Title: A pilot study of sound levels in an Australian adult general intensive care unit

Abstract:

Background/introduction: High technology and activity levels in the intensive care unit (ICU) lead to high sound levels. As noise has been shown to affect the ability of patients to rest and sleep, continuous sound levels are required during sleep investigations. Aim: The aim of this pilot study was to develop a robust protocol to measure continuous sound levels for a larger more substantive future study to improve sleep for the ICU patient. Method: A review of published studies of sound levels in intensive care settings revealed sufficient information to develop a study protocol. Results: The study protocol resulted in 10 usable recordings out of 11 attempts to collect pilot data. The mean recording time was 17.49±4.5 hours. Sound levels exceeded recommendations made by the World Health Organization (WHO) for hospitals. The mean equivalent sound level (LA_{eq}) was 56.22±1.65 dB and LA_{90} was 46.8±2.46 dB. Conclusion: The data reveal the requirement for a noise reduction program within this ICU.

Keywords: Sound levels, intensive care unit, study protocol, pilot study

Introduction

International research reveals that technology and the high number of health care personnel within the intensive care unit (ICU) creates a busy noisy environment[1-5]. High levels of noise, together with the symptoms of illness, have been shown to impact on the patient's ability to rest and sleep[1, 6-12]. The sleep of ICU patients is distributed evenly between day and night[13] therefore continuous sound level recordings are required in order to interpret the effect of noise on the quality and quantity of patients' sleep. The aims of this pilot study were to examine international research related to noise levels in intensive care settings and to investigate sound levels adult patients are exposed to within an adult Australian ICU. The results will inform a future substantive study aimed at improving sleep for intensive care patients. The paper provides a description of the instrumentation and set-up together with acoustical data.

Background: investigations of sound levels in adult intensive care units

Literature search

A search for relevant literature was performed in order to inform the development of the study protocol. The following databases were searched: PubMed, Ovid Medline, CINAHL and EMBASE. The search terms 'critical care unit' and 'noise' (text word) were used and the papers selected were restricted to those pertaining to those reporting studies of sound levels in adult intensive care units (as opposed to all critical care areas, for example post-anaesthesia, high dependency and emergency care units) published in English after 1966. In addition, journals related to acoustics were searched using this strategy. Reference lists of the papers identified were scanned manually to identify other relevant papers.

Publications regarding sleep in adult ICU patients were scanned manually to identify studies which recorded sound levels. The entire process yielded 23 papers which are briefly reviewed in this section.

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Literature review

The information presented in this section contains the main points extracted from published studies of sound levels in ICU and informed the development of the pilot study protocol described in the methods. A summary of the instrumentation and main findings of the studies is presented in Table I.

Table I (insert here)

Design

Two main study designs have been used in investigations of sound levels in ICU. The majority of studies are observational, with the primary aim of recording sound levels in ICU, while the aims of nine experimental studies were to reduce sound levels using either behavioural or environmental changes or both. The experimental investigations used the preintervention and postintervention design as it suits the introduction of unit-wide global behavioural changes and architectural acoustic interventions[3, 12, 14-17].

Instrumentation and set-up

Few of the reports of the studies fully describe the set-up and instrumentation for sound level recordings. However the model and manufacturers of sound level meters and dosimeters are given for most studies. The sound level meters used are predominately

Class 1 indicating that the instrument meets international standards for research and legal purposes[18].

It is common practice to attempt to capture the patient's experience of sound by placing the microphone close to the patient. In most studies that describe the microphone position it was usually placed adjacent to the patient's head or bed[1-4, 13, 17, 19-23]. For example in the observational study performed by Ryherd and Ljungkist[4] the microphone was 0.5 metre above the patient's head. Distances of the microphone in relation to the patient were reported to range from 0.0 to 6.5 metres. Information on the position of the microphone in relation to the floor, walls and other reflective surfaces is often omitted. Articles which provide plans of the patient rooms with the position of the microphone in relation to the patient offer the reader some indication of the possible effect of reverberation from the furniture and walls[14, 24-26]. The acoustic properties of architecture materials such as walls, ceilings and fitments in the ICU surrounds are commonly reported in interventional studies which have the specific aim of examining the effect of these materials on sound levels and reverberation. Calibration procedures (when described) follow the recommendations of the sound level meter manufacturers. Broadband parameter settings are often omitted from the study reports but the results suggest that the 'A' weighted decibel scale is used in all studies with 'C' weighting occasionally used for peak sound levels. Sampling frequencies are often omitted from study reports however when reported they range from one second to two minutes[3, 13, 17, 19, 20, 22, 23, 25].

Descriptive data

The method of reporting sound level data differs. Mean sound levels (range: 49.1 to 56.1 dBA) and mean equivalent continuous sound levels (L_{eq}) (range: 50 to 65 dBA) are commonly reported and exceed international standards for sound levels in hospitals. (The World Health Organization recommend that sound levels should not exceed L_{eq} 35 dBA in patient areas and the LAF_{max} should remain below 40 dBA at night in hospitals[27]. Other sound parameters reported are mean peak levels (range: 78.1 to 126.2 dBA) and the mean number of peak levels >80 dBA per hour (range: 19 to 250). Minimum and maximum sound levels are also reported.

Noise sources in ICU

Common sources of noise for patients are conversations amongst health care personnel, alarms emitted from monitors, sounds related to treatment, for example oxygen therapy, and equipment such as the X-ray machine. Talking amongst health care personnel can result in noise levels ≥80 dBA[3] and some equipment can emit up to 92 dBA (i.e. adjusting the bed rails)[21]. Spectral analysis indicates the presence of predominately high frequency noise (rated 'hissy') in ICU[4].

Effect of interventions to reduce noise

Some studies reporting noise reduction programs describe improvements in noise levels which are both statistically and clinically significant (mean range: 2 to 29 dBA). The remaining studies report trends towards lower noise levels. Effective interventions included sound reflective ceiling tiles[14, 25], staff behaviour modification[3, 15, 16] and noise attenuation strategies[12, 16]. The use of white noise as opposed to noise attenuation shows promise. Its use in one study resulted in less sleep fragmentation in volunteers exposed to ICU noise despite the overall increase in mean noise level[28].

Methods

We conducted an observational study of noise level exposure in 11 patients in intensive care between April 2008 and September 2008.

Setting

The pilot study reported here was part of the preparatory work for the investigation "improving sleep for the ICU patient". The study was endorsed by the Human Research Ethics Committees of the University and Health Service. The setting was a 14 bed adult general intensive care unit in a metropolitan 600-bed hospital in Sydney, Australia. The hospital is a tertiary referral centre for several specialties, including burn injury, spinal cord injury, renal disease and cardiology.

Instrumentation and set up

A hand held sound level meter and analyzer (Model 2250) (meeting international standard IEC 61672-1), microphone (Model 4189) with 3.0 metre extension lead and calibrator (Model 4231) (Brüel and Kjaer™) were used. The data were downloaded to a laptop computer (Compaq™, Windows XP Professional™ Version 2002 service pack 2) using BZ 5503 Utility Software for Hand Held Analyzers (Brüel and Kjaer™).

The microphone was placed 1.0 to 0.75 metre above the patient's head and bed (this varied slightly as the bed height was adjusted occasionally) and 1.75 metres above the ground and 1 metre below the ceiling (the nearest wall was 1.5 metres behind the patient). The two open plan six bedded spaces in which the recordings were made is divided in half by a solid half brick wall. Figure 1 is a diagram of half of a six bedded space. Ceiling tiles are wet-formed mineral fibre covered with a vinyl latex paint, with acoustic properties as follows: noise reduction coefficient of 0.55[29] and weighted sound absorption coefficient, alpha w of 0.5[29]. All walls are solid brick structure. The floor is solid concrete with an overlay of polished tiles.

Insert Figure 1. here

Five broadband parameters were set: LA_{eq}, LC_{peak}, LAF_{max}, LAF_{min} and LC_{eq} along with LZ spectra recorded at a sampling and logging frequency of one sample per second. Maximum input level was 141.07 dB and 1/3 octave bandwidth was used for the sound spectra.

Study protocol

Patients were enrolled from the ICU for the pilot study of the larger investigation. The aim was to monitor patients' sleep for 24 hours. The patients gave informed consent for sleep monitoring and for sound and light level measurements to be made in their surrounds. Sound and light level measurements were performed simultaneously with sleep monitoring in order to detect possible sources of sleep disturbance and to identify possible interventions to improve sleep, such as noise reduction. To reduce the likelihood of the transmission of multiresistant microorganisms between patients treated in the isolation section were not enrolled; only patients in the two six bedded areas were enrolled. All recordings were made in these open plan areas.

The sound level meter was calibrated by the manufacturer prior to the start of the study. The microphone was calibrated after fitting the 3.0 metre extension cable before each monitoring period. Health care personnel were advised of the presence of the microphone and reassured that the sound level was being monitored and recordings were not being made of activity and speech. Sound level recording was started and terminated at the same time as sleep monitoring. In addition individual sound level recordings were made of common sounds emitted from equipment within the ICU on another day. In this instance in order to simulate the patient's experience of the sound the SLM and microphone was held by the researcher 1 metre from the head end of a patient's bed while health care workers conversed, alarms sounded and a dressing trolley was moved nearby.

Data management

Sound level data were transferred to a laptop computer and reports generated using the Utility software for Handheld Analyzers BZ 5503 (Brüel and Kjaer™). Summarized sound level and spectral data were then transferred to an Excel™ (Microsoft™) file for management. (In the main study the entire set of sound level data will be imported into an Access™ database for analysis).

Results

Eleven sound level recordings were made between Monday and Friday. One recording was unusable. (During sound level recording the microphone was moved closer to the patient during a time when the researcher was absent. On examination of the data it appeared that the microphone had been repeatedly knocked.) The duration of the remaining 10 recordings ranged from 13 hours 33 minutes to 24 hours (mean duration17.49 ± 4.50 hours). Four recordings were made over 24 hours, from midday to midday; three from early evening to early morning; three from midday/afternoon to mid morning. Recordings were made in eight different bedspaces. Mean values for each of the parameters for all of the recordings are provided in Table II. The data were not divided into time periods (that is, day and night) but the standard deviations and a visual inspection of the sound level graph for each recording confirms that there was little variability in sound levels over the 24 hour period (Figure 2).

Background sound levels (L_{90}) ranged from 43.5 to 50.2 dBA (46.8 ± 2.46). Common sources of background noise were conversation, oxygen therapy and the electric floor polisher (characteristics of sounds are displayed in table III). Peak noises were generated by monitor and equipment alarms and elevated voices from health care personnel. Equipment typically located within 2.0 metres of the patient, for example the intravenous pump, ventilator and air mattress alarms were noted to generate sound levels up to LC_{peak} 85 dB. Examination of the 1/3rd octave bandwidth frequencies indicated that sound levels were higher at lower frequencies (Figure 3). Intravenous pump and ventilator alarms tended to display spectra of higher frequency than the background noise, that is >2 kHz.

Table II and III insert here

Figure 2 insert here

Figure 3 insert here

Discussion

The protocols in many published studies on noise monitoring in intensive care settings often have insufficient detail to be replicable. However the design of this pilot study resulted in a successful set-up and protocol for recording sound in an adult ICU. All data were usable with the exception of one recording, when the microphone was displaced and knocked. The protocol described in this paper will be used in the main study on sleep in the ICU patient.

Sound levels recorded in this Australian ICU exceed international standards for noise levels in Hospitals and are representative of levels found in some ICUs around the world. The LA_{eq} indicates that sound levels exceeded annoyance levels which are generally considered to lead to sleep disruption in the healthy population, that is 37 to 40 dBA[30]. Perhaps more concerning is the high LAF_{max} (again consistent with international reports) which was 90.89 dBA and far greater than the maximum value recommended by WHO for night time (40 dBA) in hospitals[27]. The mean LC_{peak} indicates that patients were exposed to very high intermittent noise levels. Alarms were the predominant sources of loud intermittent noise and conversations amongst health care personnel and oxygen therapy were likely the main contributors to the background noise. In summary the results of this pilot study indicate that there is scope for a noise reduction program which could potentially improve sleep for patients in this ICU.

This preliminary study highlighted a number of limitations which warrant consideration. For example a larger sample size (including more recordings of 24 hours) would have enabled inferences to be made about sound levels at different time periods. Such data would provide useful information about levels at night and times when there is a high likelihood of noise disruption, for example shift change over. This limitation will be addressed in the main study when more sound level data will be collected in order to design an effective noise reduction program. In addition the results would have been further enhanced by spectral analysis. It is well known that low frequency sound is more disrupting for humans than high frequency sound[31] and a more detailed analysis of this aspect of the sound measurement might reveal further possibilities for the design of an effective noise reduction program, for example the requirement to close the unit doors when the floor polisher, which generates low frequency noise, is used in the corridor. More sounds will be subjected to spectral analysis in the main study.

Further study is required not only to reduce noise but also to measure the effect on patient outcomes. Sleep data collected during the main study will not only provide additional information regarding the effect of these sound levels on sleep disturbance but also the patient's perception of the quality of their sleep and disturbance factors. Further data will be collected regarding the patient's sleep during recovery at home and their memory of the ICU experience. This may contribute to the growing evidence that noise, and in particular its effect on sleep, affects the experience of being a patient in ICU.

Key messages: Sound levels within intensive care units are unacceptably intrusive. Sound levels consistently exceed the recommendations of the WHO for hospitals that is L_{eq} 35 dBA in patient areas and LAF_{max} below 40 dBA at night. Interventions are required to reduce noise levels and measure the effect on patients' sleep in the intensive care unit. Potential interventions include behavioural programs to reduce noise levels such as limiting conversations at the bedside, use of sound absorbing building materials and the use headphones and earplugs.

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TABLES

Table I. Studies of sound levels conducted in adult intensive care units

Author (s)	Intensive care patient population (sample size)	Study design/outcome	Duration of monitoring period/ no. of measurements/position of microphone / ampling rate	Instruments	Intervention (Y/N) If Y type	Main sound related findings
Aaron et al.[1]	Medical and respiratory n=6	Observational Sound level No. of arousals from sleep.	24 to 48 hours on 6 occasions/directly adjacent to head of bed/ 'continuous' sampling rate 60 seconds	Sound level meter (Larson Davis model 70)	N	Mean peak sound index (number of sound peaks of ≥80 dBA/hour of sleep) and SEM 19 ± 5
Akansel and Kaymakçi[2]	Cardiothoracic n = 35	Observational Sound level and patient perception of noise disturbance	Every 15 minutes for 24 hours on 35 occasions/1.5 metres above the floor near bed/ sampling rate not stated/ diagram provided but mic not shown	Sound level meter (Model 2144 Dual Channel Frequency Analyzer, Brüel and Kjaer).	N	Mean sound level 65 dBA (range 49 to 89 dBA), lower levels at night and higher levels near to nurses' station. Common noise sources: telephone ring, alarms, vacuum cleaner, footsteps and conversation among health care personnel.
Allaouchiche et	Postanaest	Observation	Mean monitoring time per patient 55 ± 22	Sound level meter (model	N	L_{eq} 67.1 ± 5.0 dBA (LAmax. and min. 75.7 ± 4.8 and 48.6 ± 4.1 dB). Mean

al.[19]	hesia care n= 26	al Sound level and patient perception of discomfort.	min on 26 occasions/close to head/ LCpeak sampled 125ms and LAeq every 5s Monitoring occurred between 0800 to 1300hrs.	SIP 95 S; Essilor)		peak level (LC) 126.2 ±4.3dB. The source of 56% of sound pressure >65 dBA was health care personnel conversation.
Baker[20]	Surgical (not cardiac) n = 28	Observation al Sound level and relationship to heart rate.	Six hours on 26 occasions/3 feet above the head/ sampling every 12 seconds/ diagram included but mic not shown	Sound level meter (General Radio, model 1933 and analyzer)	N	Mean sound level for each hour 49.1 to 68.6 dBA. Mean over 6 hours, 60.5 to 62.4 dBA. High ambient noise (59.2 dBA) attributed to oxygen therapy. Heart rate increased 2 to 12 per min with a 6 dBA sound level increase.

Table 1. continued. Studies of sound levels conducted in adult intensive care units						
Author (s)	**Intensive care patient population (sample size)**	**Study design/outcome**	**Duration of monitoring period/ no. of measurements/position of microphone / sampling rate**	**Instruments**	**Intervention (Y/N)** **If Y type**	**Main sound related findings**
Balogh et al.[32]	General	Observational Sound levels in ICU	24 hours on two occasions in patient areas/1m above the ground and 3 to 6.5m from patients/ sampling rate not stated/ multiple 20 minute recordings of sound emitted from single items of ICU equipment (1m above the floor and from equipment). Number of alarms recorded during two 4 hr day and night periods	Sound level meter (model 2209, microphone model 4134, Brüel and Kjaer)	N	During the day for intervals of 20 minutes or more L_{eq} was 60-65 dBA. Intervals of a few minutes of 70-80 dBA recorded. Doctors rounds levels > 65 dBA. Minimum 50 dBA during daylight hours and at night around 60 dBA. Alarm sound pressure levels ranged from 60 to 70dBA some occasionally exceeding 80 dBA. Average 2.1 ± 0.8 alarms per patient/hr (maximum possible no. 42/patient/hr)
Blomkvist et al.[24]	Coronary care n= 31	Experimental comparing sound reflective	One week per phase/microphone position not stated/ 'continuous' sound	Sound level meter (model not described),	Y Sound reflective	Mean equivalent sound level (L_{eq}) fell in patient areas (56 versus 50dBA) significantly. Sound

	patients (sound reflecting phase) n= 44 patients (sound absorbing phase)	versus sound absorbing ceiling tiles (two study phases). Sound reverberation time and sound level. Speech intelligibility and health care personnel psychosocial status.	level/ sampling rate not stated/ diagram included but position of mic not shown		ceiling tiles or absorbing Ecophon ceiling tiles	reverberation time also fell (0.9 versus 0.4 seconds). RASTI was 'good' during sound reflecting periods and 'excellent' during sound absorbing period.
Buemi et al. [33]	xx		phonometer			

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Table 1. continued. Studies of sound levels conducted in adult intensive care units						
Author (s)	**Intensive care patient population (sample size)**	**Study design/outcome**	**Duration of monitoring period/ no. of measurements/position of microphone / sampling rate**	**Instruments**	**Intervention (Y/N)** **If Y type**	**Main sound related findings**
Cmiel et al.[12]	Intermediate surgical thoracic	Experimental (preintervention and postintervention) Sound level (noise reduction)	One nine hour period in each study phase (2200 to 0700hrs)/microphone 5 to 15 feet from the door of an empty patient room and a semiprivate room set-up to simulate a genuine patient room	Noise dosimeter (model 7000 Metrosonics for pre phase and Quest model Q-300 for post phase)	Y Noise reduction program – noise attenuation e. g. Padding in storage boxes, elimination of overhead paging at night and alarm modification and an awareness program	Average sound level reduced from 45 to 42 dBA. Greatest sound level reduction occurred during shift change: 113 versus 86 dBA
Freedma	Medical	Observationa	24 to 48 hours on22	Sound level meter	N	No statistically significant

n et al.[13]	n=22	l Sleep architecture Sound levels	occasions/microphone positioned 3 inches from head/ sampling rate 1 second	(model 1900, Quest Technologies)		differences between mean (59.1 ± 6.1 dBA and 56.8 ± 4.9 dBA) and mean peak 85.9 ± 5.1 dBA versus 82.8 ± 5.3 dBA) sound levels during the day and night. Arousals related to noise comprised mean of 11.5 ± 11.8% of the total arousals and responsible for 17% of awakenings.
Gabor et al.[7]	General n =7 patients n= 6 healthy volunteers	Observational (comparison between quality of sleep of patients and healthy subjects sleeping in ICU)	Continuously for 24 hours on 13 occasions/position of microphone and sampling rate not stated	Sound level meter	N	Noise levels dependent on location (noisier in open areas) Average sound level at night 53.9 ± 2.5 and 56.2 ± 2.2 dBA during the day in patient care areas. Mean max. 60.7 ± 2.3 at night and 66.1 ± 1.6 dBA during the day. Mean sound peak 67.1 ± 2.8 dBA.
Gast and Baker [25]	Coronary care n =22	Observational Trait anxiety levels, noise levels, relationship	One-hour periods twice a day (0700to 0800hrs and 1100 to 1200hrs) on twenty occasions/ Microphone placed 6ft from floor, 1ft from	Sound level meter (model 2230, calibrator model 4230, Brüel & Kjaer)	N	Overall mean Leq during 1100 to 1200hrs; 50.67 dBA (range 46.8 to 57.2) and 53.08 dBA (range 50 to 58.9 dBA) during the 0700 to 0800hrs. Trait anxiety scores lower than expected. State anxiety scores

	between state anxiety and noise levels	wall and 'toward the patient'/ Two minute sampling rate. Diagram included.		similar: 20 to 53 (32.9 ± 0.2) for the noisy hour and 21 to 59 (33.9 ± 11.9) for the quiet hour (p=0.90).

Table 1. continued. Studies of sound levels conducted in adult intensive care units

Author (s)	**Intensive care patient population (sample size)**	**Study design/outcome**	**Duration of monitoring /no. of measurements/position of microphone/sampling rate**	**Instruments**	**Intervention (Y/N) If Y type**	**Main sound related findings**
Hagerman et al.[14] (See also Blomkvist et al.)	Coronary care n= 31 preintervention n = 63 postintervention	Experimental pre/postintervention Noise and sound reverberation reduction Cardiovascular parameters Staff and patient attitudes to the environment Speech intelligibility	One 4 week period per phase during week days/position of mic and sampling rate not stated	SLM (model not stated)	Y Sound absorbing tiles (Ecophon) installation in main work area and patient areas	L_{eq} did not change between pre and postintervention phases (57 dBA versus 56 dBA) in the main work area but dropped by 5 to 6 dBA in the patient areas. Reverberation times reduced from 0.8 to 0.4 seconds in the main work area and 0.9 to 0.4 seconds in the patient area.

Hilton[21]	Cardiothoracic and general n=25	Observational	Continuously for 24 hours on 25 occasions/close proximity/ sampling rate not stated	Sound level meter	N	Measurements in several ICU areas. Continuously high noise levels (48.5-68.5 dBA, 15 LA_{eq}). Lower levels in smaller ICU areas (34.25-62.5 dBA). Equipment emitted up to 92 dBA (adjustment of bedrails).
Kahn et al.[3]	Medical and respiratory	Experimental preintervention/postintervention Cause of noise No. peak sound levels	24 hours on two occasions in each phase/near head/ sampling rate: 15 seconds during the preintervention phase and 60 seconds during postintervention phase.	Sound level meter (model 700, Larson Davis)	Y Three week behaviour modification program (including education involving the entire multidisciplinary team and regular reminders/spot checks)	Mean ± SEM peak sound levels 80.0 ± 0.1 dBA in the preintervention phase and 78.1 ± 0.1 dBA in the postintervention phase (p=0.0001). Number of sound peaks (≥80 dBA) reduced from a total of 1,363 before to 976 postintervention. (Talking was the most common occurrence of noise levels ≥80 dBA) Mean peak sound levels for 12 individual typical ICU noises ranged from 74.8 to 84.6 dBA.

Table 1. continued. Studies of sound levels conducted in adult intensive care units						
Author (s)	**Intensive care patient population (sample size if appropriate)**	**Study design/outcome**	**Duration of monitoring /no. of measurements/position of microphone/sampling rate**	**Instruments**	**Intervention (Y/N) If Y type**	**Main sound related findings**
Meyer[22]	Respiratory and medical	Observational Light and sound levels	24 hour monitoring continuously for 7 consecutive days in four locations/microphone placed near head of the bed in 3 different locations within the same unit/ 60 second sampling rate	Sound level meter (model 700, Larson Davis), calibrator (model CA250)	N	Mean peak sound levels ranged from 83.6 ± 0.1 dBA to 75.5 ± 0.1 dBA. Mean reduction in noise levels at night ranged from 2.8 to 7.2 dBA. Mean no. of sound peaks >80 dBA reached their maximum between 1200 and 1800hrs (over 250/6 hrs in one location) and the minimum between 0000 to 0600hrs (over 150/6hrs in the same location).
Meyer-Falcke et al.[34]	General	Observational	Insert when paper obtained			

Comment [MSOffice3]: Add data when paper recevied

Monsén and Edéll-Gustafsson[15]	Neurosurgical n=9 (pre) n=14 (post)	Experimental preintervention/postintervention Min, max and peak sound levels	24 hours on nine occasions preintervention and fourteen postintervention/5 minute sampling rate	Sound level meter (model 700, Larson Davis)	Y Behaviour modification program (education regarding sleep, effects of noise and recovery from illness) and guidelines on non-disturbance periods.	Results compared night by night for mean min., max. and peak noise levels. Lower sound levels on most nights (statistically significant) in postintervention phase. Mean peak sound levels consistently below 80 dBA.
Olson et al.[16]	Neurosurgical/neurological	Experimental preintervention/postintervention Number of patients observed asleep Sound and light levels	Two 2 hour periods (0200 to 0400hrs and 1400 to 1600hrs)/ 7 days a week for two months/position of microphone and sampling rate not stated	Sound level meter (model 8400029, Sper Scientific)	Y Initiation of a quiet time policy (e.g. reduced light and noise levels and fewer family visits and medical consults)	Mean sound level consistently below 60 dBA in the postintervention phase as opposed to the preintervention phase in which the sound level was consistently above 64 dBA (graphs only shown).

Table 1. continued. Studies of sound levels conducted in adult intensive care units

Autho r (s)	Intensive care patient population (sample size)	Study design/outcome	Duration of monitoring /no. of measurements/position of microphone/sampling rate	Instruments	Intervention (Y/N) If Y type	Main sound related findings
Ryherd and Ljungkvist [4]	Neurological n= 47 (nurses)	Observational Sound levels (including frequency) and staff perception of work environment	Five days continuously on one occasion/0.5m above head and 1.7m from the ground/1 minute sampling rate	Sound level meter (model 2260, Brüel and Kjaer) Dosimeter (model 750+, Larson and Davis)	N	Sound level meter: Average L_{eq} 53 to 58 dBA (4 dBA mean difference between day and night) (background noise was 47-48 dBA). Maximum sound levels exceeded 50 dBA >95% of the time and exceeded 80 dBA 3.1% of the time during the day and 1.3% during the night. Spectral analysis indicated presence of predominately high frequency noise (rated 'hissy'). Dosimeter: higher sound level recordings (average L_{eq} 65 to71 dBA)
Stanchina et	General	Experimental Effect of	Night recordings of ICU noise/ microphone position	Sound level meter (model 720, Larson	Y Mixed	Mean ICU noise 57.9 ± 0.3 dB Sleep was less fragmented when volunteers were exposed to

al.[28]	n=4 (healthy volunteers)	white noise on sleep fragmentation during exposure to ICU noise	not stated	Davis)	frequency white noise	white noise and ICU noise than to ICU noise alone. White noise increased baseline levels to 61.1 ± 0.2dB.
Stephens et al.[26]	General n=3 (patients) n=3 (relatives) n=46 (health care personnel)	Quasi-experimental (quality improvement) Noise levels	Duration and no. of recordings and sampling rate not stated/Microphone 60cm from equipment to simulate position of patient in relation to equipment	Sound level meter (model 886, Simpson)	Y Noise attenuation strategies (e.g. removal of rubbish bin lids, trolley wheel replacement, installation of sound absorbing ceiling tiles), awareness program	Effect of intervention not reported. Observational data reported. Sound levels emitted from equipment/activities commonly present in ICU; rubbish bin lid closing (78-85 dBA), mobile X ray machine (85 dBA) and alarms (72-78 dBA).
Topf and Davis[23]	Cardiothoracic n=70 (healthy	Experimental (randomized control trial) Amount of REM sleep	Six hours and 20 minutes on two occasions (2230 to 0450hrs)/microphone positioned above	Sound level meter (model 2230, Brüel and Kjaer) Audiotape	Y ICU noise was played via an audiotape while the	Sound levels recorded in the cardiothoracic ICU: Minimum 50 and 50.1 dBA, maximum 86.8 and 86 dBA and mean 56.3 and 56.1 dBA.

volunteers)	experienced by healthy volunteers	the head/2 second sampling rate	recorder (model X2000R TEAC) and amplifier (Onkyo)	subjects in the intervention group attempted to sleep	Subjects exposed to ICU noise experienced less REM and shorter REM periods than the control group.

Table 1. continued. Studies of sound levels conducted in adult intensive care units						
Author (s)	**Intensive care patient population (sample size)**	**Study design/outcome**	**Duration of monitoring /no. of measurements/position of microphone/sampling rate**	**Instruments**	**Intervention (Y/N) If Y type**	**Main sound related findings**
Tsiou et al.[35]	Surgical and respiratory n=10	Observational Sound levels and patient perception of discomfort.	72 consecutive hours on nine occasions/position of microphone and sampling rate not stated	Sound level meter (model 2231, Brüel and Kjaer)	N	LA_{eq} ranged from 60.3 to 67.4 dB, L1 70.7 to 79.2 dBA and L_{99} from 52.7 to 59.7 dBA. Levels at night were 1 to 4 dBA below daytime levels. Constant sources of noise included human discussions (75 -81 dBA), open oxygen sources (70-77 dBA) and open suction (70-82 dBA). Intermittent sources of noise included: connections/disconnections from gas supply (88 dBA), equipment such as the mobile X ray machine (90.3dBA) and alarms from equipment (84 dBA).
Vinodh kumara	General	Observationa	Twenty recordings at three minute intervals	Sound level meter, type 1	N	0900-1000hrs: LA_{eq} 58.34, LA_{min} 53.9, LA_{max} 62.5, L_{90}

dithyaa et al.[5]		l	between 0900 and 1000hrs and 1800 and 1900hrs in 14 locations within a large hospital/microphone placed at body level)	(manufacturer and model not stated)		54.27, L_{10} 60.4. 1800-1900hrs: LA_{eq} 58.70, LA_{min} 52.9, LA_{max} 61.8, L_{90} 54.02, L_{10} 60.9
Walder et al.[17]	Surgical	Experimental (pre/post intervention) Light and sound levels	Continuously for 6 hours (2300to 0500hrs) on 13 occasions preintervention and 11 occasions postintervention/microphone placed at the head of the bed. 1 second sampling rate	Sound level meter (model 4435) and microphone (model 4921) (Brüel and Kjaer)	Y Behavioural modification guidelines (night) e.g. systematic door closure, alarm volume reduction, clustering care, limited/low volume conversation	Trend towards reduction (n/s) in noise between pre and post intervention phases; mean L_{eq} 51.3 ±2.8 versus 48.3 ± 1.4 dBA, L1 58.9 ±6.5 versus 56.0 ± 3.3 dBA, L_{90} 43.8 ± 2.0 versus 44.2 ± 1.7 dBA and mean no. of alarms per night 22.1 ± versus 15.8 ± 6.5.
Wallace et al.[36]	General n= 6 (healthy volunteers)	Experimental (effect of ear plugs on sleep)	Seven 8 hour (morning, evening and night) and one 5 hour (mid-morning to early afternoon) continuous sound recording.	Sound level meter (Larson-Davis, model 720)	Y Ear plugs	Average ICU noise level was 61.7 ± 4.3dBA during nights when ear plugs were not worn and 61.8 3.4dBA when ear plugs were tested. Use of earplugs resulted in more

	Microphone placed 15 cm from patient's head. One minute sampling rate		rapid eye movement sleep.

Table II. Mean and standard deviation (SD)of sound level recordings made in the adult intensive care unit in dB

	Recording time (hrs)	LA_{eq}	LC_{eq}	LAF_{max}	LCF_{max}	LAF_{min}	LCF_{min}	LC_{peak}	L_1	L_{99}	L_{90}
Mean	17.49	56.22	62.95	90.89	94.08	42.59	53.91	107.87	66.57	45.42	46.8
SD	4.50	1.65	2.08	6.13	5.38	4.26	3.12	7.21	1.98	2.60	2.46

Table III. Characteristics of examples of sounds in the adult intensive care unit (intermittent measurement) in dB

Parameter	Example				
	Conversation	**Dressing trolley being moved**	**Intravenous fluid pump alarm**	**Mattress alarm**	**Monitor alarm (crisis)**
LAI_{eq}	75.8	78.7	73.3	64.5	66.4
LAF_{max}	60.8	76.8	72.6	66.5	61.6
LAF_{min}	55.2	66.0	48.7	51.0	54.8
LC_{peak}	78.1	94.7	90.1	85.7	75.9

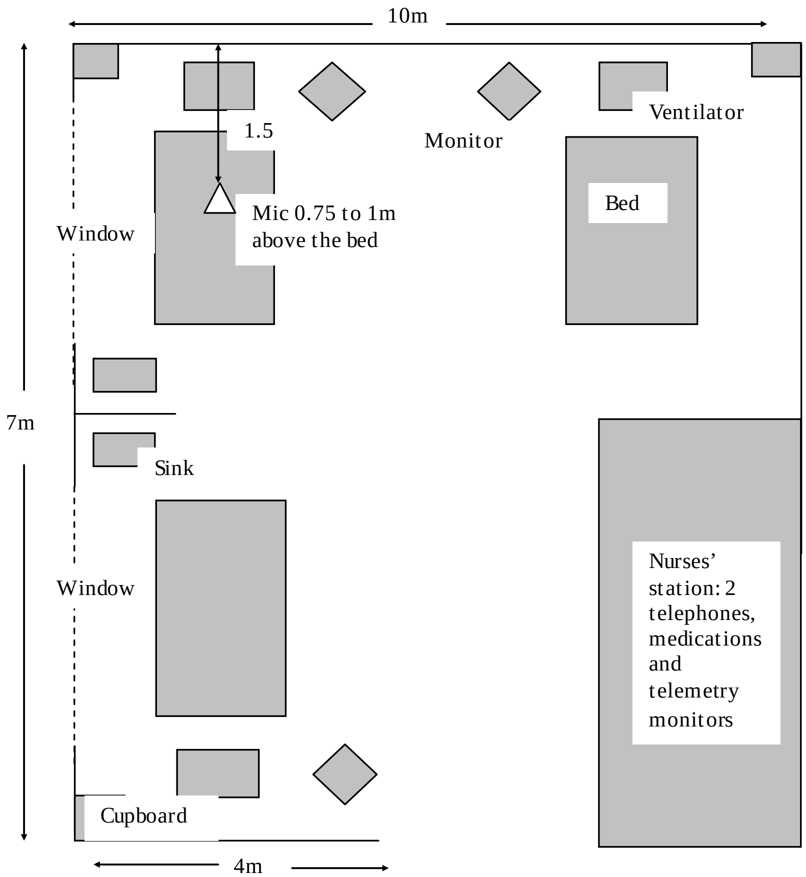

Figure 1. Plan of bed space and adjacent beds (not to scale). Three beds of one of the two six-bedded areas in which the recordings were made are shown (the other 3 beds are a mirror image of this diagram)

Not sure if we can do a full spectral analysis of the sounds without up grading the software

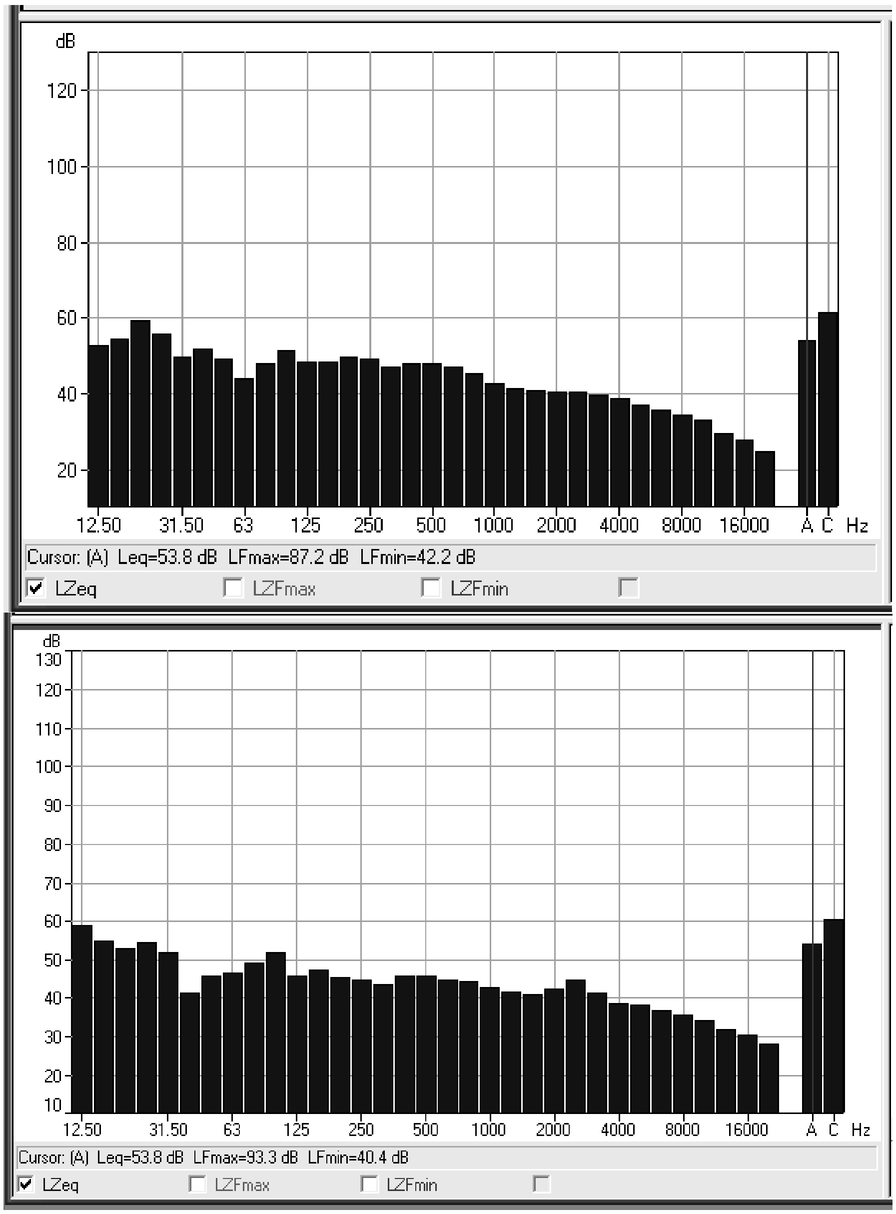

Figure 2. Spectral analysis for the entire sound pressure level recording periods patients 6 and 8.

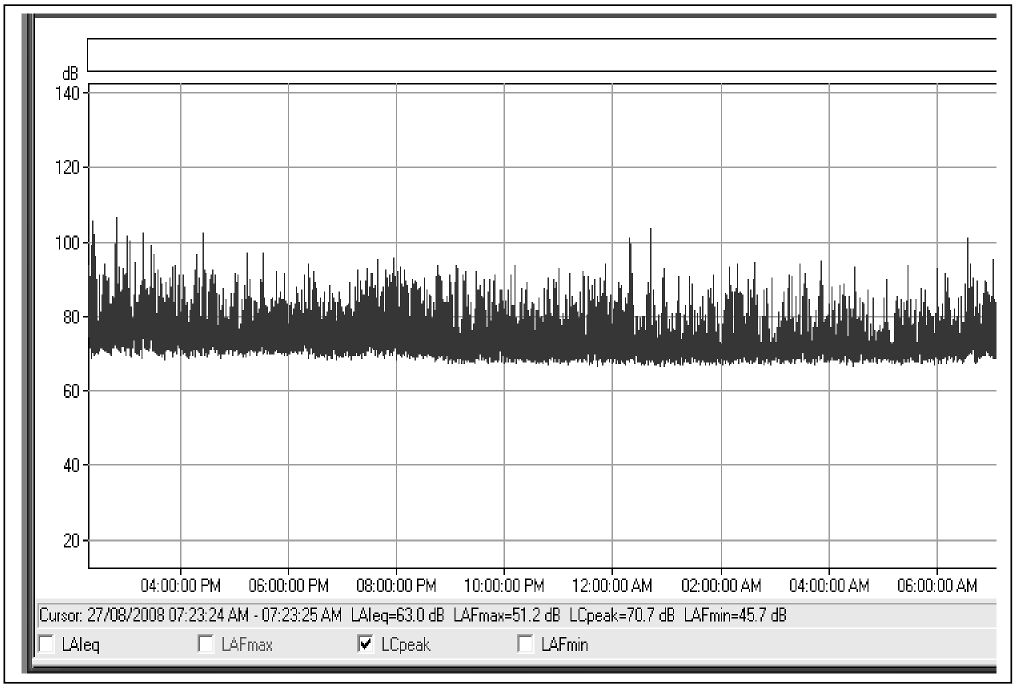

Figure 3. Peak sound levels over the entire sound level recording period for patient 8.

Comment [MSOffice4]: Insert another graph for a patient who underwent recording for a longer time period (reflective of day and night)