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NOISE CONTROL FOR QUALITY OF LIFE

Achieving a healthy sound environment in hospitals

Keynote paper

Kerstin Persson Waye¹, Erica Ryherd²,

¹Occupational and Environmental Medicine, the Sahlgrenska Academy, Gothenburg University, Sweden

²Woodruff School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, USA

ABSTRACT

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 recommendations. Furthermore, sound levels in hospitals have risen since the 1960s. The noise origins mainly from: (1) operational activities generated by the staff in their care giving activities and communication, (2) medical equipment and alarms and (3) 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

1. INTRODUCTION

Unnecessary noise is the most cruel abuse of care which can be inflicted on either the sick or the well [1]. In spite of this early insight the importance of sound environment in modern hospitals has 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.

¹ kerstin.persson.waye@amm.gu.se

² erica.ryherd@me.gatech.edu

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. Intervention studies may give specific information on means and possibilities to obtain a healthy sound environment, this paper will focus on studies where intervention of the physical environment is carried out. As most studies are carried out within the ICU, this will also be reflected in this paper.

2. THE SOUND ENVIRONMENT

2.1 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].

In summary this points to, on one hand the similarity of disturbing sources across various types of patient care units, where sounds from voices and medical equipment seem to stand out, however also the need to look at variations in source disturbance that may be at hand at specific wards as a guidance for interventions.

2.2 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_S 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. Ryherd et al 2008 [11] found an average difference of 4dB between day and night time levels which is largely in accordance with results from three intensive care units in England [13] and the burn intensive care [14]. Also most studies find that there is little variation between days e.g. [11, 14]. In [11] it was found that the sound levels measured on the staff using dosimeters were

higher than stationary measurement with a difference of the equivalent levels of about 12dB, probably reflecting noise from conversations and activities performed [15]. The dosimeter values were in accordance with stationary data slightly lower during night time.

A common problem when evaluating sound levels in hospital studies is the rudimentary 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.

2.3 Frequency and temporal characteristics of the sound

The frequency distributions of the sounds are measured in a few studies. [2] found a spectral content with high sound pressure levels in the low frequency range < 63Hz, constant sound pressure levels in the mid frequency range and lower in the frequency range above 1000Hz. [11, 16, 17] found that the ICU were dominated by high frequency sound probably originating from alarms, respirators and medical equipment.

The temporal characteristics are also of high relevance for disturbance, including sleep and restoration. Most studies merely mention the peak or maximum levels but say nothing about how often they occur or more importantly how long time is allowed between maximum levels that can be used for the patient to restore or for the personnel to work without distraction. In one 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 55dBLpAFmax. 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 poses 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.

3. EFFECTS ON PATIENTS AND PERSONNEL

3.1 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 [18]. 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 [19, 20]. An uninterrupted sleep is important for recovery and good health [21, 22] 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 [23, 24].

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. The exact contribution of noise for sleep disturbance varies between studies. In a review of current knowledge about sleep in the ICU Hardin [24] 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 [25] who report that about 11 to 17% of the arousals respective awakenings were caused by noise.

Previous research suggests that the acoustic environment in healthcare is important for cardiovascular response, length of hospital stay and hospitalization rate [26-28], while data on pain and wound healing are inconclusive.

A large proportion of all ICU patients have illusory or hallucinatory memories from the intensive care [29, 30]. 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 [31].

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 [29, 30].

3.2 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 [32]. 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. The risk for hearing damaged may be prevalent at the orthopedic surgery [33, 34] and is also the focus of an ongoing investigation in obstetrics care (Fredriksson S. unpublished data). Few studies have however investigated the effects of noise among hospital personnel and as stated in a recent review [35] "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 [36]. 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 [37] 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.

Annoyance (rather, very or extremely annoyed) to noise was in [5] reported by 43% of the ICU nurses. Noise annoyance was also significantly related to Auditory fatigue (sound sensitivity, hearing fatigue, tinnitus) and Mental fatigue (tiredness, headache, concentration difficulties, irritation), but not to Tension. No conclusions about directions of associations can be drawn from that study alone, and further studies are clearly needed. These studies should ideally comprise larger populations and include a wider context of measures of the psycho-social environment.

4. RESULTS FROM INTERVENTION STUDIES

A review by Konkani and Oakley [38] found ten studies where any type of intervention was performed. In addition to those there is at least one more study where an intervention of the physical environment was carried out [27] and at least three experimental studies where a change of the acoustical environment has been evaluated. The effects of the acoustical interventions will be described in more detail while results of the behaviour changes will not be included.

4.1 Experimental intervention of sound and sound quality aspects.

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 [8]. 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 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 12 healthy participants [39]. 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 L_{pAeq} 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 L_{pAFmax} 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 [40] 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.

4.2 Interventions of the physical environment

In a Cardiovascular intensive care unit (CIVA) in Sweden, the impact of a reflective (bad acoustics) and absorbent ceiling (good acoustics) was evaluated with regard to psychosocial work environment and patients cardiovascular health [27, 41]. The change of reflective to absorbent tiles resulted in a reduced reverberation time with 0.4-0.5s and the A-weighted equivalent sound pressure level of 1dB in the central area and 5-6dB in patient rooms. Nurses working afternoon but not morning and night shifts rated lower demand and pressure and strain when working in the good acoustics. The personnel working in good acoustics were also considered by the patients to have a better attitude. Among the 94 patients followed, no overall significant difference was seen in hospitalization and rehospitalization after 1 month, however rehospitalization after 3 months follow up was significantly lower during treatment in the good acoustics. No difference was found for measured physiological parameters between conditions, however when the patients were subdivided with regard to degree of the disease, patients in good acoustics in acute myocardial infarction and unstable angina pectoris had lower values of night time pulse amplitude, while again no difference was found for the other measured parameters.

An intervention in a neonatal intensive care unit (NICU) in USA comprised configuration of the bed space from horseshoe to rectangular, keeping the number of bed spaces intact [42]. Two central work spaces were replaced with one at each bed. The ceiling was lowered and high absorbent tiles mounted, furthermore sound attenuation was mounted to HVAC systems, and finally designing private places in the close proximity for phone calls and discussions of patient care. The interventions resulted in a reduced A-weighted equivalent sound pressure level of 4dB from 59.3 to 56.4dB, while the L_{10} and L_{pSmax} were higher after as compared to before the intervention. The authors suggest that the failed reduction of maximal levels may be due to a lack of education program among the personnel.

In an NICU in India both environmental and behavioural modification was implemented [43]. The environmental intervention comprised, putting rubber padding under furniture legs, replacing metal files with plastic files, lowering the alarms to a maximum of 55dBA, and when possible replacing audible to visible alarms, setting the volume of the phone ringer to minimum audible and always keeping the door to the washing room closed. Behavioural modification included making the personnel aware of the harmful effects of high noise levels on the neonates, requests to talk in a low voice, hold discussions during rounds in a separate room, take care in handling trays and metallic objects, and turn off the radio. Also, three persons in the staff were requested to remind the others. Measurements were done in the center of the rooms for 15 days, every hour by the staff on duty, no details are given, of for example measurement times. The results point to rather substantial reductions of sound levels with the noisiest ward, the ventilator room, being reduced from 69dBA to 59dBA, and the least noisy ward, with the extreme preterm, being reduced from 54.3 to 52.2dBA.

An ongoing intervention study in a hospital in Sweden, focused on the visual and auditory stimuli in an ICU [44]. 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.

Preliminary results from the personnel are shown in Table 1. Their description of the sound environment made in 2010 of an ordinary day in an ICU room, and their rating of the same question with reference to the intervention room in 2013, show rather clearly that the personnel consider the intervention room to be more quite, less noisy, beeping and hissing. The results are also confirmed by the question asked in 2013, about contentment ranging from “not at all” (0) to “very” (10), with direct reference to the intervention room and the control room. The contentment for the sound environment was very high with a mean value of 8.8 compared to 4.5 in the control room, and the contentment of the visual parameters were also significantly higher in the intervention room (light 8.5 vs 4.9; and esthetic 8.5 vs 4.1), while ergonomic (3.3 vs 5.2) and work space (3.0 vs 4.8) were found significantly worse in the intervention room. The latter as a result of the new equipment taking more space, and maybe also a consequence of ergonomic being less prioritized.

The results points to a large effect of the intervention with regard to subjective perception of audio and visual input. We have to await the results from the sound recordings to conclude about actual reductions of sound pressure levels and other sound quality aspects. One hypothesis is that the visual input of the room influence the personnel to move and talk more quietly, adding to a good sound environment, another is that the sound absorbents enhance the speech clarity (supported by the room acoustic measurements) whereby the personnel could use a lower voice to communicate.

Table 1. Mean values and (SE) of the personnel’s rating of the any ICU room and the intervention room.

Your description of the sound environment	*Control	Intervention	p-value
Quite	3.8 (0.29)	6.8 (0.26)	< 0.001
Noisy	4.5 (0.33)	3.2 (0.21)	< 0.05
Beeping	7.7 (0.22)	4.6 (0.31)	< 0.001
Hissing	5.1 (0.35)	3.1 (0.23)	< 0.001

*any ICU room evaluated before the intervention

In summary can be seen that none of the intervention studies included in [38] managed to meet the recommendation for a healthy sound environment given by [45]. As many of the behavioural studies show promising result e.g. [46, 47] it can be recommended to combine a physical or environmental intervention with a noise education/awareness program for the personnel in order to further reduce the sound levels in hospitals.

5. 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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