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NOISE ASSESSMENT WITHIN HEALTHCARE FACILITIES: ANNOYANCE AND INTRUSIVENESS OF SOUND SOURCES

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ABSTRACT

Noise in hospitals is an issue that is increasing over time. Therefore, investigations in this context deserve special attention. The World Health Organization (WHO) has expressed concerns about the effects of noise on human health, especially on people defined as vulnerable, as patients can be. Additionally, long-term noise exposure by healthcare personnel can lead to stress and the development of cardiovascular diseases. Most studies currently measure noise within hospital environments using parameters such as the A-weighted equivalent level (L_{Aeq}) and the A-weighted maximum level (L_{Amax}), which are in line with the recommendations made by the WHO. Nevertheless, quantifying noise and the annoyance it may cause on users is complex. Some studies use psychoacoustic parameters to describe noise and its perception by users within these contexts. In Italy, UNI/TS 11844:2022 proposes a method to quantify the intrusiveness of a sound source based on Detection Theory. This article, referring to measurements performed within an Italian medical general ward, proposes a discussion of these methods to explore their application in the hospital context.

Keywords: *noise monitoring, hospital environment, annoyance, intrusive noise*

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1. INTRODUCTION

Noise pollution is one of the most concerning environmental factors due to its potential impact on human health [1]. Specifically, it can have more significant effects on vulnerable people such as children, the elderly, the sick, and those hospitalized [2]. Hospitals are complex environments where users constantly face external stimuli [3]. In these settings, noise can negatively affect healthcare personnel and patients [4-6]. Critical effects on hospital users may include sleep disturbance, annoyance, and interference with communication and alert signals [4]. For patients, sleep deprivation can induce a state of alertness, affecting mood, behavior, coping abilities, respiratory muscle function, healing time, and length of hospitalization [5]. For these reasons, in hospitals, the A-weighted equivalent level (L_{Aeq}) should not exceed 30 dBA both day and night in all areas frequented by patients. Moreover, peak levels (L_{Amax}) should not exceed 40 dBA to avoid user disturbance [4]. Unfortunately, many studies have highlighted that noise levels in hospital wards often exceed the WHO's recommendations [7-9] and increase year by year [10].

Patients are more sensitive to noise during hospitalization due to their peculiar condition. Most of the noise reported by patients hospitalized in 2-bed rooms in Medical general wards originates from outside the room [9]. The acoustics of hospital corridors are often overlooked, even though these areas are used for manifold activities related to patient care rather than just for simple transit [11].

The quantification of sound-induced disturbances is complex and does not solely depend on the measured sound pressure levels [12-13]. A study by Nassiri et al. highlighted that no statistically significant relationship was found between the equivalent noise level (L_{Aeq}) and noise annoyance among healthcare staff [14]. Some relevant aspects in evaluating noise are spectral features and temporal characteristics. Thus, besides sound pressure levels, other aspects should be evaluated, such as the context, duration of exposure, time of day, sound increment, and individual socio-demographic characteristics. [15].

Soundscape theories and psychoacoustic parameters provide a complementary approach to noise assessment. The Fastl & Zwicker theory attempts to quantify the annoyance that noise can cause to the user based on evaluating psychoacoustic parameters [16]. In Italy, the UNI/TS 11844:2022 standard proposes an assessment of the intrusiveness of sound sources in each acoustic scenario based on the Detection Theory [17-18]. These two approaches attempt to propose a method of quantifying noise disturbance.

This paper compares the Psychoacoustic Annoyance based on Zwicker's model and the intrusiveness of the main sound sources within a hospital ward.

2. METHOD

This study is part of investigations within an Italian medical general ward. This ward has a one-corridor layout with mirrored two-bed rooms on both sides. The investigation occurred in a portion of the ward shown in Fig. 1.

Four 20-minute-long monitoring sessions were conducted during the day using a class 1 sound level meter. Sound pressure levels and spectra were detected with a fast time constant, an interval time of 0.1 s, and a frequency range of 20-20000 Hz. The audio was also recorded in .wav format with a 48 kHz sample rate.

Some healthcare staff members answered a survey to detect where the worst place is and what the most disturbing noise sources within the ward are. Since users complained that most potentially disturbing sound sources reach the patient through the corridor, monitoring occurred in the corridor (Monitoring station, in Fig.1).

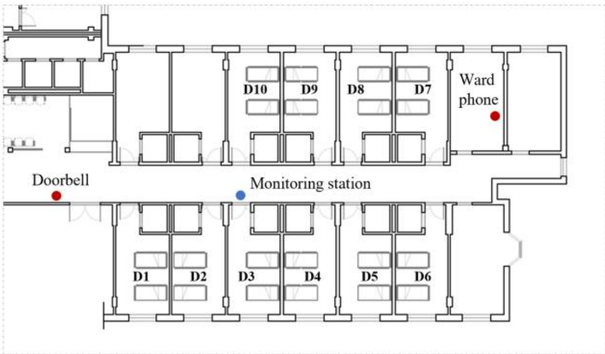

Figure 1. Floor plan of the ward area under study.

2.1 Psychoacoustic Annoyance

The noise disturbance of the sources detected during the survey was evaluated using the annoyance through Fastl & Zwicker's method [16].

The psychoacoustic annoyance (PA) is calculated using the following formula:

$$\mathrm{PA} = \mathrm{N}_5\left(1 + \sqrt{(\mathrm{w}_S^2 + \mathrm{w}_{FR}^2)}\right) \quad (1)$$

$$\begin{cases} w_S = (S - 1.75)0.25log(N_5 + 10) & S > 1.75 \\ 0 & S < 1.75 \end{cases} \quad (2)$$

$$w_{FR} = 2.18(0.4F + 0.6R)/N_5^{0.4} \quad (3)$$

where N_5 is the 5th percentile loudness in sone, the loudness level exceeded for 5% of the time, S is the Sharpness in acum, F and R are the fluctuation strength in vacil and the roughness in asper, respectively.

The model suggests that annoyance is not solely determined by loudness but is also significantly influenced by the temporal and spectral characteristics of the sound, as captured by sharpness, fluctuation strength, and roughness.

To Compare PA and the intrusiveness values, the mean annoyance MA and the percentage of highly annoyed people %HA have been used [19]. MA expresses PA values on a 0-10 scale, while %HA shows the percentage of highly annoyed people.

2.2 The intrusiveness of sound sources

The method to evaluate the intrusiveness of sound sources is based on the UNI/TS 11844. It is based on the Detection Theory, which quantifies a listener's ability to distinguish a sound in a given acoustic scenario [18]. This method involves determining the Detectability

Level (D'L) by comparing the flat frequency spectrum of the specific source to that of the residual noise.
The standard also proposes using the spectrum in critical bands (Bark scale) to account for auditory masking.
For each frequency band, the Detectability (d_i) is calculated using the following formula:

$$d_i' = \eta\sqrt{BW_i} \cdot \frac{10^{\frac{L_{si}}{10}}}{10^{\frac{L_{ri}}{10}}} \tag{4}$$

where η represents the human observer efficiency, set to 0.4; BW_i is the bandwidth; L_{si} and L_{ri} refer to the band levels (dB) of the specific source and residual noise, respectively.
The Detectability Level (D'L) is calculated as follows:

$$D'L = 10\log(d_c') \tag{5}$$

where d_c' is a cumulative value, taking into account d'_i-contributions in all N bands:

$$d'c = \sqrt{d_1'^2 + d_2'^2 + \cdots + d_N'^2} \tag{6}$$

Based on the D'L, an Intrusiveness Level is assigned to the source, referring to the scale shown in Tab. 1.

Table 1. Intrusiveness scale in relation to D'L value.

Detectability Level (dB)	Intrusiveness scale
D'L < 13	Negligible
13 ≤ D'L < 18	Very Low
18 ≤ D'L < 23	Low
23 ≤ D'L < 33	Medium
33 ≤ D'L < 43	High
D'L ≥ 43	Very high

3. RESULTS AND DISCUSSION

Four Spot 20-minute monitors were carried out within the ward corridor in the same position during the whole working day.
The sound pressure levels of each measurement are shown in Tab. 2 (ID 01-04) in terms of A-weighted equivalent, maximum and minimum levels (L_{Aeq}, L_{Amax}, and L_{Amin}), and statistical levels (L_{10}, L_{50}, and L_{90}).
L_{Aeq} and L_{Amax} are highly above the limit values specified by the WHO to protect human health (L_{Aeq}<30 dBA e L_{Amax}<40 dBA) [6].
Specifically, A-weighted equivalent sound pressure levels were never below 30 dB during the four monitorings. The difference between the statistical levels L_{10} and L_{90} represents the time variability of the sound level during monitoring.

Table 2. 20-minute sound pressure levels monitoring results.

ID	Time	LAeq (dBA)	LAmax (dBA)	LAmin (dBA)	L10 (dBA)	L50 (dBA)	L90 (dBA)
01	11:32:00	60.5	83.4	39.8	63.5	54.1	46.8
02	16:07:00	53.0	74.8	36.2	55.3	45.5	39.5
03	17:04:00	55.4	79.5	36.1	56.7	48.0	41.7
04	08:57:00	57.7	84.8	40.6	60.3	53.2	47.6

The following sound sources were predominantly observed during monitoring, according to survey responses:

- Stretcher
- Cart
- Beep alarm
- Room alarm
- Ward phone
- Doorbell
- Speech

Of these sources, the disturbance was assessed using the PA through Zwicker's model and the intrusiveness according to the Italian UNI/TS 11844.
Tab. 3 shows the results of the psychoacoustic parameters in terms of loudness (N), sharpness (S), roughness (R), and fluctuation strength (FS). Also, psychoacoustic annoyance (PA), mean annoyance (MA), the percentage of highly annoyed people (%HA), the detectability levels (D'L), and the corresponding intrusiveness classification are reported.

Table 3. Psychoacoustic parameters, Fastl and Zwicker model results, and UNI/TS 11844:2022 results.

Spot n.	Source	N (sone)	S (acum)	R (aspers)	FS (vacil)	Fastl and Zwicker and model			UNI/TS 11844:2022	
						PA	MA	%HA	D'L (Bark)	Intrusiveness
Spot 01	Stretcher 1	26.0	1.43	0.12	0.06	34.4	7.4	31	25	Medium
	Stretcher 2 (distance)	17.2	1.45	0.11	0.03	20.2	4.9	5	17.7	Very Low
	Stretcher 3	32.7	1.54	0.09	0.06	42.0	8.4	58	30.3	Medium
	Beep alarm	18.1	1.48	0.10	0.06	21.8	5.2	7	18.8	Low
	Ward phone	18.4	1.49	0.10	0.04	22.6	5.3	8	17.9	Very Low
	Speech	34.3	1.32	0.12	0.06	41.8	8.3	57	27.2	Medium
Spot 02	Room alarm (D2)	11.1	1.66	0.10	0.04	13.3	3.6	2	21.7	Low
	Doorbell	13.5	1.50	0.06	0.15	15.6	4.0	3	28.9	Medium
	Stretcher + Doorbell	25.5	1.45	0.14	0.42	34.1	7.4	30	33.7	High
	Ward phone	14.5	1.50	0.10	0.08	19.4	4.7	5	27.6	Medium
	Speech	30.9	1.33	0.11	0.12	41.5	8.3	56	39.1	High
Spot 03	Room alarm (D1)	18.6	1.53	0.09	0.06	21.2	5.1	6	25.1	Medium
	Room alarm	10.5	1.56	0.06	0.05	12.9	3.5	2	16.8	Very Low
	Beep alarm	12.4	1.73	0.09	0.10	16.6	4.2	3	21.4	Low
	Stretcher 1 (distance)	10.2	1.63	0.07	0.09	12.6	3.5	2	16.7	Very Low
	Stretcher 2	33.0	1.85	0.12	0.47	48.6	9.0	78	39.8	High
	Stretcher 3	30.1	1.34	0.11	0.09	39.6	8.1	49	35.1	High
	Ward phone	15.9	1.44	0.09	0.07	19.7	4.8	5	25.1	Medium
	Speech	23.7	1.29	0.09	0.05	34.4	7.4	31	30.2	Medium
Spot 04	Room alarm (D2)	26.1	1.59	0.09	0.19	28.6	6.5	16	27.2	Medium
	Stretcher	19.0	1.58	0.12	0.03	23.5	5.5	9	19.5	Low
	Stretcher	32.5	1.60	0.14	0.49	44.9	8.7	68	31.0	Medium
	Stretcher	24.2	1.48	0.12	0.04	30.1	6.7	20	24.2	Medium
	Cleaning cart	28.1	1.55	0.09	0.04	34.7	7.5	32	29.4	Medium
	Cleaning cart	19.4	1.39	0.12	0.05	23.8	5.6	9	18.5	Low
	Dressing cart	19.7	1.53	0.13	0.10	24.2	5.7	9	28.2	Medium
	Ward phone	18.7	1.37	0.09	0.05	22.1	5.3	7	19.5	Low
	Speech	22.8	1.26	0.10	0.07	28.6	6.5	16	20.9	Low

The intrusiveness results of each sound source showed a certain consistency across the four monitors in relation to the type of source category. Furthermore, microphone-source distances influence the results. Indeed, different levels of intrusiveness to the sources (e.g., In Tab. 5 - ID 01 - stretcher: medium intrusiveness; stretcher passing at a distance: very low intrusiveness) can be noticed. In the sources' names, the term "distance" in brackets refers to the sound sources coming from different wards from the measurement position.

Table 3 shows that Sharpness influences the psychoacoustic annoyance ($S > 1.75$, see eq. 2) only in one case, i.e., stretcher 2 during Spot 03. This case is the most annoying source, with an MA equal to 9 and 78% of highly annoyed people %HA.

It is crucial to note that the MA and %HA values presented in this table are specific to Fastl and Zwicker's model. MA and %HA models were formulated by Guoqing et al. for substation noise [19]. While both approaches aim to quantify perceived annoyance and the percentage of highly annoyed people, it is essential to understand that they employ different methodologies and might be calibrated for different types of noise. This preliminary study uses an average of the coefficients of the logistic regressions made by Guoqing et al. to calculate MA and %HA. However, results seem to give back qualitatively reliable results.

In summary, Table 3 offers a concise overview of how various psychoacoustic parameters correlate with the Fastl and Zwicker model's annoyance predictions and an independent assessment of intrusiveness for a series of everyday sounds. This type of analysis is fundamental for a better understanding of how the physical characteristics of sound influence human perception and annoyance.

Fastl and Zwicker's model aims to predict how annoying a sound is likely to be based on its acoustic characteristics and how humans perceive it. For instance, a sound with higher values in psychoacoustic parameters contributing to annoyance would likely result in higher PA, MA, and %HA values, indicating a more significant predicted annoyance. Intrusiveness, on the other hand, assessed using the UNI/TS 11844 standard, is a more qualitative evaluation of how much a sound stands out from the background noise and captures attention. It is categorized in the table as "Medium", "Very Low", or "Low". Intrusiveness seems to relate to the perceptual salience of a sound within an acoustic environment. A sound might be considered intrusive if it is unexpected, intermittent, or has characteristics that make it easily noticeable against the ongoing background, regardless of its overall loudness or predicted level of long-term annoyance. The downside of PA parameters is represented by the need to record audio, which is not always possible because of privacy issues. A sound could be highly intrusive (e.g., a sudden beep) but not necessarily lead to high long-term annoyance, especially if it is short-lived or infrequent. Conversely, a continuous, low-level sound might have low intrusiveness but can still cause significant annoyance over time due to factors like interference with activities or sleep [18].

4. CONCLUSIONS

The research increasingly focuses on noise within hospitals due to its effects on both patients and staff. Hospitals are complex environments characterized by high and continuously increasing sound pressure levels. However, it is crucial to recognize that sound pressure levels alone are insufficient to quantify the sound-induced disturbance experienced by individuals fully.
To broaden the analysis of source noise in healthcare settings, assessing intrusiveness and annoyance based on psychoacoustic parameters offers two complementary approaches. Both methods, psychoacoustic assessment and intrusiveness evaluation, provide additional insights by considering sound spectral and temporal characteristics beyond simple sound pressure level measurements. Specifically, Fastl & Zwicker's model attempts to quantify the annoyance that noise can cause to users by evaluating psychoacoustic parameters. The Italian UNI/TS 11844:2022 standard proposes a practical method for assessing the intrusiveness of sound sources in specific acoustic scenarios based on on-site measurements of sound pressure levels and spectra. Therefore, these methods, including quantifying psychoacoustic annoyance and assessing intrusiveness, can serve as additional valuable tools for improved design and diagnostics in critical spaces such as hospitals. While the assessment of intrusiveness is characterized by a practical approach based on on-site measurements, the investigation of psychoacoustic annoyance adopts a more conceptual approach that aims to understand the user's subjective perception. Further work is needed to deepen the understanding and refine the application of the psychoacoustic parameters and intrusiveness metrics used in these evaluations within diverse healthcare contexts.

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