

Review

Clinical review: The impact of noise on patients' sleep and the effectiveness of noise reduction strategies in intensive care units

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Abstract

Excessive noise is becoming a significant problem for intensive care units (ICUs). This paper first reviews the impact of noise on patients' sleep in ICUs. Five previous studies have demonstrated such impacts, whereas six other studies have shown other factors to be more important. Staff conversation and alarms are generally regarded as the most disturbing noises for patients' sleep in ICUs. Most research in this area has focused purely on noise level, but work has been very limited on the relationships between sleep quality and other acoustic parameters, including spectrum and reverberation time. Sound-absorbing treatment is a relatively effective noise reduction strategy, whereas sound masking appears to be the most effective technique for improving sleep. For future research, there should be close collaboration between medical researchers and acousticians.

Introduction

Noise, defined as unwanted sounds, could affect people both psychologically and physiologically [1], with reported negative effects including cardiovascular stimulation, hearing loss, increased gastric secretion, pituitary and adrenal gland stimulation, suppression of the immune response to infection, as well as female reproduction and fertility [2-7]. The World Health Organization (WHO) recommended that noise levels inside hospital wards should not exceed 30 dBA at night in terms of sleep disturbance [8]. Unfortunately, most case studies, especially the recent data, show that noise levels inside hospitals are much higher than the guideline values. Since the 1960s, the average noise levels inside hospitals have increased by an average of 0.38 dBA (day) and 0.42 dBA (night) per year [9].

The noise level in intensive care units (ICUs) ranges from 50 to 75 dBA, with the highest night peak level even reaching 103 dBA [10]. Sleep disturbance is thus a common problem for patients. Sleep is a complicated and active process. In terms of the measurement of eye movement, sleep is divided

into two main types, namely rapid eye movement (REM) and non-rapid eye movement (NREM) sleep. Each type may have a distinct set of associated physiological, psychological and neurological functions.

Numerous general studies have been carried out on the effects of noise on sleep [11-16]. However, many of them are not directly related to the influence of noise on patients' sleep in ICUs. Firstly, healthy subjects, rather than patients, were normally used in most existing studies. Secondly, road/rail/air traffic noise sources were considered, and their acoustic characteristics are rather different from those of the complicated, multiple and dynamic noise sources in ICUs. Thirdly, multiple factors, such as patients' discomfort, pain, as well as lighting and ventilation conditions, would definitely contribute to patients' inability to sleep.

Therefore, the aim of this review paper is to answer the following questions. First, is noise the most disruptive factor to sleep for ICU patients, or is noise only responsible for a small percentage of the sleep disruption? Second, from the patients' point of view, what is the most disturbing noise source for their sleep? Besides the noise level, what are the effects of other room acoustic parameters, such as the noise spectrum and reverberation time (RT), on ICU patients' sleep quality? Third, how effective are the noise reduction strategies/interventions to decrease the sleep disturbance in ICUs?

Methods

The Cochrane Collaboration method was used for this review. An extensive literature search was conducted using the following electronic databases: MEDLINE (1966 to June 2008), CINAHL (1982 to June 2008), Scopus (1966 to June 2008), Cochrane Library (1991 to June 2008), and ISI Web of Knowledge (1900 to June 2008). The major medical subject heading (MeSH) and text words used in the search

ICU = intensive care unit; IL = interleukin; NREM, non-rapid eye movement; REM = rapid eye movement; RT = reverberation time.

were: 'sleep', 'sleep disorder', 'sleep deprivation', 'noise' in conjunction with 'intensive care', 'intensive care unit' and 'critical care'. Related references of all identified papers displayed in the above databases were also scanned. To study the effectiveness of noise reduction strategies/interventions, additional search terms were used, including 'spectrum', 'reverberation time', 'sound masking' and 'acoustic absorber'. The searches were restricted to the research literature concerning the relationships between noise and patients' sleep during their hospital stay and published in full in the English language.

Of the 167 papers found by the search strategy, 23 finally met the inclusion criteria. A number of methods have been applied in those studies, including polysomnography, observation, patient self-assessment/questionnaire, and environmental noise recording. Some methods were effectively integrated by the investigators in order to enhance the accuracy and reliability of the research outcomes. Table 1 summarises the characteristics of the key studies.

Importance of noise on sleep disturbance

Although it has been widely recognised that noise has negative effects upon the sleep of ICU patients, there are some disagreements in the literature on the importance of sleep disturbance from ICU noises, as can be seen in Table 1. Of the 11 selected previous original papers, 6 studies suggest that noise is responsible for only a small proportion of the overall arousals and awakenings from sleep, whilst 5 papers believe that noise is the most significant cause of sleep disturbance. Based on the SPSS statistic analysis, no significant differences were found between the two groups that argue whether or not noise is the major factor in sleep disturbance, in terms of sleep evaluation method, publication year, type of ICU, age of patients, number of patients and duration of stay.

Jones and colleagues [17], according to their questionnaire outcome, indicated that the inability to lie comfortably was the most important factor in preventing patients' sleep, and then pain, noise and anxiety followed subsequently. A large-sample survey was conducted by Freedman and colleagues in 1999 [18] to investigate the ICU patient perception of sleep quality and etiology of sleep disruption. They further explained the patients' quick adaptability to ICU noise and noise's inability to cause awakenings as the two possible reasons for the low mean sleep-disruptive scores collected in their study. Meyer [19] also mentioned the same point that patients would gradually be conditioned to environmental noise in ICUs. After continuously monitoring the noise level and performing polysomnography over 24 hours, Freedman and colleagues in 2001 [20] concluded that only 17% of awakenings and 11.5% of arousals from sleep under mechanically ventilated conditions were due to the environmental noises. Frisk and Nordstrom [21] found the noise level rated by the patients to be low, which indicated that noise was not

the major etiologic factor responsible for sleep disruption in ICUs. Pain was considered to be the commonest reason of disrupted sleep. According to Gabor and colleagues [22], loud noise accounted for 20.9% of the observed sleep disruption, while the cause of the majority of sleep disturbances under mechanically ventilated conditions remained unknown. According to Ugras and Oztekin [23], 57.6% of the patients indicated that being in a noisy environment was the second most frequently sleep disturbing factor, only after being kept immobile (63.6%).

On the other hand, Hilton used polysomnography, continuous investigator observation over 24 hours and patient interviews to identify that most sleep disturbances of selected patients in the respiratory ICU were caused by noise [24]. Aaron and colleagues [25] confirmed a significant correlation with sound peaks over 80 dBA and electroencephalogram arousals from patients' sleep, as well as a significant difference between the number of arousals in quiet periods and that in very loud periods based on the number of noise peaks. In another study, although the sample size was small (nine subjects), the sleep observation together with the continuous recordings of noise and light level enabled Cureton-Lane and Fontaine to determine that noise was the strongest indicator of sleep state. The louder the noise was, the greater the awakening possibility of the children in the pediatric ICU [26]. Richardson and colleagues [27], after examining the impact of earplugs and eye masks on the critical care patients' sleep, found that 58.8% of the patients in the intervention group and 25% of the patients in the non-intervention group voted noise as the main factor of their sleep disturbance. Hweidi's [28] research supported that patients interpreted the unfamiliar and loud noises as the major cause preventing them from sleeping during their ICU stay.

The impact of sleep disturbance on patients

Sleep disturbance is a factor in the development of delirium, as well as producing specific effects on the respiratory, cardiovascular and immunological systems. Critical care patients are especially prone to delirium, as their normal circadian pattern of adrenocorticotrophic hormone and melatonin levels is changed markedly by sepsis. Rather than there being a peak of adrenocorticotrophic hormone at dawn and an elevation in melatonin levels during the period after midnight (peaking around 3 am), a flattening of this response is seen. This encourages a disturbance in sleep patterns leading to sleep during the day [29-31] and a reduction in sleep at night as well as general sleep fragmentation, with a reduction in both slow wave sleep and REM sleep. Hallucinations may occur during the transition from wakefulness into NREM sleep and from NREM sleep to wakefulness and are a major problem for critical care patients. Patients may also develop state dissociation disorders, which will appear as hallucinations or as REM sleep behavioural disorders. These episodes promote delusional memories, which in turn increase the likelihood of post-traumatic stress disorder.

Table 1**Summary of the studies on the influence of noise upon intensive care unit patients' sleep**

Author and year published	Method	Number of patients	Mean age of patients	ICU type	Duration of ICU stay (days)	Main noise sources	Number ventilated	Is noise the most significant cause of sleep disruption?
Hilton, 1976 [24]	Polysomnography + continuous researcher observation over 24 h + patient interview/recall	10	34-81	1 respiratory ICU in Canada	Not stated	Staff communication; environment (phone, tap, chair, side rails, bottles, metal)	Not stated	Yes
Jones <i>et al.</i> , 1979 [17]	Questionnaire	100	Not stated	1 ICU in UK	1.65	Noise from staff, equipment, and other patients	22/100	No
Aaron <i>et al.</i> , 1996 [25]	Polysomnography + noise monitoring over 24 h	6	66.8 ± 2.8	1 intermediate respiratory care unit in USA	Not stated	Not stated	Not stated	Yes
Cureton-Lane and Fontaine, 1997 [26]	Researcher observation + noise monitoring less than 24 h	9	4.7 ± 3.51	1 pediatric ICU in USA	2.3	Not stated	Not stated	Yes
Freedman <i>et al.</i> , 1999 [18]	Questionnaire	203	58.6 ± 15.4	1 cardiac care unit, 1 cardiac intermediate, 1 medical, and 1 surgical in USA	8.6 ± 17.5	Talking and telemetry alarms	32/203	No
Freedman <i>et al.</i> , 2001 [20]	Polysomnography + noise measurement over 24 h	22	61 ± 16	1 medical ICU and 1 ICU in USA	18 ± 20	Not stated	20/22	No
Frisk and Nordstrom, 2003 [21]	RCSQ	31	59	1 ICU in Sweden	2.86	Noise from fellow patients	Not stated	No
Gabor <i>et al.</i> , 2003 [22]	Polysomnography + noise measurement over 24 h	7 patients + 6 healthy subjects	56.7 ± 19.2	Patients in CCU; healthy subject in medical/surgical ICU, in Canada	48.3 ± 40.2	Talking, alarm	All	No
Ugras and Oztekin, 2007 [23]	Questionnaire	88	46.57	1 neurosurgery ICU in Turkey	2.83	Alarm	Not stated	No
Richardson <i>et al.</i> , 2007 [27]	Controlled clinical trial + questionnaire	64	Not stated	1 CCU in UK	>1	Staff talking, telephone, alarms	Not stated	Yes
Hweidi, 2007 [28]	Questionnaire	165	53.38 ± 9.76	3 ICU in Jordan	Not stated	Not stated	Not stated	Yes

CCU, critical care unit; ICU, intensive care unit; RCSQ, Richard Campell sleep questionnaire.

Drugs used in hospital may further aggravate the levels and appropriateness, as well as timing, of either wakefulness or sleep and, on withdrawal (for example opioids), may precipitate a rebound increase in REM sleep, which in itself can precipitate nightmares, hypertension, tachycardia and hypoventilation. Noise will exaggerate these phenomena by triggering a transition from sleep towards wakefulness. All these factors increase the risk of delirium, which may occur in up to 70% or 80% of ICU patients [32-33]. Delirium increases length of stay, morbidity and even mortality [33].

Sleep disturbance may also disrupt immune function [34-35]. Two days of sleep deprivation has been shown to impair cell-mediated immune reactions as measured by lymphocyte production and adhesiveness [36] and to nullify the beneficial effect of immunisation in mice immunised against the influenza virus [37]. In humans, sleep deprivation increases IL1, IL2 [38], IL6 and tumour necrosis factor levels [39] and probably reduces natural killer cell activity [34,38,40]. Cardiovascularly, episodes of increased sympathetic activity may occur during noise disturbance. From a respiratory perspective, increases in REM sleep produce a reduction in ventilatory response to hypoxia and hypercapnia, particularly in the obese, men and those prone to apnoeas. This may also be a problem during weaning from mechanical ventilation [41] as well as a cause of respiratory deterioration towards the end of a critical illness, potentially increasing readmission rates to critical care.

Acoustic characteristics

Noise sources

The major noise sources identified by the previous studies vary from ventilator noise, ventilator alarm, suctioning, heart monitor alarm, nebulizer, pulse oximeter tones and alarm, telephones ringing, air conditioning, television, radio, banging, rubbish bin or trolley noises, intercom, staff bleeps, talking (staff, nurses), visitors, fellow-patients, and general activities [42,43]. According to the occurrences in the literature, staff conversation (five papers) and alarm (four papers) seem to be the most disturbing noises for ICU patients' sleep. It is interesting to note that alarms are not usually perceived as helpful by the ICU staff [44].

Noise spectrum

Sound spectrum, a plotted relationship between frequency and sound level, is important for sound perception [1], whereas in the existing studies the consideration of this facet is very limited. Busch-Vishniac [45] and colleagues showed that the spectra at a pediatric ICU were flat over 63 Hz to 2 kHz, with higher sound levels at lower frequencies, and a gradual roll off above 2 kHz. Livera and colleagues [46] analysed the spectrum of equipment and activity noises in the neonatal ICU, showing that the noise was predominant in the range of 1 to 8 kHz. Ryherd and colleagues [47] provided detailed information concerning the noise characteristics in a neurological ICU, with the background noise measured in 1/3 octave bands, indicating that high frequency noise dominated in the

case study. However, it is noted that none of the three papers studied the impact of noise spectrum on patients' sleep.

Reverberation time

RT is an important index to evaluate room acoustics. It is defined as the time taken for a sound to decay 60 dB after the source has stopped [1]. Blomkvist and colleagues [48] replaced the old sound reflecting ceiling tiles by the sound absorbing tiles in an intensive coronary care unit. The RT was markedly reduced by 0.4 s in the main working space and 0.5 s in a patient ward, which had a positive effect, including better general care quality and improved staff working efficiency. MacLeod and colleagues [49] installed the sound absorbing panels made of wrapped fibre-glass and anti-bacterial fabric on the ceiling and corridor walls in a haematological cancer unit. The reverberation dramatically dropped, and the excessively prolonged RT that had existed in the 800 Hz 1/3 octave band was eliminated. While only one of the above two studies was carried out in an ICU, the relationship between sleep disruption and RT was not analysed.

Effectiveness of noise reduction strategies

Although descriptive studies have defined and increased understanding of noise problems and serious sleep disturbance in ICUs, relatively few interventional studies have been carried out. Interventions that have manifested observable improvements in patients' sleep can be categorised into earplugs, behavioural modification, sound masking, and acoustic absorption. The effectiveness of these interventions is compared in Table 2. The average noise level reduction and sleep improvement of each intervention protocol are listed in Table 3.

Earplugs/earmuffs

Three controlled clinical trials [27,50,51] claimed that earplugs or earmuffs generally have a positive effect on patients' sleep in hospitals. A study by Zahr and Raversay [50] involved the behavioural and physiological responses of 30 premature infants to noise reduction by earmuffs. When the infants wore the earmuffs, the noise level was significantly decreased by 7 to 12 dB, and their average oxygen saturation levels were higher and more stable than those of the infants without earmuffs. In Wallace and colleagues' pilot study [51], six healthy subjects were exposed to simulated ICU noise to evaluate the effect of earplugs on sleep measures. The use of earplugs was found to result in a significant increase in the REM sleep measured by polysomnography. Richardson and colleagues [27] undertook the first study to determine the combined impact of two interventions, earplug and eye mask, on the sleep experience of patients. Longer periods of sleep were successfully achieved for the patients of the intervention group at a very cost-effective price (£2.50 each).

Behavioural modification

Behavioural modification is a treatment approach, based on the principles of operant conditioning, that replaces un-

Table 2**Effectiveness of noise reduction strategies in intensive care units**

Author and year published	Method	Participants	Setting	Intervention	Outcome
Zahr and Traversay, 1995 [50]	Controlled clinical trial	30 premature infants	NICU in USA	Earmuffs	Improve sleep by 39.0%
Wallace <i>et al.</i> , 1999 [51]	Controlled clinical trial; polysomnography	6 healthy adult subjects	Sleep Lab in USA	Earplugs	Improve sleep by 33.7%
Richardson <i>et al.</i> , 2007 [27]	Controlled clinical trial; patient self-report	64 adult patients	CCU in UK	Earplugs + eye masks	Improve sleep by 10%
Mann <i>et al.</i> , 1986 [53]	Controlled clinical trial; nurse observation	41 premature infants	Newborn nursery in UK	Behaviour modification	Improve sleep by 13.8%
Kahn <i>et al.</i> , 1998 [54]	Noise monitoring	All the ICU staff	Medical ICU in USA	Behaviour modification	Decrease noise by 1.9 dBA
Walder <i>et al.</i> , 2000 [55]	Nurse observation for sleep; noise monitoring	17 adult ICU patients	Surgical ICU in Switzerland	Behaviour modification	Decrease noise by 3 dBA
Olson <i>et al.</i> , 2001 [56]	Controlled clinical trial; nurse observation for sleep; noise monitoring	843 adult ICU patients	Neurocritical care unit in USA	Behaviour modification	Improve sleep by 18.3%
Monsén and Edéll-Gustafsson, 2005 [57]	Controlled clinical trial; noise monitoring; documentation of sleep disturbance factors	23 adult ICU patients	Neurointensive care unit in Sweden	Behaviour modification	Decrease noise by 1.9 dBA
Gragert, 1990 [58]	Controlled clinical trial; RCSQ; researcher observation	40 old ICU patients	Coronary care unit in USA	Sound masking	Improve sleep by 22.9%
Williamson, 1992 [59]	Controlled clinical trial; RCSQ	60 CABG patients	A public hospital in USA	Sound masking (ocean sound)	Improve sleep by 37.5%
Stanchina <i>et al.</i> , 2005 [60]	Polysomnography	4 healthy adult subjects	Sleep lab in USA	Sound masking (white noise)	Improve sleep by 67.6%
Johnson, 2001 [61]	Noise monitoring	65 premature infants	NICU in USA	Acoustic material	Decrease noise by 3.3 dBA
Blomkvist <i>et al.</i> , 2005 [48]	Noise monitoring	NA	Coronary ICU	Acoustic material	Decrease noise by 4 dBA

CABG, coronary artery bypass graft; CCU, critical care unit; ICU, intensive care unit; NA, not applicable; NICU, neonatal intensive care unit; RCSQ, Richard Campbell sleep questionnaire.

desirable behaviours and reactions with more desirable ones through biofeedback and positive or negative reinforcement [52]. Two conditions are important for the selection of guidelines of behaviour modification: they must be easy to implement and they must not diminish the safety of the patients. Both noise and light are often the primary paired concerns of behaviour modification.

A randomised trial was accomplished by Mann and colleagues [53] to test the effect of night and day on infants in a newborn nursery. Besides turning off the radio, lights and

covering the windows with thick and dark curtains, the behaviour of the staff and visitors were changed by the researchers to avoid generating unnecessary noise. Infants from the intervention group slept longer and gained more weight than those from the control nursery. Kahn and colleagues [54] concluded that many of the noises causing sound peaks over 80 dBA were amenable to behaviour modification and that it was possible to reduce the noise levels in an ICU setting significantly through a comprehensive educational program of behaviour modification towards all the ICU staff. Walder and colleagues [55] implemented five

Table 3

Comparison of the effectiveness of noise reduction strategies in intensive care units

Outcome	Intervention			
	Earplugs	Behavioural modification	Sound masking	Acoustic absorption
Average noise level reduction	NA	2.7dBA	NA	3.6 dBA
Average sleep improvement	25.3%	16.1 %	42.7 %	NA

NA, not applicable.

guidelines to significantly lower the noise level and the number of alarms of hemodynamic monitoring in the surgical ICU. Noise reduction strategies included cutting down the intensity of the alarm sound and talking, and switching off the phone, television and radio. A “quiet time” (2 to 4 am, 2 to 4 pm) protocol was carried out in Olson and colleagues’ study [56] to promote sleep in a large sample size in neurocritical care units. The increase in sleep behaviour was associated with decreased sound and light levels achieved during the quiet time. Patients observed during the intervention period were 1.6 times more likely to be asleep during the quiet time than were patients observed during the control period ($p < 0.001$). Monsén and Edéll-Gustafsson [57] introduced non-disturbance periods during afternoon and night, and changed nursing and medical routines, which resulted in reduced sleep disturbance factors and partly reduced noise levels in the neonatal ICU.

Sound masking

The sound masking system is often used to increase speech privacy and to minimize distractions from other sounds. The system is being introduced to hospitals while patient confidentiality is becoming more of an issue where responsible handling of personal details forms an essential part of a data protection policy. Limited case studies have also shown that using the systems in hospital wards could improve patient satisfaction [58-60]. In Gragert’s study [58] the masking signal was proved to be an effective intervention and should be considered a viable method of enhancing the sleep quality of patients in noisy ICU environments. Patients with sound masking intervention believed that they slept better and that it was quieter than in the control group. Williamson [59] investigated the influence of ocean sounds (white noise) on the night sleep pattern of postoperative coronary artery bypass graft patients after being transferred from an ICU. The group receiving ocean sounds reported higher scores in sleep depth, awakening, return to sleep, quality of sleep, and total sleep scores, indicating better sleep than the controlled group. The study by Stanchina and colleagues [60] suggested that white noise increased arousal thresholds in healthy individuals exposed to recorded ICU noise. The change in sound from baseline to peak, rather than the peak sound level, determined whether an arousal

occurred. From Table 3 it can be seen that sound masking has the most significant effect in promoting ICU patients’ sleep, producing an improvement of 42.7%.

Acoustic absorbers

Johnson [61] tested the effect of acoustic foams on the level of noise inside the incubator and examined neonatal response behaviours to changes in environmental noise. Acoustic foam pieces were placed in each of four corners of the incubator. The noise was reduced by 3.3 dBA inside the incubator. In a study by Blomkvist and colleagues [48], after the replacement of the ceiling tiles the noise level was reduced by 4 dB.

Limitation of previous studies and directions for future work

Previous studies, especially in medical sectors, have mainly been based on simple measurements of sound levels, whereas the influence of other room acoustic conditions, such as reverberation and reflection patterns, have not been paid enough attention. The sound level based approach has many limitations, even though different kinds of noise reduction protocols have been implemented and their effectiveness in improving patients’ sleep has been demonstrated. Further research including other sound characteristics is required.

Besides noise, many other factors - for instance, light, medication and pain - would all contribute to the disturbed sleep of ICU patients. Some arousals may even mistakenly be attributed to noise [62]. However, research on the relative influence and the combined effects of those factors has been limited and this should be pursued in the future.

There has been very little research on the influences of acoustic conditions on healthcare staff. The patients are the centre of every hospital; however, the degree of staff satisfaction with the working environment directly affects working efficiency, enthusiasm and the quality of care provided.

No study has been found to compare noise conditions in different types of ICUs, for example, respiratory ICU, pediatric ICU, neonatal ICU, cardiac ICU, medical ICU, surgical ICU, and neuro ICU.

Conclusion

Based on a number of original papers, the impact of noise on patients' sleep and the effectiveness of noise reduction strategies in ICUs have been reviewed. These have shown: noise is just one of a number of factors that may disrupt the sleep of patients on the ICU; staff conversation and alarms are generally regarded as the most disturbing noises for patients' sleep in ICUs; no research has been done on the relationships between ICU patients' sleep quality and the other room acoustic parameters besides sound level; and there are generally four interventions for sleep improvement, including earplugs, behavioural modification, sound masking, and acoustic absorption. Sound-absorbing treatment is a relatively effective noise reduction strategy, whereas sound masking appears to be the most effective technique for improving sleep.

There are some limitations of the existing studies, including the lack of attention to other room acoustic conditions in addition to sound level, the combined effects of different sleep disturbing factors, and the effects of noise on staff. For future research, there should be close collaboration between medical researchers and acousticians to examine the different characteristics of sound.

Competing interests

The authors declare that they have no competing interests.

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