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Noise and Legal Dispute: Applications and Limits of the Italian Standard UNI/TS 11844

Fabio Serpilli [1,*,†], Samantha Di Loreto [2,†], Valter Lori [1,†] and Sergio Montelpare [2,†]

1 Department of Industrial Engineering and Mathematical Sciences, Università Politecnica delle Marche, Brecce Bianche 12, 60131 Ancona, Italy; v.lori@univpm.it
2 Engineering and Geology Department (INGEO), University "G. d'Annunzio" of Chieti-Pescara, Viale Pindaro 42, 65127 Pescara, Italy; samantha.diloreto@unich.it (S.D.L.); sergio.montelpare@unich.it (S.M.)
* Correspondence: f.serpilli@univpm.it
† These authors contributed equally to this work.

Abstract: In forensic acoustics, a possible area of analysis is represented by unwanted sound that is perceived as a source of intrusion or disturbance within a certain auditory context. This context is defined as the "auditory scene" and refers to the set of sounds present in a specific environment. The presence of unwanted sounds in the auditory scene can cause a wide range of negative effects, including disturbance, discomfort, moral or immoral harm, and other types of negative impacts on the health and well-being of individuals exposed to noise. In 2022, the technical specification UNI/TS 11844:2022 dedicated to the measurement and analysis of intrusive noise was published. The standard introduces the concept of intrusive noise and defines its calculation methods based on environmental measurements. The purposes of this technical specification is to provide an objective support to methods already in used in acoustic disputes, where the assessment of the annoyance of a noise is often a subjective evaluation of the technician. This work delves into application to some real cases, identifying the potentiality and limits of the standardized method.

Keywords: intrusive noise; signal detection theory; acoustic standard; acoustic disputes

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1. Introduction

Noise is, to a great extent, a purely subjective personal phenomena. Perhaps, the best definition of it is as an unwanted sound [1].

Noise does, however, have two basic characteristics: the first is the physical phenomenon which can be measured and thus used in technical specification, and the second is the psychoacoustic characteristic which attempts to judge the effect of noise on human beings [2].

Quality of life is strongly influenced by the acoustic quality of the buildings where we live, work, and rest. The perceived well-being in these spaces is heavily conditioned by the presence of noises coming from the outside or adjacent units, as well as by the discomfort derived from excessive internal reverberation [3].

Researchers have long questioned the efficacy of current metrics and measurement methods in representing people's perception [4–6].

In industries that use small cooling fans, fan noise simply interferes with the ability of the people working nearby to concentrate on their work [7].

The factors that are of greatest importance to system designers are the psychological influences on the person rather than the physical influences of sound on the human ear [8–10].

Many industries represent an important cause of occupational noise-induced hearing loss (NIHL), a significant yet underappreciated problem in many developing countries [11–13].

Noise tolerance refers to the vulnerability of an individual to noise. People with reduced noise tolerance may not tolerate sounds at intensity levels considered comfortable by most other people [14].

In [15], the task encompasses a methodical examination of scientific literature, while considering the repercussions of noise exposure and the documented harm to various apparatuses.

The sound that is perceived as disturbance can be described using a combination of objective and subjective parameters.

Objective parameters are defined by the physics of sound and propagation and include features such as intensity, frequency, duration, and directionality of the sound. Subjective parameters, on the other hand, are defined by psychoacoustics and encompass factors such as age, sex, personality, expectations, and individual listening experiences [16].

However, the relationship between these objective and subjective parameters is complex and depends on many factors, including the listener's perception, the context in which the sound occurs, and environmental conditions. For example, the same sound can be perceived differently by different individuals based on their experiences, moods, and expectations.

Therefore, to assess the impact of a sound on the listener's perception, it is necessary to consider both objective and subjective parameters and their intricate interaction.

However, researchers disagree over the reliability of objective parameters in relation to subjective perception. In particular, they study how much human beings can be sensitive to changes in relation to indoor acoustic conditions [17–20].

A soundscape refers to the collection of sounds present in a specific environment or geographic area. Sound intrusiveness, on the other hand, refers to the subjective perception of a sound as annoying, disruptive, or harmful [21].

This perception can be influenced by the composition of the soundscape, that is, the type, quantity, and quality of the sounds present. For example, a sound that is considered pleasant and integrated into the soundscape in one area might be perceived as annoying or intrusive in a different context if it does not blend well with the other sounds present [22].

In general, a healthy and harmonious soundscape should involve a proper distribution of sounds to avoid certain sounds being deemed intrusive and disturbing [23].

The themes of acoustics can be framed within the categories defined by law, in which cases and behaviors are configured, considering that the phenomenon of noise is well described by the laws of physics that define its propagation in terms of generation, transmission, and reception in various acoustic reference contexts. Noise disturbances are among the most common legal cases and often involve disputes that arise in the context of neighborhoods.

In Italian civil law, where the majority of disputes concerning intrusive noise arise, the main reference is Article 844 of the law [24], which deals with the acceptable level of neighboring interference.

Lastly, in the realm of Italian penal law, the primary reference is Article 659 of the penal law [25], specifically aimed at protecting against the disturbance of public peace and tranquility.

In addition to this legal framework, there exists a substantial system of technical regulations aimed at both standardizing measurement and evaluation methods for noise in specific contexts and defining and calculating significant parameters.

The contribution of this work is to explore methodologies incorporating a decision support system to integrate perceived noise to noise perception indicators and annoyance criteria, consequently using the Italian standard 11844, which proposes an interpretation of community response to intrusive noise taking into account other methodologies now used in other countries [26].

This paper is organized as follows. Section 2 presents the methods, focusing on the case study and measurements. In Section 3, the results of the standardization model are presented. Conclusions are reported in Section 4.

2. Materials and Methods

2.1. Signal Detection Theory and Intrusive Noise

The new Italian technical specification UNI/TS 11844 [27] defines the measurement procedure and evaluation parameters for sound levels generated by one or more specific sources in a given context, with the purpose of objectively and quantitatively assessing the disturbance associated with one or more specific noise sources.

When these noise sources are distinguishable within the environmental context in which they are located, they are called intrusive noise [28].

The intrusiveness of a sound emission S in an acoustic context characterized by pre-existing noise N can be characterized in terms of the signal-to-noise ratio (SNR). Sound emission S is considered intrusive when it is distinguishable from noise N. The human auditory system can be simplified as a system of bandpass filters, where the listener perceives the output signal of the filter system with a predominant contribution from the filter with the highest masking signal-to-noise ratio.

Masking is mainly determined by the sound energy contained in a narrow frequency band centered on the S signal (critical band). The critical band width B shall increase in proportion to the central band frequency throughout the audible frequency range. For frequencies f > 500 Hz, the critical bandwidth B is approximately equal to that of bands at 1/3 octave, while for frequencies f < 500 Hz, B is almost constant and equal to about 100 Hz.

In the presence of intrusive noise, it may be useful to refer to Signal Detection Theory (SDT), which is applicable to sensory stimuli, including auditory stimuli [29–31].

The general premise of SDT is that decisions about whether or not the S signal is present are made in a context of uncertainty, and the goal of the decision maker is to correctly identify and discriminate the S signal from the N masking noise.

The theory of signal detection is a theoretical framework used to analyze and understand decision-making processes in the presence of uncertainty or noise [32]. It originates from the field of psychology but has been widely applied in various disciplines, including neuroscience, economics, and engineering.

The main objective of SDT is to examine how individuals differentiate between informative signals (also called "signals") and background noise (also called "noise").

In the context of the SDT, a signal refers to a meaningful stimulus or event that an individual is trying to detect, while noise refers to irrelevant or distracting stimuli.

In the presence of intrusive noise, it is possible to refer to SDT, the concepts of which form the basis of the recent technical specification UNI/TS 11844:2022. This specification aims to provide guidance in selecting methods for investigating and assessing intrusive noise [33].

The evaluation methodology involves measuring environmental noise and background noise and then estimating intrusive noise from the specific source. The analysis procedure consists of estimating the noise from the specific source under examination, denoted as Ls, using the following relationship in Equation (1):

$$LA_{eqs} = 10\log_{10}(10^{\frac{LA_{eqa}}{10}} - 10^{\frac{LA_{eqr}}{10}}) \quad (1)$$

where, according to [34]:

- LA_{eqa} is the equivalent level of environmental noise (dB(A));
- LA_{eqr} is the equivalent level of background noise (dB(A)).

This equation permits the evaluation of the noise source level under test as the difference between the environmental sound pressure level when the source is on and the sound pressure level in the same field when the specific source is off.

Equation (1) provides reliable estimates of Ls for algebraic differences, as in Equation (2):

$$\Delta L = LA_{eqa} - LA_{eqr} \succeq 3 \quad (2)$$

In reality, noise disturbance is not only correlated with the overall A-weighted sound level but also with the intrusiveness of the noise. The intrusiveness of noise, in turn, depends on many factors, including the following:

- The frequency distribution of sound energy (spectrum) from the investigated source in relation to the background noise;
- The presence of distinct tonal components;

- The impulsive nature of the noise;
- The duration of the noise;
- The investigation period (daytime, nighttime, etc.).

To address this gap, the UNI/TS 11844 standard introduces the Detectability level D'L to estimate the intrusiveness of a specific sound source in relation to the background noise. Estimating the intrusiveness of the sound emission from the specific source can be managed using a detection theory, a psychophysical theory that analyzes an observer's response to signal exposure in the presence of noise. This theory examines the observer's ability to distinguish the signal from the interfering noise.

The D'L is based on comparing the estimated spectrum for the specific source s (intrusive noise) with the measured spectrum for background noise r.

For each frequency band, the parameter d' is determined as shown in Equation (3):

$$d_i = \eta\sqrt{BW_i}x\frac{\frac{L_{si}}{10}}{\frac{L_{ri}}{10}} \tag{3}$$

where:

- η represents the assumed efficiency of the human observer, which is taken to be 0.4 (a parameter estimated from the literature) [28,32];
- L_{si} represents the estimated band level in dB for the i-th band for s (specific source);
- L_{ri} represents the estimated band level in dB for the i-th band for r (background noise);

For the cumulative value dc that takes into account the contributions of N frequency bands, Equation (4) is applied:

$$d_c = \sqrt{d_1^2 + d_2^2 + d_3^2 + \ldots + d_n^2} \tag{4}$$

The corresponding D'L parameter is obtained as shown in Equation (5):

$$D'L = 10\log_{10}(d'_c) \tag{5}$$

The value of D'L is directly proportional to the intrusiveness of the noise from the specific source. In other words, increasing values of D'L correspond to progressively higher levels of intrusiveness.

The introduction of this parameter prevents excessive simplification by considering only a single weighted A-weighted global value and overlooking the frequency characteristics of the compared sounds. As a result, there is a numerical scale for the level of intrusiveness that depends on the difference between the level of intrusive noise and the level of background noise, evaluated for each frequency band of the sounds.

Table 1 shows the indications of intrusiveness magnitude reported in Table 3, UNI/TS 11844:2022.

Table 1. Indications of Intrusiveness Magnitude, Table 3, UNI/TS 11844:2022 [27].

Detectability Level D'L	Magnitude of Intrusiveness
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

The calculation of D'L, which is based on the signal-to-noise ratio between the spectra of the specific source and the background noise, takes into account the possible presence of tonal components as well as impulsive events that, as is known, tend to distribute their energy throughout all frequency bands. Tonal components could be evaluated according to [35–37].

Moreover, the comparison of these spectra allows highlighting the bands with the highest d′ values and guiding any interventions aimed at reducing intrusiveness.

2.2. The Measurement and Selection of Samples

The methodology was applied to some different types of noise sources. In particular, it was applied and analyzed in 5 cases:

1. Road traffic noise;
2. Railway noise;
3. Noise from an HVAC system;
4. Noise from a laboratory and shop point;
5. Noise from an industrial site.

To identify characteristic spectra, preliminary assessments will be necessary regarding the selection of a representative time period for the analyzed events, specifically referring to the guidelines provided by UNI/TS 11844 and according to Italian laws on environmental noise control and measurements [38–41].

The five cases indicated above were analyzed using the same study methodology.

The preliminary analysis involves identifying the activity times, the characteristics of the sound source, and the operating cycle (repetitive hourly/daily/weekly, continuous/discontinuous, etc.).

For case 4 (laboratory), it was also interesting to obtain information on noise induced by customers and workers. Hourly traffic flows were acquired for the road and railway, as well as other information relating to the seasonal use of the infrastructure.

Measurement operations were carried out following methods proposed from time to time by the UNI or ISO standards.

The operating procedure used in all five cases is the same. From the acoustic measurements, the representative acoustic spectra of the sources were identified. Then, the theory described above was applied to calculate the noise intrusiveness indicators. In all cases, the final result of each one is not unique but can vary depending on the methods in which the operator technician makes the preliminary postprocessing choices. For the purposes of this work, it is important to understand what the critical issues are during the application of the theory and methodology. For this reason, it is not interesting to present the detailed results of all five cases analyzed. Considering that the method is more critical in the case of noise coming from more random sources, such as industrial or handicraft sources, only case 4 is analyzed in more detail below. The general conclusions, which are exposed later, can be considered the same for the five cases studied. The observations can then be extended to the other cases as well.

3. Results

Based on the measured values summarized in the previous section, the process proceeded to determine the critical bands and calculate the Detectability Level D′L. A crucial decision with significant implications for the final result is related to the methods used to determine the 1/3-octave aggregated spectra of the ambient and background noise, following Section 7.2 of UNI/TS 10844.

The standard itself proposes different methodological approaches, leaving it to the technician to choose the strategy based on specific needs and analyzed situations.

Specifically, the standard suggests using the following:

- Time-averaged spectrum of measurement;
- Band percentile levels with values to be defined case by case.

As has already been stated several times, according to the approach chosen by the technician, the information to be used as input for calculating the intrusiveness of the noise is different.

Some technical choices that the technician could make during operations, according to the national (UNI) and international (EN, ISO, IEC) standards in use, are described below, which will lead to a different result.

1. Choice 1: Environmental noise measured continuously from opening to closing and background noise measured in the same period in the closing day;
2. Choice 2: Environmental noise measured continuously from opening to closing and background noise calculated as L95 in the same period;
3. Choice 3: Environmental noise measured when the main noise sources are on and background noise measured in the same period in the closing day;
4. Choice 4: Environmental noise measured when the main noise sources are on and background noise calculated as L95 in the same period;
5. Choice 5: Environmental noise measured forcing all the sources working at maximum level and background noise measured in the following minutes forcing the sources to all be switched off.

Table 2 presents the measured overall sound levels and the calculation of the specific source sound level for each choice. The measurement time (TM) was 1 continuous week. Using a postelaboration software, the sound pressure level values reported in Table 2 were extrapolated on a case-by-case basis.

Table 2. Measured sound levels.

Choice	LA_{eqa}	LA_{eqr}	LA_{eqs}
1	28.2	21.4	27.2
2	31.1	19.4	30.8
3	34.6	19.1	34.5
4	34.6	31.1	32.0
5	49.9	21.1	49.9

Based on the chosen representation, Tables 3–7 show the spectra obtained.

Table 3. Sound spectra used for the calculation of D'L (Choice 1).

Freq	L_A	L_{ri}	L_{si}
25	35.8	30.7	34.1
31.5	25.7	22.5	22.9
40	31.9	28.7	29.1
50	35	32.7	32
63	30.3	21.7	29.6
80	38.7	24.5	38.6
100	34.3	26.7	33.5
125	34.1	22.1	33.8
160	34.7	18.4	34.6
200	28.8	16.2	28.6
250	22.9	16.1	21.9
315	24.4	11.2	24.2
400	19.2	12.1	18.2
500	19.4	10.7	18.7
630	17.5	9.5	16.8
800	16.3	7.7	15.7
1000	10.8	6.9	8.6
1250	10.9	6.8	8.7
1600	7.6	7.4	4.6
2000	6.2	7.7	3.2
2500	5.8	7	2.8
3150	6	6.9	3

Table 3. *Cont.*

Freq	L_A	L_{ri}	L_{si}
4000	7.1	7.2	4.1
5000	7.9	8	4.9
6300	10.1	10.1	7.1
8000	9.9	9.9	6.9
10,000	10.5	10.6	7.5

Table 4. Sound spectra used for the calculation of D′L (Choice 2).

Freq	L_A	L_{ri}	L_{si}
25	35.8	35.4	24.7
31.5	20.9	20.2	12.7
40	25.5	23.9	20.4
50	34.1	31.1	31.4
63	30.3	30.1	15.9
80	41	40.9	20
100	36.4	36	26
125	35.6	35.6	14.6
160	38.5	38.5	12.6
200	32.5	32.4	9.5
250	24.7	24.5	10.8
315	27.8	27.8	7.7
400	21.9	21.8	5.5
500	23.3	23.3	5.9
630	21	20.9	4.6
800	20.5	20.5	3.4
1000	12.9	12.4	3.2
1250	12.8	12.3	3.4
1600	5.7	2.7	3.5
2000	4.6	1.6	3.9
2500	4.7	1.7	4.6
3150	5.5	2.5	5.5
4000	7	4	6.6
5000	7.8	4.8	7.8
6300	10	7	10
8000	9.8	6.8	9.9
10,000	10.5	7.5	10.5

Table 5. Sound spectra used for the calculation of D′L (Choice 3).

Freq	L_A	L_{ri}	L_{si}
25	39	25	38.8
31.5	23.2	12.4	22.9
40	27.8	19.8	27
50	36.5	29.3	35.6
63	32.1	14.3	32
80	41.1	18.7	41.1
100	35.6	22.2	35.4
125	36.3	14.1	36.3
160	45	11.7	45
200	33.2	8.5	33.2
250	27.4	9.6	27.4
315	35.4	6.4	35.4
400	22	4.5	21.9
500	21.5	4.9	21.4
630	20.8	4	20.7
800	18.2	3.1	18

Table 5. *Cont.*

Freq	L_A	L_{ri}	L_{si}
1000	12.8	2.8	12.4
1250	6.9	3	4.6
1600	4.8	3.3	1.8
2000	4.4	3.8	1.4
2500	4.8	4.6	1.8
3150	5.6	5.5	2.6
4000	7	6.6	4
5000	7.8	7.8	4.8
6300	10	9.9	7
8000	9.9	9.9	6.9
10,000	10.5	10.5	7.5

Table 6. Sound spectra used for the calculation of D′L (Choice 4).

Freq	L_A	L_{ri}	L_{si}
25	39	34.7	37
31.5	23.2	17.6	21.9
40	27.8	23	26
50	36.5	32	34.7
63	32.1	29.3	29.1
80	41.1	38.3	38.1
100	35.6	33.3	32.6
125	36.3	34.1	33.3
160	45	38.3	44
200	33.2	30.2	30.2
250	27.4	23.8	25
315	35.4	30.4	33.7
400	22	19.7	19
500	21.5	18.6	18.5
630	20.8	17.3	18.2
800	18.2	14.6	15.7
1000	12.8	10.2	9.8
1250	6.9	5	3.9
1600	4.8	3.1	1.8
2000	4.4	3.1	1.4
2500	4.8	4	1.8
3150	5.6	5	2.6
4000	7	6.1	4
5000	7.8	7.1	4.8
6300	10	8.7	7
8000	9.9	9.1	6.9
10,000	10.5	10	7.5

Table 7. Sound spectra used for the calculation of D′L (Choice 5).

Freq	L_A	L_{ri}	L_{si}
25	1.2	30.7	1.8
31.5	8.4	22.5	5.4
40	13.4	28.7	10.4
50	16.6	32.7	13.6
63	16.6	21.7	13.6
80	17.6	24.5	14.6
100	25.1	26.7	22.1
125	25	22.1	22
160	24	18.4	22.6
200	30	16.2	29.8

Table 7. *Cont.*

Freq	L_A	L_{ri}	L_{si}
250	31	16.1	30.9
315	37	11.2	37
400	30.1	12.1	30.1
500	35	10.7	35
630	37.1	9.5	37.1
800	38.5	7.7	38.5
1000	40.1	6.9	40.1
1250	35.9	6.8	35.9
1600	33.7	7.4	33.7
2000	37.8	7.7	37.8
2500	33.6	7	33.6
3150	34.8	6.9	34.8
4000	33.5	7.2	33.5
5000	35.6	8	35.6
6300	31.9	10.1	31.8
8000	27.1	9.9	27
10,000	20.5	10.6	20

From the spectra, the next step involves estimating the intrusiveness. The values of D'L for the three examined cases are reported in Table 8.

Table 8. Obtained D'L values.

Case	Detectability Level D'L	Magnitude of Intrusiveness
1	22	Low
2	31	Medium
3	38	High
4	15	Very Low
5	43	Very High

The table above shows which different results are obtained depending on the different approaches of the specialized technician. All the results originate from choices made in accordance with the legislation in force. The variability of the result, both for the in-depth case of the laboratory and shop but also for the other four cases studied, depends on several factors. In general, these factors could be the following:

- Measurement time representative of the activity analyzed and of the background;
- Measurement period (day/evening/night);
- Difficulty of measuring background noise when the noise source cannot be deactivated;
- Choice of representative noise spectrum (LAEq/percentile/etc.);
- Choice of a correct measuring point, representative of the situation to be analyzed;
- In long-period measurements (example: road traffic noise), problems in distinguishing the source from the context;
- Need for ancillary equipment for event recognition.

Given the analysis of complex scenarios with multiple noise sources or different configurations, it is evident that the D'L parameter introduced by the UNI/TS 11844 [27] offers a more comprehensive approach to comprehend the impact of noise on human perception and the related discomfort. In particular, UN/TS 11844:2022 is essential for providing an objective quantification of the actual disturbance compared with the commonly used comparative criterion. It is also highly desirable that further operational guidelines be established with the purpose of ensuring the uniqueness of the input data used for the calculation of D'L.

4. Conclusions

In the context of noise disputes, issues and conditions related to the multisensory perception of discomfort are often highlighted. These fall under the categories of noise annoyance and disturbance. These conditions can be subjects of legal disputes or conflicts among stakeholders, such as residents, industries, or government entities, where noise is considered a form of environmental pollution.

To assess the intrusive effect of noise and analyze complex scenarios characterized by multiple overlapping noise sources or different source configurations, the parameter D′L was introduced by the technical specification UNI/TS 11844:2022. This parameter represents a significant contribution in assessing the amount of disturbance caused by noise in specific situations. The D′L parameter takes into account the human perception of noise, considering not only the sound level but also temporal characteristics, spectral structures, and other sound properties. This enables a more accurate assessment of the noise's effect on perception and human comfort.

Intrusive noise can have both auditory and nonauditory effects on humans that extend beyond direct hearing damage. Annoyance and noise disturbance are common issues associated with intrusive noise. To analyze complex scenarios with multiple noise sources or different configurations, the D′L parameter introduced by the technical specification UNI/TS 11844:2022 provides a more comprehensive evaluation method to understand the effect of noise on human perception and associated discomfort.

Depending on the somewhat subjective approach of the competent technician, the obtained result varies from a low intrusiveness assessment to a high intrusiveness assessment. This demonstrates and confirms that initial choices, usually based on subjective evaluations and grounded in techniques and jurisprudence, can significantly influence the final judgment. Therefore, it is desirable that operational guidelines are established based on the existing appendices in the standard and the experience derived from the initial practical applications. These guidelines should support the selection process, aiming for clarity in input data for D′L calculation.

In future work, authors could evaluate noise according to whether or not people feel discomfort. This would be useful for comparing objective and subjective assessments.

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