Sound Pressure Levels in 2 Veterinary Intensive Care Units

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Background: Intensive care units (ICUs) in human hospitals are consistently noisy environments with sound levels sufficient to substantially decrease sleep quality. Sound levels in veterinary ICUs have not been studied previously, but environmental sound has been shown to alter activity in healthy dogs.

Hypothesis: Veterinary ICUs, like those in human medicine, will exceed international guidelines for hospital noise.

Animals: NA.

Methods: Prospective, observational study performed consecutively and simultaneously over 4 weeks in 2 veterinary ICUs. Conventional A-weighted sound pressure levels (equivalent continuous level [a reflection of average sound], the sound level that is exceeded 90% of the recording period time [reflective of background noise], and maximum sound levels) were continuously recorded and the number of spikes in sound >80 dBA were manually counted.

Results: Noise levels were comparable to ICUs in human hospitals. The equivalent continuous sound level was higher in ICU1 than in ICU2 at every time point compared, with greatest differences observed on week day (ICU1, 60.1 ± 3.7 dBA; ICU2, 55.9 ± 2.5 dBA, P < .001) and weekend nights (ICU1, 59.9 ± 2.4 dBA; ICU2, 53.4 ± 1.7 dBA, P < .0001) reflecting a 50% difference in loudness. Similar patterns were observed for the maximum and background noise levels. The number of sound spikes was up to 4 times higher in ICU1 (162.3 ± 84.9 spikes) than in ICU2 (40.4 ± 12.2 spikes, P = .001).

Conclusions and Clinical Importance: These findings show that sound in veterinary ICUs is loud enough to potentially disrupt sleep in critically ill veterinary patients.

Key words: Critical care; Hospital soundscape; Noise; Sleep.

Sleep plays an essential role in long-term health in humans and animals. Disruption of normal sleep has been unequivocally demonstrated in human patients within the intensive care unit (ICU) environment over the past 3 decades. Using both objective (polysomnography) and subjective (patient reporting) measures, several studies have demonstrated that sleep disruption in the ICU is a major source of patient anxiety (ranked second after pain), and is characterized by a loss of circadian rhythm, fragmented sleep, and reduction in sleep quality. In addition, short-term sleep disturbances, associated with respiratory, metabolic, immunologic, and psychological dysfunction, lead to increased morbidity and mortality.

Environmental noise, defined as unwanted sound, is a major source of sleep disruption in ICU patients, accounting for up to 53% of arousals (transition to a lighter sleep stage) and awakenings. High environmental noise has been identified within ICUs in several countries with reported average sound pressure levels (A-weighted equivalent continuous sound pressure level [LA_{eq}]) ranging from 50 to 72 dBA. This range far exceeds the US Environmental Protection Agency (EPA) and World Health Organisation (WHO) recommendations (EPA, not greater than LA_{eq} 45 dBA [day time] and 35 dBA [night time]; WHO, LA_{eq} 30–35 dBA [day time] and A-weighted maximum sound pressure level over the recording time [LA_{max}] 40 dBA [night time]). Furthermore, spikes (sudden increases) in sound >75 dBA are not uncommon and are particularly disruptive to sleep, associated with 30–35% of arousals or awakenings.

A common rule of thumb used to interpret dBA levels is that perceived loudness doubles with a 10 dBA increase in sound pressure level (Table 1). Increases in sound levels of approximately 1 dBA (less if the sound pressure level is >50 dBA) are noticeable to the human ear and small increases in sound levels (in the range of 2 dBA) can result in increased arousal and awakenings.
Dogs have a sleep architecture similar to that of humans, and serve as an animal model for narcolepsy. Like humans, dogs have a 24-hour rest-activity cycle with the majority of sleep occurring at night. Auditory stimulation (sound pressure level, sound duration, and frequency) alters the circadian rhythm of dogs. A pilot study of healthy dogs housed in an artificial ICU environment showed significantly higher diurnal and nocturnal activity levels during periods of high auditory and light stimulation, compared with times of lower stimulation.

In ICUs in human hospitals, causes of increased sound levels include patient-associated noise, staff conversation, heating and cooling systems, alarms, and operational noise from life support devices. In veterinary ICUs, a similar soundscape can be expected, with the obvious addition of animal noise.

To the authors’ knowledge, no studies have been published in the veterinary literature reporting noise levels within veterinary ICUs. We hypothesized that veterinary ICUs, similar to those in human hospitals, would exceed WHO and EPA recommendations. We also postulated that day time periods would be louder than night time periods and that week days would be louder than weekends. A prospective observational study was undertaken in 2 referral veterinary ICUs to investigate these hypotheses.

### Materials and Methods

In a prospective, observational, multicenter study, sound levels were continuously and simultaneously recorded over 4 weeks in the ICUs of 2 private veterinary referral centers in Calgary, Alberta (Canada). Each ICU had a different floor plan and infrastructure (Fig 1). The construction of each ICU was similar, with the exception of 5 mm tempered glass forming the top half of 3 walls in ICU1. Construction materials were: ICU1—ceiling (acoustic tile; noise reduction coefficient, 0.55), floor (epoxy coated concrete), walls (gyp-rock over a metal frame) and ICU2—ceiling (acoustic tile; noise reduction coefficient, 0.45), floor (epoxy coated concrete), walls (dry wall over a timber frame).

A calibrated hand-held sound level meter and analyzer was attached by an extension lead to a microphone which was suspended from the ceiling in the center of each ICU at a height of approximately 2.5 m above floor level. Sound data were downloaded using a secure digital (SD) card to a laptop computer at least once daily and analyzed off-line. No changes were made to daily routine or practice in either of the participating ICUs.

Matched data were compared from pooled week day and weekend daytime (0800–1959) and overnight (2000–0759) periods from both centers over the recording period. The sound level meter recorded sound at 1 minute intervals and these data were averaged to give a single value for the day and night time periods. An A-weighted decibel scale was used to facilitate comparison with

### Table 1. Relationship between dB and perceived loudness.

| Sound Pressure Change | dB Change | Increase in Perceived Loudness (%) |
|-----------------------|-----------|-----------------------------------|
| 2-fold                | 3         | 20                                |
| 3-fold                | 5         | 50                                |
| 10-fold               | 10        | 200                               |

The relationship between sound pressure level (dB) and intensity is described by: Sound pressure level (dB) = 20 \log_{10} \left( \frac{p}{p_0} \right), where sound pressure, \( p \) (pascals), is compared to a reference value, \( p_0 \) (20 \times 10^{-6} pascals), the threshold of human hearing. A logarithmic scale is used to facilitate reporting of the wide range in audible sound pressures. Associated changes in perceived loudness are based on reported responses from humans.

Fig. 1. Floor plans of intensive care units (ICU)1 and ICU2. Drawing is not to scale. Mic, microphone suspended 2.5 m above floor level.
existing medical literature. Three parameters were recorded (Fig. 2): LAeq, Lmax, and A-weighted sound pressure level which exceeded 90% of the recording time (LA90). A-weighted equivalent continuous sound pressure level is a standard method for the representation of fluctuating sound levels and is calculated by integrating recorded sound pressure over the duration of the reporting period to generate a single sound pressure level. A-weighted sound pressure level which is exceeded 90% of the recording time represents background noise levels because it is the sound pressure level that is exceeded for 90% of the recording period. A-weighted maximum sound pressure level over the recording time is the maximum sound pressure level during the recording period. Together, these parameters create a soundscape of the environment. In addition, the number of minutes during which sound levels exceeded 80 dBA (visual inspection of Lmax trace) were manually counted over the entire recording period. Patient occupancy of each ICU was recorded at the start and end of each 12 hour recording period.

Statistical Analyses

Nonparametric statistics were applied if data failed (P > .05) a D’Agostino and Pearson Omnibus normality test or if sample size was <30 (ICU occupancy data). A 1-way analysis of variance (ANOVA) with repeated measures was performed if data failed parametric tests. Unless otherwise stated, data are presented as mean ± SD. Statistical analyses were performed with commercial software.

Results

Overall, ICU1 was noisier than ICU2 for all sound pressure level parameters (LAeq, Lmax, LA90) and at all time points compared (Table 2 and Figs 2–6). This observation was made despite higher occupancy levels in ICU2 during the study period (Fig 7).

Sound Pressure Levels

The equivalent continuous sound level (LAeq) was higher in ICU1 than in ICU2 at every time point compared (Fig 3). The mean differences ranged from 2.3 to 6.8 dBA (Table 2) indicating that ICU1 could be as much as 50% louder, such as when comparing weekend nights (ICU1, 59.9 ± 2.4 dBA; ICU2, 53.4 ± 1.7 dBA; P < .0001; Fig 3). The next largest observable mean difference was during week nights (mean difference, 4.1 dBA; P < .001), followed by week days (mean

Table 2. Sound pressure level parameters recorded from intensive care units (ICU)1 and ICU2.

| Parameter | ICU1       | ICU2       | ICU1       | ICU2       | ICU1       | ICU2       | ICU1       | ICU2       |
|-----------|------------|------------|------------|------------|------------|------------|------------|------------|
| LAeq (dBA) | 62.74 ± 2.9†† | 59.42 ± 1.5 | 60.12 ± 3.7 | 55.98 ± 2.5 | 59.15 ± 2.2†† | 56.89 ± 1.6†† | 59.85 ± 2.4 | 53.35 ± 1.7†† |
| Lmax (dBA) | 78.32 ± 3.3 | 74.88 ± 1.7 | 75.52 ± 4.2†† | 71.12 ± 2.4† | 74.67 ± 2.5*** | 72.35 ± 1.6*** | 75.14 ± 2.7††*** | 68.34 ± 1.5††*** |
| LA90 (dBA) | 49.22 ± 1.5†† | 46.97 ± 1.1†† | 47.97 ± 1.5††† | 45.11 ± 2.1 | 47.23 ± 1.7††*** | 44.91 ± 1.3†† | 48.15 ± 1.6††*** | 42.81 ± 1.4 |

For comparisons within each intensive care unit (week days versus week nights, weekend days versus weekend nights, week days versus weekend days and week nights versus weekend nights), matching symbols illustrate significant differences with the number of symbols representing the level of significance: †P < .013, ††P < .01, †††P < .001, ***P < .001. Results of statistical comparisons between each ICU are presented in the text. Values are mean ± SD.
Differences in LA eq within ICU1 and ICU2 were approximately 3 dBA between week (62.7 ± 2.9 dBA) and weekend days (59.2 ± 2.2 dBA; P < .01; ICU1), and weekend days (56.9 ± 1.6 dBA) and nights (53.4 ± 1.7; P < .001; ICU2; Table 2). These results approximate a difference in loudness of approximately 20% (Table 1).

This pattern of differences persisted for both the maximum sound levels (LA max) and background noise levels (LA eq) during both week and weekend time points (Table 2 and Figs 4, 5).

The largest difference in LA max between ICU1 and ICU2 was recorded during weekend nights (ICU1, 75.1 ± 2.7 dBA; ICU2, 68.3 ± 1.5 dBA; P < .0001; Fig 4) with a mean difference of nearly 7 dBA, comparable to a difference in loudness in excess of 50% between ICUs. For the other time periods compared, mean differences were in the range of 3 dBA (Fig 5). In ICU1, LA max changed minimally between week and weekend nights, and between weekend days and nights (Table 2). The same comparisons in ICU2 showed a larger difference between weekend days and nights, with a mean difference of 4 dBA.

A similar pattern was observed for LA eq. As with LA max and LA eq, the largest difference between the ICUs occurred on weekend nights (ICU1, 48.2 ± 1.6 dBA; ICU2, 42.8 ± 1.4 dBA; P < .0001; Fig 5) with background noise in ICU1 being 50% louder than in ICU2. At other time periods, the mean differences ranged from 2 to 3 dBA (Fig 5). Within each ICU, LA eq did not differ by more than 2 dBA among the compared time points, showing little variation in the levels of background noise regardless of the time of day or time of week (Table 2).

**Sound Spikes**

The number of sounds spikes >80 dBA in ICU1 was considerably higher than in ICU2 during the majority
of the compared time points (Fig 6). The largest differences were observed during week nights, when the number of observed spikes was double in ICU1 (188.4 ± 119.0) compared with ICU2 (92.4 ± 47.9; \( P = .003 \)) and during weekend nights, when the number of observed spikes was 4-fold higher in ICU1 (162.3 ± 84.9) compared with ICU2 (40.4 ± 12.2; \( P = .001 \)). A smaller difference in spike number was observed during week days (ICU1, 240.5 ± 126.3; ICU2, 168.2 ± 65.2; \( P = .003 \)) and no difference was observed during weekend days (ICU1, 152.9 ± 86.8; ICU2, 109.3 ± 49.1; \( P = .24 \)). Examination of spike frequency within each ICU showed that the number of spikes did not differ between days in ICU1 (week days versus week nights, \( P = .23 \); weekend days versus weekend nights, \( P = .63 \); week days versus weekend days, \( P = .18 \); week nights versus weekend nights, \( P = .65 \)). In contrast, ICU2 had the fewest sound spikes during weekend night time periods (week nights versus weekend nights, \( P = .004 \); weekend days versus weekend nights, \( P = .004 \)) with approximately half as many sound spikes observed. There were no differences between week days and week nights (\( P = .34 \)) and week days and weekend days (\( P = .37 \)).

**ICU Occupancy**

Occupancy rates differed between ICUs during week days (ICU1, 6 [3,11] patients; ICU2 9 [4,13] patients; \( P = .003 \)) and week nights (ICU1, 6 [3,11] patients; ICU2, 9 [4,13] patients; \( P = .003 \); Fig 7). There were no significant differences at other times (weekend days and nights, ICU1, 7.5 [4,9] patients; ICU2 6.5 [4,12]; \( P = .8221 \)).

**Discussion**

The crucial findings of this study were: (1) a marked difference in sound levels between the 2 veterinary ICUs studied, with ICU1 being consistently noisier than ICU2 despite lower occupancy rates; (2) a significantly higher number of sound spikes >80 dBA in
which can be inflicted either on sick or well. Sleep necessary noise, then, is the most cruel absence of care.

Florence Nightingale documented concerns regarding the impact of noise on human patients in 1859: “Unnecessary noise, then, is the most cruel absence of care which can be inflicted either on sick or well.” Sleep disruption (largely as a result of noise) however, has been consistently documented in ICUs in human hospitals, along with a progressive annual increase in noise levels. The causal relationship between noise and sleep has been identified using both objective (polysomnography) and subjective (patient self-reports) measures.

Sleep disruption in the ICU is multifactorial, with extrinsic (e.g., light, treatment interventions, temperature) and intrinsic (e.g., patient factors: pain, anxiety, disease) sources. Noise is a major cause of sleep disruption in the ICU, responsible for 17–53% of awakenings and arousals depending on the patient population and reporting methods.

Similar studies in the human literature (using continuous sound recording for ≥24 h), found mean equivalent sound levels (LAeq) of 50–72 dBA in ICU environments. These findings are consistent with our data, confirming that ICUs in both human and veterinary medicine exceed current EPA and WHO recommendations.

Stress in hospitalized dogs has been documented using physiological, behavioral, and biochemical measurements. Although noise level recommendations for veterinary ICUs do not exist, it has been shown that the behavior of dogs is affected by environmental noise, both within a simulated ICU environment and in a rescue shelter. In addition, noise within the ranges typically recorded in ICUs can have detrimental effects on staff performance and stress.

Our data show that even background sound levels (LAeq) exceeded WHO and EPA recommendations for LAeq during both day and night times at the majority of time points assessed. In comparison to the higher EPA guidelines, LAeq levels were regularly 2–4 dBA higher in both ICUs during the day and 7–13 dBA higher at night, corresponding to 20–200% increases in loudness.

Without spectral analysis it is not possible to identify specific causes of background noise, but common contributors are air conditioning systems, conversation, life-support devices, and cleaning equipment. Night time LAmax levels in both ICUs were consistently 30–35 dBA above the WHO recommendation of 40 dBA, 8 times louder than recommended.

Few studies in human hospitals have reported LAmax and LAeq parameters. Similar to our findings, these studies have reported high levels for these parameters, including LAmax >50 dBA for 90% of the recording period (continuous recording over 5 wk days), and LAeq, LAmax, LA90, and LAeq of 47, 56, and 90 dBA, respectively, over a 6-month period.

The difference in sound levels between the 2 ICUs studied is similar to the documented variability among ICUs in human hospitals. Because small differences in dBA level (as little as 2 dBA) can result in sleep disruption (arousals and awakenings), these inter-ICU differences are clinically relevant.

The existence of diurnal variation in LAeq in ICUs in human hospitals is unclear. Differences in 3–4 dBA are reported frequently but not all studies performed statistical comparisons. In our data, a significant difference was observed only in ICU2 (weekend day versus weekend night).

Evidence from studies in human medicine suggests that both the number of sound spikes (>70–80 dBA) and the overall noise level contribute to arousal and awakening from sleep. Few studies have reported spectral frequency in the hospital environment, with limited investigation on the relationship between spectral frequency and sleep disturbance, but low frequency noise is a reported cause of sleep disturbance.

A study of ICU patients, 31% of arousals and awakenings were caused by sound spikes exceeding 75 dBA. A similar arousal level (35%) has been identified in healthy volunteers exposed to short (0.5 s) sound spikes (85 dBA).

The number of spikes occurring per hour varies widely among studies, ranging from 10 to 460 during the day and from 2 to 147 at night. Differences in classification of day and night time periods and counting methods account for some of the variation. The numbers of spikes observed in our study fell within ranges reported for ICUs in human hospitals. Evidently, the number of sound spikes >80 dBA shows diurnal variation, higher during the day than at night. Data collected from ICU2 showed a similar diurnal pattern, with significantly fewer sound spikes on weekend nights, but week days and nights did not differ. In contrast, ICU1 did not exhibit diurnal variation and had consistently more sound spikes than ICU2.
Whenever the sources of sound spikes have been identified, many have been associated with modifiable causes. In one report, television and human conversation accounted for 50% of sound spikes >80 dBA, and in another report the highest frequency of spikes >80 dBA occurred during staff shift changeover.

The observed differences in noise levels between ICUs in our study were not associated with differences in patient occupancy. It is likely, therefore, that ICU location and dimensions contributed to the observed differences.

The ICU1 has a smaller floor area than ICU2, resulting in a higher density of patients (and staff). Building materials at each location were similar, consisting primarily of hard surfaces with no specific noise reduction material. In addition, ICU1 is located at the center of the hospital and can function as a thoroughfare for staff, whereas ICU2 is located at the periphery of the building and does not form a shortcut to other areas. Although ICU1 has the potential to form a more enclosed space with the presence of sliding doors (versus the sliding windows of ICU2, which are kept open. Together these factors are likely to have resulted in increased reverberation time (time for sound to decay) in ICU1. The presence of staff in the ICUs was not recorded and no steps were taken to modify staff behavior. Although it is possible that staff behavior differed between ICUs, it is equally likely that differences in ICU size (as well as being more noisy than ICU2) ICU1 was consistently more noisy.

The A-weighted dB scale was employed to facilitate comparison with the existing human and veterinary literature. The few studies that examined noise and behavior in veterinary ICU dogs have used the A-weighted scale. This scale approximates the response of the human ear to sound frequencies, eliminating lower and higher frequency sounds not audible to humans. Although the range of frequencies audible to dogs (approximately 67–45 kHz) differs from those detectable by the human ear (approximately 20–20 kHz), the A-weighted decibel scale spans most frequencies encountered in the hospital environment. In addition, higher frequencies attenuate more rapidly and hence are potentially less detrimental. Therefore, low frequency sounds in particular may adversely affect sleep and recovery of dogs in a veterinary ICU.

In conclusion, sound pressure levels in the 2 veterinary ICUs studied were similar to those previously reported in ICUs in human hospitals, exceeding international guidelines for hospital noise. Unexpected significant differences in noise levels and sound spikes >80 dBA were observed between the 2 veterinary ICUs. In general, fewer significant differences in sound levels were observed in ICU1 than in ICU2, indicating that (as well as being more noisy than ICU2) ICU1 was consistently more noisy.

Similar to ICUs in human hospitals, the noisier ICU did not display diurnal variation in noise levels. The observed differences between veterinary ICU noise may result from differences in infrastructure between centers. The effects of environmental noise on sleep in veterinary patients is unclear, but there is some documented evidence of its effects on activity and behavior. Additional research is required to understand noise perception in dogs and its physiological impact on sleep quality and behavior, as well as the current limitations of noise reduction strategies in a veterinary ICU. To facilitate these studies, accurate identification of arousal states is essential, necessitating the use of polysomnography.
Footnotes

* Sound level meter Type 2250, fast response time (125 ms), reference 20 μPa, 16.6–140 dB(A), (Brul and Kjær, Nærum, Denmark, DK-2850)

* Prepolarized free-field condenser microphone, Type 4189, with 65 mm windscreen (Brul and Kjær, Nærum, Denmark, DK-2850)

* BZ 5503 Utility Software for Hand Held Analyzers (Brul and Kjær, Nærum, Denmark, DK-2850)

* Graphpad Prism version 6.0c (GraphPad Software Inc., La Jolla, USA, 92037)

* IBM SPSS Statistics version 20 (IBM Canada Ltd., Markham, ON, Canada, L3R 9Z7)

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Off-label Antimicrobial Declaration: Authors declare no off-label use of antimicrobials.

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