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Identifying determinants of noise in a medical intensive care unit

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Abstract

Continuous and intermittent exposure to noise elevates stress, increases blood pressure, and disrupts sleep among patients in hospital intensive care units. The purpose of this study was to determine the effectiveness of a behavior-based intervention to reduce noise and to identify determinants of noise in a medical intensive care unit. Staff were trained for six weeks to reduce noise during their activities in an effort to keep noise levels below 55 dBA during the day and below 50 dBA at night. One-min noise levels were logged continuously in patient rooms eight weeks before and after the intervention. Noise levels were compared by room position, occupancy status, and time of day. Noise levels from flagged days (>60 dBA for >10 hrs) were correlated with activity logs. The intervention was ineffective with noise frequently exceeding project goals during the day and night. Noise levels were higher in rooms with the oldest heating, ventilation, and air-conditioning system, even when patient rooms were unoccupied. Of the flagged days, the odds of noise over 60 dBA occurring was 5.3 higher when high-flow respiratory support devices were in use compared to times with low-flow devices in use (OR= 5.3, 95% CI = 5.0 −5.5). General sources, like the heating, ventilation, and air-conditioning system, contribute to high baseline noise and high-volume (>10 L/min) respiratory-support devices generate additional high noise (>60 dBA) in Intensive Care Unit patient rooms. This work suggests that engineering controls (e.g., ventilation changes or equipment shielding) may be more effective in reducing noise in hospital intensive care units than behavior modification alone.

Keywords

Hospital; quality improvement; Respiratory device; sound; ventilation

INTRODUCTION

Continuous noise exposure throughout the day contributes to elevated stress[(1)] and can lead to increases in heart rate and blood pressure,[(2)] which may delay recovery in intensive care

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unit (ICU) patients. Noise exposure during the night can have even greater detrimental effects on patient recovery because it disrupts patients' sleep. ICU patients often spend insufficient time in restorative sleep stages and are easily awakened by noise even if occurring for brief intervals.[3–5] To promote patient sleep and recovery in hospitals, the World Health Organization (WHO) established recommended limits for noise.[1] These guidelines recommend that noise expressed as sound equivalent levels (L_{eq}), remain below 35 dBA throughout the day and below 30 dBA overnight.[1] The WHO further recommends that maximum levels not exceed 40 dBA overnight to ensure that no brief loud noises interrupt patient sleep.

Noise in ICUs often exceeds these guidelines[6] with levels consistently reported in exceedance of 45–50 dBA.[7–9] Researchers have attempted to associate noise in ICUs with specific locations, such as patients rooms and nurses' stations,[10] or activities, including conversation and television.[11, 12] Sources of noise identified include monitor alarms, televisions, intercoms, and speech, all with noise levels ranging from 75 dBA to 85 dBA.[11] Intervention studies typically focus on how staff can reduce noise from easily modifiable sources, such as conversations and televisions.[13, 14] Most studies have reported little success in reaching WHO guidelines.

The goals of this study were: 1) to determine the effectiveness of a behavior-based intervention to reduce noise; and 2) to identify determinants of noise in a medical ICU (MICU). The noise assessment was one portion of a larger continuous quality improvement (QI) project, the SOund, Light, and circadian Rhythm (SOLAR) project, designed to strengthen circadian rhythms in critically ill patients through non-pharmacological interventions. Details from the larger study will be published separately. One-minute noise levels were measured continuously in patient rooms for an eight-week period before and after a six-week learning period during which the intervention was introduced. The intervention was implemented by nursing and physician champions and employed a variety of methods to educate and engage the staff in efforts to reduce noise. The intervention was designed to provide weekly feedback of real data for staff to review and track their progress, which, combined with the long-term duration of the study, increased the likelihood of successful behavior modification and continuous improvement.

METHODS

Site Description

Approved by the University of Iowa Institutional Review Board, the QI study was conducted from November 2014 to April 2015 in the MICU of the University of Iowa Hospital and Clinics. At the time of the study, the MICU consisted of 26 patient rooms separated into five pods (Pod 1 through Pod 5), each containing four to six patient rooms (Figure 1). The heating, ventilation, and air-conditioning (HVAC) system for Pod 1 was part of the oldest construction in the MICU, whereas that for the other pods was recently renovated. A central nurses' station was located near the entrance of each pod. The approximately 80 nursing staff assigned to the MICU during the study period typically rotated through three to four 12-hr shifts per week. Two rooms (one nearest and one farthest from the central nurses' station) within each of four pods (Pod 1, Pod 3, Pod 4, and Pod 5) were included in this

study (8 rooms in total). Pod 2 was only used for overflow patients and was excluded a priori due to anticipated low occupancy.

Sampling Protocol

Noise levels from 30 dBA to 130 dBA were logged every min in each of the selected rooms with a sound level meter (SLM, SDL 600, Extech Instruments, Nashua, NH) set to A-weighting, slow response. SLMs were attached to the wall within six feet of the head of the patient and calibrated to 114.0 dBA using a sound level calibrator (407766, Extech Instruments, Nashua, NH). Once per week, data were uploaded manually from the SLM to a central database. Baseline noise measurements were collected for eight weeks prior to the intervention, which was then implemented during a six-week learning phase and continued for the duration of the study. Post-intervention measurements were collected for eight weeks after the learning phase was completed. SLMs were post-calibrated at the end of the sampling period.

Noise Reduction Intervention

Nursing champions and research team members developed an evidence-based ICU Noise Reduction Bundle informed by (a) a systematic review of prior investigations of ICU noise, (b) a baseline survey of staff nurses' knowledge of the physiologic effects of noise and potential sources of noise, and (c) pre-intervention measurements of ICU noise as detailed below. The main elements of the ICU Noise Reduction Bundle included (a) raising staff awareness of the harm caused by ICU noise and potential sources of noise in the ICU; (b) avoiding loud noises in the nurse charting areas (pods); (c) limiting visitation during times of patient rest to one to two people who are willing to remain quiet; (d) adjusting (reducing) monitor alarm levels when clinically appropriate; and (e) bundling patient care activities at night to avoid unnecessary noise and/or interruptions. Nurses were the main targets for the educational program because they have the most contact time with patients.

During the intervention, project researchers and designated "nursing champions" provided one-on-one education for 61 of the 79 MICU nurses on the adverse health effects of noise, recognition of sources, and methods for reduction. Additional methods to implement change included the placement of posters in patient rooms and common areas and the weekly dissemination of just-measured MICU and pod-level sound data of occupied rooms to MICU staff with tips for creating change (Figure 2). Project staff constructed weekly time-series plots and heat maps of one-minute noise levels with project goals (<55 dBA in day and <50 dBA at night) super imposed. Staff were encouraged to relate their activities to the plots in order to raise awareness of their own contributions to noise in patient rooms. Project researchers also conducted weekly rounds with random room spot checks to promote awareness and to provide additional one-on-one education to nurses.

Data Analysis

All one-min data were imported into SAS (Version 9.3. SAS, Cary, NC) for analysis. These data included date, time, noise in dBA, pod number (1, 3, 4, and 5), room position (near, far), and room occupancy status (occupied, unoccupied). Additional variables were coded into the dataset as follows: "time period" described measurements recorded during the day

(07:00–22:59) or at night (23:00–06:59); “intervention” signified measurements recorded during the pre-or post-intervention phases of the study. Fewer than 2% of the 1,452,255 one-min data collected were eliminated from further analysis because they were missing or deemed unusable (missing occupancy status or instrument malfunction). Post-calibration indicated the SLMs were operating within 0.8 dBA of pre-calibration measurements.

Hourly L_{eq} values (L_{eq-H}) values were calculated from one-min noise measurements by determining the sound pressure level of the average sound pressure over each 60-min period.[15] Consolidating the noise measurements in this way allowed us to compare observed noise levels to project goals and WHO guidelines. Descriptive statistics were generated (SAS, PROC UNIVARIATE). Normality tests indicated data were not normally distributed. Due to the large sample size (n=24,095 hr) and resulting power of our tests, statistically significant differences ($p < 0.05$) in nonparametric tests were found but they were not clinically significant (e.g., differences of <1 dBA are not discernible to the human ear). We therefore generated cumulative frequency plots and boxplots displaying quartile distributions of the L_{eq-H} to compare noise levels between pods, positions, and time periods by intervention phase.

One-min noise data were queried to identify 29 days when noise in a room was consistently elevated (>60 dBA) for an extended time (>10 hr). Ten hr were chosen as the cutoff to try and insure shorter-term happenings, which might not have consistent causes, were excluded. For these “flagged” days, MICU activity logs were generated from a review of the electronic medical records of the 19 patients involved, in order to identify when specific medical interventions took place. Interventions included respiratory support using oxygen (O_2) delivery systems that operate at a range of flow rates measured in liters per min (L/min). Delivery systems included bilevel positive airway pressure (BiPAP), continuous positive airway pressure (CPAP), face mask (>10 L/min), nasal cannula (NC, 1–10 L/min), and high flow cannula (15–50 L/min). For comparison purposes, logs were also reviewed to identify respiratory support for the same room on the day prior to that which was flagged. Any minutes missing respiratory support information (n=2150) were excluded from the data subset. The remaining one-min data (n=39,553) were coded as either low flow or closed systems (BiPAP, CPAP, NC) or high flow (face mask >10 L/min, high flow cannula). An odds ratio (OR) and confidence intervals (CI) were calculated based on exposure (high flow or low flow/closed) and outcome (noise >60 dBA or noise <60 dBA).

RESULTS

Approximately 50% of the daytime L_{eq-H} in both phases exceeded the project goal of 55 dBA, whereas 68% of the nighttime pre-intervention L_{eq-H} and 62% of the post-intervention L_{eq-H} exceeded the goal of 50 dBA (Table 1). Noise was significantly louder in Pod 1 than in other pods ($p < 0.01$) in both pre-and post-intervention phases with a median L_{eq-H} of approximately 58 dBA compared to Pods 3, 4, and 5 which all had median L_{eq-H} at approximately 54 dBA. The difference of approximately 4 dBA is substantial because an increase in 3 dBA indicates a doubling of sound energy.[16] The L_{eq-H} was consistently higher in occupied rooms (n=18,810, median = 54.9 dBA) than in unoccupied rooms (n=5,285, median= 49.6 dBA). Additionally, unoccupied rooms in Pod 1 had a higher

median L_{eq-H} (56.5 dBA) than all of the occupied rooms in other pods (53–54 dBA) (Figure 3). There was little difference in median L_{eq-H} measured between near and far rooms for each pod. The most substantial difference occurred in Pod 1 where the far room measured 3.3 dBA lower than the near room. Differences in median L_{eq-H} values, in near and far rooms in Pods 3, 4, and 5, differed by less than 2 dBA: −0.7 dBA, 1.9 dBA, and 0.7 dBA respectively.

Of the 29 flagged days, the odds of noise over 60 dBA occurring was 5.3 higher when high-flow respiratory support devices were in use compared to times when low-flow devices were in use (OR= 5.3, 95% CI = 5.0 −5.5). Substantially higher noise levels occurred when oxygen delivery devices were operated at higher flow rates (Figure 4, Panels B, D, and F) compared to levels observed on the comparison days (Panels A, C, and E) (i.e., day prior to the flagged day). The highest noise levels coincided with the use of facemasks with flow rates of 15 L/min and 40 L/min (65 dBA −70 dBA; Figure 4, Panels B, D, F). Although generally lower, noise on comparison days was higher when oxygen delivery devices were in use and when they were operated at higher flow rates. For example, noise was higher (~60 dBA) when the oxygen was delivered through a facemask at 10 L/min (Figure 4, Panels C, D) than when delivered through a NC at 5 L/min (~55 dBA; Figure 4, Panel C). Respiratory failure was common and frequently severe in this subgroup, which had an in-hospital mortality rate of 31.6% (6/19).

DISCUSSION

The behavioral intervention applied in this study was ineffective in substantially reducing noise in the MICU. Noise, well above WHO guidelines pre-intervention, was reduced only slightly after an intensive six-week intervention (Table 1, ~1.0 dBA in day; ~1.5 dBA in night). The median L_{eq-H} measured in this study is consistent with observations of others [10, 17, 18] remaining at approximately 55 dBA for daytime periods and 52 dBA for nighttime periods during both phases of the intervention (Table 1). Our results are consistent with Tainter et al.[19] who reported that the implementation of an overnight “quiet time” resulted in noise reductions that were statistically significant but clinically irrelevant. Similar to our study, the noise reductions they achieved did not meaningfully reduce patient exposure relative to potential adverse health effects.

General mechanical sources (e.g., HVAC system) dominated the high noise baseline, whereas major deviations from that baseline were driven by the use of high-flow respiratory oxygen delivery systems. Although L_{eq-H} values were higher in occupied rooms than unoccupied rooms, this difference was rather small, suggesting an ongoing high baseline L_{eq-H} in patient rooms even when patients and staff are not present. In general, L_{eq-H} was highest in Pod 1 in both phases of the study, and furthermore, unoccupied rooms in Pod 1 were consistently louder than all of the occupied rooms in the other pods (Figure 3). It is likely that the older HVAC system here contributed to the overall higher noise levels in this pod. If true, it serves as at least a partial explanation as to why even the unoccupied time periods in Pod 1 were louder than the rest of the MICU and supports our findings that most noise is coming from a general source.

We identified high-flow respiratory support devices as primary contributors to high noise in patient rooms of the MICU. High-flow respiratory support devices were in operation when high noises were observed on each of the three of the flagged days (Figure 4, Panels B, D, F). Additionally, high-flow devices were in use for longer periods of time during flagged days than on comparison days and high noise was not observed when high-flow devices were not operating (Figure 4). Thus, we recommend shielding these support devices or placing a partition between them and the patient to reduce noise levels. Some investigators have explored the use of earplugs in this environment, although Kamdar et al. found overall use of earplugs in promoting sleep in the ICU to be low. [20] Moreover, earplugs are often uncomfortable and their use is dependent on patient participation so shielding would likely be more effective in reducing noise exposure than hearing protection.

Overall, our findings indicate that behavioral interventions alone are likely to be insufficient at lowering MICU noise levels to acceptable targets, suggesting the need for engineering controls to reduce patient exposure. This finding conflicted with our initial hypothesis that the main contributors to noise in the MICU were human sources, generated from either the central nurses' stations, conversations, or television use. Staff conversation has been documented in the literature as a common noise source, accounting for as much as 62% of recorded noise measurements [12] with mean peak levels as high as 84.6 dBA.[11] We, therefore, expected to see marked differences in $L_{eq\text{-}H}$ between the rooms nearest and the rooms farthest from the nursing stations. Our analysis, however, indicated that noise was similar between rooms in each pod regardless of position. Since we did not see any substantial differences between the $L_{eq\text{-}H}$ in the near and far rooms, and we did not see a consistent pattern between pods, it suggests that staff are not the main contributors of noise in the MICU. Similar to our results, Cordova et al. reported no significant difference in noise levels between nursing stations and patient rooms. [10] Additionally, electronic sounds have been found to be more disruptive to sleep than human voices, [21] suggesting that future interventions that are heavily focused upon staff conversation are likely to be less effective than interventions that target electronic sources as well.

There are considerable strengths to this study including the multiple methods of education and reinforcement implemented during the learning and post-intervention phases. The use of real data fed back to nursing staff on a weekly basis allowed them to review and track their progress. This aspect of the education program, along with the repeated consultations with champions and display of posters, created an environment that promoted continuous evaluation and quality improvement. Another strength was the prolonged measurement period, which lessens the likelihood of the Hawthorne effect that may have affected other studies. Finally, the interdisciplinary team made up of physicians, advanced practice providers, nurses, respiratory therapists, physical therapists, and industrial hygienists offered unique insights into this complex problem. Indeed, our success in meeting other project goals (i.e., strengthening the light-dark cycle and increasing patient mobilization) provides evidence for the efficacy of the QI intervention.

The limitations in this study include omitting octave-band analyses. Collecting this information could give more insight into the frequencies over which the noise in the MICU is occurring. These data would help in the implementation of any engineering controls such

as shielding noisy equipment, or installing sound-absorbing materials in celling or floor tiles since different materials can absorb and reflect sound at different frequencies. As this quality improvement study is an ongoing project, there is ample opportunity to design new interventions based upon our results.

CONCLUSIONS

A multifaceted behavioral intervention consisting of educating nursing staff on ways to limit noise during their activities was ineffective in substantially reducing noise in a MICU despite being successful in other aspects of the larger QI study. The HVAC system contributed to a generally high baseline noise level, with high-flow respiratory support devices in operation when noise was highest. We recommend dampening sounds from the HVAC system and shielding support devices as a more effective way to lower noise in ICUs than behavioral interventions. In future work, we will characterize sources more completely by performing octave band analyses in order to identify effective controls.

RECOMMENDATIONS

Area and source noise measurements should be made prior to a noise reduction intervention. General sources such as HVAC systems should be monitored with a sound level meter to determine baseline noise levels. Engineering controls guided by octave-band analysis of noise sources should be prioritized in ICU noise reduction efforts.

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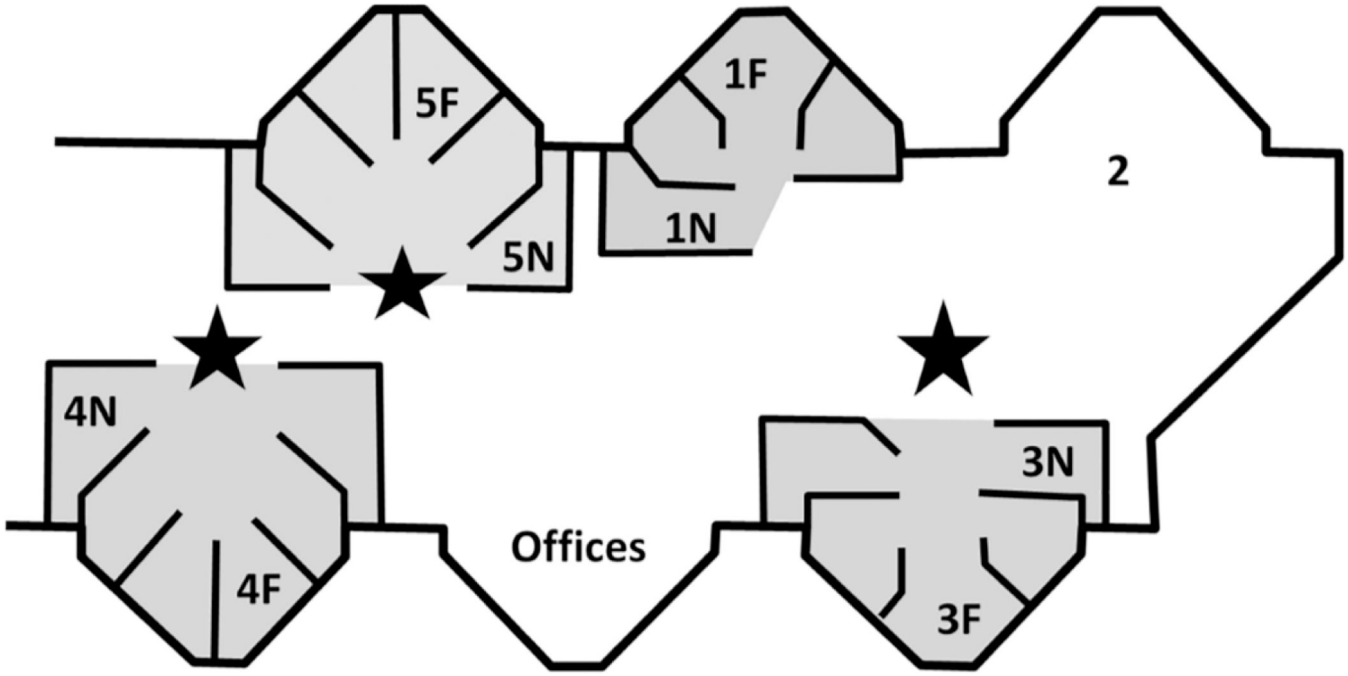

Figure 1.
Layout of the MICU with Pods 1–5 numbered. Sound Level Meters were placed in a near (N) room and a far (F) room for each of the four included pods. Central nurses' stations are shown as stars.

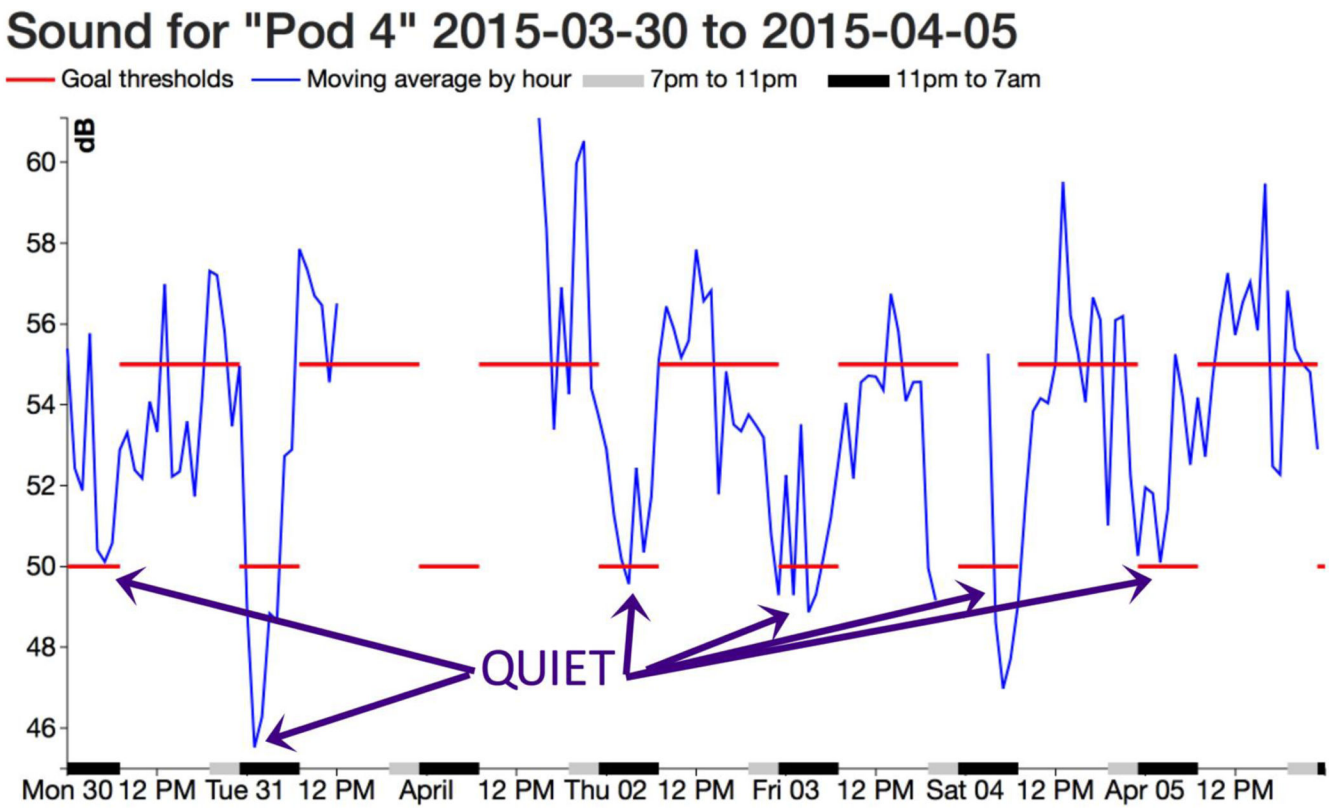

Figure 2.

Example of the weekly feedback provided to MICU staff during the intervention. Each week the project leaders generated summary data and figures using a custom web application. Messages incorporating these data were disseminated via email and posted at each nursing station, and frequently referenced by project leaders during weekly bedside rounds. The gap in the sound data tracing indicates the instrumented rooms were unoccupied during this time. Sound levels shown are measured in A-weighted decibels.

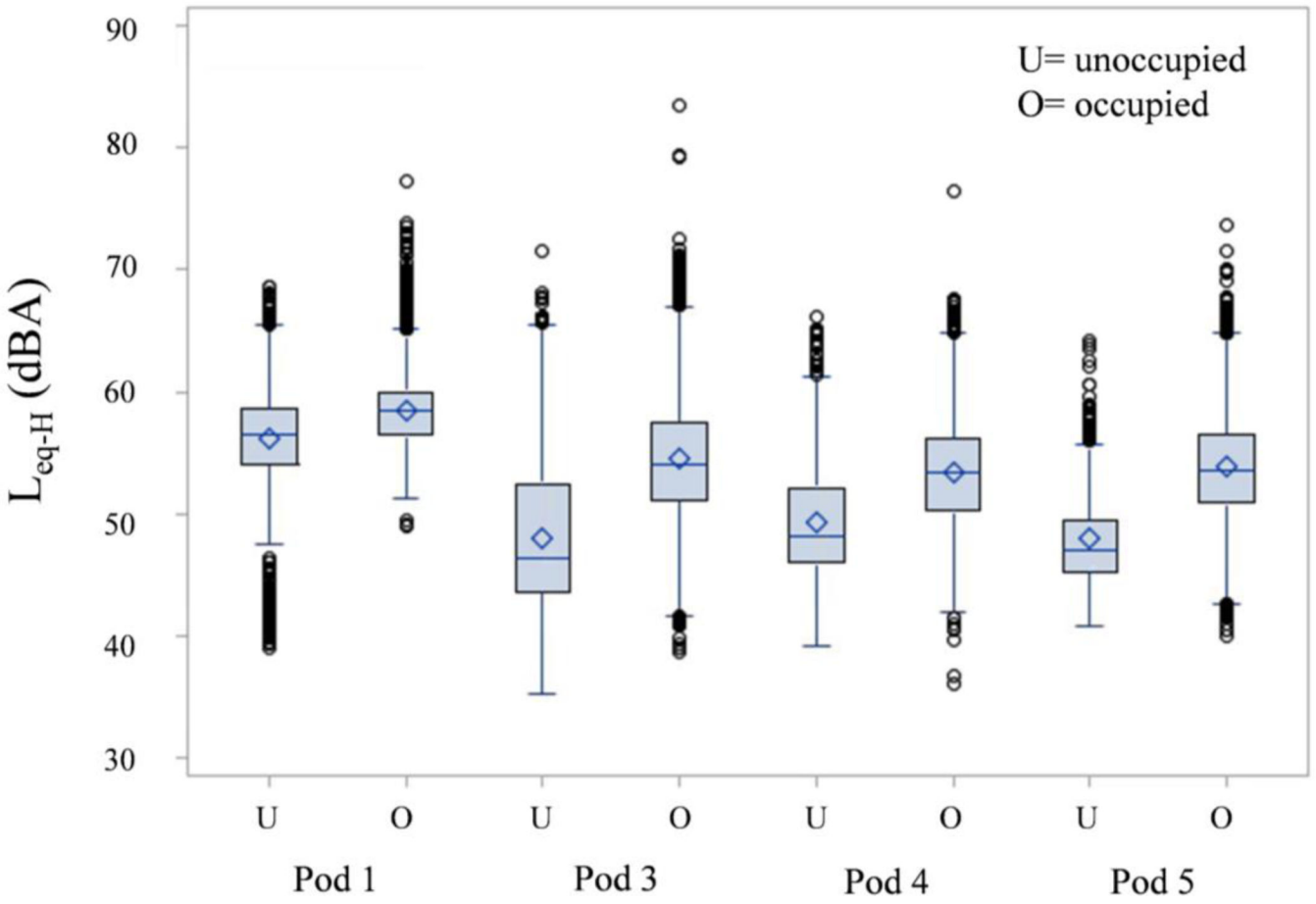

Figure 3.
Boxplot comparing hourly sound equivalent levels (L_{eq-H}) in each pod during occupied (O) and unoccupied (U) time periods.

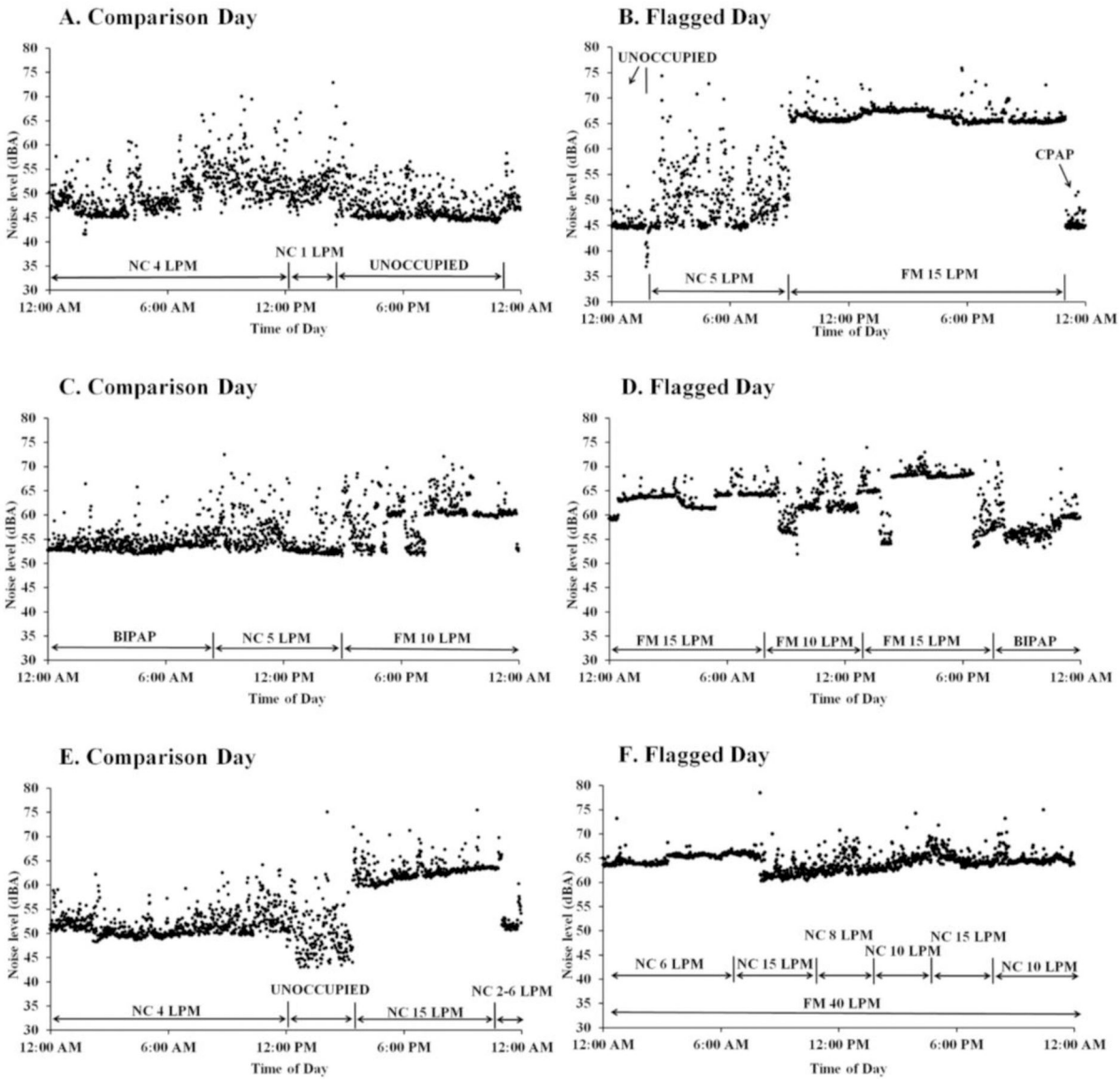

Figure 4.

One-min noise measurements over full days with medical interventions in use. Time periods shown in Panels B, D, and F were identified as having >10 hr of noise >60 dBA. Panels A, C, and E show the same rooms one day prior as a baseline comparison. Interventions include oxygen delivery systems such as a face mask (FM), nasal cannula (NC), CPAP, and BIPAP device which are shown in liters per minute (L/min).

Table 1.

Sound equivalent levels (dBA) for day (7:00 am −10:59 pm) and night (11:00 pm −6:59 am) time periods compared by intervention phase.

	Day (goal: < 55 dBA)		**Night (goal: < 50 dBA)**	
Quantile	PRE (n=7446)	POST (n=8673)	PRE (n=3661)	POST (n=4315)
5%	46.3	45.7	43.9	42.9
25%	52.1	51.3	48.9	47.4
50%	55.2	55.0	52.6	52.4
75%	58.6	58.2	55.9	56.3
95%	63.0	62.2	60.2	60.2