

# SoundEar noise warning devices cause a sustained reduction in ambient noise in adult critical care

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## Abstract

**Introduction:** Elevated sound levels in critical care are associated with sleep deprivation and an increased incidence of delirium. We aimed to determine whether a sound-activated visual noise display meter could cause a sustained reduction in sound levels overnight in an adult critical care unit.

**Method:** Sound levels were recorded overnight for eight days before and after the introduction of a visual noise display meter, with a further eight days recorded four months later after continued use of the visual noise display meter.

**Results:** Median ambient sound levels were significantly reduced from 57.4 dB by 3.9 dB, with a sustained reduction of 3.6 dB from baseline after four months of the device operating. Peak ambient sound levels had a small but significant reduction from 66.0 dB by 0.7 dB, with a sustained reduction of 0.8 dB after four months.

**Discussion:** Sound-activated visual noise display meters can be effective in providing a sustained reduction in ambient sound overnight in adult critical care units, which would appear to be driven by behavioural change.

## Keywords

Delirium, noise, sleep, sleep promotion, sound

## Introduction

Critical care units are noisy and busy environments, with patients being subjected to disturbances throughout the day and night.<sup>1,2</sup> Elevated ambient sound levels are associated with adverse physiological and psychological effects on hospitalised patients, including annoyance, sleep disturbance and interference with rest and recovery.<sup>3–5</sup> Furthermore, the physiological and psychological effects of poor sleep, including its association with delirium, is becoming increasingly recognised.<sup>3–7</sup> Delirium in critical care is independently associated with a longer inpatient length of stay, prolonged recovery and a higher patient mortality and morbidity.<sup>7,8</sup>

Polysomnography, a multi-parametric sleep study tool used to investigate and diagnose sleep disorders, has demonstrated poor sleep-wake cycles in mechanically ventilated critical ill patients.<sup>9</sup> It is also evident that critical care patients' exhibit severely altered sleep architecture, with patients frequently experiencing broken sleep cycles, large variations in total sleep

time, and loss of the normal circadian rhythm with a higher frequency of daytime sleeping compared to night-time sleeping. One of the key contributors to this is postulated to be noise.<sup>10,11</sup>

The World Health Organisation (WHO) recommendations for noise levels suggest that hospitalised patients in observation or treatment areas should not be exposed to ambient sound levels of greater than 35 dB, with a night-time peak noise level of 40 dB.<sup>12</sup> Lack of compliance with these recommendations in

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the critical care setting has been demonstrated by multiple studies, with elevated sound levels being attributed to both equipment and human activity.<sup>1,2,6,13,14</sup> It is thought that hospitals are becoming increasingly louder, and some studies suggest that maintaining levels of ambient sound below the WHO recommendations is not achievable without a specific noise reduction management programme.<sup>15–17</sup>

In a previous study, our critical care unit trialled a bundle of measures to reduce night-time environmental noise and light, with the aim of limiting iatrogenic sleep disturbance.<sup>18</sup> The measures taken to reduce sound included: limiting staff conversation around patient bed-spaces, reducing alarm levels on equipment, reducing sound levels on phones and pagers, and offering patients earplugs overnight. The measures taken to reduce environmental light and promote normal circadian sleep patterns included: offering patients eye masks; switching off overhead lights from 23:00 h until 07:00 h; and grouping together patient care activities and interventions to allow a minimum of 2 h of undisturbed sleep. Within the controlled conditions of the trial, the bundle was shown to improve sleep, half the incidence of delirium, and reduced mean ambient sound overnight by 6.9 dB within two weeks of implementation. However, outside of research conditions the adoption of these measures has not been sustained, as it is felt that the measures are not ingrained in routine staff practice.

*SoundEar* is a noise monitoring and visual warning device, which can constantly measure, document and display ambient sound levels to provide a visual representation of noise levels in a given environment.<sup>19</sup> It can be used to visually alert staff when noise levels are approaching or breach a pre-set threshold. The use of *SoundEar* devices in neonatal critical care units and operating theatres in this manner has demonstrated a reduction in sound levels that patients are exposed to.<sup>20,21</sup>

This study aimed to evaluate whether the use of the *SoundEar* device can reduce night-time noise levels in the adult critical care environment, and whether continued use of its warning system could lead to a sustained reduction in night-time noise levels.

## Methods

### Study design

The study took place in a 24-bedded, mixed medical, surgical, and neurosciences adult critical care unit in Preston, Lancashire, UK. A *SoundEar 3* device (*SoundEar A/S*, Birkerød, Denmark), a noise meter with visual feedback capabilities, was deployed over the nurses' station in the centre of seven-bedded closed bay within the critical care unit, containing five beds within the bay and two side rooms. The microphone was positioned over the centre of the nurses' station, as this was found to be the loudest

point in the area during our pilot study, and calibrated prior to the start of the study. The display on the device was visible from all bed spaces.

Baseline data collection was undertaken over a period of eight consecutive nights. Following this the *SoundEar 3* device's visual warning system was introduced and a further eight consecutive nights data collection was taken. Follow up data was collected after four months of continued use of the device. No investigators were present in the clinical environment during data collection periods. Neither the staff in the unit nor the patients were made aware that this study was being conducted or that noise levels were being recorded. No other interventions targeting the night-time environment were implemented at this time.

The study was registered with the Research and Innovation Department at Lancashire Teaching Hospitals, and ethical approval waived.

### Data collection

Ambient (LAS, or A-weighted) and peak (LCpeak, or C-weighted) sound levels<sup>22</sup> were recorded overnight, defined as 23:00 h to 07:00 h. Recordings were made by the *SoundEar* for eight days with the visual warnings on the device not activated.

Following this the visual warnings on the device were activated. They were set to display green if ambient sound was less than 60 dB, orange if ambient sound was between 60 dB and 70 dB, and red if ambient sound was above 70 dB. Warnings remained off during the day-time (07:00 to 23:00 h). Data on ambient and peak overnight sounds levels was then recorded for a subsequent eight days.

After initial data collection, the devices were left in clinical practice with warning devices activated overnight. Four months after the initial data collection, the same recordings on ambient and peak overnight sounds levels were collected for a further eight days.

### Data analysis

Data were exported from the noise meters as comma-separated values (CSV) files. LAS readings were made every second, LCpeak up to 10 times a second. Data were analysed in *R 3.2.3* (R Core Team, Vienna, Austria)<sup>23</sup> using the *ggplot2* package. Sound levels for each day were summarised as a time series to check for anomalous values.

As sound levels were non-normally distributed, ambient and peak sound levels between intervention phases are presented as median [interquartile range]. Non-normality of data also prohibits the use of *t* tests and ANOVA, whilst the non-symmetry of the distributions prohibits the use of Wilcoxon signed rank test. We therefore opted to test that there was a difference in time under a given threshold using the Kolmogorov-Smirnov test. However, since this does

not indicate the reason for the difference (median, variance, outliers, etc.), we explicitly tested for a reduction in median sound level using Mood's median test.<sup>24</sup>

## Results

Median ambient sound levels were significantly reduced by 3.6 dB from 57.4 dB [51.6–59.6] to 53.5 dB [50.9–58.3] after intervention with the *SoundEar 3* device ( $p < 0.0001$ ). This effect persisted after four months of the intervention being in place with ambient sound levels remaining at 53.8 dB [50.7–57.7] ( $p < 0.0001$ , Table 1).

Median peak sound levels had a small but significant reduction of 0.7 dB from 66.0 dB [64.4–67.9] to 65.3 dB [64.4–66.5] after intervention with the *SoundEar 3* device ( $p < 0.0001$ ). This effect also persisted at four months with peak sound levels remaining at 65.2 dB [63.6–67.2] ( $p < 0.0001$ ).

The effect of the *SoundEar* device on sound levels through time during the night can be visualised using threshold plots showing the proportion of total time spent below a specified sound level threshold (Figure 1). These demonstrate that both ambient and peak sound levels spent a greater proportion of time at a lower level both after intervention (green) and at four months follow-up (blue) when compared to the pre-intervention baseline (red).

Ambient sound levels spent more time below a threshold of 49.4 to 64.8 dB (shown with dotted lines) after intervention and at follow up when compared to the pre-intervention baseline. Peak sound levels spent more time below a threshold of 64.0 to 73.5 dB after intervention, with peak levels remaining below the baseline up to 84.2 dB at four months follow-up. Two-sample Kolmogorov-Smirnov testing

demonstrated a significant difference comparing baseline and post-intervention and comparing baseline with four months ( $p < 0.0001$  in both cases).

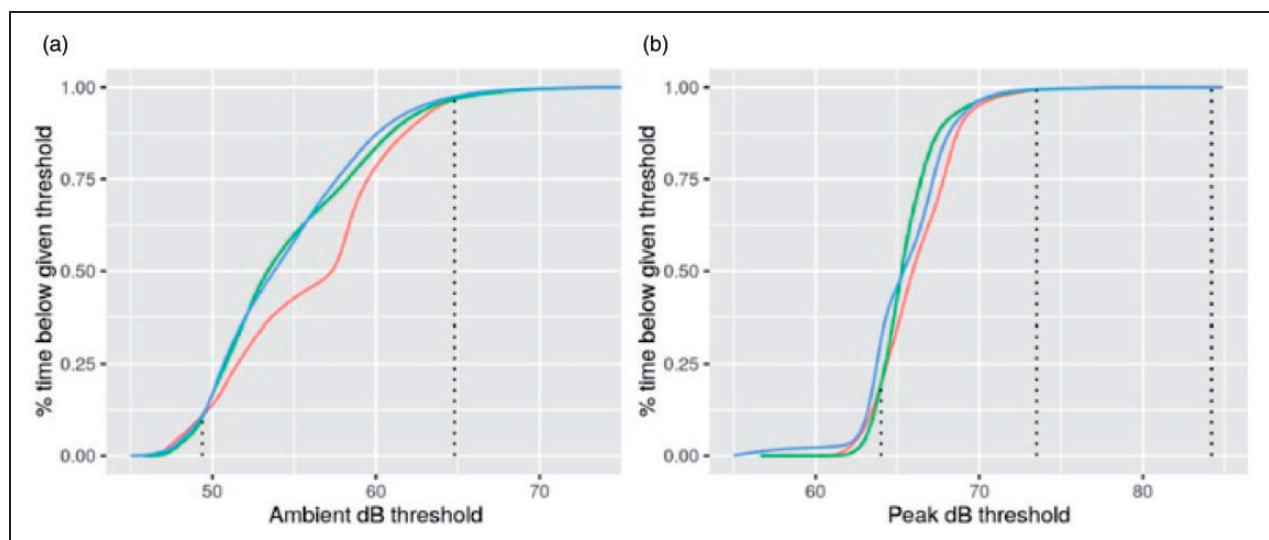
During the study period the bed occupancy remained at  $> 95\%$ , which is the norm for this critical care unit. Whilst no unusual clinical patterns of patient-related or staffing-related activity were identified, this was not specifically measured for the purposes of this study, thus the results are not adjusted for activity levels or acuity of patients.

## Discussion

This study demonstrated that introduction of a *SoundEar 3* visual noise warning device during night-time hours within an adult critical care unit can offer a sustained and significant reduction in both ambient and peak sound levels. The device acted as an isolated intervention to significantly reduce night-time ambient and peak sound levels, a change that was sustained after a four-month period.

Greater reductions in ambient rather than peak sound levels were produced using the *SoundEar 3* visual warning system. It is plausible that the greater reduction in ambient sound levels was due to direct visual feedback regarding noise levels passively affecting modifiable human behaviours, such as volume and quantity of speech. The lesser reduction observed in peak sound levels may be explained by the *SoundEar3* having a reduced influence on less-modifiable or non-modifiable noises, such as medical devices, monitoring alarms, and unintentional peak noises from doors, bins and moving equipment.

Staff members were intentionally not made aware that the device was being introduced, nor that sound levels were being recorded in addition to the visual demonstration of noise levels being displayed.



**Figure 1.** Proportion of time per intervention phase that (a) ambient and (b) peak sound levels remained below a given threshold. Red: baseline; green: after introduction of visual noise warning devices; blue: at four month follow up.

**Table 1.** Change in total peak and ambient sound levels at different intervention stages.

	Peak sound (median[IQR] dB)	Median difference (dB)	Ambient sound (median[IQR] dB)	Median difference (dB)
Pre-intervention	66.0 [64.4–67.9]		57.4 [51.6,59.6]	
Post-intervention	65.3 [64.3–66.5]	–0.7*	53.5 [50.9,58.30]	–3.9*
4 months following intervention	65.2 [63.70–67.2]	–0.8*	53.8 [50.7,57.7]	–3.6*

\*Significantly different ( $p < 0.0001$ ) by Mood's median test.

This was therefore an isolated intervention, rather than being part of a concomitant programme of noise reduction or environmental modification, yet demonstrated a sustained reduction in sound levels just by the device being present, without any form of education being required. Although feedback from clinical staff to demonstrate the extent to which they modified their behaviour in accordance with the *SoundEar 3* visual noise display was not formally gathered as part of this study, staff commented to the investigators in routine clinical practice that the *SoundEar3* reminded them overnight to reduce their volume of speech. Feedback also suggested that the system reminded staff to promote sleep via other measures, such as grouping interventions to minimise disruptions to sleep.

Based on these results, we suggest that sound-activated visual noise warning devices should be considered in adult critical care units as part of an effort to promote healthy sleeping patterns in critically ill patients. The benefits of the *SoundEar 3* system include a system that is easy to introduce and maintain, and which can record and produce visual feedback to noise levels that are not dependent on staff monitoring.

The limitations of the study included recording noise in a central area, within a seven-bedded closed bay in the critical care unit, as opposed to taking measurements at individual bed-spaces or at the patients' ear level. Any variation in sound levels in the immediate environment around individual bed-spaces, including clinical and non-clinical equipment, was not measured in this study. It can be postulated that patients in the same clinical area could have been exposed to differing sound levels during the course of the study. We also note that despite the positive results of this intervention and the significant impact that this intervention had on noise levels, patients continued to be exposed to noise levels above the WHO recommendations for hospitalised patients.<sup>12</sup>

Furthermore, whilst it is clear that noise reduction can be achieved with the use of the *SoundEar 3* device, the question of its link to the incidence of delirium was not investigated in this study. Further research is now underway to ascertain whether the *SoundEar* devices can act synergistically with an environmental night-time modification programme, to improve sleep quality and reduce the incidence of delirium, and hence have potential to reduce the overall cost of treating critical illness.

A priority is now to assess whether the introduction of a bundle of sleep promoting measures as used in our previous study<sup>18</sup> alongside the *SoundEar* device can act synergistically to reduce both ambient sound and delirium rates. Nevertheless, we feel that the *SoundEar3* is a valuable addition to the technological landscape that can offer a moderate and sustained reduction in night-time noise levels.

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### References

1. Konkani A, and Oakley B. Noise in hospital intensive care units – a critical review of a critical topic. *J Crit Care* 2012; 27: 522.e1–522.e9.
2. Christensen M. Noise levels in a general intensive care unit: a descriptive study. *Nurs Crit Care* 2007; 12: 188–197.
3. Aaron JN, Carlisle CC, Carskadon MA, et al. Environmental noise as a cause of sleep disruption in an intermediate respiratory care unit. *Sleep* 1996; 19: 707–710.
4. Wenham T, and Pittard A. Intensive care unit environment. *Contin Educ Anaesth Crit Care Pain* 2009; 9: 178–183.
5. Pugh RJ, Jones C, and Griffiths RD. The impact of noise in the intensive care unit. *Yearbook of intensive care and emergency medicine*. Berlin/Heidelberg: Springer, 2007, pp. 942–949.
6. Redeker NS. Sleep in acute care settings: an integrative review. *J Nurs Scholarsh* 2000; 32: 31–38.
7. Kamdar BB, Needham DM, and Collop NA. Sleep deprivation in critical illness: its role in physical and psychological recovery. *J Intensive Care Med* 2012; 17: 97–111.

8. Weinhouse GL, Schwab RJ, Watson PL, et al. Bench-to-bedside review: delirium in ICU patients-importance of sleep deprivation. *Crit Care* 2009; 13: 234.
9. Friese RS, Diaz-Arrastia R, McBride D, et al. Quantity and quality of sleep in the surgical intensive care unit: are our patients sleeping? *J Trauma* 2007; 63: 1210–1214.
10. Freedman NS, Gazendam J, Levan L, et al. Abnormal sleep/wake cycles and the effect of environmental noise on sleep disruption in the intensive care unit. *Am J Respir Crit Care Med* 2001; 163: 451–457.
11. Xie H, Kang J, and Mills G. Clinical review: the impact of noise on patients' sleep and the effectiveness of noise reduction strategies in intensive care units. *Crit Care* 2009; 13: 208.
12. Berglund B, Lindvall T, and Schwela DH. *Guidelines for community noise*. Geneva: World Health Organization, 1999.
13. Kahn DM, Cook TE, Carlisle CC, et al. Identification and modification of environmental noise in an ICU setting. *Chest* 1998; 114: 535–540.
14. Akansel N, and Kaymakci S. Effects of intensive care unit noise on patients: a study on coronary artery bypass graft surgery patients. *J Clin Nurs* 2008; 17: 1581–1590.
15. Darbyshire JL, and Young JD. An investigation of sound levels on intensive care units with reference to the WHO guidelines. *Crit Care* 2013; 17: R187.
16. Elliott RM, McKinley SM, and Eager D. A pilot study of sound levels in an Australian adult general intensive care unit. *Noise Health* 2010; 12: 26–36.
17. Busch-Vishniac IJ, West JE, Barnhill C, et al. Noise levels in Johns Hopkins Hospital. *J Acoust Soc Am* 2005; 118: 3629–3645.
18. Patel J, Baldwin J, Laha S, et al. The effect of a multi-component multidisciplinary bundle of interventions on sleep and delirium in medical and surgical intensive care patients. *Anaesthesia* 2014; 69: 540–549.
19. *SoundEar 3 Manual – UK*. Birkerød: SoundEar A/S, 2015.
20. Wang D, Aubertin C, Barrowman N, et al. Reduction of noise in the neonatal intensive care unit using sound-activated noise meters. *Arch Dis Child Foetal Neonatal Ed* 2014; 99: 515–516.
21. Engleman CR, Neis JP, Kirschbaum C, et al. A noise-reduction program in a pediatric operation theatre is associated with surgeon's benefits and a reduced rate of complications: a prospective controlled clinical trial. *Ann Surg* 2014; 259: 1025–1033.
22. Vos J. A- and C-weighted sound levels as predictors of the annoyance caused by shooting sounds, for various façade attenuation types. *J Acoust Soc Am* 2003; 113: 336–347.
23. R Development Core Team. *R: A Language and Environment for Statistical Computing*. Vienna: the R Foundation for Statistical Computing, 2015.
24. Babbs CF, Kemeny AE, Quan W, et al. A new paradigm for human resuscitation research using intelligent devices. *Resuscitation* 2008; 77: 306–331.