Cardiology in the Young

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Increased sound levels in the cardiac ICU are associated with an increase in heart rate, blood pressure, and sedation

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Original Article

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Abstract

Background: Several organizations including the Environmental Protection Agency, World Health Organization and American Academy of Pediatrics recommend that hospital sound levels not exceed 45 decibels. Yet, several studies across multiple age groups have observed higher than recommended levels in the intensive care setting. Elevated sound levels in hospitals have been associated with disturbances in sleep, patient discomfort, delayed recovery, and delirium. *Methods:* We measured sound levels in a pediatric cardiac intensive care unit and collected vital signs data, sedation dosing and delirium scores. During a 5-week study period, sound levels for 68 patients in 22 private and 4 semi-private rooms were monitored. *Results:* Sound levels were consistently above stated recommendations with an average daytime level of 50.6 decibels (maximum, 76.9 decibels) and an average nighttime level of 49.5 decibels (maximum, 69.6 decibels). An increase in average and maximum sound levels increased the probability of sedation administration the following hour (p-value < 0.001 and 0.01, respectively) and was predictive of an increase in heart rate and blood pressure (p-value < 0.001). *Conclusion:* Sound levels in the CICU were consistently higher than recommended. An increase in heart rate, blood pressure and sedation utilization may suggest a stress response to persistent and sudden loud sounds. Given known negative impacts of excessive noise on stress, sleep, and brain development, as well as the similar adverse effects from the related use of sedative medications, reducing excessive and sudden noise may provide an opportunity to improve short- and long-term hemodynamic and neurodevelopmental outcomes in the pediatric cardiac intensive care unit.

Introduction

A sound is something that is heard, while noise is an unpleasant or undesired sound.[1] Paediatric cardiac ICUs (CICUs) are stressful environments with multiple alarms and equipment generating noise,[2] as well as multiple staff members communicating necessary clinical information. The World Health Organization (WHO) recommends that the average hospital A-weighted sound level in decibels (dB(A)) does not exceed 35 dB(A) in patient rooms while maximum sound should not exceed 40 dB(A).[3] The Environmental Protection Agency (EPA) recommends average indoor sound levels not exceed 45 dB(A),[4] and the American Academy of Pediatrics (AAP) also recommends sound levels for infants and neonates be less than 45 dB(A).[5] For reference, examples of sound decibel levels are shown in Table 1. Several studies have demonstrated that ICUs, which care for the sickest patients in hospitals, consistently record sound levels that exceed recommendations.[2,6–10]

High sound levels in the CICU environment can lead to haemodynamic instability related to patient agitation as well as to increased sedation use.[2] Elevated environmental noise may also disrupt sleep,[11] normal growth, and development in infants through physiological responses [12] and contribute to delirium and post-intensive care syndrome.[13] Both behavioural responses and vital sign changes indicate that noise can have a deleterious effect on patients of all ages in the ICU. We, therefore, hypothesised that sound levels in our paediatric CICU exceed the recommended sound levels and that increased sound levels would be associated with increased sedation utilisation, delirium, and haemodynamic changes such as increases in heart rate and blood pressure.

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Table 1. Examples of noise at increasing decibels. Decibels are on a logarithmic scale. An increase in 10 dB(A) is a doubling in loudness[18–20]

Sound level dB(A)	
0	Lowest detectable human hearing
10	Normal breathing
20	Rustling leaves
30	Whisper
40	Quiet library
50	Rainfall/refrigerator
60	Dishwasher
70	Freeway traffic
80	Alarm clock/vacuum
85	Heavy traffic/handsaw
90	Lawnmower/hair dryer
100	School dance/pro sports game
110	Dog barking/baby crying
120	Rock concert/plane taking off
130	Jackhammer
140	Gunshot

dB(A) = A-weighted sound level in decibels.

Materials and methods

Patient selection and data collection

We performed a prospective observational cohort study. All children admitted to the CICU at Children's National Hospital between 25 January 2021 and 28 February 2021 were enrolled in this study.

Demographic and clinical data were collected prospectively during the study period via chart review and were managed using Research Electronic Data Capture (REDCap) electronic data capture tools hosted at Children's National Hospital.[14,15] REDCap is a secure, web-based application designed to support data capture for research studies, providing (1) an intuitive interface for validated data entry, (2) audit trails for tracking data manipulation and export procedures, (3) automated export procedures for seamless data downloads to common statistical packages, and (4) procedures for importing data from external sources. Physiological data were captured and stored on secure servers using the Etiometry platform (Etiometry Inc., Boston, MA). This study was approved by the Institutional Review Board at Children's National Hospital.

Patient diagnoses were coded into one of four categories described by Clancy et al., previously shown to predict both hospital mortality and morbidity: Class I, 2 ventricles with no aortic arch obstruction; Class II, 2 ventricles with aortic arch obstruction; Class III, single ventricle without arch obstruction; and Class IV, single ventricle with arch obstruction.[16] Delirium was captured by obtaining the Cornell Assessment of Pediatric Delirium (CAP-D) scores[17] documented by nurses every shift. Sedative medications were collected retrospectively via chart review and were also managed using REDCap electronic data capture tools.[14,15] Sedation included only bolus intermittent medication for analgesia and sedation including benzodiazepines, opioids, and dexmedetomidine. Continuous infusion doses were not collected or evaluated as continuous infusion doses are changed based on intermittent medication and evaluations of sedation over the preceding 6–12 hours and therefore not related to acute changes that may correlate with sound levels.

Sound level acquisition

Sound decibel metres (TekcoPlus Ltd. data logging sound decibel metres, Hong Kong) were placed in all 26 bedspaces within the CICU near the bedside patient monitor, thought to be the best location to obtain sound samples similar to what the patient hears. Sound decibel metres continuously sampled slow A-weighted decibel dB(A) levels within a range of 30 dB to 130 dB every 1 s and recorded every 5 minutes for 24 hours per day for a 5-week period. Every 3–4 days, sound data from sound decibel metres were downloaded to a hospital laptop using the manufacturer's software. At the time of download, decibel metres were checked to be sure the time matched with the Etiometry monitor to ensure accurate timestamps for decibel metres and physiological data.

Statistical analysis

For statistical analysis, daytime hours were defined as 7:00 am to 6:59 pm and night-time hours as 7:00 pm to 6:59 am. For each hour, a maximum and an average sound level was calculated. Maximum and average sound level predictions were calculated and compared between the daytime and night-time hours using a multilevel mixed-effects linear regression model. This model included sound level as the dependent variable, day of measurement and day/night-time period as independent variables, and random effects for patients and slopes across days. This model allowed each patient to have multiple sound measurements during the same day and over multiple days. Here, the focus was differences in sound between daytime and night-time hours over all days and an evaluation of differences at each day if an appropriate interaction between day and time period was observed.

For the assessment of the relationship between heart rate or blood pressure and noise levels, mixed-effects models were again used. The dependent variable was heart rate or blood pressure measured at 5-minute intervals. The independent variable was the average noise levels for each hour. In addition, the model included random effects for patient and slope across day. The focus of this analysis was to assess whether the average noise level was predictive of heart rate or blood pressure during the same hour.

For the assessment of the relationship between CAP-D scores and noise levels, a mixed-effects model was used. The dependent variable was the CAP-D assessments made once per 12 hours. The dependent variable was average noise levels for the 12-hour period corresponding to the CAP-D assessment. Random effects as described above were included. CAP-D assessments were taken at roughly noon and midnight, although the actual time of assessment was not recorded and several assessments were not recorded; therefore; we have used these models to assess the relationship between a CAP-D assessment at approximately noon with noise levels between 7:00 am and 7:00 pm and a CAP-D assessment at approximately midnight with noise levels between 7:00 pm and 7:00 am. We understand that the average noise levels corresponding to each CAP-D assessment take into account noise levels measured both before and after the CAP-D assessment, a limitation of the analysis.

Lastly when predicting the likelihood of sedation, only the prior hour's sound level was analysed. The assumption is that high sound levels from prior days likely have little effect on the current

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Table 2. Patient characteristics and demographics

Variable	n (%)
Age	
<30 days	11 (16)
30 days–1 year	26 (38)
>1 year–18 years	26 (38)
>18 years	5 (7)
Sex	
Male	41 (60)
Female	27 (40)
Race	
Asian	2 (3)
Black or African American	24 (35)
White	19 (28)
Unknown	23 (34)
Hispanic ethnicity	16 (24)
Cardiac diagnosis class	
I	43 (63)
II	12 (18)
III	6 (9)
IV	7 (10)
Genetic disorder present	15 (22)
Cardiac surgery during study period	35 (51)
Cardiac surgery during admission (not during sound measurement period)	49 (72)

need for sedation. Therefore, we utilised a multilevel mixed-effects logistic regression model to assess the relationship between hourly average sound and the use of sedation in the next hour. These models included sedation as the dependent variable, sound in the prior hour as the independent variable, and a random effect for patient to allow for multiple time periods per patient to contribute to the model. The fit of all models was assessed using the appropriate regression diagnostics. All analyses were performed using STATA V17 (College Station, TX), and a significance level of ≤ 0.05 was considered statistically significant.

Results

Patient demographics and characteristics

Sixty-eight patients were enrolled in the study with an average daily census of 17.8 patients. The cohort was predominantly male (60%). There were 5 patients older than 18 years old and 11 neonates (<30 days). About half the patients (51%) had cardiac surgery during the 5-week data collection. The majority of patients had cardiac diagnosis class I, two ventricles with no aortic arch obstruction. Patient demographics and characteristics are shown in Table 2.

Sound levels in the cardiac ICU

Sound levels were monitored in 26 rooms, of which 22 are private and 4 are semi-private (2 rooms each with curtains separating 2 bedspaces). There were 166,228 individual decibel metre recordings. Sound levels were consistently above 45 dB (A) during all times and significantly higher by an average of 1.06 dB (95% CI 0.92–1.20; $p < 0.001$) during the daytime hours than night-time hours. The average daytime sound level was 50.6 dB(A) with a maximum level of 76.9 dB(A). The average night-time sound level was 49.5 dB(A) with a maximum of 69.6 dB(A) (Figure 1). Average noise levels over all days were calculated for each room. Given there were only 4 semi-private rooms, testing for differences was not specifically performed though there was no noticeable difference from the other 22 rooms.

Sedation and physiological parameters

An increase in the average (p-value < 0.001) and maximum (p-value 0.001) sound levels, specifically during the night-time hours, significantly increased the probability of sedation administration the following hour (Figure 2*a*). An increase in average sound by 1 dB(A) during the night increased the odds of sedation by 1.07 times (95% CI 1.02–1.12; $p = 0.008$). An increase in average and maximum sound levels was not associated with delirium scores. An increase in average and maximum sound levels was predictive of an increase in heart rate as well as systolic, diastolic, and mean blood pressure ($p =$ value < 0.001 for all parameters) (see Figure 2*b* and 2*c*).

Discussion

This study evaluating sound levels in a 26-bed paediatric CICU demonstrated that both average and maximum levels exceed the recommended sound levels set by the WHO, EPA, and AAP during both day and night shifts. On average, the sound in the CICU was 5–15 decibels higher than maximum recommendation of 45 decibels by the EPA and AAP. It is important to note that decibels increase on a logarithmic scale; therefore, an increase of 10 dB may not appear to be a large increase in volume; however, 10 dB represents a doubling in sound and is likely to be clinically important. For reference, average values in our CICU were similar to quiet conversation or moderate rainfall, and maximum sounds could be as loud as a freeway traffic, a loud radio, a vacuum cleaner, or even a power motor.[18–20] We also found that an increase in sound was associated with an increase in heart rate and blood pressure as well as an increase in sedation utilisation, suggesting that persistently elevated or suddenly excessive noise may precipitate acute stress in vulnerable patients. Lastly, our study did not find an association between sound levels and delirium as noted by CAP-D scores.

Only one previous study has evaluated noise levels in a paediatric CICU as well as its association with sedation use. To our knowledge, no previous studies have evaluated sound and its effects on physiological parameters in children with heart disease. Guerra et al.[2] evaluated the effect of sound on sedation within the next 5 hours, while we evaluated sound affecting sedation utilisation the next hour and more likely attributable to the acute effects noise can have on intermittent sedation needs. Overall, this demonstrates that increased sound may lead to an increase in stress in very vulnerable paediatric patients, which has not been noted previously.

Our finding that sound levels in the CICU exceed recommended sound levels is consistent with previous studies in many types of ICUs including one study in a paediatric CICU.[2,6–10] Similar to what has been reported in other studies, we observed

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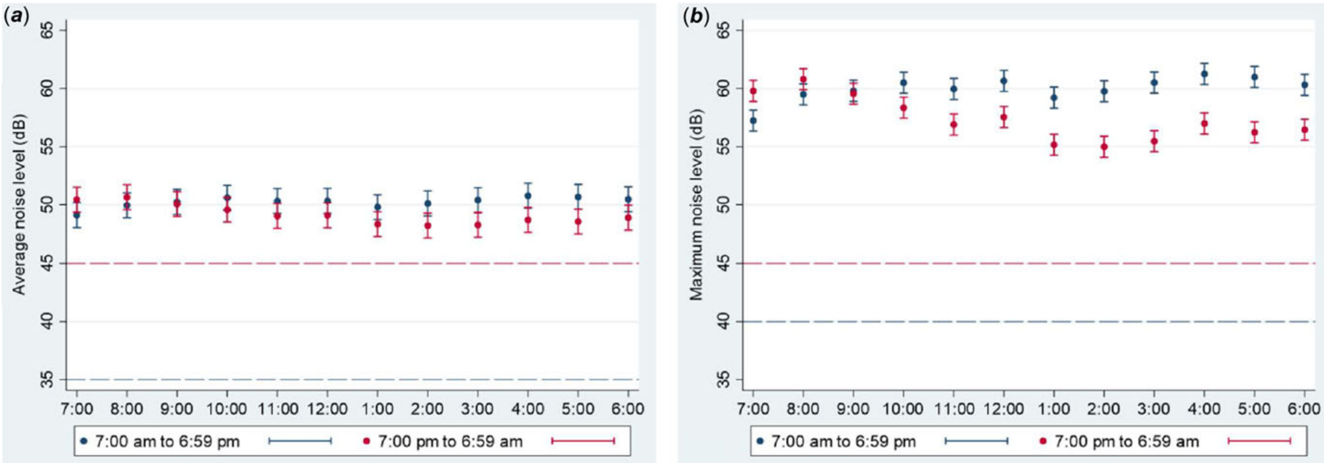

Figure 1. Predicted average (***a***) and maximum (***b***) sound levels by hour. Reference lines for the World Health Organization, American Academy of Pediatrics, and Environmental Protection Agency daytime recommended average sound level (35.0 and 45.0 dB(A)) and recommended maximum sound level (40.0 and 45.0 dB(A)) are shown. dB(A) = A-weighted sound level in decibels.

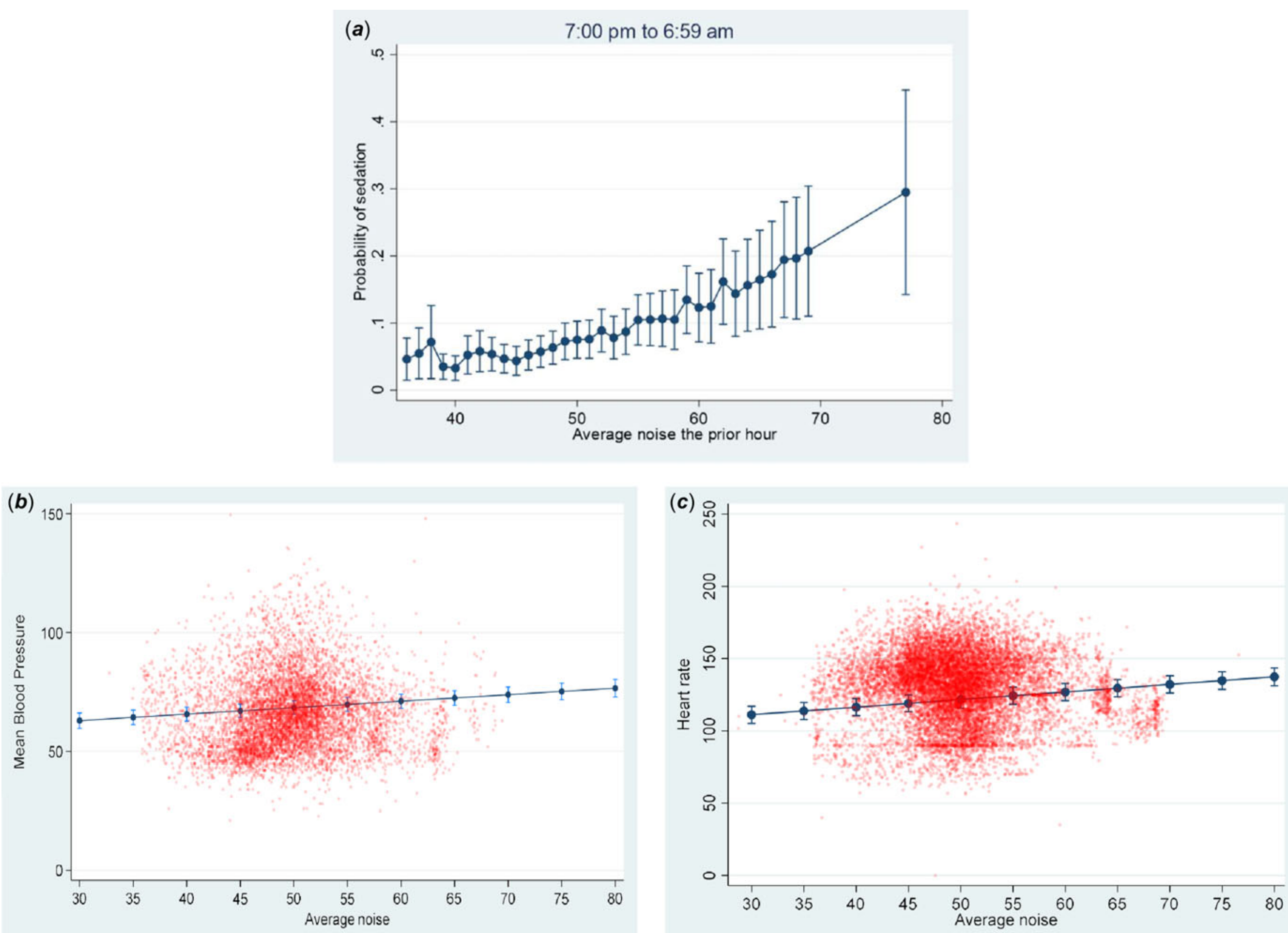

Figure 2. (***a***) Probability of receiving sedation at the shown average noise level during the prior hour over the night-time hours. (***b*** and ***c***) Noise levels as a predictor of mean blood pressure (***b***) and heart rate (***c***) in all patients for all hours of the day and night.

spikes in sound up to a maximum of 76.9 dB(A) during the day, while elevations in sound in many studies have been noted to reach as high as 85 dB(A).[7,9,21] Like Guerra et al., we demonstrated that an increase in noise is associated with an increase in sedation use[2] the following hour suggesting that noise increases discomfort and possibly interrupts sleep. In contrast to our findings,

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Weatherhead et al.[10] evaluated sound levels in children in the paediatric ICU and noted an association between night-time sound levels and elevated CAP-D scores.

A review of the effects of sound on newborns suggests that the effect of sound on heart rate and respiratory rate may vary and can be dependent on age as well as the type of sound heard. Voice and music, for example, may decrease heart rate.[22] A recent study demonstrated that preterm infants exposed to white noise versus the mother's voice had an increase in oxygen saturation during the 20 minutes they were exposed to white noise, but not during exposure to the mother's voice.[23] Elevated sound levels have also been associated with a change in physiological parameters. Cardoso et al.[24] evaluated the exposure to sound on low-weight newborns in the neonatal ICU. They found that the neonates had an increase in heart rate and a decrease in oxygen saturation at higher sound levels. Another study found that increased sound resulted in an increase in heart rate, though this was not associated with a change in blood pressure.[25]

Sedation and/or analgesia may be used when there is pain or discomfort, which may be manifested by increased heart rate or blood pressure, as well as to allow for necessary medical cares, decrease anxiety, and maintain safety with lines and tubes as well as maintain appropriate mechanical ventilation. However, opioids and benzodiazepine exposure have been associated with lower IQ scores along with poorer motor and cognitive outcomes[26,27] and have been negatively associated with neurodevelopmental outcomes at 2 years of age.[28] Oversedation can lead to haemodynamic instability and has been associated with increased time on mechanical ventilation, delirium, and medication tolerance and withdrawal.[28–30] These consequences can lead to an increased length of stay,[31] which in cardiac patients has been associated with overall worse neurodevelopmental and cognitive outcomes.[32–34] These known risks along with our study findings suggest that a decrease in noise, particularly at night-time, may help reduce the sedation burden and ultimately improve neurodevelopmental outcomes in patients in the CICU. Strategies to reduce noise in the ICUs to align with the WHO, EPA, and AAP recommendations may decrease acute stress, improve sleep, and enhance patient recovery.

There were a number of limitations in this study. Most previous studies were done in open pod units, while our ICU has primarily private rooms. Also, many "booms" where bedside monitors are placed are mobile. While we keep our booms in a similar location in every patient room at the head of the bed, not all units will keep mobile booms in this location, thus limiting the generalisability of these results. Our study did not evaluate factors that contributed to the sound in our paediatric CICU. With regard to the device itself, the device we used and others similar to it may have an error range of ± 1.5 dB affecting true decibel levels. However, with this, sound levels still exceeded recommendation, and trends would remain accurate. In our study, we measured heart rate and blood pressure but did not evaluate respiratory rate or oxygen saturation. We noted an increase in heart rate and blood pressure with an increase in maximum and average sound levels though we did not specifically look at sudden spikes in sound. While we evaluated sound levels and their effects on heart rate and blood pressure, there are many reasons a child's heart rate and blood pressure may be elevated in a cardiac ICU, including pain and stranger anxiety with nurses and other medical staff, as well as the presence of vasoactive infusions. Similarly, we found a relationship between sound levels and sedation. In an ICU however, sedation may be given for many reasons, and thus this relationship is not necessarily causal. We also did not evaluate a child's rhythm at the time of tachycardia. Lastly, with regard to delirium, while we collected scores every 12 hours, we did not track the collection of CAP-D scores, and we noted gaps in documentation for many patients. The perceived lack of association may thus be related to the limited number of CAP-D scores we had to correlate with sound levels.

Given previous studies and our study presented here, in the future, it will be imperative to evaluate different types of sound, including voice, music, and white noise, and study its effect on physiological parameters, sedation needs, and neurodevelopmental outcomes in patients with cCHD in the CICU.

Our study is the first to show a relationship between haemodynamic parameters and increasing sedation utilisation associated with increased sound in a paediatric CICU. In addition, our work supports previous studies that have shown that sound levels in different types of ICUs are consistently higher than recommended values. This observed change in physiological parameters suggests a stress response to persistent and sudden loud noises that can result in increased sedation requirements. Given the impact of stress, sleep disruption, and sedative medications, future research should focus on noise reduction in the CICU and its impact on short- and long-term neurodevelopmental outcomes.

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Competing interests. The authors have no disclosure to declare.

Ethical standard. The authors assert that all procedures contributing to this work comply with the ethical standards of the Helsinki Declaration of 1975, as revised in 2008, and have been approved by the institutional committee at Children's National Medical Center.

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