



Noise exposure patterns and health risk assessment among nurses in a Chinese paediatric intensive care unit

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Starting from the hypothesis that occupational noise exposure among paediatric intensive care unit (PICU) nurses at our hospital exceeds the recommended health guidelines and is associated with adverse non-auditory health outcomes, the aim of this cross-sectional study was to quantify personal noise exposure patterns and assess correlations with perceived stress, sleep quality, and hearing handicap in a convenience sample of 60 registered nurses wearing personal noise dosimeters over a 12-hour shift. The participants also completed a survey including the 10-item Perceived Stress Scale (PSS-10), the Pittsburgh Sleep Quality Index (PSQI), and the Hearing Handicap Inventory for Adults (HHIA). The main finding was that the cohort's mean 8-hour time-weighted average ($L_{Aeq,8h}$) exposure to noise was 78.5 ± 4.2 dBA, and that all measured shifts exceeded the World Health Organization (WHO) hospital guidelines. Peak noise levels (L_{Cpeak}) frequently surpassed 115 dBC. Most nurses ($N=39$) were classified as "poor sleepers" ($PSQI > 5$). Significant positive correlations were found between $L_{Aeq,8h}$ and PSS-10 scores ($r=0.45$, $p<0.001$) and global PSQI scores ($r=0.52$, $p<0.001$). For every 1 dBA increase in $L_{Aeq,8h}$, the odds of being a poor sleeper increased by 25 % (odds ratio 1.25; 95 % CI: 1.05–1.48). Even though this is a "snapshot study", it clearly indicates that PICU noise bears significant occupational risks of high stress and poor sleep, which warrants immediate intervention. Further research should focus on longitudinal measurements to get a better idea of noise exposure in healthcare environments, PICUs in particular.

KEY WORDS: HHIA; poor sleep; PSQI; PSS-10; stress

In the context of hospital patient environments, paediatric intensive care units (PICUs) are somewhat unique and highly complex owing to the convergence of highly advanced, life-sustaining technology, critical patient states, and intensive, high-frequency activities of a large multidisciplinary team required for their care (1). Such a density of technology and human activity inherently creates a "sound intensive" environment (2). The acoustic landscape of a modern PICU is not one of quiet healing but is instead dominated by a near-constant barrage of noise from equipment such as mechanical ventilators, infusion pumps, and cardiovascular monitors, loud staff conversations, bedside rounds, and handovers, and a complex array of alarm signals designed to alert staff to physiological changes or equipment issues (3). This acoustic reality reflects an intrinsic conflict between the operational requirements of delivering critical care and the environmental conditions necessary to promote rest and healing.

An extensive body of literature has firmly established that noise levels within hospital settings, and most acutely in intensive care units (ICUs), consistently and significantly exceed international health guidelines (4, 5), most notably the World Health Organization (WHO) Guidelines for Community Noise which specifically refer

to the protection of vulnerable hospital patients (6). These guidelines advise that average sound levels in hospital treatment rooms should not exceed 35 dBA L_{Aeq} , with night-time peaks (L_{Amax}) not exceeding 40 dBA. Empirical measurements in PICUs, however, reveal a drastically different reality, with average peaks often exceeding 80 dBA and frequent, disruptive peak noise levels reaching well above 100 dBA (7). The deleterious effects of such cacophonous environments on the paediatric patients are well-documented and include fragmented sleep, sleep deprivation, an increased risk of delirium, heightened medical anxiety, and altered pain perception (8, 9).

However, hospital noise research has given much less attention to the nursing staff as the "primary, continuous occupants of the ICU soundscape" (6) and therefore subject to chronic, full-shift occupational noise exposure as a major source of stress. Namely, besides the well-documented auditory risks of prolonged noise exposure, such as hearing loss (10), a growing body of evidence now links occupational noise to a wide constellation of non-auditory health effects, including adverse cardiovascular outcomes, hypertension, chronic fatigue, and persistent headaches.

The stakes are even higher in ICUs, as recent studies directly link ICU noise exposure to agitation, irritability, fatigue, stress, and symptoms consistent with professional burnout among the nursing staff as well as a significant association between high noise exposure and a lower professional quality of life (11, 12).

Despite this established link, a significant gap persists in the literature. Many studies assessing the impact of noise on nurse well-being have relied on self-reported exposure data or on data from stationary, environmental sound level meters (13). While useful, these methods fail to capture the true, personal noise dose experienced by a highly mobile nurse, who moves between loud patient bedsides and relatively quieter charting stations. Conversely, many traditional occupational hygiene studies have accurately measured personal dosimetry but have failed to connect these objective exposure metrics to validated health outcomes. Therefore, the aim of this study was to objectively characterise personal noise exposure patterns among PICU nurses and to quantify the association between noise levels and self-perceived stress, sleep quality, and hearing loss.

PARTICIPANTS AND METHODS

To characterise occupational noise exposure at a single point in time and to assess associated health risks we adopted cross-sectional observational design, as it allows simultaneous measurement of exposure and outcome variables without experimental intervention. The study took place in a 30-bed PICU of a large, urban, university hospital. The unit consists of 18 single-bed patient rooms and three four-bed rooms. All data were collected from 1 January to 31 March 2025.

In the same PICU we recruited a convenience sample of 60 nurses who met the following inclusion criteria: 1) full-time employment status, defined as working 5 or more hours per week; 2) a minimum of one year of clinical experience working in this specific PICU to exclude confounding effects of new-employee orientation stress; and 3) currently working a 12-hour rotating day and night shift schedule. The exclusion criteria were 1) self-reported hearing disorder (diagnosed or self-perceived); and 2) holding a primary administrative or managerial role (e.g., charge nurse, unit manager) with limited direct patient care responsibilities. All nurses gave their informed consent to participate in this study, which was approved by the hospital ethics committee (approval No. 20241207). The study was conducted in accordance with the principles of the Declaration of Helsinki.

Personal noise exposure was measured with the Svantek SV 104A personal noise dosimeter (Svantek, Warsaw, Poland) fully compliant with the IEC 61252 and ANSI/ASA S1.25-1991 (R2020) specifications for personal noise dosimeters. The instrument utilises a robust ST 104C MEMS microphone, which has a stated frequency range of 20 Hz to 10 kHz. The dosimeter's linear operating range is 55–140.1 dBA, making it suitable for capturing both the ambient

baseline and the high-impulse peaks expected in a PICU environment.

Each of the 60 participating nurses wore this dosimeter for one complete 12-hour shift. 30 nurses were monitored over a day shift (07:00–19:00 h) and 30 over a night shift (19:00–07:00). Each dosimeter was field-calibrated immediately before wearing and was verified again immediately after the 12-hour shift to ensure no calibration drift occurred. The dosimeter was attached to the nurse's uniform on the shoulder, so that the microphone would be placed within the hearing zone, as recommended for occupational monitoring (14). The dosimeter settings were configured to align with the recommendations of the National Institute for Occupational Safety and Health (NIOSH): a 3-dB exchange rate, A-weighting for time-weighted averages, and a slow time constant (15). The key metrics captured for analysis were the A-weighted equivalent continuous sound level over the full 12-hour shift ($L_{Aeq,12h}$), the C-weighted peak sound level (L_{Cpeak}) to assess impulse noise, and detailed 1-second logged time-history data to analyse noise patterns. All noise dosimetry data were downloaded using the manufacturer's software. The primary exposure metric, the 12-hour L_{Aeq} was normalised to an 8-hour-weighted average ($L_{Aeq,8h}$) for each nurse. This normalisation is a standard procedure that allows for direct comparison of the exposure dose to the 8-hour NIOSH Recommended Exposure Limit (REL) of 85 dBA (15).

To complement personal dosimetry and characterise the acoustic environment, we also measured environmental noise with a sound level meter (TES-1358C sound analyser, TCH Instrument Co., Ltd., Zhengzhou, China) capable of analysing real-time 1/3 octave band frequency, which is necessary for identifying the spectral content of noise sources (16). It was used for stationary 15-minute measurements during peak activity (11:00 h) and the night “quiet time” (03:00 h) at two representative, high-traffic locations: the central nursing station and an unoccupied patient bedside (with all standard monitoring equipment active). These measurements served to identify dominant ambient noise frequencies and to help pinpoint primary noise sources.

Immediately following the completion of their monitored 12-hour shift, each nurse was asked to complete a survey consisting of sociodemographic and occupational data, including age, gender, marital status, highest nursing qualification, total years in nursing, and total years of experience at the PICU. The remainder of the survey package consisted of three validated psychometric instruments to assess the primary health outcomes of interest.

Perceived stress was measured using the 10-item Perceived Stress Scale (PSS-10), a widely adopted instrument that assesses self-reported stress over the previous month. It has demonstrated strong concurrent validity with related measures of anxiety and depression (17).

Sleep quality was measured using the 19-item Pittsburgh Sleep Quality Index (PSQI), which assesses self-reported sleep quality and disturbances over one month (18). It yields a total score ranging from 0 to 21, which is the sum of seven domains: subjective sleep

quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleeping medication, and daytime dysfunction. A total PSQI score >5 is the standard clinical threshold to distinguish “poor” from “good” sleepers (≤ 5). The PSQI’s utility in assessing sleep in occupational health and shift-work populations is well-established (19).

Finally, self-perceived hearing handicap was measured using the 25-item Hearing Handicap Inventory for Adults (HHIA) (20), whose updated version is designed to measure self-perceived emotional (12 items) and social/situational (13 items) consequences of hearing difficulties (21). Responses are scored for each item, where “Yes” scores 4 points, “Sometimes” 2 points, and “No” 0 points, yielding a total score ranging from 0 (no handicap) to 100 (total handicap).

Statistical analysis

All statistical analyses were run on SPSS version 28.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics (means, standard deviations, medians, and ranges) were calculated for all noise metrics ($L_{Aeq,8h}$, L_{Cpeak}) and for the total scores of the health outcome measures (PSS-10, PSQI, HHIA). An independent-samples *t*-test was used to compare mean $L_{Aeq,8h}$ values between the day shift and night shift groups. Pearson correlation coefficients (*r*) were calculated to assess the strength and direction of linear relationships between the primary continuous exposure variable ($L_{Aeq,8h}$) and the primary continuous health outcome scores (PSS-10, PSQI, HHIA) (22) as well as potential confounders (age, years in PICU). Finally, we ran a multivariate logistic regression analysis (23) to model the odds of being a “poor sleeper” (a binary outcome defined as PSQI >5) as a function of $L_{Aeq,8h}$. This model was used to isolate the effect of noise by controlling for potential confounders identified from the literature, including age, years in PICU, and PSS-10 score. A *p*-value <0.05 was considered statistically significant for all analyses.

RESULTS

Participant characteristics

Table 1 shows the sociodemographic and occupational characteristics of the 60 participating PICU nurses. The cohort was predominantly female ($N=53$), with a mean age of 34.2 ± 8.1 years. This sample represents an experienced and stable workforce, with an average of 10.1 ± 7.3 years in nursing and a mean of 7.4 ± 4.5 years in the noise-exposed PICU. The staff was also highly educated, with 46 of them holding a Bachelor of Science in Nursing (BScN) or equivalent degree. These demographics are critical, as they suggest the health outcomes observed are unlikely to be confounded by the acute stress of inexperience or acclimation to a new role, but rather reflect a chronic condition of long-tenured, professional critical care providers.

The sample was perfectly balanced between nurses monitored on the day shift ($N=30$) and those monitored on the night shift ($N=30$).

Objective noise exposure patterns

Table 2 shows the results of the full-shift personal noise dosimetry for the 60 12-hour shifts and that the mean $L_{Aeq,8h}$ for the entire cohort was 78.5 ± 4.2 dBA ($SD=4.2$). These values demonstrate significant variability, ranging from 69.1 dBA to 86.2 dBA, which highlights the central conclusion that the PICU environment in our study is within a “regulatory grey area” in terms of noise exposure. From a traditional industrial hygiene perspective focused purely on hearing conservation, our PICU would be considered compliant, but this “compliance” masks a significant underlying health hazard. A critical finding is that all 60 personal dosimeter measurements across the shifts drastically exceeded the

Table 1 Sociodemographic and occupational characteristics of the PICU nurse cohort ($N=60$)

Demographic and job-related characteristics		N (%) or Mean $\pm$ SD
Age (years)		34.2 $\pm$ 8.1
Gender	Female	53 (88.3 %)
	Male	7 (11.7 %)
Marital status	Married	32 (53.3 %)
	Single/other	28 (46.7 %)
Highest nursing qualification	Secondary nursing school	7 (11.7 %)
	BScN/BN	46 (76.7 %)
	Master’s degree	7 (11.7 %)
Years in nursing		10.1 $\pm$ 7.3
Years in PICU		7.4 $\pm$ 4.5
Monitored shift	Day shift (07:00–19:00)	30 (50.0 %)
	Night shift (19:00–07:00)	30 (50.0 %)

SD – standard deviation; PICU – paediatric intensive care unit

35 dBA L_{Aeq} guideline recommended by the WHO for patient treatment areas (5). While this guideline is patient-focused, its premise is equally applicable to the staff who occupy the space full-time. Furthermore, the environment was characterised by high-intensity impulse noise. The mean peak sound level (L_{Cpeak}) was 116.8 ± 5.1 dBC, with the maximum recorded peak of 130.1 dBC. These sudden, loud events, while below the 140 dBC occupational impulse limit, are known to be highly disruptive and a potent activator of the body's acute stress response.

Noise sources and characteristics

The detailed 12-hour time-history analysis of logged dosimetry data (Figure 1) provides an insight into the pattern of noise exposure, which is often as important as the cumulative average. It clearly illustrates that individual noise exposure was not steady but consisted of a fluctuating L_{Aeq} baseline of approximately 65–70 dBA, with constant peaks of rapid-onset acoustic events that frequently exceeded 85–90 dBA. When cross-referenced with nurse activity logs, these peaks were confirmed to correspond to critical alarm signals, staff handovers at 07:00 and 19:00, and noise-intensive bedside procedures. This pattern of intermittent, unpredictable, and meaningful noise (i.e., alarms that cannot be ignored) is well-documented as being more disruptive and stress-inducing than a constant, predictable noise level, even if the total energy (L_{Aeq}) is the same (24).

When the noise exposure data were stratified by shift, we found a statistically significant difference between the mean $L_{Aeq,8h}$ for day and night shifts (80.1 ± 3.5 dBA vs 76.9 ± 4.1 dBA; $p < 0.001$). This finding is expected, given the higher level of activity, presence of ancillary staff, and patient procedures during daytime hours. However, the night shift noise levels are still exceptionally high and remain well above the WHO-recommended nighttime guideline of 40 dBA L_{Amax} . This debunks the common assumption that night shifts offer a period of acoustic restoration and suggests that nurses are exposed to a physiologically relevant noise burden 24 hours a day.

Table 3 shows the specific sources of noise exposure and associated peak levels identified by the environmental acoustic survey. High-priority alarms from mechanical ventilators (mean $L_{Cpeak} = 112.4$ dBC) and IV pumps (mean $L_{Cpeak} = 105.8$ dBC) were the loudest sources of staff-generated noise, including phone ringing at the central station (94.2 dBC) and group conversations (85.0 dBC), were also significant contributors. These data are valuable as they provide specific, actionable targets for engineering and administrative noise control interventions.

The 1/3 octave band frequency analysis, presented in Figure 3, reveals the acoustic signature of the PICU. This analysis is crucial for understanding why the noise is so disruptive. Both the central nurse station (Figure 3A) and the patient bedside (Figure 3B) exhibit what is known as a “hissy” acoustic profile (25), defined by a concentration of dominant sound energy in the mid-to-high

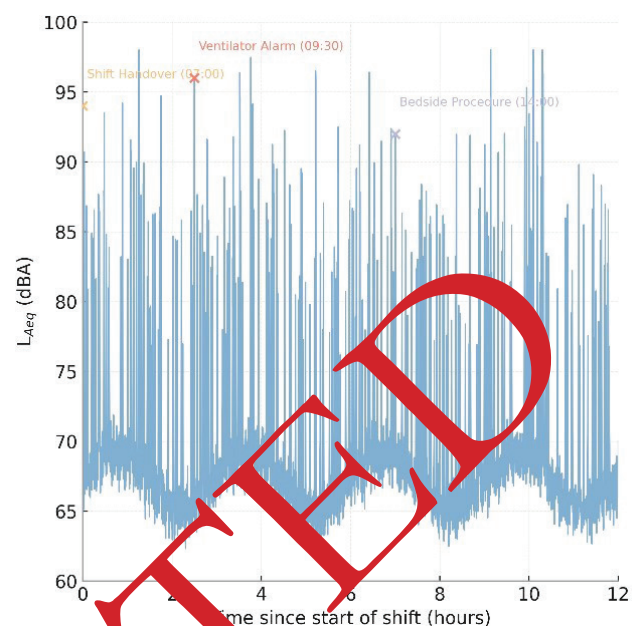


Figure 1 Time-history plot of noise exposure (L_{Aeq}) for a representative 12-hour PICU nurse shift

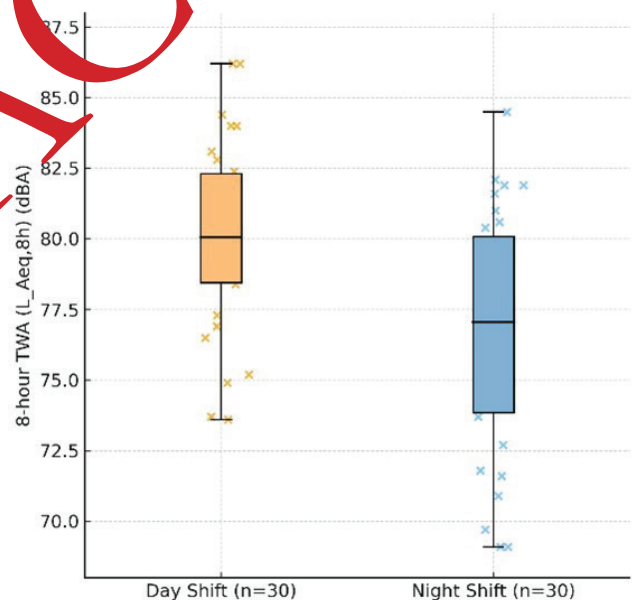


Figure 2 Distribution of 8-hour TWA noise exposure ($L_{Aeq,8h}$) by shift type (day vs night); TWA – time-weighted average

frequencies, specifically from 1,000 Hz to 8,000 Hz. This spectral content is consistent with the electronic alarms identified in Table 3 and the persistent hum of electronic equipment fans. The human ear is particularly sensitive to this frequency range, and high-frequency noise is widely considered more annoying and more disruptive to concentration and communication than lower-frequency noise of equal intensity (26).

Table 2 Descriptive statistics of full-shift noise-exposure measurements with personal dosimeters (N=60)

Noise exposure	Mean±SD	Median	Min	Max	Dosimetry measurements > NIOSH REL (85 dBA/8 h)	Dosimetry measurements > WHO (35 dBA)
L_{Aeq} (12-hr) (dBA)	77.0±4.2	77.1	67.6	84.7	N/A	60
$L_{Aeq,8h}$ (dBA)	78.5±4.2	78.6	69.1	86.2	2	60
L_{Cpeak} (dBC)	116.8±5.1	115.9	107.2	130.1	0 (>140 dBC)	60 (>40 dBA L_{Amax})

SD – standard deviation

Table 3 Primary identified noise sources and associated peak levels (L_{Cpeak})

Noise source	Location	Mean L_{Cpeak} (dBC)	SD
Mechanical ventilator alarm (high priority)	Bedside	112.4±3.1	
IV pump alarm	Bedside	105.8±4.5	
Phone ringing (central station)	Nurse station	99.0±3.2	
Staff conversation (group, 1 m)	Nurse station	85.0±5.7	
Overhead paging system	Unit-wide	88.6±3.9	
Equipment Cleaning (metal-on-metal)	Utility Room	96.1±6.4	

SD – standard deviation

Table 4 Descriptive statistics for health outcome variables (N=60)

Health outcome variable	Scale	Mean ± SD	Median	Min	Max	Prevalence of poor outcome
Perceived stress (PSS-10)	0–40	19.8±6.1	20.5	8	32	N/A
Sleep quality (PSQI)	0–21	8.4±3.3	8.0		17	39 of 60 (PSQI>5)
Hearing handicap (HHIA)	0–100	12.4±10.1	10.0	0	44	7 of 60 (Score>16)

SD – standard deviation

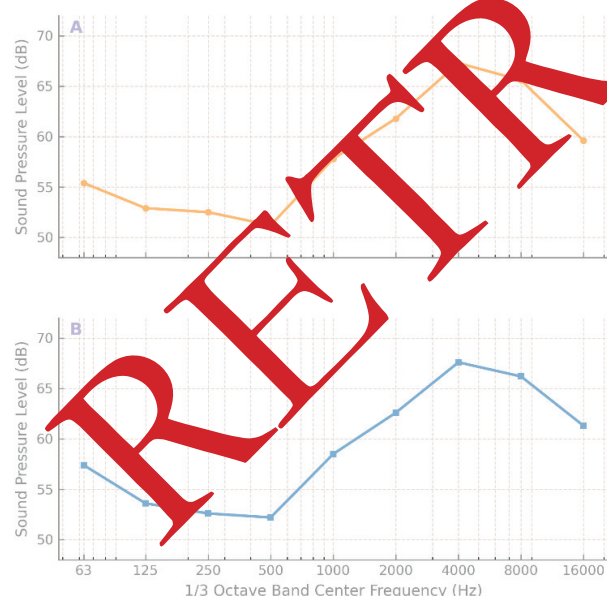


Figure 3 Acoustic characterisation of the PICU environment; A) 1/3 octave band frequency analysis at central nurse station; B) 1/3 octave band frequency analysis at patient bedside

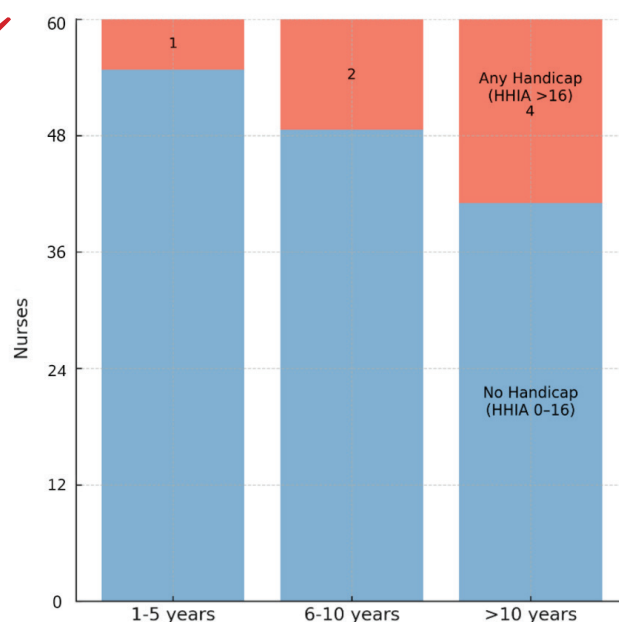


Figure 4 Prevalence of hearing handicap (HHIA categories) by years of work at the PICU

Health risk assessment outcomes

The health outcomes self-reported by the 60 participant nurses and summarised in Table 4 reveal a significant and widespread health burden. Mean PSS-10 score was 19.8 ± 6.1 , which indicates moderate perceived stress.

The most striking finding, however, is related to sleep quality. Mean global PSQI score for the cohort was 8.4 ± 3.3 , which significantly exceeds the clinical cutoff of 5 designating “poor sleep quality”. In total, 39 of the 60 nurses assessed themselves as poor sleepers. A prevalence this high is alarming.

In contrast, mean HHIA total score was 12.4 ± 10.1 , which is within the range (of 0–16) interpreted as “no hearing handicap”. However, seven nurses had the HHIA score above the threshold for complaints of impaired hearing of >16 according to Newman et al. (20). Further analysis revealed a concerning relationship between years at work and hearing complaints (Figure 4), as nurses working for longer at the PICU complained more of hearing impairments. While these data are cross-sectional, this trend strongly points to a cumulative effect and implies that chronic exposure to noise levels below the NIOSH REL of 85 dBA but far above the WHO health guidelines may still be contributing to an insidious, long-term decline in auditory health that only becomes self-perceived after many years of exposure.

Figure 5 shows another clear dose-response relationship between poor sleep prevalence and noise exposure measurements. The cohort was dichotomised based on the median $L_{Aeq,8h}$ (78.6 dBA). In the lower exposure group ($L_{Aeq,8h} < 78.6$ dBA), 14 nurses were classified as poor sleepers, while this prevalence soared to 25 nurses in the higher exposure group ($L_{Aeq,8h} \geq 78.6$ dBA). This difference is statistically significant ($\chi^2=9.88$; $p=0.002$) and provides strong

evidence of the association between objective noise exposure and subjective sleep quality assessment.

Correlations between noise exposure and outcome variables

Table 5 shows the correlations between the six variables of interest in our study. The Pearson analysis confirms statistically significant correlations between $L_{Aeq,8h}$ and mean PSS-10 score ($r=0.450$; $p<0.001$) and mean total PSQI score ($r=0.521$; $p<0.001$). A very strong correlation between the PSS-10 and PSQI scores ($r=0.610$; $p<0.01$) suggests a deleterious and synergistic interrelationship between perceived stress and sleep disturbance. Another significant but weaker positive correlation is the one between $L_{Aeq,8h}$ and the mean HHIA score ($r=0.279$; $p=0.031$). As expected, the mean HHIA score does not significantly correlate with stress or sleep but strongly correlates with age ($r=0.412$, $p<0.01$) and years in the PICU ($r=0.445$, $p<0.01$), reinforcing the finding that hearing handicap is a function of cumulative, long-term exposure (Figure 4) and aging.

Figure 6 summarises the critical correlations between $L_{Aeq,8h}$ and the three target health outcomes. Both A and B plots for correlations between $L_{Aeq,8h}$ and stress or sleep clearly evidence the positive slope of the linear regression line, visually confirming the statistical finding that as objective noise exposure increases so do perceived stress and poor sleep. Plot 6C shows a similar but visibly weaker positive trend between noise exposure and hearing complaints, consistent with the lower correlation coefficient reported in Table 5.

To further parse these complex relationships and isolate the impact of noise we built a multivariate logistic regression model to predict the odds of an individual nurse being a “poor sleeper” (the binary outcome, $PSQI > 5$). The results are presented in Table 6 and

Table 5 Pearson correlation matrix for $L_{Aeq,8h}$, health outcome scores, and confounders

Variable	$L_{Aeq,8h}$	PSS-10 score	PSQI score	HHIA score	Age
$L_{Aeq,8h}$	1				
PSS-10 score	0.450***	1			
PSQI score	0.521***	0.610**	1		
HHIA score	0.279*	0.198	0.245	1	
Age	0.089	0.152	0.177	0.412**	1
Years in PICU	0.103	0.133	0.160	0.445**	0.891**

* $p=0.051$; ** $p<0.01$; *** $p<0.001$; HHIA – Hearing Handicap Inventory for Adults; PSQI – Pittsburgh Sleep Quality Index; PSS-10 – 10-item Perceived Stress Scale

Table 6 Multivariate logistic regression analysis for predictors of poor sleep quality ($PSQI > 5$)

Variable	Log-odds ratio with $PSQI > 5$	SE	Wald	p-value	Adjusted odds ratio (OR)	95 % CI for OR
$L_{Aeq,8h}$ (per 1 dBA)	0.223	0.088	6.39	0.012*	1.25	1.05–1.48
PSS-10 score (per point)	0.270	0.089	9.15	0.003**	1.31	1.10–1.55
Age (per year)	0.041	0.055	0.56	0.454	1.04	0.93–1.16
Years in PICU (per year)	-0.029	0.061	0.23	0.633	0.97	0.86–1.09
Constant	-18.75	7.11	6.97	0.008		

* $p<0.05$; ** $p<0.01$; PSQI – Pittsburgh Sleep Quality Index; PSS-10 – 10-item Perceived Stress Scale

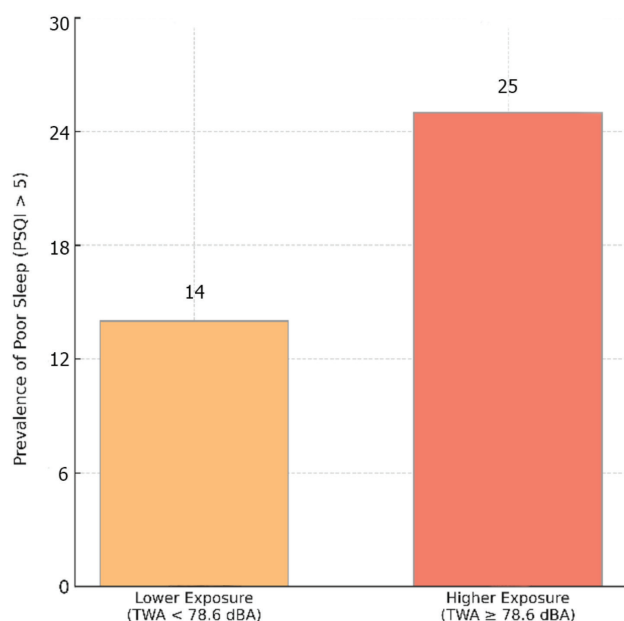


Figure 5 Prevalence of poor sleep quality (PSQI>5) stratified by noise exposure groups

visualised in the forest plot in Figure 7. After adjusting for the potential confounding variables of age, years in PICU, and PSS-10 score, $L_{Aeq,8h}$ remained a significant, independent predictor of poor sleep status with the adjusted odds ratio of 1.25 ($p=0.012$, Table 6). This finding indicates that for every 1 dBA increase in noise exposure, the nurse's odds of suffering from clinical-level poor sleep increase by 25 %. Another significant independent predictor is perceived stress (PSS-10 score) ($p=0.003$, Table 6), whose odds ratio confirms its critical role in relationship with sleep. Age and experience are not significant predictors in this model.

DISCUSSION AND CONCLUSION

The primary finding of our study is that nurses at PICU are chronically exposed to noise levels (mean $L_{Aeq,8h}=78.5$ dBA) that are within a “regulatory grey area”, as they mostly keep below the 85 dBA NIOSH REL that would trigger mandatory action for hearing conservation. This apparent compliance with industrial standards may lull hospital administrators and occupational health departments into a false sense of security. However, these same noise levels are more than 40 dBA above the health-based guideline of 35 dBA recommended by the WHO for patient rooms (5), and our study provides strong, quantitative evidence that this kind of occupational noise exposure is associated with a significant and measurable health burden on the nursing staff.

The strong, dose-dependent correlation between $L_{Aeq,8h}$ and global PSQI scores ($r=0.52$) and the independent predictive power of noise on poor sleep status ($AOR=1.25$) are the study's most critical findings. The high prevalence of clinical-level poor sleepers (39 of 60 nurses) in this cohort is an alarming statistic with profound implications for staff health and patient safety. These findings support a hypothesised mechanism wherein noise acts as a chronic occupational stressor that extends its influence beyond the hospital walls (27). High-frequency, alarm-based noise characteristic of the PICU contributes to a heightened state of physiological arousal and perceived stress. This stress, in turn, is strongly linked to an inability to initiate and maintain restorative sleep, as evidenced by the strong PSS-PSQI correlation, and the cycle is self-perpetuating: poor sleep then impairs cognitive function, emotional regulation, and attention, making the nurses even more susceptible to stress at work and less resilient to the impacts of the acoustic environment (28, 29). This cycle of noise, stress, and sleep deprivation has direct implications for the two most critical challenges in modern healthcare: patient safety and staff retention. A nursing workforce suffering from chronic, widespread sleep disturbance is at a significantly higher risk for performance deficits, communication failures, and medical

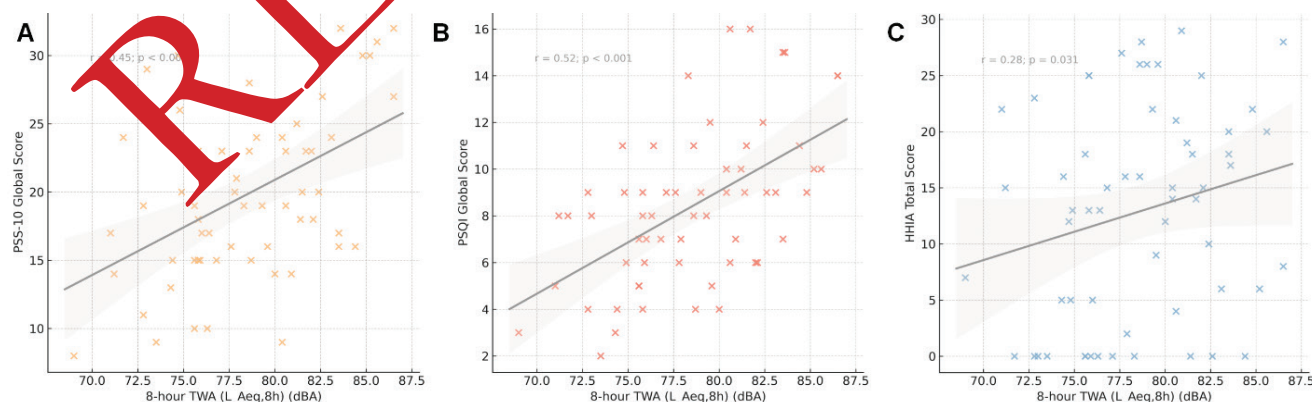


Figure 6 Scatter plots of 8-hour TWA ($L_{Aeq,8h}$) vs Perceived Stress Scale (PSS-10) score(A), Pittsburgh Sleep Quality Index (PSQI) total score (B), and hearing handicap inventory (HHIA) total score (C)

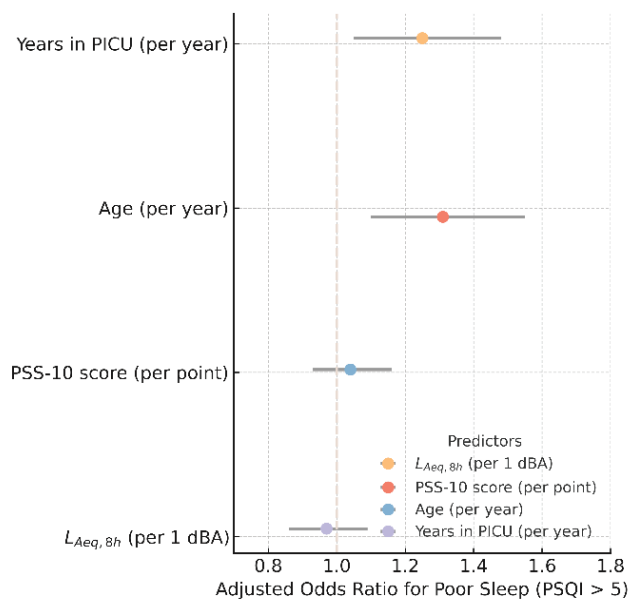


Figure 7 Forest plot of adjusted odds ratios for poor sleep quality (PSQI>5); PICU – paediatric intensive care unit; PSQI – Pittsburgh Sleep Quality Index; PSS-10 – Perceived Stress Scale

errors. Concurrently, the burnout, fatigue, and lower professional quality of life that are demonstrably linked to noise exposure are the primary drivers of turnover and intention to resign (30). Given the astronomical organisational costs of nurse turnover, this study reframes noise abatement as a critical, high-return-on-investment strategy for both patient safety and workforce stabilization.

Our findings urge for a fundamental shift in perspective: from the passive acceptance of noise as “the sound of our reality” to active management as a modifiable, high-priority occupational hazard. Here we propose a way to control noise in the PICU environment as an adaptation of the established hierarchy of control taken from NIOSH (15) (Figure 8). It consists of four steps with diminishing

effectiveness, starting with elimination of noise, substitution, engineering controls, and administrative controls. Considering that noise elimination is impossible in a critical care setting, we believe that substitution with visual alert systems (where it does not jeopardise patient care) and implementation of engineering controls offer the most effective and sustainable solutions for the specific targets identified in our study – the high-frequency, high-decibel alarms (Table 3, Figure 3). They could be redesigned so as to integrate individual alarms into a single, intelligent system that reduces alarm frequency and uses less shrill, lower-frequency tones. Furthermore, reverberation and ambient noise level could be reduced by installing high-performance, high-frequency sound-absorbing ceiling tiles and wall panels. Administrative controls offer more immediate yet less effective solutions. Our finding of higher noise on day shifts (Figure 2) and peaks at handovers (Figure 1) points to a need for behavioural change, which could be addressed by staff education. The use of personal protective equipment (PPE), such as earplugs, remains a poor and impractical solution in this environment, as it impairs the critical communication and hearing of alarms that are essential for patient safety.

Finally, this study has several limitations. Its cross-sectional design is only capable of demonstrating associations but cannot prove that noise exposure causes poor sleep and stress. It is plausible that individuals who are already highly stressed are simply more sensitive to noise. The sample size of 60 nurses from a single hospital limits the generalisability of our findings to other PICU or hospital settings. Furthermore, there is a temporal mismatch between the 12-hour shift dosimetry and the one-month recall of the PSQI and PSS-10 questionnaires, as the measured shift may not have been representative of their entire preceding month. To address these limitations, future research should involve longitudinal studies to track nurses’ health metrics (stress, sleep) over time as a function of cumulative noise exposure. Most importantly, future research should move from observation to intervention, using robust designs to assess the efficacy of the proposed engineering and administrative

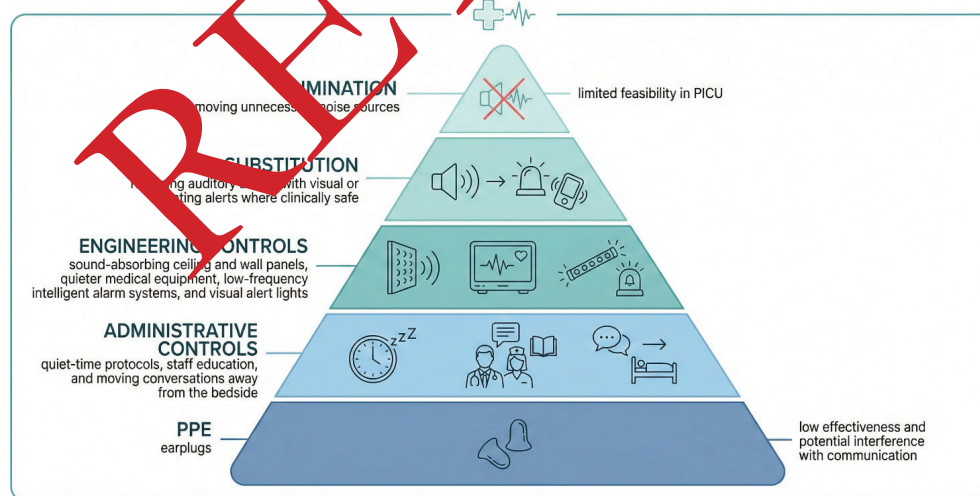


Figure 8 Conceptual model of the hierarchy of noise control adapted for paediatric intensive care units

controls by measuring their impact on both the objective acoustic environment and the validated health metrics identified in this paper.

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Conflict of interests

None to declare.

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Obrasci izloženosti buci i procjena zdravstvenog rizika među medicinskim sestrama i tehničarima u kineskoj jedinici intenzivne njege za pedijatrijske bolesnike

Polazeći od hipoteze da izloženost buci na radnom mjestu među medicinskim sestrama u pedijatrijskoj jedinici intenzivne njege u našoj bolnici premašuje preporučene zdravstvene smjernice te da je povezana s nepovoljnim ishodima za zdravlje koji nisu vezani za sluh, cilj ovog presječnog ispitivanja bio je kvantificirati obrasce osobne izloženosti buci i utvrditi njihovu korelaciju s percipiranim stresom, kvalitetom sna i oštećenjem sluha na uzorku od 60 ispitanika koji su nosili osobne dozimetre buke tijekom 12-satne smjene. Sudionici su također ispunili anketu koja je obuhvatila Ljestvicu percipiranog stresa (PSS-10), Pittsburgh indeks kvalitete sna (PSQI) i Inventar oštećenja sluha za odrasle (engl. *Hearing Handicap Inventory for Adults* – HHIA). Prosječna buka tijekom 8 sati ($L_{Aeq,8h}$) iznosila je $78,5 \pm 4,2$ dB(A) te su sve smjene premašile smjernice Svjetske zdravstvene organizacije za bolnice. Vršne razine buke (L_{Cpeak}) često su premašile 115 dB. Većina ispitanika ($65,0\%$) klasificirana je kao “loši spavači” ($PSQI > 5$). Utvrđene su značajne pozitivne korelacije između $L_{Aeq,8h}$ i rezultata PSS-10 ($r=0,45$; $p<0,001$) te ukupnih rezultata PSQI-a ($r=0,52$; $p<0,001$). Za svaki porast $LA_{eq,8h}$ od 1 dB(A), vjerojatnost da osoba bude loš spavač povećala se za 25% (omjer izgleda 1.25 ; 95% CI: $1,05$ – $1,48$). Iako se radi o presječnom ispitivanju kojim se utvrđuje trenutno stanje, rezultati jasno upozoravaju na to da buka u pedijatrijskoj jedinici intenzivne njege donosi značajne profesionalne rizike od visokog stresa i lošeg sna, što zahtijeva neodgodivu intervenciju. Daljnja istraživanja trebala bi obuhvatiti longitudinalna mjerenja kako bi se stekao bolji uvid u izloženost buci u zdravstvenim ustanovama, posebice u pedijatrijskim jedinicama intenzivne njege.

KLJUČNE RIJEČI: poremećaji spavanja; PSQI; PSS-10; stres