hyperventilation may induce fainting. In the corresponding way a strong stimulating music effect may induce vertigo due to a lowered carbon dioxide content in the blood. Such strong effects may even induce constriction of some of the brain arteries – amplifying this effect.



Photo Johan Person /LU

Perhaps this small experiment (Lingham and Theorell 2009) may illustrate music's role in modern society. While the most commonly stated belief regarding music and health is that music is relaxing, most of our listening to music seems to be for stimulation and vitalisation. And music is frequently used in order to increase the arousal level even when this is not health promoting. For instance, many adolescents use music for staying awake at night when they should be sleeping.

It has been proven in many scientific studies that pieces of music selected for relaxation by experts (music therapists), collaborating with the participants themselves do induce a decreased psychophysiological arousal level. Some hundred years ago this knowledge may have been more widespread. It may not be a coincidence that there are parallels between activity in structures related to rhythm in the brain and rhythmic structures in some types of oriental music. Bettermann and others (2002) have formulated the hypothesis that rhythmic structures in music may have been invented because human beings have had a bodily perception of their own biological rhythms related to cardiovascular and respiratory function. Bernardi and Sleight (2007) have shown that the monotonous recital of many catholic prayers has a pace that the respiration and cardiac functions try to synchronize with,

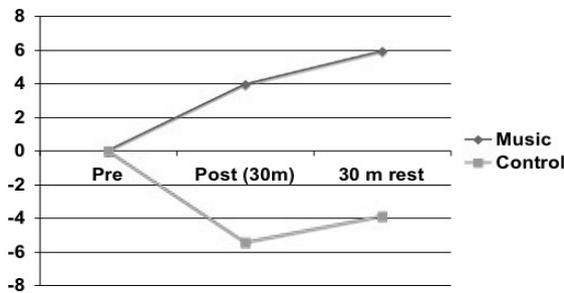
Bernardi and Sleight have furthermore shown that the monotonous repetition of Catholic prayers or yoga mantras are synchronizing breathing with parts of heart rate variability (low frequency power). This part of heart rate variability is related to the activity in the sympathetic nervous system, and one result of the synchronization could be that the sympathetic nervous system is lowering its activity while the parasympathetic counter regulatory system is activated when these prayers or mantras are being read. Similar observations have been made for slow hymns in folk songs, for instance traditional ones from Dalecarlia in Sweden.

Also, when you listen to music there is an adaptation of heart rate and breathing to the rhythm and character of the music. One study by Bernardi et al showed a very clear relationship between rhythm and breathing frequency and in that experiment other aspects of the music were unimportant. Two types of slow music (raga and slow classical music) corresponded to approximately the same breathing frequency (around 15 breaths per minute), while rap, techno music and classical music with a higher tempo corresponded to considerably higher breathing frequency (17-18 breaths per minute). There are however

also specific effects of different types of music and research on this subject has been very detailed.

A more detailed and scholarly discussion of the complex relationships between music and emotion can be found in Juslin and Sloboda (2013)

Interestingly, oxytocin, the release to the blood of a hormone produced by the posterior part of the pituitary, the neuro-hypophysis, seems to be stimulated by factors that create a sense of security. An study with random control trial design in Örebro (Nilsson 2009) showed that patients who woke up from heart surgery and who were allowed to listen to selected music had increasing oxytocin up to 30 minutes post awakening while patients in the control group who woke up in silence had decreasing levels. This is of particular importance since oxytocin has analgesic and anxiolytic properties.



Plasma concentration av oxytocin (pmol/l) in patients waking up after open heart surgery "Music" versus "control" group  
P=0.004 immediately after and p=0.024 30 minutes later

Nilsson Ulrica: Soothing music can increase oxytocin levels during bed rest after open-heart surgery: a randomized control trial  
J Clinical Nursing 18:2153-2161, 2009

We could also take music reactions to unexpected bodily domains. New research tools make it possible for us to record what goes on in most parts of the body while subjects listen to music. For instance, there could also be a direct effect on the movements in the gastrointestinal system. In one experiment (Chen et al 2005), an equipment recording pressure changes was introduced into the ventricle. It was shown that sound influenced the patterns of pressure changes. Calm music induced slow coordinated movements (bradygastria) while disorganised noise was associated with fibrillating rapid uncoordinated movements. It is well known in psychosomatic medicine that the gut and the ventricle are sensitive organs that react to all kinds of psychological stressors.

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# Music intervention and acute illness

Per Thorgaard, M.D.

*Head of Department of Anesthesia and Intensive Care,  
Aalborg University Hospital, Aalborg, Denmark*

**T**he environment as an essential part in the recovery from diseases has recently gained increasing attention among healthcare professionals. Particularly, music interventions have received extensive scientific interest with a steep increase in yearly scientific publications from 10 papers in 1990 to close to 250 papers in 2013. Thus a solid scientific documentation of the effects of music intervention in various disease states is now available (Drahota A, et al. Sensory environment on health-related outcomes of hospital patients. *Cochrane Database of Systematic Reviews* 2012; 14(3)).

Music impacts our auditory environment, affective states, behavior, cognition and physiology. These effects can be utilized to improve patient care. In somatic disorders music interventions have been shown to offer alternative auditory stimulus to the existing noise on the medical wards. By having music available the patients can deliberately direct their attention towards the pleasant stimulus. Also cognitive distraction and the release of endogenous opioids in the midbrain are thought to be contributing mechanisms (Roy M, et al. Emotional valence contributes to music-induced analgesia. *Pain* 2008;134(1-2):140-7).

A high level of anxiety is common in patients suffering from acute illness. Worries about loss of control, being in unfamiliar environment and the risk of morbidity and mortality contribute to this unpleasant and potentially harmful condition. Especially ambulance transport, admittance to emergency departments and stay at Intensive Care Units are highly distressing for most patients. We have for the last years focused on improvement of the sound environment during acute illness and ambulance transport – the prehospital scenario.

There are more than 150.000 emergency ambulance responses in Denmark each year, where patients are transported to the hospital in an ambulance using sirens. In critical cases, where the patient is in a life threatening condition, factors such as stress and anxiety may negatively influence the chances for survival. It is previously documented that noise actively increases displeasure, heart rate and vasoconstriction in healthy individuals (More BCJ. An introduction to the psychology of hearing. Academic Press, 5.Edition, 2003. ISBN 0-12-505628-1). Regarding patients, previous studies of the prehospital environment have documented very high levels of noise (Mikaelsen MA, Oddershede, JM. Analysis and improvement of the acoustic conditions during ambulance transports. Master Thesis 2009, Section of Acoustics, Aalborg University, Denmark) and very high levels of patient anxiety and distress. In most cases distress and anxiety are potentially harmful to the patients – in some cases with a resultant Increase in morbidity. A recent (unpublished) RCT-study of music intervention in ambulances is presented as well as the preceding pilot studies and noise profile analyses. The latter are shortly described below.

Music intervention in acute illness is challenging compared to other clinical situations due to several factors. Access to the patients head and face should be undisturbed as supply for oxygen and/or ventilatory support is mandatory. Likewise hygienic considerations call for alternative “distribution lines” of music than music pillows and ear-phones. The patients wish to communicate with ambulance staff also excludes the use of ear phones. A Danish Loud-speaker company (Sound Focus) developed special loudspeakers for music distribution during ambulance transport. The solution allows free access to the patients head and airways as well as other demands for unhindered medical activity was met.

Without any doubt the most critical phases of acute illness is the prehospital stage and during treatment at the Emergency Department. The use of music intervention as a complementary therapeutic tool is well documented and should from both a therapeutic and ethical point of view be implemented in clinical practice. It should however be pointed out that in other phases of illness (rehabilitation, etc.) other types of music intervention are relevant. Thus specific types of music sound environment and loudspeakers should ideally be designed for optimal individual therapy in these later phases of disease. Further research and documentation is needed to improve holistic therapeutic quality.



# Report on pilot studies of music intervention in ambulances during patient transport

Patients may experience severe distress during ambulance transport to hospitals in relation to acute illness. A study group headed by head of Dep. of Anaesthesia and Intensive Care Per Thorgaard at Aalborg University Hospital, Aalborg, Denmark and associate professor Philip Anderson at BIDMC, Harvard medical School, Boston, USA established two preliminary studies with focus on the sound environment in ambulances – briefly reported here.

The studies were performed in corporation with Falck®, Section of Acoustics, Aalborg University, Aalborg, Denmark, Composer Jacob Gurevitsch and Sound Focus® (a Danish company producing specialized loudspeaker solutions). Music intervention was added “on top” of the existing acoustic conditions during ambulance transport – technically described in a master thesis performed by Mark Mikaelson and Jesper Oddershede at Department of Electronic systems, Section of Acoustics, Aalborg University, Aalborg, Denmark.

In the first preliminary study a nurse accompanied 17 patients with a suspected life threatening cardiac condition during their transportation to the Emergency Department (ED) at the regional University Hospital. All sounds were recorded close to the patient’s ear. The patients were interviewed with regard to their level of distress 3 times during transportation (at the retrieval site, during transportation and at arrival to ED). All patients experienced severe distress – with noise from the vehicle and the siren as dominant eliciting causes. Human voice was on the other hand a significantly calming factor (and sound experience).

Based on these experiences a second preliminary study was established. In preparation for this the company Sound Focus® developed loud speakers placed in the ceiling of the ambulance above the patient’s head enabling undisturbed handling of the patient during transport. The loud speakers used a special “array technique” creating a “sound bubble” around the head of the patient (with much lesser sound volume in the rest of the stretcher room). Sound volume was adjusted automatically during transport with an increase in volume adjusted by the speed of the ambulance. The music was specially

designed to fit the sound environment of the ambulance. The composition of the music was made in a neutral and “un-dynamic” character by composer Jacob Gurevitsch. Adjustments of “default” sound volume and music composition were performed several times during this preparation phase.

The pilot study included 53 consecutive, unselected patients for acute ambulance transportation expected to exceed 10 minutes – with or without use of siren. During the first 10 minutes of transportation the patients were exposed to the specially designed music environment. Thereafter the music was turned off and the patients were questioned for level of distress. An offer of turning the music on was given. A positive wish for continued music environment was given by 80% (42/53). A negative wish for music was given by 11% (6/53). The rest had no opinion on the issue. Thus in patients, who could express a preference 88% (42/48) preferred designed sound environment.

Conclusion: These preliminary studies indicated that a majority of patients have a positive wish for specially composed music environment during ambulance transport. Further studies awaiting publication – with a randomized controlled design – have recently been performed in Denmark.

### **Music Intervention - not music therapy**

*Music intervention can be described as a supportive therapeutic tool using recorded music in creating a sound environment to initiate and maintain relaxation, well-being and comfort, as well as a self-managemant technique to reduce or control distress. Music intervention is an important tool to improve comfort and well-being and reduce physiological stress for patients in various clinical scenarios and disease states.*

Contacts: Per Thorgaard ([pt@rn.dk](mailto:pt@rn.dk)), Falck\* ([kjb@falck.dk](mailto:kjb@falck.dk)), Sound Focus\* ([jlm@soundfocus.dk](mailto:jlm@soundfocus.dk)) Section of Acoustics, Aalborg University ([fc@es.aau.dk](mailto:fc@es.aau.dk)), Jacob Gurevitsch ([jacob@quietplease.dk](mailto:jacob@quietplease.dk))



# WHY Tired Soul

## - Sound effect on people

Maria Quinn

*Coronary care nurse, Concept Developer, Ecophon, Sweden*



**I**magine going to work in the morning and being handed a ticking bomb! You put it in your pocket knowing that at any given time during your shift it might go off ..... and it does go off, if there is a cardiac arrest elsewhere then in your own department you have about 1-2 minutes to prepare the body while adrenaline flowing.

Hit the button to get the emergency elevator to your floor, mentally focus before running again. Once you are in the room it is usually chaotic to start with. One person must keep the group together and confirms all the medical instructions such as "1 mg Adrenaline" whereupon the person delivering it replies with the same words after giving the drug. The CPR is quite physically hard so to save energy and to work effectively, unnecessary talk is avoided. Once you are in place it is often surprisingly quiet, everyone is very focused on what they are doing. In this, one of the most stressful situations you may find yourself in, it is quiet! A paradox? No - a well thought through and well-rehearsed strategy! There is no room for error due to that you couldn't hear what the other person said. Concentration is at a peak while you interpret cardiac rhythms and calculate drug doses

Someone always has the task of taking away other people who are in the vicinity of a cardiac arrest, such as another patient or visitors. This is usually done by an assisting nurse. They put great effort in terms of allocating time to support. We use to make sure the patient feel somewhat safe and seen, we provide a calm atmosphere and offer warm beverages and see that they will not be left on their own. Situations like these can stay in peoples mind for a long time and come back to haunt you if not minded well.

So we are very good at caring for the patient in best possible way. We are also very good at trying to fulfill the needs of loved ones or family. But—how well do we take care of the careers? They are supposed to last a full career in these surroundings. What is their purpose of Health Care? From the perspective of the patient it is for you as a nurse to try your best to: - in line with proven scientific data - to: 1) heal 2) ease pain, 3) provide comfort and hope. I am thinking back at when I just started as a newly graduated nurse (RN). How stressful are not sounds for the sick, especially when you do not know what they mean! As new RNs I sat at the report in the morning to start my shift in the Coronary Care Unit (CCU) and became nervous when no one responded to the alarms that constantly made sounds around us! We were a group of 5-6 people and I was the new kid on the block. Finally I had to ask them if they couldn't hear all the alarms? It turned out of course that they didn't miss a beat and they were in full control over what all these sounds meant. A few months later, I was so familiar that I could also interpret the alarms without jumping off the chair. But relatives and patients (for most of the times) feel exactly how I felt, when I didn't know if anyone even saw what was happening. And I was healthy, not a patient worried sick in a bed. I have tried to bear that feeling with me during my nursing career.

We sometimes, if it is possible, try to spare relatives from stress by turning off monitors they see, explain certain sounds and prepare the patient on how certain treatments and examinations will sound and feel. We believe that well-informed patients are a desirable part of how we conduct health care today.

Let's look at the perspective of the staff. What is the purpose? I would say it is to provide high-quality care and having the possibility and conditions to actually do that. When we analyze what features that actually form your inputs of everyday life, we come down to our five senses. Luckily we are now focusing on one of these senses, where we still have a lot of good things ahead of us! We have an opportunity to work with sound issues and I think we will be able to see great result from that work. In doing so we will be able to create better conditions for staff to give the excellent care that they strive to do. Work on one more fields more intensely just as we have worked on improving the other senses especially with Evidence Based-Design. We are all part of increasing the focus on human aspect by participating at this symposium and we have a opportunity to direct the thoughts and focus to this issue.

The sound environment also affects the patient outcome as we have heard here today. Directly as we see in studies, patients do not get the peace and quiet needed to heal optimally. Sleep patterns are disturbed and disturbing sounds affects blood pressure and so on. But it also possibly can affect the patient outcome indirectly, due to the fact that a caregiver cannot work optimally in stressful sound environments, our ability to concentrate is affected and we get tired and more unmotivated to go deeper into commitment (1).

We have a career of maybe 30 to 40 years ahead of us when most of us start working, but will we last? We are often very good at arranging things to be best for the patient. We find solutions and fix it all. True Mc Gywer spirit! But how do we take care of ourselves?



## HOW Tired Brain - Illustrating the problems

Staff: The problem is that we have brains. Hearing is created as a protection (2) for us. We have two ears at the same height in order to quickly determine where the sound came from and how far away. We can separate with a one degree difference which direction in the horizontal plane the sound comes from. Our brain analyzes in a second if the sound means danger for us, or fight or flight? Or is everything still safe?

We are created to have this built-in watchdog and it's a wonderful thing. But not all the time – if we are exposed to elevated levels of these hormones and have no break from the exposure, it will in the long run affect our own health and wellbeing; the negative health aspects are well recognized (3).

Patients: All who work with anesthesia know how important it is to keep the room completely silent when inducing anesthesia in order to create an optimal experience for the patient. Even if the patient is under anesthesia his/hers hearing is still functioning!

One of our most vulnerable groups of patients is the ICU patients. They have a high risk of developing delirium, and sound is a factor that can contribute to it. Around 40% of patients admitted to the ICU are at risk of developing this condition (4). This affects not only the patient experience and suffering, but has strong economic aftermath in the form of increased mortality and increased health care costs. We have heard Kerstin Persson-Waye talk about that here today to. Sound is not the only thing, of course, but it is one thing that we can influence!

Sound is also a source of great joy for us, our minds are created to function optimally in an outdoor environment and we often seek the sounds of nature to feel good. Today we do not spend our lives outdoors in an especially large extent. Someone has figured out that we are indoors 90 % of our time (5)! We use our knowledge of these sounds however, and take the outdoor soothing sounds into care instead. We have relaxing music during unpleasant or loud treatments or examinations, we have pleasant background music in waiting rooms, and during labor the couple can bring their own music to aid in delivery process.

But would someone get the idea to play disco-music in the recovery room? Of course not. Our instinct knows what kind of sounds will support the feeling I crave for the moment. None of us want to be without hearing, hearing enrich our lives in harmony with the other four senses. But we humans are a bit smart too so we use the knowledge of how sound affects our alertness.

Medical-technical alarm sounds are designed to arouse our attention, that's exactly why they sound like they do! Tuned into just the right frequencies for us to respond! Our hearing focuses, just as it does with human voices as well, we do not want to miss anything! This is something Florence Nightingale wrote about. The worst thing you could do to the patient, she said, was a low-key conversations just beyond the patient between family members and doctors. Just where she could not hear what was being said. Wanting to hear but not quite able to make out what is said is frustrating (6).

It has been calculated that about 40 % of the working time of health professionals involves acts of communication. Being able to communicate freely without fear that what is said could be misunderstood or misinterpreted, or possibly overheard by someone not intended, is desirable. We want to have health care premises that support this, but there has been a worrying development, as studies shows that sound volume (7) has increased by 15 dB over the past 40 years in health care premises! Why is this?

We have a faster tempo, faster logistics, and shorter stays due to efficiency goals, more technical features and machines to provide better care. How does that affect us and the patients?



## WHAT Tired Ears - Solution

During my years as a nurse in the CCU I would often sit and work with the patient chart by the computer, beside me two monitors with a total of about 20 heart rhythms would be running, that I needed to keep a close eye on. The alarms from this surveillance had three levels – third one being an acute severe incident. There could be up to 200 alarms an hour! And for each alarm I had to respond to it, make a decision of the severity, look, interpret and act or not act. When that was done, it was time to get back into what I was doing at the pc. How long does it take to get back into concentrated work mode? There are of course different figures around that (8) but let's estimate it takes 30-60 seconds? I am not a mathematician but I know there is 60 minutes in an hour and 200 alarms per hour and a time to get back into concentrated work mode of between 30-60 seconds – that just doesn't add up!

Usually there is no action taken due to the alarms. So my question is - how can we construct alarm functions, eliminating the unnecessary alarms, only filtering out what we need to see? Using light and/or vibration? Some people think that is one way to go. There were a lot of focus on suggestions like that at the recent Internoise conference in Austria. Should we give feedback to the technical industry that designs the systems? One idea would be to record the patient's own rhythm at arrival to see if there if deviations arise from that person's normal heart rhythm. In that case we would only have the alarms tailored to that specific patient and not standardized ones?

The technical development is something good and helpful to aid in our care and make things easier and safer. There are for example drugs with a very short halving time (9) implying immediately action if a fault with the infusion arises. Must the tube feeding infusion make sounds? A colleague told me about a patient who wondered why we had played Beethoven's 5th symphony during his hospital stay (10). Strange, they thought – we don't play music here? What had happened? The infusion device works like a little wheel doing half a lap at the time, making this soft sound ...tada tada! Beethoven was a fantastic composer and I am sure you all recognize this tune . He wrote the piece between the years 1804-08, in his mid thirties during the process of going more and more deaf. I certainly wouldn't want to listen to this beat for every meal with no possibility to turn it off!

Probably the manufacturer didn't notice how the sound could be perceived.

We are not machines, we are affected by all five senses whether we like it or not. My personal experience is that healthcare staff has a huge need for silence after work. Many other workplaces would demand the same, but in this case alarm fatigue plays an important role.

What is the solution? How do we communicate? Is it a spin-off effect where it just gets louder and louder for us to be heard above the roar? Just like in kindergarten, where children try to overpower each other and do not know any other way (11)? Maybe it's time to say stop? Maybe we should take a proper look at how we experience sound and what kind of acoustical behavior we support or/and want to support? Maybe we could find better ways than the existing?

Yes - we need to take control over the sound environment and responsibility of not only our behavior but also expectations of the technical industry. Just as we are becoming increasingly aware of the importance of light, color and nature we need to address the sense of hearing as well.

Clients, staff, architects, functional planners, property owners, acousticians and others participant - planning for building with FULL activity for REAL people. Take into consideration all of our senses that help shape our everyday experience of life.

To come back to the possible paradox of how quiet an alarm can be after the "bomb" has exploded - I think that if we have developed a strategy and have raised the question of how sound affects *both* staff and patients, it will be possible to create good healing sound environments in hospitals.

Awareness is the key; therefore this symposium will live on and disseminate experiences shared today to a larger audience.

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# Care for Sound

## *Sound Environment, Healing & Health-Care*

Texts from an interdisciplinary symposium the 17th october 2013 arranged by Sound Environment Center at Lund University.

Patrik Grahn | Johannes Van der Berg | Kerstin Persson Waye  
Töres Theorell | Per Thorgaard | Maria Quinn

Research shows the importance of sound environment in health-Care for healing processes to be effective. Intensive care environments are often characterized by heavy work load for staff in combination with underdimensioned localities, personnel and economy. Results are stress and tension that also affects the well being and recovery for patients. To find yourself in an intensive care unit has more than once been likened to ending up in the middle of a mainline railway station.

This collection brings forth current research on different aspects of sound environments and acoustics in health care for both patient and staff.



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