The Acoustic Environment in Typical Hospital Wards in China

Zhixiao Deng [a], Hui Xie [b,c,*], Jian Kang [d]

[a] Faculty of Architecture and City Planning, Kunming University of Science and Technology, Kunming, Yunnan 650500, China

[b] Faculty of Architecture and Urban Planning, Chongqing University, Chongqing 40044, China

[c] Key Laboratory of New Technology for Construction of Cities in Mountain Area, Chongqing University, Chongqing 40044, China

[d] Institute for Environmental Design and Engineering, The Bartlett, University College London - 14 Upper Woburn Place, London WC1H 0NN, UK

Abstract

Excessive noise has become a significant problem in hospitals around the world, as revealed by a number of studies. This study aimed to investigate the acoustic conditions in typical ICU wards and general wards in a Chinese hospital through a series of field measurements and a questionnaire survey. In terms of the sound field, the results showed that the reverberation times (500-1 kHz) of thirteen selected wards ranged from 0.34 to 0.67 s and that their 24-hour equivalent noise level ranged from 57.3 to 63.9 dBA. Most general wards contained higher noise levels than ICU wards during the daytime, whereas ICU wards became the noisiest at night. In terms of noise sources and their impact, 'equipment alarms' were recognized as the major noise source in ICU wards, whereas 'talking from others' was more significant in general wards. A total of 43.6% of the interviewed patients from general wards were interrupted once by noise while sleeping. To improve the acoustic conditions in general wards, the introduction of effective management to 'reduce the talking level' was recommended primarily by staff, whereas providing 'more single wards' was recommended by most patients. For the ICU ward, 'acoustic treatments' and 'reduced alarm levels' were considered more suitable strategies by staff.

Keywords: acoustic environment; hospital ward; patient; medical staff

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* xh@cqu.edu.cn

1. Introduction

It has been widely recognized that the acoustic environment plays an important role in the healthcare setting. To minimize the effects of noise on sleep disturbance, annoyance and communication, the World Health Organization (WHO) suggested that the noise level should not exceed 30 dBA in the therapy room or hospitalization area [1]. Similar limitations on the noise level of hospital wards in related guidance and standards have been published in several countries [2-4]. However, excessive noise has become a significant problem in hospitals in a number of countries [5]. For China, the number of hospitals and their healthcare quality have significantly increased in recent decades as a result of healthcare reform, which has been ongoing since 1996 [6].

However, research on the acoustic conditions of Chinese hospital wards is still very limited. The aims of this study were therefore (a) to reveal the acoustic characteristics in different types of wards in a general hospital in China, (b) to explore the impacts of noise on patients and staff, and (c) to discuss appropriate strategies to improve the overall acoustic environment in Chinese hospital wards.

1.1 Previous studies

For many years, intensive care units (ICUs) have been considered the noisiest department due to the noise generated by various medical equipment, frequent alarms and general medical activities. A large number of studies have indicated that the noise levels in ICU, neonatal ICU and pediatric ICU wards exceed 60 dBA during both daytime and nighttime [5, 7-15]. Other studies have even shown that peak noise levels in ICU wards are over 100 dBA during shift changes [16, 17]. Noise levels in operating rooms (ORs) are also known to be high, as noises from drills, saws, and other pieces of operative instruments are normally within the range of 100–110 dB [18, 19]. In recent years, increased attention has been given to general wards. Noise levels in general wards have been found to be relatively lower, at 50-65 dBA in the daytime and 40-55 dBA in the nighttime, by very limited studies [20-22].

As one of the principal environmental factors that patients most frequently complain about, noise has remarkable negative impacts on the physiological and psychological factors of patients. One study in a sleep laboratory suggested that common noise in hospitals was linked to sleep disturbances among healthy people by influencing cortical brain activity and cardiovascular function during sleep [9]. In addition, several physiological indicators of patients, including blood pressure, heart rates and respiratory rates, can be affected by excessive noise, which may result in annoyance and an extended rehabilitation time for patients [23-29].

Furthermore, hospital noise can also potentially have serious negative effects on stress symptoms, working performance, and the health status of medical staff. Several studies have shown that noise is correlated with tachycardia, annoyance and short-term memory and might result in working and medical errors such as incorrect medication administration [8, 30-37]. Moreover, staff hearing loss was linked with frequent use of noisy surgical equipment in ORs [38].

1.2 Potential noise problems in Chinese hospital wards

With the sustained and rapid development of the economy, healthcare resources in China, including healthcare facilities, employees, beds, and health insurance covered by the central government, are continually growing through ongoing healthcare reforms. China's healthcare access and quality (HAQ Index) increased from 42.6 in 1990 to 77.9 in 2016 (the global average was 54.4 in 2016) [6]. Meanwhile, personal medical needs are growing as well, along with the expanding number of outpatients and inpatients.

According to a report of inpatient data from over 128 countries from the Organization for Economic Co-operation and Development (OECD) and Global Health Data Exchange (GHDx), China’s ratio of inpatient admissions increased the most quickly in the ten years preceding 2016, going from 0.08 to 0.17 [39]. According to official Chinese statistics in 2015, there were 13,069 public hospitals in China with approximately 4.3 million beds, accounting for 61.2% of the total number of beds among all healthcare facilities [40]. However, almost all Chinese patients (88.0%) were received in public hospitals, with a total number of inpatient admissions as high as 137 million and 9.8 bed-days on average in 2015 [41].

A shortage of beds therefore became a common problem in Chinese public hospitals, with a 92.8% bed occupancy rate and 101.8% bed occupancy rate in Grade III hospitals (top-tier classification) [40]. To address the excess number of inpatients, very few single wards have been established in Chinese public hospitals. Even worse, a number of hospitals have to set up temporary beds in corridors for extra patients. This makes patients and staff much more likely to be exposed to a crowded environment with potential noise problems. In recent years, increased attention has been given to the sound environment of Chinese hospitals. One study [11] demonstrated the acoustic issue of outpatient waiting areas in a Chinese general hospital through measurements and questionnaires. Excessive noise levels over 70 dBA were observed in the tested area, which were largely due to speech from large numbers of people. However, detailed information on acoustic conditions, including noise level, reverberation time, spectrum and characteristics of noise sources, and the impact of noise on patients and medical staff in hospital wards is lacking.

2. Methods

2.1 Case study site

As a branch of West China Hospital, Sichuan University, the case study site, Yibin 2nd People's Hospital is a typical Grade III general hospital located in southwestern China; it represents the top-level medical services and technology, with a bed capacity exceeding 3000, and it serves as a medical hub providing care to the local region in Sichuan Province.

To compare the acoustic conditions between the ICU and general wards, three ICU wards and ten typical general wards from cardiology, orthopedics, obstetrics, oncology, and gynecology in four inpatient buildings were selected as the case study sites (Table 1). Even though the selected wards were furnished or renovated after 2000, their current ceilings, floors and wall finishes were without any acoustic treatments, as shown in Fig. 1. The configuration of sliding windows and thin wooden doors also led to poor sound insulation from the corridor. This study was carried out between May and September 2018. Ethical approval was authorized by the Ethical Committee of Yibin 2nd People's Hospital prior to the formal conduct of this study (Ethics approval number: 029-01), and informed consent was obtained from all the participating patients and staff.

Table 1. Basic information and RT (average 500-1 kHz) of the tested wards.

Department	Ward type	Room Size W*L*H (m)	Finishes		RT (s)
			Ceiling	Floor	
ICU	single	3.6*5.6*2.8	Aluminum	PVC	0.67
	4-bed	5.6*6.7*2.8	Aluminum	PVC	N/A
	9-bed	12.7*10.6*2.8	Aluminum	PVC	N/A
Obstetrics	double	3.3*6.0*3.2	None	Terrazzo	0.52
	3-bed	3.3*5.8*3.2	None	Terrazzo	0.35
Cardiology	double	3.6*3.3*3.2	None	Terrazzo	0.52
	5-bed	3.3*8.8*3.2	None	Terrazzo	0.55
Oncology	double	3.2*5.7*2.5	Gypsum	PVC	0.51
	6-bed	5.6*6.9*2.5	Aluminum	Ceramic	0.57

Orthopedics	double	3.6*3.3*3.2	None	Terrazzo	0.41
	6-bed	6.8*7.9*3.2	None	PVC	0.39
Gynecology	Single	3.7*6.1*2.6	Gypsum	PVC	0.60
	double	3.4*6.3*2.6	Gypsum	PVC	0.56

Fig. 1. General layout and photos of selected wards of Yibin 2nd People's Hospital.

2.2 Measurement procedures

Long reverberation time (RT) can be detrimental to speech intelligibility [42], which can impact staff work efficiency by reducing communication quality, such as when staff are answering telephones and talking with patients and other staff. The integrated impulse response method recommended by ISO 18233:2006 [43] was followed in the RT measurement. All RTs in the wards were tested under the unoccupied condition with doors and windows closed. A Type I AWA6228+ sound meter with a RT test function was used to record balloon pops and to automatically calculate the T_{30}.

Continuous sound level measurements were used to investigate the actual operating environment while the wards were fully occupied by patients. Two Type I AWA6228+ sound meters were placed to record the sound pressure level every second for continuous 24 hours on working days. To minimize their interference with general healthcare activities, the meters were placed on the ceiling of the wards at least 0.5 m away from all of the reflecting surfaces. L_{eq}, L_{10} and L_{90} were used to give indications of equivalent continuous sound level, impulsive peak noise level and background noise level. The highest noise value often originates from unpredictable and sudden impulse noises, which are likely to cause a startle response; hence, the loudest noise level (L_{max}) and the percentage (%) of high noise events with a SPL above 70 dBA (e.g., trolleys, medical alarm, door closing, and phone rings [20]) in each ward were analyzed.

2.3 Questionnaire survey

Two sets of questionnaires were designed separately for both staff and patients who stayed in the ward for more than 24 hours. The questionnaires had two sections, and most questions were designed on a five-point scale. The first section was designed to collect basic information, including participation gender (male or female), age range (age$<$20, 20$\leq$age$<$40, 40$\leq$age$<$60, 60$\leq$age$<$80), department, profession (doctor or nurse, for staff) and ward type (number of beds, for patients). The second section contained five main questions (Q1-Q5) as follows.

Q1 provided an overview of the acoustic environment in the ward, including the degree of intensity of noise perceived in the ward and the importance of the acoustic environment. Q2 concerned fourteen common noise sources (multiple choice) that were preidentified by the staff and the most unwanted sound (open question). Q3 assessed the influence of noises on patients' 'communication', 'emotion', 'sleep' and 'recovery', to be evaluated by both patients themselves and staff, and the influence of noises on staff's 'working efficiency'. Q4 included a ranking of the degree of urgency of the improvement of five indoor physical environments in the hospital. Q5 proposed seven appropriate strategies to improve the acoustic environment (multiple choice).

In total, 480 questionnaires were initially distributed to patients and staff from general wards and ICU wards in the six departments, and 434 valid questionnaires were eventually collected with a response rate of 90.4%, including 243 from patients and 191 from staff. The characteristics of the participating staff and patients can be found in Table 2. As most of the patients were unconscious or sedated during critical care, only patients in the ICU were excluded from the questionnaire survey.

The statistical software SPSS 18.0 was applied to statistically test the significance on noise levels and subjective evaluations. A T-test was used to analyze the significance of the differences in terms of noise levels. As all the questionnaire results were not normally distributed, nonparametric tests (Kruskal–Wallis ANOVA) were adopted accordingly to test whether age, gender, department and ward type (number of beds within ward) might affect the perception of staff or patients of the acoustic environment. The significance level was set at 5% (p=0.05) for all tests, with * representing $p<0.05$ and ** representing $p<0.01$.

Table 2. Characteristics of the participating staff and patients.

	ICU	Obstetrics	Cardiology	Oncology	Orthopedics	Gynecology	Total
Number of staffs	33	25	48	14	41	30	191
Female	28(84.8%)	24(96.0%)	33(68.8%)	7(50.0%)	26(63.4%)	29(96.7%)	147(77.0%)
Doctor	10(30.3%)	11(44.0%)	22(45.8%)	10(71.4%)	17(41.5%)	8(26.7%)	78(40.8%)
Nurse	23(69.7%)	14(56.0%)	26(54.2%)	4(28.6%)	24(58.5%)	22(73.3%)	113(59.2%)
Age<20	0(0.0%)	0(0.0%)	6(12.5%)	0(0.0%)	0(0.0%)	9(30.0%)	15(7.9%)
20≤Age<40	32(97.0%)	21(84.0%)	37(77.1%)	11(78.6%)	40(97.6%)	20(66.7%)	161(84.3%)
40≤Age<60	1(3.0%)	3(12.0%)	5(10.4%)	3(21.4%)	1(2.4%)	1(3.3%)	14(7.3%)
60≤Age<80	0(0.0%)	1(4.0%)	0(0.0%)	0(0.0%)	0(0.0%)	0(0.0%)	1(0.5%)
Number of patients	0	51	31	30	76	55	243
Female		51(100%)	10(32.3%)	11(36.7%)	33(43.4%)	55(100%)	160(65.8%)
Ward type, ≤2 beds		36(70.6%)	9(29.0%)	26(86.7%)	25(32.9%)	31(56.4%)	127(52.3%)
Ward type, >2 beds		15(29.4%)	17(54.8%)	3(10.0%)	37(48.7%)	19(34.5%)	91(37.4%)
Ward type, corridor	N/A	0(0.0%)	12(38.7%)	0(0.0%)	13(17.1%)	0(0.0%)	25(10.3%)
Age<20		2(3.9%)	0(0.0%)	0(0.0%)	5(6.6%)	2(3.6%)	9(3.7%)
20≤Age<40		47(92.2%)	2(6.5%)	3(10.0%)	27(35.5%)	28(50.9%)	107(44.0%)
40≤Age<60		2(3.9%)	7(22.6%)	9(30.0%)	28(36.8%)	18(32.7%)	64(26.3%)

60≤Age<80	0(0.0%)	19(61.3%)	16(53.3%)	11(14.5%)	5(9.1%)	51(21.0%)

3. Results

3.1 Acoustic characteristics among different wards

3.1.1 Reverberation times

Since the ICU 4-bed and 9-bed wards were occupied for 24 hours and RT measurement would disturb the patients, the RT measurement was not performed in the two wards. The RT values of the remaining eleven wards ranged from 0.34 s to 0.67 s at middle frequencies (average 500-1 kHz), as shown in Table 1.

Under the condition that all of the tested wards were hard surfaces without any acoustic treatment, more beds in the wards could become larger areas of absorption. Hence, a lower RT could be found in the ward with more beds in each department regardless of the size of the room. Another study [20] similarly found that without any acoustic treatment, more beds can result in lower RT after simulating ten patient rooms in two UK hospitals.

In addition, internal finish could highly affect the RT of a ward. Relatively longer RTs were found in the ICU single ward (0.67 s) and the gynecology single ward (0.60 s) due to the large area of glass windows in the wards (Fig. 1e and Fig. 1i), which could affect the decay of reverberant sound. Another study from the author [44] similarly obtained an even longer RT over 1.2 s at 500 Hz in a larger ICU single ward with large windows for observation needs. On the other hand, the orthopedics 6-bed ward, which was featured as a monitoring room, obtained a relatively shorter RT (0.39 s). This was largely due to the fabric curtains used to separate private spaces for each bed, which can also absorb sound energy inside the room (Fig. 1).

According to the Danish Building Regulation (BR18), the reverberation time should not exceed 0.6 s for patient bedrooms ranged from 125 to 4 kHz [45]. Four tested wards (specifically, the ICU single ward, the Oncology 6-bed ward, and the single ward and double ward in the Gynecology Department) obtained excessive RT over 0.6 s at low frequencies (125-500 Hz) due to the relatively larger area of smooth and hard surfaces, such as glass windows and ceramic floors, as shown in Fig. 1.

3.1.2 Noise levels

As shown in Table 3, the noise level of all the tested wards exceeded the WHO recommended level (30 dBA) by a large scale. No obvious difference was found among the thirteen wards during the daytime (6:00-22:00), with the L_{eq_day} of the most wards being over 60 dBA. However, the noise levels of all the tested wards were found to significantly decrease (p <0.05) during the nighttime (22:00-6:00). It should be noted that a considerable gap was observed during the nighttime, with L_{eq_night} ranging from 36.3 dBA to 57.0 dBA. The three ICU wards were found to have significantly higher L_{eq_night} over 50 dBA, mainly due to the multiple pieces of equipment operating constantly and frequent nursing activities. More medical equipment and nursing operations could be found in the ICU ward with more patients. Compared with the other twelve wards, the ICU 9-bed ward became the noisiest ward during the nighttime, with a higher L_{eq_night} reaching 57.0 dBA (p <0.05). On the other hand, the L_{eq_night} in the ten general wards were normally in the range of 40-50 dBA.

Similar to the pattern of L_{eq}, the L_{10} and L_{90} in the three ICU wards were significantly higher than those tested in the general wards during the eight consecutive hours at night (p <0.05). Furthermore, the ICU wards revealed smaller differences between L_{10} and L_{90}, indicating a relatively stable sound environment during both daytime and nighttime.

It was an unexpected finding that the ICU was not the noisiest department during the daytime. Three double wards from Obstetrics, Cardiology and Orthopedics obtained significantly higher (p <0.05) noise levels than the ICU wards, with L_{eq_day} over 65 dBA. Meanwhile, accounting for 6.1% to 8.1% of the daytime, the noise event above 70 dBA was observed in these three double wards. These were much larger than the noise events with the same SPL (>70 dBA) measure in two UK general hospitals [20]. It should also be noted that the double ward in each general department was always found to have significantly higher noise levels (p <0.05) than a single ward or a large ward with more than two beds during both daytime and nighttime. According to the observation, patients in the double wards were much more likely to talk with each other in a loud voice. In contrast, patients in the large ward with more beds rarely talked to each other to avoid interrupting the rest of the other patients. Even though the frequency of high noise events decreased considerably in all the tested wards during the nighttime, countable noise occurrence was still measured in most of the tested wards, such as medical alarms and phone rings with L_{max} values ranging from 74.3 to 82.4 dBA. Frequent high noise events are likely to result in medical errors and sleep disturbances in patients, especially at night.

Table 3. The L_{eq}, L_{max}, L_{10}, L_{90} and percentages with SPL above 70 dBA of the tested wards.

Department	Ward type	L_{eq} (dBA)			L_{max} (dBA)		L_{10} (dBA)		L_{90} (dBA)		>70 dBA (%)	
		24 hrs	day	night	day	night	day	night	day	night	day	night
ICU	single	59.6±4.8	60.9±5.0	51.8±3.3	86.9	78.8	63.2	56.9	51.0	47.9	1.8%	0.1%
	4-bed	58.8±5.1	60.0±4.5	51.5±3.9	83.7	77.5	62.9	56.5	51.7	46.9	0.8%	0.1%
	9-bed	62.7±5.6	63.6±5.9	57.0±4.6	83.8	81.9	67.3	63.1	51.7	51.7	4.6%	1.1%
Obstetrics	double	63.0±11.6	64.5±10.3	53.1±8.3	90.3	82.0	67.7	50.6	40.2	30.6	6.7%	1.1%
	3-bed	61.9±11.7	63.5±9.3	48.3±7.0	88.9	76.1	66.5	45.7	42.0	31.5	4.7%	0.3%
Cardiology	double	63.9±13.2	65.6±10.4	42.9±6.4	88.1	74.6	69.0	42.9	41.6	28.8	8.1%	0.0%
	5-bed	61.1±10.7	62.8±9.0	37.6±2.4	84.5	75.3	66.3	39.9	41.4	36.2	4.0%	0.0%
Oncology	double	57.4±12.2	58.9±9.0	47.1±10.5	85.5	77.3	61.7	53.3	38.8	25.6	1.1%	0.1%
	6-bed	57.5±12.1	59.3±9.7	36.3±2.4	80.2	78.8	62.7	35.8	37.5	30.7	1.0%	0.0%
Orthopedics	double	62.9±12.6	64.6±9.9	49.9±7.8	92.8	80.5	66.9	48.9	39.6	31.1	6.1%	0.4%
	6-bed	59.0±6.6	60.5±6.0	48.6±4.1	85.8	74.3	63.9	53.5	48.0	44.6	1.5%	0.0%
Gynecology	Single	57.3±7.6	58.8±7.3	45.7±5.2	82.4	82.4	62.0	48.2	41.2	38.4	1.2%	0.0%
	double	59.9±6.2	61.6±6.5	49.7±3.5	91.4	80.2	63.6	54.9	37.3	47.1	1.7%	0.1%

[a] L_{eq} values are expressed as the mean ± S.D.

[b] Day: 6:00-22:00, Night: 22:00-6:00 [46].

As shown in Fig. 2a, the noise levels of the three ICU wards were consistent with those measured in eight ICU wards in a tertiary hospital in the U.S. [21], and six ICU wards in a general hospital in the UK [47]. Similar noise levels, accounting for a 1-2 dBA difference in L_{eq}, could be found both during the daytime and nighttime among the three hospitals. This is largely due to the similar layout, same medical equipment, and consistent management. This makes noise sources in different ICUs basically the same, which results in a similar noise level.

However, a significant difference in noise levels was found among the general wards during the daytime (Fig. 2b). Compared with eight general wards from the tertiary hospital in the U.S. [21], as well as 24 general wards from two general hospitals in the UK [20], the average L_{eq_day} of the ten general wards was 10.9 dBA and 7.5 dBA higher than those of the U.S. and UK, whereas L_{eq_night} was only 1.9 dBA and 1.6 dBA higher than those of the U.S. and UK, respectively. This was possible due to the different characteristics of noise sources in the ward, which is discussed in a later section.

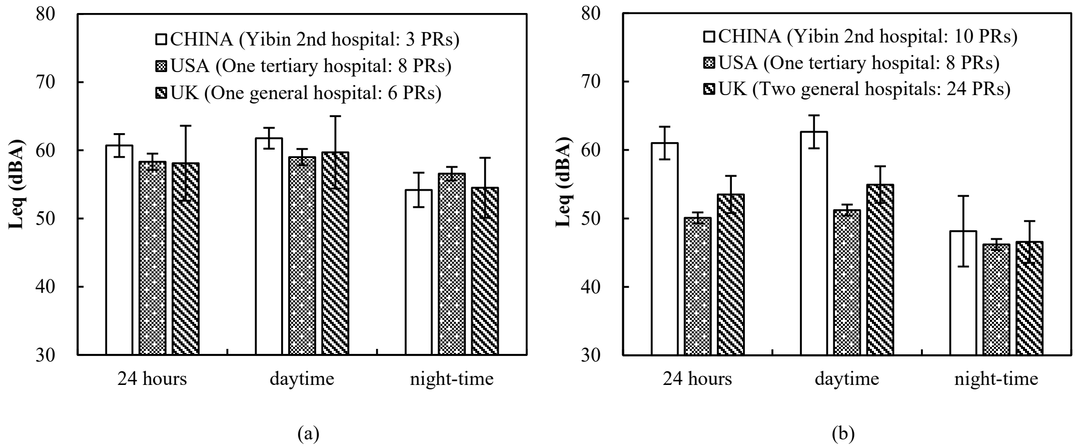

Fig. 2. Comparison of equivalent noise levels with standard deviations among hospital wards in China, the USA [21] and the UK [20, 47], (a) ICU wards, (b) general wards

Note: "PRs" indicates patient rooms (wards)

As shown in Fig. 3, the variations in noise levels over 24 hours were found to be associated with routine activities based on the researcher's on-site observation and conversations with staff and patients. A very consistent pattern was found among the most general wards. Noise levels increased gradually since the day shift early in the morning at approximately 06:00 am and decreased after the night shift in the evening at approximately 22:00 pm. As expected, the nursing peak hours from 8:00 to 10:00 am and 14:00 to 16:00 pm were normally noisier. An obvious decrease in noise level could be observed at lunch time at approximately 13:00 pm in most wards, including ICU wards, by observing fewer medical activities, and most patients and staff would take a nap during the lunch break. Patients in large wards with more patients usually had a more regular sleep schedule since a more consistent pattern can be found in large wards with more than two beds. Very less variation in noise level was found in the three ICU wards during the nighttime. In contrast, the noise level fluctuated greatly in the general wards, with a notable peak with a noise level arranged from 45 to 55 dBA at approximately 01:00 am due to the vital index checking for some patients.

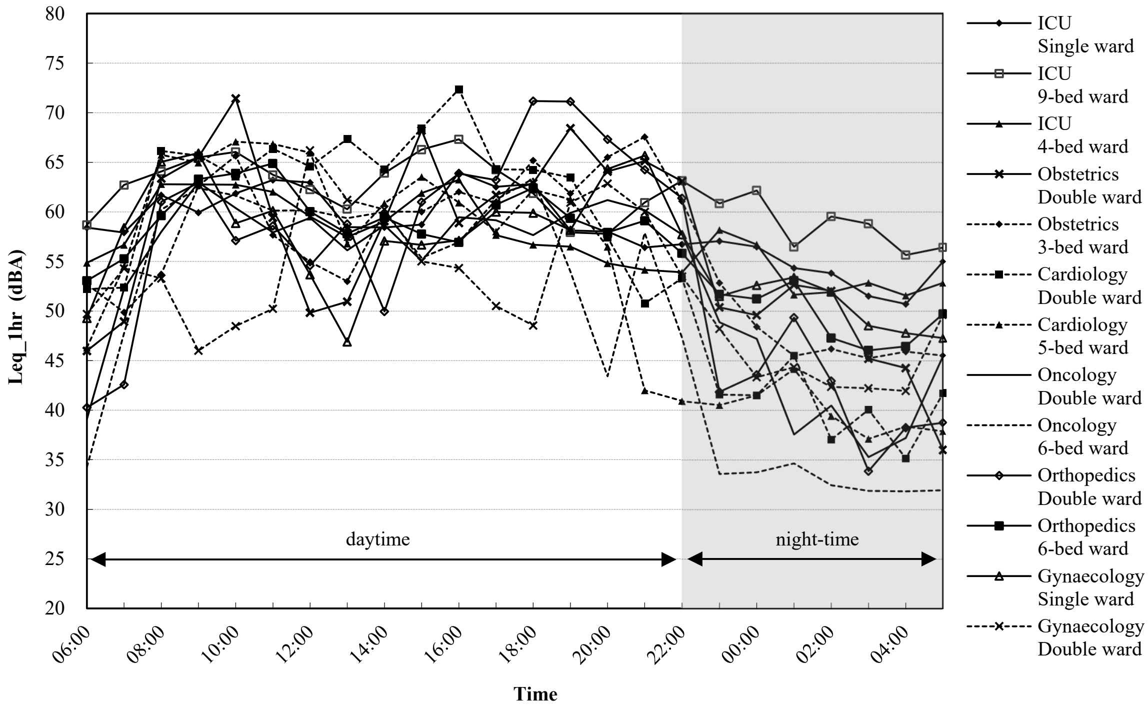

Fig. 3. L_{eq_1hr} over 24 hours in the thirteen tested wards.

As shown in Fig. 4, the noise spectra among the general wards presented a very similar trend. The dominant frequencies of all these curves appeared at approximately 500 Hz, with levels between 50-60 dB. Consistent with a previous study [5], the patterns of these curves were similar to the spectrum of human voices, which indicates that talking might be the primary noise source in wards. The noise spectrum of the three ICU wards was relatively flat due to strict regulations on visits. In addition, higher levels could be observed at frequencies of 2-4 kHz due to the frequent alarms generated by a large number of medical devices, such as ECG monitors, ventilators and pumps.

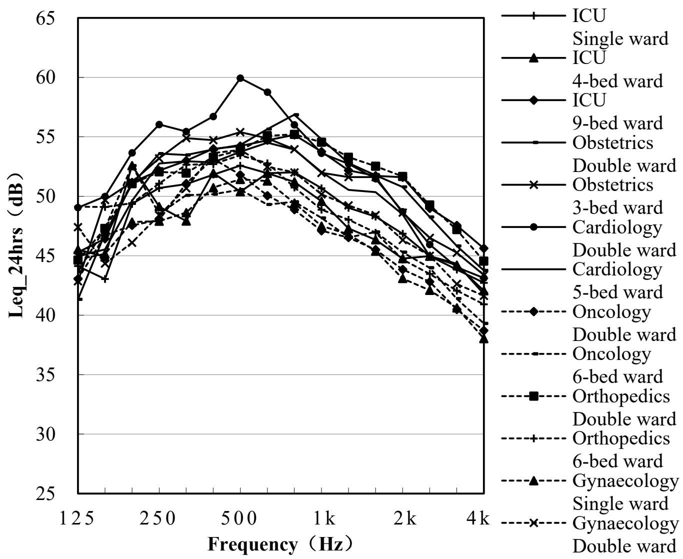

Fig. 4. Noise spectrum of the thirteen tested wards.

3.1.3 Perceived noise sources

According to Table 4, most patients (48.9%) considered noise to be mainly generated from internal wards. The staff considered the noise to more likely originate from the corridor (37.3%), followed by the internal wards (34.1%), which could largely be due to the very frequent use of corridors by staff. Patients and staff from cardiology and orthopedics wards thought that placing temporary beds in the corridors would make the corridors noisier. Thus, they could perceive more noise from the corridors through the wooden interior doors due to the poor sound insulation.

In terms of noise types, patients and staff from general wards pointed out that they perceived ‘noise from people’ more than noise from ‘equipment’ or ‘general activity’. Consistent with the results of the noise spectrum (Fig. 4), ‘visitors talking’ was considered the main noise source, supported by 69.6% of medical staff and 47.9% of patients in total. Several previous studies also found that staff conversations and noise generated by other patients and visitors were major noise sources in general departments [48-50]. ‘Shouting’ and ‘loud talking’ were also considered to be the most disturbing sounds by most of the interviewed patients and staff, which was similar to the results of a previous study [51].

Table 4. Noise sources and the corresponding locations in wards from different departments, identified by patients and staff (%).

Locations/Noise sources	ICU	Obstetrics	Cardiology	Oncology	Orthopedics	Gynecology	Overall

		Staff	Staff	Patient	Staff	Patient	Staff	Patient	Staff	Patient	Staff	Patient	Staff	Patient
Locations	Indoor	63.6	36.0	19.6	43.7	35.4	7.2	76.6	7.3	63.2	50.0	47.2	34.1	48.9
	Out-window	15.2	36.0	41.2	18.8	32.3	35.7	16.7	43.9	9.2	16.7	18.2	28.6	22.9
	Corridor	21.2	28.0	39.2	37.5	32.3	57.1	6.7	48.8	27.6	33.3	34.6	37.3	28.2
Noise from people	Staff talking	54.6	32.0	11.8	31.3	16.1	57.1	20.0	12.2	10.5	23.3	1.8	33.5	13.3
	Visitors talking	18.2	84.0	29.4	85.4	54.8	85.7	43.3	78.1	59.2	70.0	32.7	69.6	47.9
	Footsteps	12.1	16.0	17.7	8.3	41.9	14.3	10.0	22.0	11.8	20.0	21.8	14.3	18.1
Equipment	Alarms	75.8	24.0	7.8	22.9	16.1	0.0	6.7	29.3	27.6	10.0	7.3	33.5	17.0
	Calling buzzer	30.3	12.0	0.0	10.4	9.7	14.3	30.0	12.2	2.6	6.7	1.8	15.5	7.5
	Air conditioner	21.2	8.0	2.0	4.2	6.5	35.7	40.0	0.0	4.0	23.3	14.6	9.9	9.6
	Internal phone	27.3	40.0	0.0	27.1	3.2	0.0	0.0	29.3	2.6	26.7	5.5	27.3	1.6
	TV	0.0	24.0	2.0	6.3	3.2	7.1	6.7	29.3	6.6	50.0	21.8	13.7	4.8
General activity	Medical activity	39.4	8.0	13.7	12.5	16.1	21.4	30.0	9.8	7.9	3.3	5.5	17.4	14.4
	Trolleys	30.3	44.0	35.3	43.8	35.5	0.0	6.7	63.4	46.1	63.3	18.2	42.2	35.1
	Cleaning	9.1	4.0	17.7	4.2	16.1	50.0	16.7	2.4	4.0	20.0	10.9	8.7	11.7
Other	Phone ringing	39.4	40.0	5.9	29.2	32.3	0.0	0.0	31.7	10.5	26.7	12.7	31.1	11.2

Notable differences in noise sources were found in the ICU ward. ‘Equipment alarms’ were the main noise source selected by most staff (75.8%) from the ICU, which was consistent with the results from a number of previous studies [5, 7-14]. Loud and frequent ‘equipment alarms’ were also recognized as the most annoying noise by ICU staff.

‘Trolleys’ were considered the second major noise source, reported by 44.2% of staff and 35.1% of patients, and ‘trolleys’ were considered the most disturbing sound by a number of patients due to the aggravating noise generated when they were moving. According to observations, most departments used metal trolleys to transport medical supplies and garbage, with the noise when moving exceeding 75 dBA. Another possible reason that patients disliked trolley sounds was that they would receive drug treatment after hearing the sound from medical supply trolleys, as indicated by another study [52]. The use of a lighter weight plastic trolley with a silent roller may effectively alleviate this issue. As the only department using silent trolleys, almost no medical staff or patients from oncology considered ‘trolleys’ to be a main noise source.

3.2 Noise impacts on patients and staff

The acoustic conditions in the ward were considered ‘important’ by both patients (3.9) and staff (4.2) from all six departments without a significant difference (p>0.05). However, gender was likely to influence the evaluation of the ‘importance of the acoustic environment' (p<0.01) in the staff group, as shown in Table 5. A higher rating was found in the female group, indicating that female staff might be more sensitive to the acoustic environment in the wards than male staff. An auditory input test [53] proved that women's average maximum comfort level was consistently approximately 8 dB lower than that of men when exposed to loud tones at different frequencies. A similar study [54] that was recently conducted also revealed that compared with men, a stressful environment makes women more sensitive to sound. No significant difference was observed between doctors and nurses in terms of the subjective evaluations of the staff group.

Table 5. Statistically significant differences in subjective evaluations for various demographic factors of patients and staff (p value).

	Patient group				Staff group			
	Dept.	Gender	Age	Number of beds	Dept	Gender	Age	Profession
Subjective noise level	0.110	0.555	0.068	0.044*	0.677	0.591	0.248	0.661
Importance of sound environment	0.125	0.555	0.715	0.712	0.073	0.002**	0.538	0.054
Influence on communication	0.019*	0.243	0.114	0.218	0.260	0.750	0.765	0.784
Influence on sleep	0.024*	0.499	0.077	0.025*	0.053	0.190	0.415	0.996
Influence on emotion	0.334	0.296	0.561	0.005**	0.061	0.837	0.207	0.777
Influence on recovery	0.053	0.151	0.619	0.001**	0.052	1.000	0.585	0.926
Degree of urgency to improve	0.436	0.612	0.519	0.084	0.006**	0.697	0.233	0.204
Influence on work efficiency	N/A				0.020*	0.362	0.768	0.565

For each general ward, the subjective noise level perceived by staff was higher than that perceived by patients. Significant differences were found among oncology (p <0.01), orthopedics (p <0.01) and gynecology (p <0.01), as shown in Fig. 5. In addition, significant differences in terms of noise impact on 'communication' (p <0.01), 'emotion' (p <0.01), 'sleep' (p <0.01) and 'recovery' (p <0.01) were found between patients and staff from the general wards, as shown in Fig. 6a-6d. The above results indicated that medical staff might be more sensitive to noise or pay more attention to the ward acoustic environment than patients.

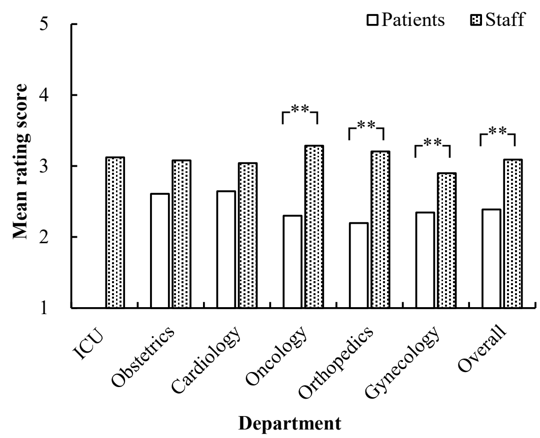

Fig. 5. Subjective evaluations of noise levels in the ward (1='Very quiet', 5='Very noisy').

This might largely be due to the different durations that staff and patients stay in the hospital. The interviewed medical staff usually had worked a full 8-10 hours per day in each department for at least three months, while for most patients, the whole hospitalization period was only approximately 3-14 days. A much longer stay might result in staff considering the noise to be more disturbing than patients in hospital wards. Another possible reason could be related to the insufficient medical resources of public hospitals in China, as mentioned above. There is no guarantee that the hospital always has sufficient beds for every single inpatient, even though that is their basic need. For this reason, patients might be more tolerant of a poor-quality physical environment. Nearly half of the interviewed patients (43.6%) from general wards pointed out that their sleep was interrupted by excessive noise during hospitalization, but they reported only a 'a little' influence on sleep, with a mean value of 2.0.

Significant differences in 'communication' (p <0.05) and 'sleep' (p <0.05) were found between each department based on the patients' evaluations (Table 5). Patients from the orthopedics and cardiology departments were more likely to be affected by noise during their sleep. The probable reason was that patients from these two departments who were bothered by noise came from not only the internal ward but also from the congested corridor with a large number of temporary beds.

In addition, a significant difference (p <0.05) in staff working efficiency was observed between the ICU and general wards, as shown in Fig. 6e and Table 5. Unexpectedly, ICU staff reported being less susceptible to noise during their work. One possible reason is the different major noise sources between the ICU and general wards. This might largely be due to the main noise sources and differences in the degrees of emergencies between the ICU and general departments. The influence of ‘talking’ from other people seemed to affect concentration more than ‘equipment alarms’. Meanwhile, in life-threatening medical conditions, there was a higher level of medical urgency among ICU staff than among staff from general wards. However, laboratory findings suggest that adequate performance under high noise levels is maintained by increasing effort, as evidenced by heightened cardiovascular response and other physiological mobilizations [55]. This implies that the ICU staff may be able to maintain an equal performance level in noisier circumstances (but at the cost of exerting greater effort and becoming much more easily fatigued) than other staff from general wards.

Compared with a relatively higher noise level, more patients in the ward would negatively affect patients’ perceptions of the acoustic environment. No significant correlation was observed between noise levels and patient perception from the ten tested general wards. However, the number of beds in the ward was likely to influence patients’ evaluations of their ‘sleep’ ($p<0.05$), ‘emotion’ ($p<0.01$) and ‘recovery’ ($p<0.01$), as shown in Table 5. Even though the noise levels in the 2-bed wards were higher than in the multi-bed wards of each general department, patients in small wards with 1-2 beds were more likely to perceive a relatively quiet environment and less noise impact than those patients in large wards. A possible reason might be more accompanying individuals or visitors and more disliked sounds generated in large wards.

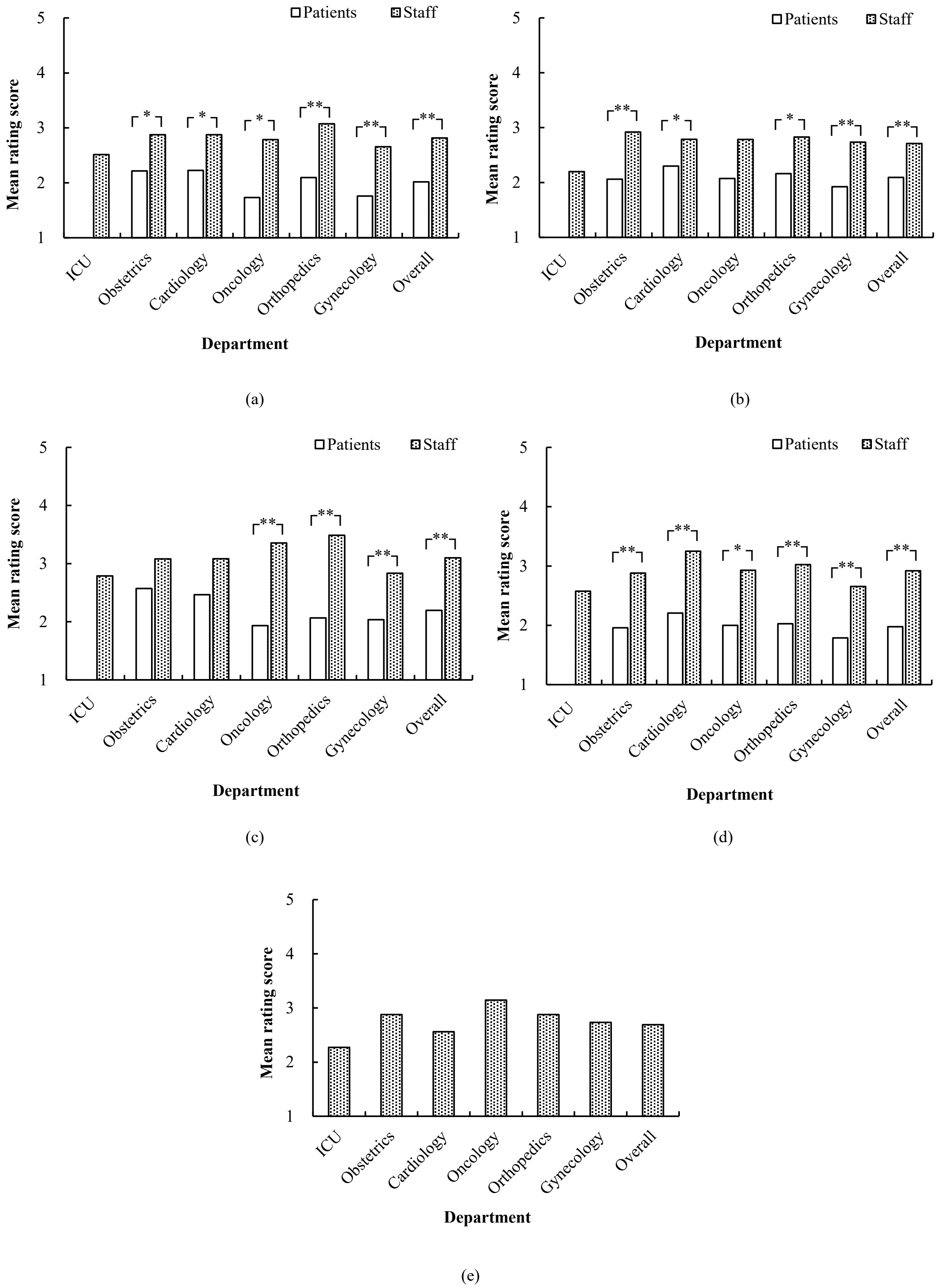

Fig. 6. Influence of noise on participants' (a) communication, (b) emotion, (c) sleep, (d) recovery, (e) work efficiency (staff only) (1 = 'not at all', 5 = 'extremely').

3.3 Noise control strategies

Even though the impact of excessive noise on patients was not as significant as expected according to their subjective evaluation, most of them were not satisfied with the current acoustic environment in their wards. As shown in Fig. 7, among the five major physical environmental issues, 'acoustics' was regarded as the issue to be improved most urgently in their wards by both staff (4.2) and patients (3.7), followed by 'air quality'. The other three indicators, namely, 'temperature', 'humidity' and 'lighting', received less attention as environmental issues in hospital wards.

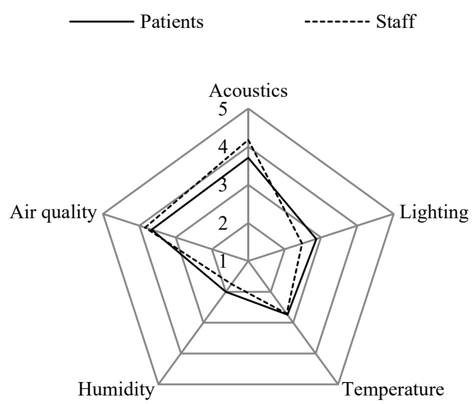

Fig. 7. Comparison of the degree of urgency of improving five physical environmental issues (1 = 'not at all', 5 = 'extremely').

According to Table 6, participants' evaluation of seven appropriate strategies to improve the acoustic environment of wards was closely affiliated with the main noise sources in their wards, as shown in Table 4.

To reduce the noise from medical equipment in the ICU ward, most ICU staff preferred 'absorption treatment' and 'reduce equipment noise' (57.6%). Installation of sound-absorbing ceiling tiles was considered a feasible approach to reduce the noise level of ICUs in a UK hospital [47]. Recommendations for reducing equipment noise often include introducing medical equipment with grading alarm systems in ICU wards and adopting a noiseless paging system or wireless communication devices that can be carried by staff. Several studies also indicated that shifting from overhead paging to wireless communication networks was not effective in reducing noise levels, but patients and medical staff reported fewer disturbances after the interventions [30, 56, 57]. Meanwhile, evidence from several studies highlights that changing staff behavior through noise awareness and education programs can significantly reduce peak noise levels, and the perception of bothersome noise decreases [47, 58-60].

For the general wards, medical staff and patients have different considerations for noise reduction. As noise mainly stemmed from the presence of patients, staff or visitors in the wards, the staff preferred behavior modification as an effective strategy for noise reduction. As expected, ‘reduce visitors’ talking level’ received the most votes, namely, from 64.4% of staff. However, arranging ‘more single-bed wards’ was recommended by most patients from the general wards (with a proportion of 33.7%), followed by reducing the ‘talking levels’ of visitors (32.9%). Patient satisfaction data provided in similar studies also indicated that patients in a single ward, compared to those with roommates, were vastly more satisfied with the acoustic environment [61-63]. Numerous studies have also indicated that the use of single wards is probably the most effective strategy for eliminating noise from other patients [64-67]. This might indicate that a better acoustic environment could be perceived by patients in wards with fewer beds, even though the real noise level was relatively higher, as shown in Table 3.

To deal with extra patients and guarantee medical efficiency, general wards with 2-6 beds are the most common and effective configuration in public hospitals in China. Thus, at the current stage, efforts related to effective management and acoustic treatments might be more practical strategies to improve ward acoustic conditions than increasing the percentage of single wards. For instance, a strict visiting guideline in general wards, such as adhering to visiting hours between 9:00 and 20:00, and a limit of two visitors at a time, may have positive impacts. In addition, indoor soundscape design may be a feasible approach to improve the sound environment for both new and existing hospitals. ‘Play music or natural sound’ could reduce the people’s perception of ambient noise, as voted by 31.4% of patients and 21.8% of staff. Evidence has also shown that the introduction of natural sounds resulted in positive effects on anxiety levels and the rated tranquility of patients [68].

At the current stage, research on hospital acoustics has been very limited in China, and there is no special standard or guideline for acoustic environment evaluation and design in Chinese hospitals. Thus, it is difficult for designers, managers and users to find evidence on the effects of acoustic treatments in environmental design, which we will consider in our next work.

Table 6. Appropriate strategies recommended by staff and patients to improve the acoustic environments of the wards (%).

	ICU	Obstetrics		Cardiology		Oncology		Orthopedics		Gynecology		Overall	
	Staff	Staff	Patient	Staff	Patient	Staff	Patient	Staff	Patient	Staff	Patient	Staff	Patient
Acoustic treatment	57.6	32.0	25.5	35.4	25.8	21.4	26.7	48.8	10.5	40.0	20.0	41.4	19.8
Play music or natural sound	36.4	28.0	23.5	31.3	29.0	35.7	16.7	36.6	22.4	20.0	18.2	31.4	21.8
Reduce staff talking level	54.5	40.0	19.6	35.4	22.6	57.1	13.3	56.1	15.8	43.3	7.3	46.6	15.2
Reduce visitors' talking level	36.4	88.0	27.5	56.3	38.7	71.4	23.3	75.6	34.2	70.0	38.2	64.4	32.9
More single wards	48.5	48.0	47.1	35.4	35.5	21.4	43.3	39.0	25.0	20.0	27.3	36.6	33.7
Reduce equipment noise levels	57.6	52.0	29.4	35.4	29.0	28.6	20.0	63.4	32.9	46.7	16.4	48.7	26.3
Reduce TV sound	12.1	32.0	21.6	20.8	9.7	50.0	10.0	58.5	27.6	63.3	34.5	37.7	23.5

4. Conclusions

This study has provided detailed information about the acoustic environment in typical ICU wards and general wards in China through acoustic measurements and a questionnaire survey.

The results show that Chinese hospitals are facing the problem of excessive noise in wards, especially general wards. The 24-hour noise levels of the thirteen tested wards were greatly in excess of the WHO guidelines. Several general wards obtained higher noise levels during the daytime than the ICU wards. However, the ICU became the noisiest department at night, with a relatively lower variation in sound pressure level. 'Noise from people', especially 'talking from others', was the most significant noise in general wards, whereas 'equipment alarms' were recognized as the major noise in the ICU wards.

The impact of excessive noise on patients was not as significant as expected according to the subjective evaluation. The patients considered that noise had 'a little' impact on their 'communication', 'emotion' and 'recovery' and that a large ward with more patients could result in a greater noise impact on themselves. Sleep interruption due to high noise levels was found to be a major issue, reported by 43.6% of the interviewed patients from general wards. Staff considered noise to have 'moderately' affected their working efficiency.

Staff and patients have different opinions on how to improve acoustic conditions. Most patients from general wards preferred the strategy of arranging 'more single wards' to avoid noise impacts from other patients and their guests. However, introducing effective management to 'reduce the talking level' was primarily recommended by staff when considering the shortage of beds. Meanwhile, a large number of ICU staff considered 'acoustic treatments' and 'reduced alarm levels' to be more suitable for the ICU ward.

The findings of this study have two major limitations. First, the study focused on a small sample size from one general hospital in China. Second, the impacts of noise were only evaluated through a questionnaire survey. Considerably more work will need to be performed to explore the impacts of noise on the physiological states of patients and staff.

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