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Acoustic environments of patient room in a typical geriatric ward

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ABSTRACT

This study aims to investigate background noise levels and noise sources in geriatric ward, and to examine the sound fields of the patient room. Acoustic measurements were carried out over 24-h period in five typical rooms in a geriatric ward in the UK. Based on these measurements, noise levels and sources were analysed in terms of the A-weighted equivalent (L_{Aeq}) and maximum Fast time-weighted sound pressure levels (L_{AFmax}) over three different periods of time during the day. It was found that the measured noise levels of the rooms exceeded the World Health Organisation's guide levels by at least 25 dBA of average levels and at least 10 dBA of the maximum noise level. The most common noise sources in the geriatric ward were talking/voices, door closing/squeaking and general activity. Noise events most frequently occurred during daytime and the majority were talking/voices emanating from patients, staff and visitors. It was also observed that talking/voices produced the highest median value of maximum noise levels, followed by general activity and then door closing/squeaking. Measured reverberation time (T_{20}) at high frequencies in an empty six-bedded room was less than 0.8 s, whereas T_{20} at low frequencies was greater than 1.2 s. Computer simulations showed that absorptive treatments in the ceiling contributed to significant changes in reverberation time and sound pressure level.

1. Introduction

Noise is considered a threat to public health and well-being [1]. Previous studies [2–4] have reported that noise in healthcare facilities negatively influences staff as well as patients. For example, high background noise disrupts patients' sleep at night [2] and greater noise levels can lead to elevated heart rates amongst nurses [3]. The World Health Organisation (WHO) includes guidelines for hospitals in its 'Guidelines for Community Noise' published in 1995. The WHO guidelines [1] recommend noise levels for daytime, evenings and night-time in terms of the A-weighted equivalent (L_{Aeq}) and maximum Fast time-weighted sound pressure levels (L_{AFmax}). According to these guidelines, the background noise level (L_{Aeq}) in a patient's hospital room should not exceed 35 dBA during the day and 30 dBA at night. These guidelines further suggest a L_{AFmax} of no more than 40 dBA at night when measured on the fast setting.

Many studies have conducted noise level measurements in hospitals and, unfortunately, most [5–8] have shown that hospital background noise levels are considerably above the recommended values. Furthermore, since 1960, noise levels in hospitals have increased at an average of 0.38 dB per year during daytime and 0.42 dB during the night [5]. More specifically, the noise levels in intensive care units (ICUs) have varied from 50 dBA to 75 dBA and peak levels at night have reached almost 100 dBA [6]. Busch-Vishniac et al. [5] suggested that the large variation in noise levels across rooms in the hospital was due to the different forms of activity taking place in patient's rooms. However, most research has focused on ICUs: higher and varied sources of noise across different types of patient rooms are therefore rarely investigated. In particular, there has been little investigation into noise exposure in geriatric wards occupied by a high number of elderly patients.

The proportion of elderly patients in hospitals has been increasing in line with an aging population. In the UK, more than 60% of hospital beds are occupied by older patients aged 65 or over [9], while older people account for one-third of all hospitalisations in the USA [10]. The geriatric wards accommodate elderly people who suffer from a range of diseases and disabilities, with dementia being one of the most common medical problems presented in geriatric admission [11]. Older people in hospital often require help with activities of daily living, this requires increasing support and patient contact time. Care on geriatric medicine wards is often provided by a large multi-disciplinary team, this results in increased frequency of staff visits per patient. People with dementia or delirium can often exhibit symptoms of agitation which can include shouting out. These activities might cause an increase in background noise levels; however, noise exposure levels in geriatric wards and the

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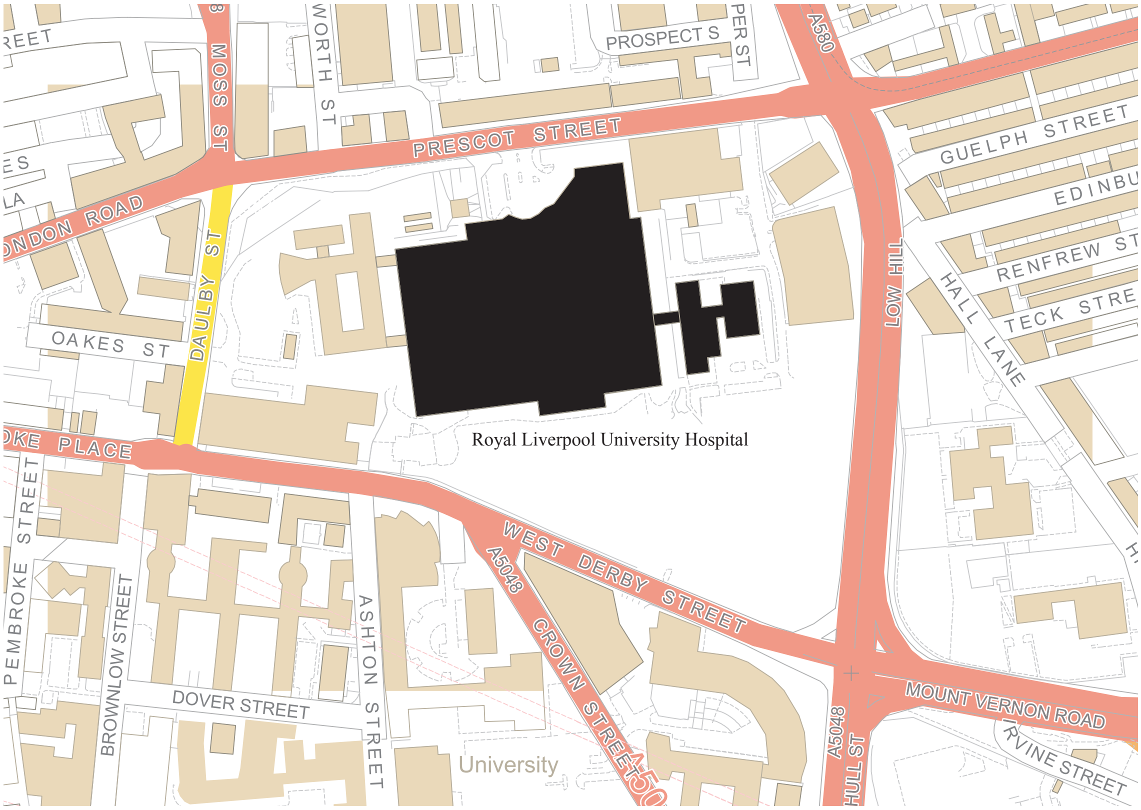

Fig. 1. Site plan of the Royal Liverpool University Hospitals.

contribution of patients' behaviour to this remain unknown.

The aim of this study, therefore, was to investigate noise levels and sources of noise in a typical geriatric ward using measurements collected over a period of 24 hours and to then examine changes in acoustic environments using an acoustic computer simulation. Sound recordings were undertaken, following which A-weighted equivalent and maximum noise levels (L_{Aeq} and L_{AFmax}) were analysed. Noise sources in the geriatric ward were also determined with regard to maximum noise levels. Furthermore, computer simulations were conducted after validating the model against field measurements.

2. Methods

2.1. Case study site

Designed as a case study, measurements were taken on geriatric ward at the Royal Liverpool University Hospitals in the UK in December 2015. The location of site shown in Fig. 1 and it is located along the minor roads (e.g., B5340). As shown in Fig. 2, one ward was included in the study including: two single-bedded rooms, two four-bedded rooms, and one six-bedded room. Single-bedded rooms were facing the North, whilst other rooms were facing the South. All room dimensions are listed in Table 1 in the form 'width × length × height' in metres. All the rooms had an identical height of 2.8 m with larger rooms having greater width and length. The patients on the ward were aged between 66 and 98; 66% were male and 33% were female. Among the patients, 33% were known to have dementia, 33% were admitted with delirium and 13% developed a new delirium during their admission.

Temperature and relative humidity were measured three times a day (11 am, 1 pm and 3 pm) at the centre position of each room using a Maplin 4-in-1 Multi-Function Environment Meter. Room temperatures ranged between 23.0 °C and 24.6 °C with very small variation across the rooms. This result is extremely close to the winter optimal temperature range, 22–24 °C, recommended by the CIBSE Guide A [12]. Relative humidity in the rooms was also acceptable [13], ranging from 43.1% to 51.6%.

2.2. Measurement procedure

Noise measurements were undertaken over three days during typical UK wintertime weather. Noise levels in the patients rooms were measured from one morning through to the next, a total period of 24 hours. Noise was recorded using a half-inch free field microphone (Behringer ECM8000) attached to a portable sound recorder (Zoom H4n) connected to a power supply. The microphone was mounted on a tripod and positioned 0.5 m above the patient's head, and approximately 1.0 m above floor level. The microphone was placed as far away as possible from sound reflecting surfaces (e.g., walls), medical equipment and general daily activity. The noise levels were monitored continuously and all data were transferred to an external hard drive prior to the next recording period. Before the data collection, the entire measurement system was calibrated using an acoustic calibrator (B&K Type 4280).

2.3. Data analysis

From the sound recordings, the A-weighted equivalent sound pressure level (L_{Aeq}) and A-weighted maximum sound pressure level with Fast time-weighting (L_{AFmax}) were calculated at one minute intervals. The recordings were analysed using dBTrait software from 01dBmetravib. In the present study, 24-hour period is divided into the day (07:00–19:00), evening (19:00–23:00), and night (23:00–07:00); therefore, noise levels were calculated for three different periods as well as for 24 hours. Noise events and sources were identified once the noise levels exceeded WHO guideline values. The noise sources were subjectively identified by listening to small sections of the recordings and analysing time histories and frequency characteristics [14].

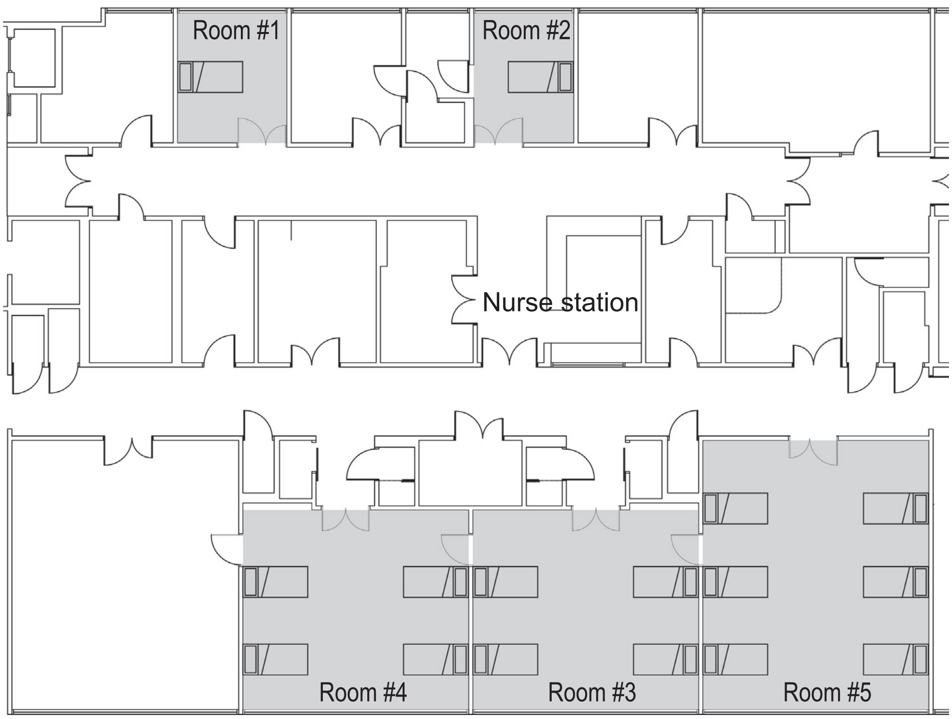

Fig. 2. Floor plan of geriatric ward.

Table 1
Dimensions of rooms in geriatric ward and information of patients.

Room	No.	Dimension (width × length × height)	Age	Diagnosis
Single-bedded	1	3.4 × 3.9 × 2.8	92	Dementia
	2	3.7 × 3.9 × 2.8	98	Pneumonia
Four-bedded	3	6.9 × 6.0 × 2.8	77–8	Pneumonia, spinal complaint, vascular event
	4	6.9 × 6.0 × 2.8	75–92	Fall, infection, acute
Six-bedded	5	6.9 × 8.2 × 2.8	66–95	Infection, seizure, pulmonary embolism, pneumonia, acute renal failure

Table 2
Logarithmic averages and standard deviations (in brackets) of A-weighted equivalent ($L_{Aeq,1min}$) and maximum sound pressure levels (L_{AFmax}). The highest maximum noise level measured in each space is also presented.

	Room	$L_{Aeq,1min}$ [dBA]				L_{AFmax} [dBA]				
		Overall 24-h	Day 07.00–19.00	Evening 19.00–23.00	Night 23.00–07.00	Overall 24-h	Day 07.00–19.00	Evening 19.00–23.00	Night 23.00–07.00	Maximum value
Single-bedded rooms	1	63.4 (9.9)	66.3 (10.6)	51.3 (5.2)	49.9 (3.9)	79.8 (12.3)	82.7 (12.6)	69.9 (7.4)	68.8 (6.4)	96.5
	2	64.5 (7.0)	65.2 (6.6)	65.6 (6.4)	62.3 (7.3)	79.2 (7.8)	80.2 (7.0)	80.4 (7.2)	76.0 (8.5)	91.4
Four-bedded rooms	3	59.0 (5.6)	60.7 (3.6)	58.9 (3.5)	53.4 (4.9)	74.6 (6.1)	75.9 (5.4)	74.7 (5.6)	70.9 (5.8)	91.7
	4	58.3 (8.1)	60.0 (6.1)	56.9 (6.1)	54.6 (6.9)	75.5 (9.4)	77.1 (7.0)	74.4 (7.1)	72.0 (9.3)	92.3
Six-bedded room	5	60.4 (6.1)	62.5 (3.9)	59.0 (4.2)	52.9 (3.7)	76.5 (8.4)	78.5 (5.7)	75.7 (6.4)	69.9 (7.5)	94.9

3. Results

3.1. Noise levels

Logarithmic averages and standard deviations of A-weighted equivalent ($L_{Aeq,1min}$) and maximum Fast time-weighted sound pressure levels (L_{AFmax}) for the complete 24-hour period, day, evening, and night, are listed in Table 2. It was found that all the levels exceeded the recommended WHO values for hospitals. A-weighted equivalent sound pressure levels for 24 hours ranged between 58.3 dBA and 64.5 dBA with single-bedded rooms displaying greater noise levels than other rooms. Noise levels in the single-bedded rooms were greater than 45 dBA after noise emanating from the patients themselves is removed. Noise levels during the daytime were greatest followed by the evening and then the night-time, with the exception of Room #2, where the medical staffs visited the patient several times in the evening. The highest maximum noise levels exceeded 90 dBA in every room.

Table 3 shows the percentages of $L_{Aeq,1min}$ for the full 24-hour

Table 3
Percentages of one-minute A-weighted equivalent sound levels ($L_{Aeq,1min}$).

(a) Single-bedded rooms	1-min L_{Aeq} level percentages				
	% ≤ 40 dBA	40 < % ≤ 50 dBA	50 < % ≤ 60 dBA	60 < % ≤ 70 dBA	% > 70 dBA
Overall 24-h	0.0	36.5	18.8	40.4	4.3
Day (07:00–19:00)	0.1	23.7	19.1	49.4	7.8
Evening (19:00–23:00)	0.0	38.2	19.1	41.5	1.2
Night (23:00–07:00)	0.0	54.6	18.2	26.8	0.4
(b) Four-bedded rooms	1-min L_{Aeq} level percentages				
	% ≤ 40 dBA	40 < % ≤ 50 dBA	50 < % ≤ 60 dBA	60 < % ≤ 70 dBA	% > 70 dBA
Overall 24-h	4.6	23.4	50.6	21.1	0.2
Day (07:00–19:00)	0.0	8.8	56.6	34.5	0.1
Evening (19:00–23:00)	0.0	16.4	67.4	16.2	0.0
Night (23:00–07:00)	14.2	50.3	32.7	2.4	0.4
(c) Six-bedded room	1-min L_{Aeq} level percentages				
	% ≤ 40 dBA	40 < % ≤ 50 dBA	50 < % ≤ 60 dBA	60 < % ≤ 70 dBA	% > 70 dBA
Overall 24-h	0.0	22.4	40.9	36.5	0.3
Day (07:00–19:00)	0.0	1.4	34.8	63.2	0.6
Evening (19:00–23:00)	0.0	6.2	72.2	21.6	0.0
Night (23:00–07:00)	0.0	62.8	34.0	3.1	0.0

Table 4
Percentages of A-weighted maximum sound levels (L_{AFmax}).

(a) Single-bedded rooms	L_{AFmax} level percentages				
	% ≤ 50 dBA	50 < % ≤ 60 dBA	60 < % ≤ 70 dBA	70 < % ≤ 80 dBA	% > 80 dBA
Overall 24-h	1.3	26.5	17.0	34.1	21.1
Day (07:00–19:00)	0.5	15.5	16.6	36.1	31.3
Evening (19:00–23:00)	0.2	25.5	25.7	27.8	20.7
Night (23:00–07:00)	3.1	43.7	13.0	34.3	5.7
(b) Four-bedded rooms	L_{AFmax} level percentages				
	% ≤ 50 dBA	50 < % ≤ 60 dBA	60 < % ≤ 70 dBA	70 < % ≤ 80 dBA	% > 80 dBA
Overall 24-h	1.8	11.3	39.9	40.6	6.4
Day (07:00–19:00)	0.0	3.1	35.4	52.1	9.5
Evening (19:00–23:00)	0.2	6.0	44.4	44.4	5.0
Night (23:00–07:00)	5.3	27.1	45.3	20.3	2.0
(c) Six-bedded room	L_{AFmax} level percentages				
	% ≤ 50 dBA	50 < % ≤ 60 dBA	60 < % ≤ 70 dBA	70 < % ≤ 80 dBA	% > 80 dBA
Overall 24-h	0.3	15.7	30.7	45.0	8.3
Day (07:00–19:00)	0.0	0.8	23.0	63.2	12.9
Evening (19:00–23:00)	0.0	5.4	39.4	47.3	7.9
Night (23:00–07:00)	0.8	43.8	38.2	16.1	1.0

period, day, evening, and night. For single-bedded rooms, most noise levels were above 40 dBA and less than 1% were lower than 40 dBA. During the daytime and evening, over 40% of noise levels were between 60 dBA and 70 dBA, while around 55% of noise levels were between 40 dBA and 50 dBA. Similar results were found in the four-bedded and six-bedded rooms, where most noise levels exceeded 40 dBA. In four-bedded rooms, levels between 50 dBA and 60 dBA were most common during daytime and evening, whereas during the night-time approximately 50% of noise levels were under 50 dBA. In six-bedded rooms, 62.8% of noise levels during the night-time were below 50 dBA.

Percentages of L_{AFmax} for the 24-hour period (day, evening, and night) are listed in Table 4. Most levels were greater than 50 dBA in all the rooms. In the single-bedded rooms, noise levels over the 24-hour period were distributed more or less evenly between 50 dBA and 80 dBA; however, during the night-time, a range between 50 dBA and 60 dBA was more common. In four-bedded and six-bedded rooms, the most common ranges were 70–80 dBA, 60–70 dBA, and 50–60 dBA for the daytime, evening, and night-time, respectively.

Noise levels measured over 24 hours in the rooms are plotted as a function of time in Fig. 3. Black and grey lines represent $L_{Aeq,1min}$ and L_{AFmax}, respectively. There were quiet periods between 11 pm and 6 am in the four-bed and six-bedded rooms, showing that noise levels

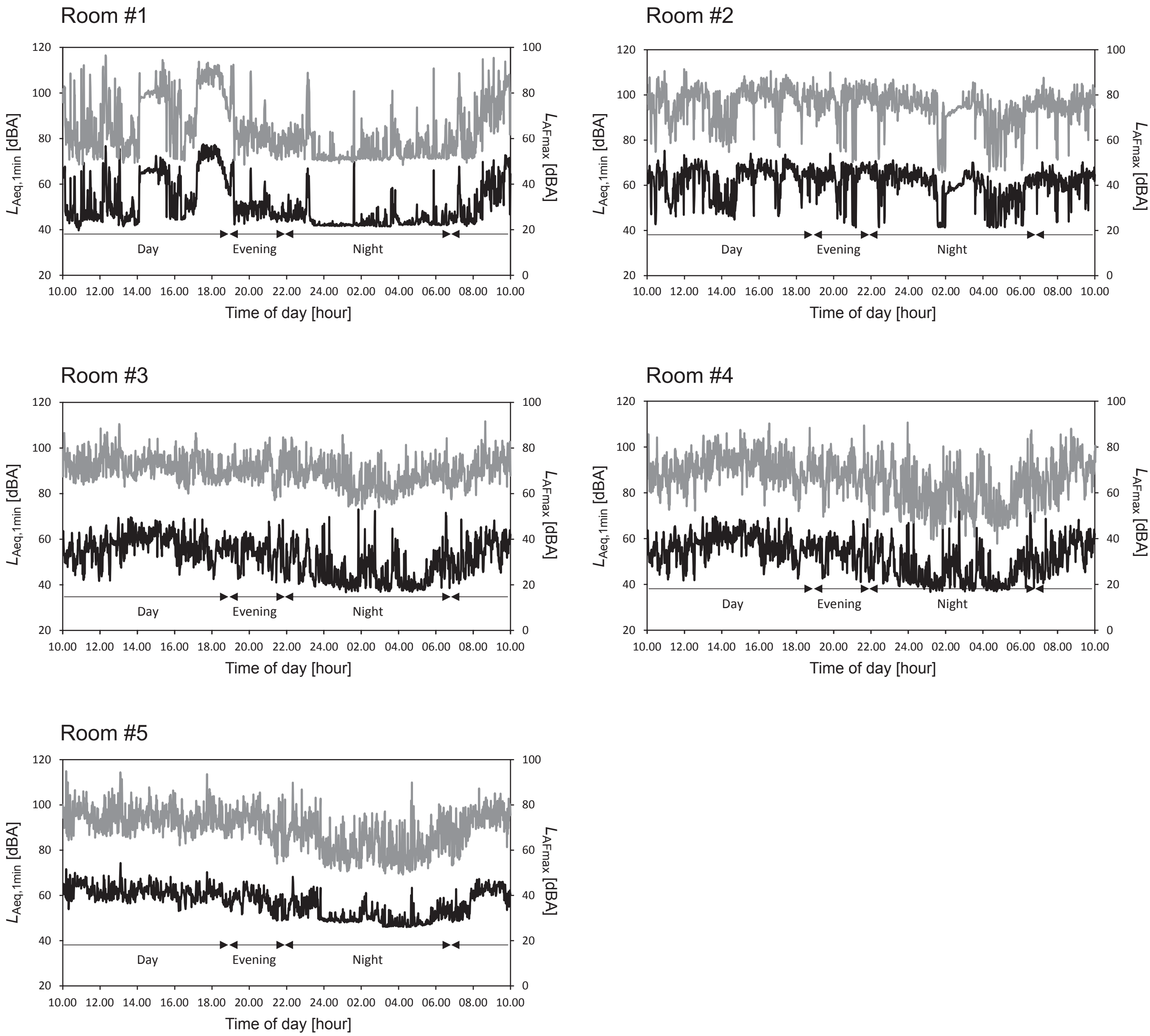

Fig. 3. Noise levels in the patient rooms for 24-h. Black lines represent $L_{Aeq,1min}$ and grey lines represent L_{AFmax}.

decreased at night and then increased on the following day. However, night-time levels were only about 10–15 dB quieter than the rest of the day and there were even loud noises during this period. In contrast, noise levels in two single-bed rooms fluctuated considerably, particularly during the daytime. For example, the noise level ($L_{Aeq,1min}$) of Room #1 exceeded 70 dBA due to patient noise, whereas the noise level decreased to around 40 dBA in the absence of patient noise. It was observed that maximum noise levels were greater than 80 dBA, even at night.

3.2. Noise sources

The number of noise events occurring during the 24-hour period across the rooms is listed in Table 5. The number of such events was similar across all rooms, exceeding 1000 events. Talking/voices was the most frequently occurring noise source in most of the geriatric ward, followed by door closing/squeaking, general activity (e.g. noise from cleaning equipment and cutlery sound), and talking from outside the rooms. For talking/voices, single bed Room #2 produced the largest number of events due patient noise: the patient had a persistent cough. However, most noise events were intermittent and short-lived, although several sources such as talking/voices and TV lasted for several minutes.

Table 6 shows the number of noise events per different type of noise source during the day, evening and night. More than 50% of noise events occurred during the daytime and more noise events occurred during the night-time than the evening. It was found that approximately 50% of the noise events during the daytime consisted of talking/voices emanating from patients, staff, and visitors. Talking/voices were also a major source of noise during the evening and at night due to continuous coughing and raised voices from patients.

During the night-time, talking from outside the rooms accounted for about 15% of noise events. There were two reasons for this; (1) all the patient rooms were very close to a nursing station where the medical staff were located at night and (2) the door was not sealed well against the door frame so that the sound insulation performance of the door was reduced.

Fig. 4 contains boxplots illustrating the maximum noise levels

Table 5
Number of noise events for 24-h across the rooms. Asterisk indicates the sources which last longer than one minute.

Sources	Single-bedded		Four-bedded		Six-bedded	Total
	1	2	3	4	5	
Talking/voice*	328	979	672	528	494	3001
Door closing/Squeaking	423	193	86	161	188	1051
General activity	90	53	146	306	323	918
Talking (outside)*	271	7	5	203	47	533
Cough/Clearing throat	4	48	156	92	129	429
TV*	0	0	258	0	26	284
Bins	58	11	46	10	73	198
Equipment sounds*	65	84	1	20	4	174
Furniture scraping	6	14	14	43	12	89
Bed clinking/Rail	1	16	13	20	12	62
Laughing	2	1	12	24	14	53
Dropped object	4	1	13	13	16	47
Alarm/Phone ringing	28	6	1	0	11	46
Wheel	8	0	6	6	11	31
Cough (outside)	8	0	1	1	0	10
Footsteps	4	0	0	0	0	4
Total	1300	1413	1430	1427	1360	6930

Table 6
Number of noise events across types of the source for day, evening, and night. Asterisk indicates the sources which last longer than one minute.

Sources	Day 07:00–19:00	Evening 19:00–23:00	Night 23:00–07:00	Total
Talking/voice*	1548	596	857	3001
Door closing/squeaking	546	179	326	1051
General activity	592	108	218	918
Talking (outside)*	120	90	323	533
Cough/clearing throat	213	53	163	429
TV*	177	61	46	284
Bins	135	27	36	198
Equipment sounds*	39	8	127	174
Furniture scraping	64	13	12	89
Bed clinking/rail	33	12	17	62
Laughing	40	12	1	53
Dropped object	25	11	11	47
Alarm/phone ringing	16	11	19	46
Wheel	16	5	10	31
Cough (outside)	4	4	2	10
Footsteps	3	0	1	4
Total	3571	1190	2169	6930

(L_{AFmax}) from four major noise sources: (1) talking/voices, (2) door closing/squeaking, (3) general activity and (4) talking (outside). Amongst the major noise sources, talking/voices gave rise to the highest median value, followed by general activity and door closing/squeaking. The median value of noise from talking outside the rooms was much lower than that of other noise sources.

4. Discussion

4.1. Noise levels and sound sources in the geriatric ward

The results of this study showed that noise levels on the geriatric ward significantly exceeded the recommended WHO guideline [1] – by at least 25 dBA of average levels and at least 10 dBA of the maximum noise level. This is in accordance with the findings of previous studies [5,7,8,15] which reported that noise levels in wards and patient rooms do not meet the recommended guidelines. Noise levels in three surgical wards, including multi-bed wards, exceeded the guideline values; for example, the daytime noise level ($L_{Aeq,1h}$) ranged between 50 and 60 dBA, while night-time levels varied from 40 to 45 dBA [7]. Another study [8] also showed that noise level in general medical ward from

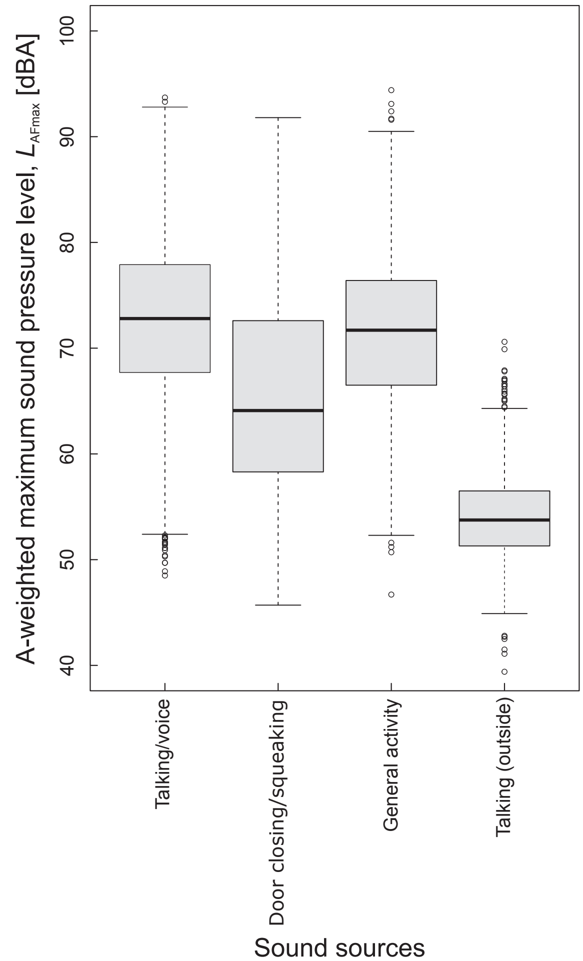

Fig. 4. Boxplots of A-weighted maximum sound pressure levels (L_{AFmax}) for dominant noise sources.

7am to 11 pm was around 67 dBA. Moreover, Bayo et al. [4] measured noise levels at 232 grid positions on one floor in a hospital between 9am and 1 pm, and again between 4 pm and 8 pm. The mean and maximum noise levels (L_{Aeq}) in ward areas were 58 dBA and 69.5 dBA, respectively, significantly above the guideline values. According to Busch-Vishniac et al. [5], the measured noise levels in Johns Hopkins Hospital also exceeded the WHO guidelines; L_{Aeq} varied from 50 to 60 dBA and L_{AFmax} ranged between 60 and 70 dBA. Based on previous findings and those in the present study, it can be concluded that noise levels are likely to exceed WHO guidelines in most wards and patient rooms.

The present study also revealed that the noise levels for a 24-hour period, daytime, evening, and night-time in single-bedded rooms were greater than those in four-bed and six-bedded rooms. In contrast, Xie and Kang [16] reported that nocturnal noise levels in multi-bed rooms were higher than in single-bedded rooms located in Intensive Care Units. The difference between the findings of the current study and those of previous research [16] suggest that noise levels and sources of noise are affected by the types of room and the nature of the patients.

The present study showed that the main sources of noise in the geriatric ward were talking/voices, door closing/squeaking, and general activity. Most notably, talking/voices accounted for 43.3% of all noise events. This is inconsistent with the findings of MacKenzie and Galbrun [15] who sought to identify noise sources in an ICU and high dependency unit (HDU). They reported that use of the rubbish bin was the greatest source of noise, followed by general activity and then talking. They also observed that the number of occurrences of noise were evenly distributed across all sources. Inconsistency between the current study and previous research [15] may be due to a difference in

Fig. 5. Typical six-bedded room in the Royal Liverpool University Hospitals, Liverpool.

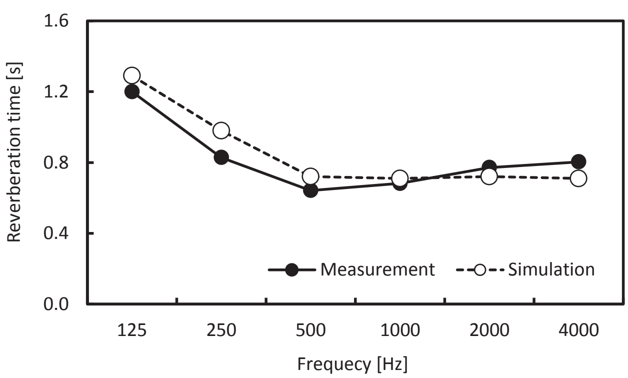

Fig. 6. Measured and predicted reverberation time (T_{20}). Filled and open circles represent measured and predicted values, respectively.

the type of rooms investigated. Unlike the ICU and HDU, geriatric ward accommodates elderly patients who require extra help compared to younger patients. Thus, staff working in geriatric ward visit the patient rooms more frequently and this may lead to an increase in the occurrences of doors closing/squeaking and talking. Moreover, two patients in the single-bedded rooms were responsible for a number of occurrences of talking/voices. The overall percentage of talking/voices significantly decreased to 30.1% when occurrences from single-bedded rooms were excluded. Many previous studies [15,17,18] have referred to medical equipment alarms, conversations between staff and visitors, caregiving activities, and closing doors as dominant noise sources which were also identified in the geriatric ward, as seen in Table 5. However, in contrast with ICUs, medical equipment alarms are not a dominant noise source in geriatric ward.

4.2. Sound field of a patient room in the geriatric ward

A computer simulation of an unoccupied and fully furnished six-bedded room (see Fig. 5) was conducted to investigate the sound field of the patient room and to explore how a change in material finish affects the sound field. Prior to the computer simulation, a simple acoustic measurement was performed in the six-bedded room. Room impulse responses were measured at two positions using a balloon pop as an excitation signal. The measured reverberation time (T_{20}) at 1 kHz was 0.68 s, whereas T_{20} were longer than 1.0 s at low frequencies. The room was later modelled using 3D computer software and then imported into acoustic software (Odeon version 14.0). This software has been widely used to predict the acoustic environments of auditoria and outdoor spaces [19–21]. Simulations were performed by setting the transition order (TO) = 2, using 1000 rays and a reflection order of 1000. Impulse response lengths were fixed at 1000 ms throughout the simulation. Prior to the computer simulation, the simulated room was validated in relation to the measured reverberation time. As shown in Fig. 6, the predicted reverberation time at 1 kHz showed good agreement with a measured value, falling within a 5% error range. The final acoustic inputs for each surface of the fitted model are listed in Table 7. In the simulation, scattering coefficients of 0.05 were applied to all the surfaces. In terms of alterations, two highly absorbent suspended ceiling systems were introduced; (1) 19 mm mineral fibre board with 200 mm cavity (ALT 1) and (2) 20 mm glass wool boards with 30 mm cavity (ALT 2).

Table 8 shows changes in the acoustic environments with absorptive

Table 7
Acoustic inputs of each surface element of the fitted model.

Elements	Details	Scattering coefficient	Absorption coefficients by frequency					
			125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Floor	Average absorption of floor [20]	0.05	0.02	0.03	0.03	0.04	0.04	0.04
Ceiling	30 mm plaster on metal lath	0.05	0.14	0.10	0.06	0.05	0.03	0.03
Wall	Average absorption of floor [20]	0.05	0.23	0.12	0.08	0.05	0.05	0.05
Window	Double glazing, 2–3 mm	0.05	0.10	0.06	0.04	0.03	0.02	0.02
Cabinet/Drawer	Absorption of cabinet/drawer [20]	0.05	0.03	0.05	0.04	0.01	0.03	0.02
Bed	Absorption of bed [20]	0.05	0.04	0.25	0.75	0.98	0.99	0.99
Small chair	Absorption of small chair [20]	0.05	0.07	0.11	0.18	0.20	0.23	0.26
Folded curtain	Cotton cloth folded to ½ area	0.05	0.07	0.31	0.49	0.81	0.66	0.54
Ceiling: ALT1	Suspended ceiling system (Armstrong, Ultima +): 19 mm mineral fibre board, 200 mm cavity	0.05	0.4	0.5	0.65	0.85	0.95	1.00
Ceiling: ALT2	Suspended ceiling system (Ecophon Focus A): 20 mm glass wool board, 30 mm cavity	0.05	0.1	0.45	0.85	1.00	1.00	1.00

Table 8
Differences in reverberation time (T_{20}) and sound pressure level (SPL) between current and improved conditions.

		Frequency [Hz]					
		125	250	200	1000	2000	4000
T_{20} [s]	ALT 1	0.56	0.43	0.31	0.34	0.36	0.37
	ALT 2	−0.23	0.40	0.35	0.37	0.38	0.37
SPL [dB]	ALT 1	2.47	2.70	2.63	3.20	3.70	3.80
	ALT 2	−0.77	2.40	3.30	3.93	3.87	3.80

suspended ceiling systems in terms of reverberation time and sound pressure level (SPL). There were great changes in T_{20} and SPL in environments with highly absorptive ceilings. Reverberation times were significantly decreased for two alterations except for 125 Hz of ALT2. Xie and Kang [20] also reported that a patient room with an acoustic ceiling had a shorter reverberation time and lower SPL compared to a patient room without an acoustic ceiling. Significant changes in sound pressure level were also found across all in all frequency ranges. In particular, the decreases of sound pressure level at high frequencies above 500 Hz were greater than 3 dB which is recognisable. The present study indicates that internal noise largely originates from people in the patient room. As Woods [22] previously explained, staff were generally unaware of the noise they were creating; thus, noise levels in the patient rooms were highest close to the nursing station where staff frequently move about. Thus educating the staff could also be a practical measure when changing the finishing materials is not available to reduce levels of noise coming from sources such as general activity, dropped objects, and talking/voices [8,15].

5. Conclusion

In the present study, noise measurements were collected over a 24-hour period in the typical geriatric ward in the UK. The average and maximum noise levels over 24 hours (day, evening, and night) were analysed. Noise levels in all the patient rooms were in excess of the recommended WHO guidelines during both the daytime and night-time. Noise levels for daytime were above 60 dBA in all the rooms and noise levels at night ranged from 50 to 62 dBA. Talking/voices were most frequently heard, followed by door closing/squeaking and then general activity. Most noise events occurred during the daytime, accounting for more than 50% of the total number of noise events. With regard to maximum noise levels across all noise sources, the median value for talking/voices was the greatest, followed by general activity and then door closing/squeaking. The reverberation time of a furnished and unoccupied six-bedded room was less than 0.8 s at high frequencies but greater than 1.0 s at low frequencies. Results of the computer simulation indicate that an acoustic ceiling with high absorption coefficients leads to significant reductions in reverberation time and sound pressure level. In future, a questionnaire survey will need to be conducted amongst patients and staff in order to investigate the effects of noise exposure on psychological well-being.

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