Urban environment soundscape evaluation: Milan case study of noise events perceptions by citizens

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ABSTRACT

As one of the main urban environmental pollutants, noise is becoming a real public health concern due to its impact on citizen's well-being. Real-operation noise monitoring can help policy makers in improving the quality of urban environments. To this end, Wireless Acoustic Sensor Networks (WASNs) have been deployed in crowded city centers in both America and Europe. The main application of WASNs is to measure the noise levels from road traffic. Yet, other types of sounds can be found in urban areas, which may also affect citizen's health. Here, we aim to evaluate the citizen's perception of different urban sounds considering their psychoacoustic characteristics, namely loudness, sharpness, roughness, fluctuation strength and tonality. To this end, we have conducted an on-line and off-site listening test using a urban acoustic event dataset collected by WASNs in Milan. The dataset includes seven common urban noises such as sirens, horns, people talking, truck, works, among others. Participants have been asked to rate the level of agreement with adjectives such as loud, shrilling, disturbing, sharp or pleasant. The test responses from one hundred volunteers allow us to gather valuable information about people's perceptions of common urban noises.

1. INTRODUCTION

Noise has been identified by several studies as one of the main environmental pollutants and as a public health issue in urban areas [1, 2]. The effects of noise pollution on health include, among others, cardiovascular disease, cognitive impairment, sleep disturbance, tinnitus and annoyance [3]. The impact of these harmful effects has been quantified in terms of loss of healthy life years both at a local [4] and global scale [3]. Furthermore, noise pollution involves serious social and economic

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consequences that have been widely studied (e.g. see [5]). To deal with this problem, the World Health Organisation (WHO) has recently released a new set of environmental noise guidelines [6].

Real-time monitoring of noise has been addressed in several projects by means of Wireless Acoustic Sensor Networks (WASNs), which are able to collect data for the elaboration of noise maps. These maps mainly focus on Road Traffic Noise (RTN), which has been identified as one of the main sources of noise pollution [7, 8]. WASNs, however, typically measure environmental noise in terms of the equivalent continuous sound level (L_{eq}), without discriminating between the different acoustic sources. In this regard, the LIFE DYNAMAP project has deployed a road traffic noise monitoring network [9, 10] that includes an algorithm to discard Anomalous Noise Events (ANEs), i.e. events non-related to road-traffic noise such as train pass-bys, sirens, people talking, etc [11].

Although ANEs are generally discarded when noise maps are drawn up, they are an essential part of the sonic environment and, as such, they should be considered. In this respect, the soundscape approach proposes to assess all the sounds perceived by a person or group of people in an environment in all its complexity and in context [12]. This assessment can be done through perceptual tests such as those conducted in studies on the effects of noise pollution on citizens [13]. Most studies on acoustic pollution have analysed the degree of annoyance a sound provokes in relation with objective acoustic measurements such as the L_{eq} [14]. Nevertheless, the soundscape approach has been continuously looking for indicators that could represent how people perceive and experience acoustic environments better than what conventional equivalent sound levels might achieve [15–17]. Even if originally developed for relatively simple signals, psychoacoustic metrics have been increasingly used for more complex environmental sounds and have become important indicators in soundscape studies [18, 19].

In order to assess the citizen's perception of different sounds from a urban soundscape, in [20] we proposed several off-line perceptual tests designed according to the data gathered by a WASN deployed in the city of Milan in the framework of the LIFE DYNAMAP project [9]. These tests were also devised to study how sounds are perceived in relation to their psychoacustic characteristics. For instance, in [21] a preliminary study was done to analyse the relation between sharpness and annoyance with an A/B test [22]. Several audio pairs were presented to the participants, which had to chose the most annoying audio of each pair. The test was designed so each comparison was done between two audios of the same type, coming from the same sensor, with similar characteristics but different sharpness. Although some tendencies were observed for some of the comparisons, there was not a clear relation between sharpness and the degree of annoyance.

This work aims at evaluating citizen's perception of several urban sounds and analysing the relation between this perception and the psychoacoustic characteristics of the assessed samples. To this end, the participants in the off-line perceptual test were asked to rate several audios in a five-point Likert scale according to their level of agreement with five dimensions, namely: *loud, pleasant, disturbing, shrill and sharp* [23]. The results from the test are compared with several psychoacoustic parameters extracted from the audios to look for potential correlations.

This paper is structured as follows. Section 2 details the basic details of the WASN used to gather the data used in this paper, Section 3 explains the conducted tests and the psychoacoustic analysis conducted in this proposal. Finally, Section 4 reflects the discussion about the results and the future lines of this work.

2. WIRELESS ACOUSTIC SENSOR NETWORK DATA GATHERING

The acoustic data used to design the perceptual tests was gathered in the same recording conditions, all the sensors part of a 24-node acoustic sensor network, deployed in the context of the LIFE DYNAMAP project [9] in District 9 of the city of Milan [24].

2.1. Sensor Nodes

Figure 1 shows the location of the 24 low-cost sensors of the WASN deployed in Milan. The recordings were conducted for two days in the same week, in order to capture both traffic noise and anomalous noise events in two different city activity conditions. One week day (Tuesday, November 28, 2017) and one weekend day (Saturday, December 2, 2017). The acoustic data was recorded in continuous audio clips of 20 minutes at the start of each hour, with a sampling frequency of 48 kHz, using sensors developed by BlueWave [25], in order to have samples at all the times of the day. The recordings were manually annotated by expert labellers [26], using several labels such as *people talking, horn, works, siren,* among other typical urban sounds.

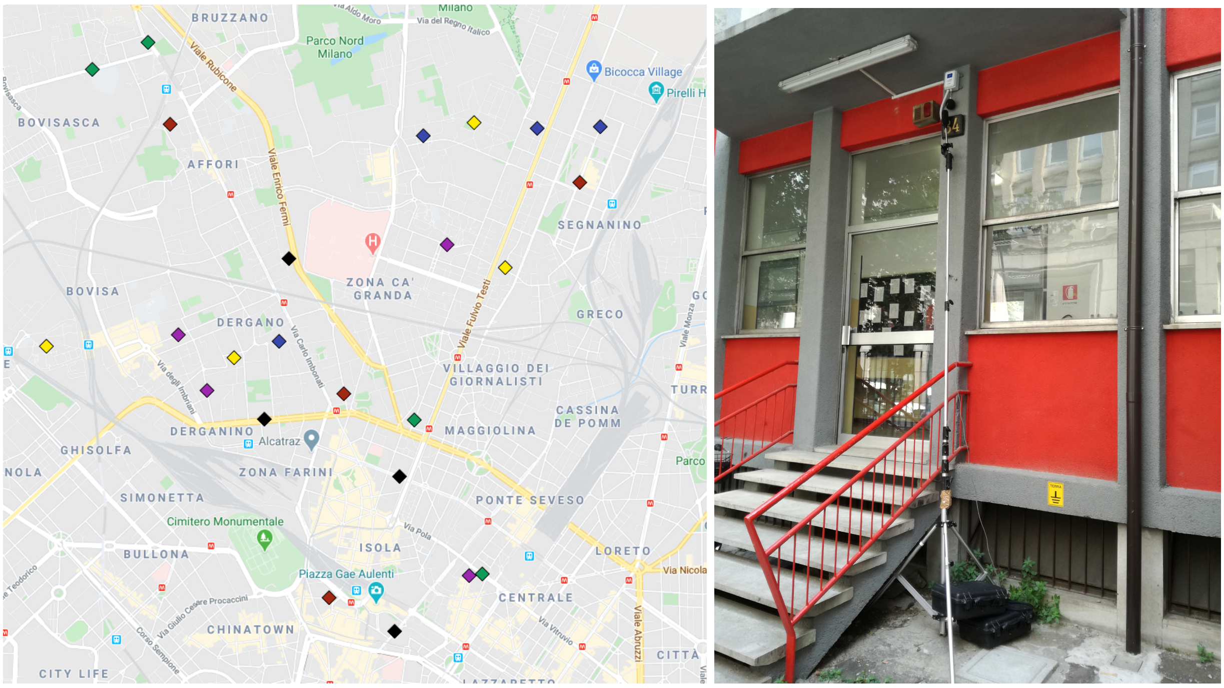

Figure 1: Map of the recording locations of the DYNAMAP's WASN sensors in Milan, and sensor in Via Fara (hb115), which data was finally used to conduct this experiment.

2.2. Data Selection

Several types of sounds have been recorded in the used dataset that are not related to road traffic, e.g. sirens, construction works, dogs' barks, horns, airplane flyovers, people talking. However, not all types of anomalous events have enough samples recorded to use them for a comparative study. Thus, the selection of the events contains the most relevant types of events, i.e., the ones with a bigger representation in the dataset.

As the perceptive test can only be applied comparing data of the same sensor, the number of events occurred in each sensor must be taken into account, as well as the definition of the most interesting types of sound to include in the test [20]. This way, the same acoustic conditions are guaranteed for all the tests and all the audio samples. In order to have enough samples of each type and the widest variety of loudness levels, sounds are gathered from four sensors: hb115, hb124, hb127 and hb133, which present the larger dataset of audio samples of the types under study. Further information about the anomalous noise event selection can be found in [21].

In Table 1, the number of seconds of each selected event captured in each sensor is presented.It was determined that hb115 captured the largest range of recordings from a wide set of audio label types. As such, recordings from hb115, located at Via Fara (see Figure 1) were used to design the test analyzed in this contribution.

Table 1: Total recording seconds for each type of anomalous noise events used in this work classified by sensor (in seconds).

Sounds	hb115	hb124	hb127	hb133
BRAKE	101.9	33.9	296.8	34.8
DOOR	282.6	165.6	182.1	128.5
HORN	96.7	26.0	47.4	33.3
PEOPLE	323.1	670.5	755.1	407.5
SIREN	203.0	193.9	234.6	84.6
TRUCK	1.8	2.2	21.8	14.3
WORKS	658.3	N/A	261.7	360.0

3. LISTENING EXPERIMENT AND PSYCHOACOUSTIC ANALYSIS

In the context of this study, a listening test was conducted with an experimental design based on seven audio excerpts representative of different auditory events labeled as: brake, door, horn, people, siren, truck, and works. One-hundred participants were presented with the seven sounds in a randomized order; for each sound, participants had to score it on five perceptual dimensions - namely: *loud*, *pleasant*, *disturbing*, *shrill*, *sharp* - using a five-point Likert scale ranging from "not at all" (1) to "extremely" (5). For each stimulus the following psychoacoustic metrics were computed using the Artemis software (HEAD acoustics GmbH, v.11): sound pressure level (SPL), loudness, sharpness, roughness, fluctuation strength and tonality. The experiment was conducted online, participants were required to use headphones, to adjust the level to a comfortable one and not changing it once the listening session had begun. Because the test was conducted remotely it was not possible to determine an exact calibration value and control for actual exposure of single participants. For this reason, when analyzing the psychoacoustic metrics, it was decided not to use the actual levels of the sound excerpts (i.e., as recorded on site via the sensor), but rather their standardized values. In this way, the relationships between the variables is maintained and their relative effects can be analysed, but conclusions cannot be drawn about the impact of the absolute levels of the psychoacoustic metrics. Figure 2 shows the z-scored levels of the different psychoacoustic metrics across sounds.

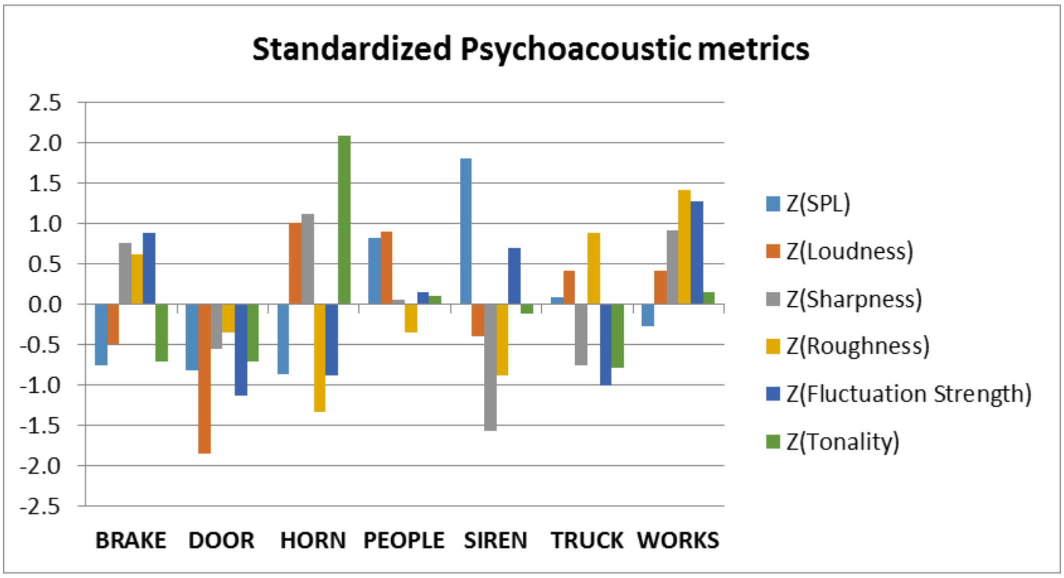

Figure 2: z-scores of the psychoacoustic metrics for the seven sounds used in the listening experiment.

Furthermore, the median values (N = 100) of the individual scores for the five scales were calculated for each sound [12] as reported in Figure 3. The sounds siren and truck stand out as being the loudest and most disturbing. Overall, all other sounds score equally on all scales, except people, which is considered to be the most pleasant. Range was considered as a measure of dispersion, its value being 4 for all cases except for the item *pleasant* for people, when it was 3.

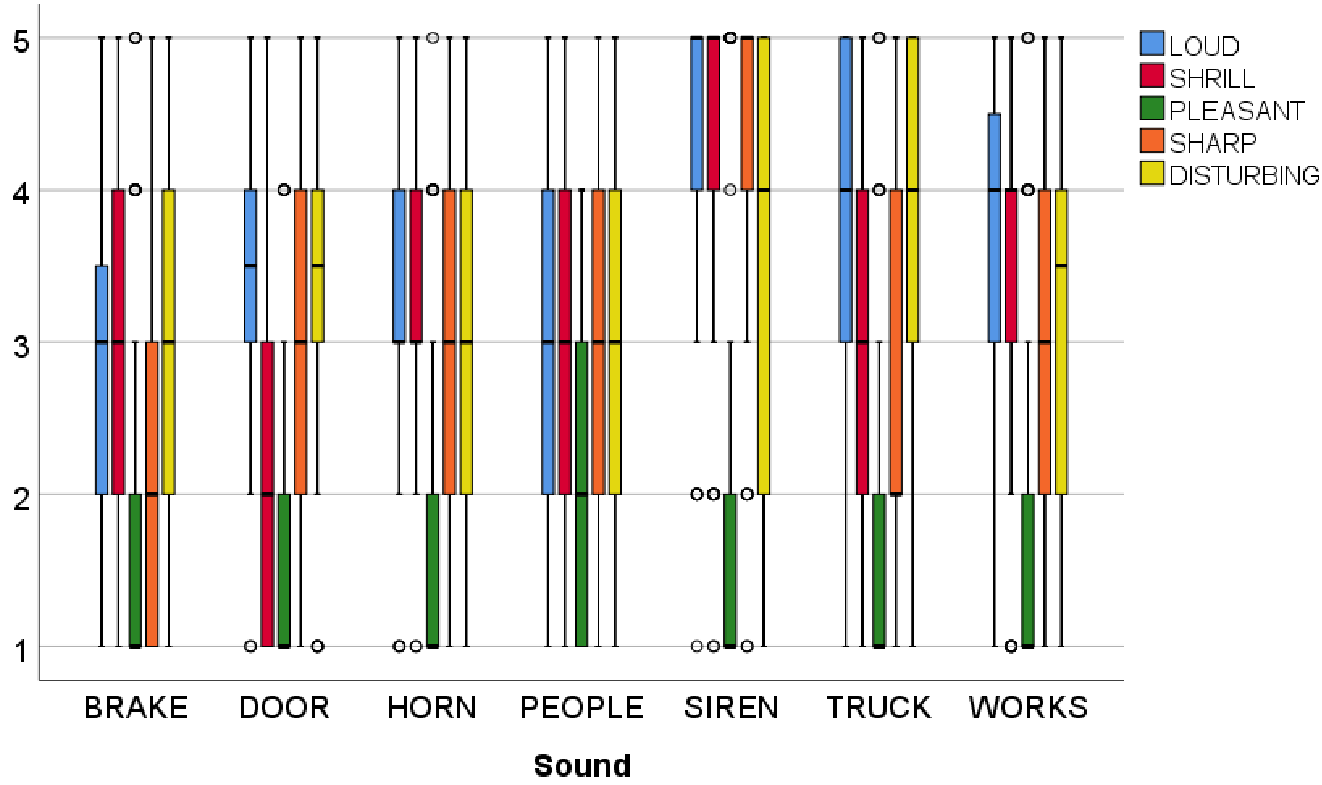

Figure 3: Box-plot of the seven sounds for the scores of the five perceptual items.

In order to provide further insights into possible associations between perceptual scores and objective parameters, a set of Spearman's rank-order correlations was run to assess the relationship between the median scores of the five perceptual attributes for the seven sounds and the z-scores of the psychoacoustic metrics [27]. There was a statistically significant, strong negative correlation between the median scores of the item *disturbing* and the Sharpness z-scores, rho = -.756, p = .049. No other statistically significant associations were observed.

Figure 4 shows the linear relationship between the median *disturbing* scores for the seven sounds of the experiment and the Sharpness z-scores: the higher the disturbance score, the lower the Sharpness value (which was the only one resulted to be statistically significant from the Spearman's rank-order correlation analysis); this seems to be in contrast with previous literature as higher disturbance/annoyance is typically associated with sharper sounds [28].

4. DISCUSSION AND CONCLUSIONS

This article presents preliminary analyzes of psychoacoustic parameters on a set of data recorded in real-operation in the framework of a WASN in Milan. The authors recorded, labeled and studied the number of occurrences of different types of habitual urban noise that can be associated with the feelings they cause in citizens (pleasantness, etc.). Sensor data with more occurrences were used to extend the on-line perceptual tests off-site, and other test sets were saved for the performance of other tests that took into account the evaluation of other sensations.

The first analysis performed, using the HEAD Acoustics Artemis software, lead us to a challenging first approximation. The *disturbing* evaluation increases as the *sharpness* decreases, which is just

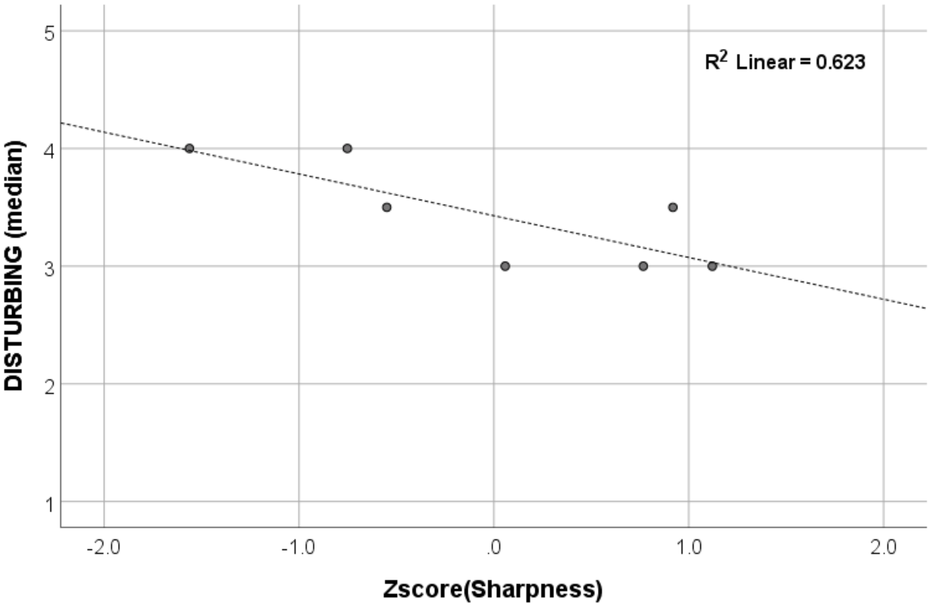

Figure 4: Median scores of the seven sounds for the item "annoying" as a function of their Sharpness z-scores.

the opposite of what is typically reported in literature, including the formula for psychoacoustic annoyance [28]. This could possibly reveal the disconnect between the relatively simple and product-focused sounds the psychoacoustic metrics were initially designed for and the more complex characteristics of environmental sounds. Particularly when discussing a higher-level psychoacoustic phenomenon such as annoyance, it's possible the findings based on simpler sounds no longer hold for more complex sounds, particularly those to which listeners assign semantic meaning. This fact encourages us to continue studying this parameter compared to the totality of psychoacoustic parameters that can be extracted from audio, and to expand the contrast of other recorded audio pieces with the *sharpness* and the evaluation of *disturbance*.

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