Assessment of annoyance, noisiness and loudness caused by environmental noise sources

Nicolás Urquiza (a)

(a) Tres de Febrero National University (UNTREF), Argentina, nurquiza@untref.edu.ar

Abstract

In this research, the study of environmental noise in downtown Caseros, located in Buenos Aires Province, was addressed through the analysis of six sound events by objective and subjective methods. In order to do this, physical properties of each sound stimulus were evaluated and auditory surveys were conducted to study the effects of noise from the psychoacoustics point of view. Afterwards, the correlation between objective acoustical parameters and three subjective attributes (annoyance, noisiness and loudness) was investigated. To assess the subjective attributes three carefully designed surveys were conducted; an online pilot survey and two auditory surveys performed under laboratory conditions by paired comparison test and verbal rating scale method. Moreover, objective variables from each sound events were analysed through their frequency spectrums and acoustic descriptors. Afterwards, the correlation coefficients between objective parameters and the subjective response of people were studied. Results indicated that the most annoying sound events had tonal characteristics and loudness was the only subjective attribute that showed good correlation with several objective acoustic descriptors. In addition, surveys confirmed that pairwise comparisons and verbal rating scale method have excellent correlation for the same subjective attribute. Finally, it was concluded that is necessary to perform subjective studies in order to complement the purely objective measurements when the existence of annoyance in a population exposed to noise is evaluated.

Keywords: environmental noise; annoyance; noisiness; loudness
Assessment of annoyance, noisiness and loudness caused by environmental noise sources

1 Introduction

Several research teams dedicated to evaluate noise pollution in urban centres used to concentrated their investigations on two main areas: the objective analysis of the acoustics environment and the subjective response to noise [1-3]. The objective analysis includes since sound pressure measurements to the current simulation techniques for predicting the acoustic performance in any given space-time. Instead, in the field of subjective evaluations, the psychological response of people to noise is evaluated by mean of socio-acoustic surveys.

Moreover, urban noise indicators and descriptors are usually used for relate, in a simplified way, the exposing of people to noise and its health effects. However, there is evidence that different types of noise, even at the same level, cause different degrees of discomfort [1]. Paul Schomer, found that aircraft noise is more annoying than road traffic noise for the same day and night levels (DNL) [4]. In addition, J. A. Molino, confirmed that those noises which fluctuating over time are more annoying than the same noise at constant levels [5]. So, the traditional acoustic indicators, which aims to assess health effects caused by urban noise, could not be providing completely meaningful results if subjective evaluations on the population are not made.

In order to carry out the experiment of this research, a calibrated microphone recorded ambient noise for an extended period of time and six sound events were selected from the soundscape of Caseros’ downtown in Buenos Aires Province, Argentina. Subsequently, auditory surveys were conducted under laboratory conditions and the correlation between objective acoustic descriptors (obtained from each sound stimulus) and three psychological attributes was analysed. These psychological attributes are annoyance, noisiness and loudness, and were assessed through carefully designed surveys. Also, it aims to analyse the correlation between objective acoustic descriptors and subjective attributes of each sound event.

1.1 Location

Caseros is the head town of “Tres de Febrero” which form part of the greater Buenos Aires. It is located at the northwest of Buenos Aires City and has an estimated population of 106,421 inhabitants concentrated on an area of 11.2 km² [6].

Sound events recordings were carried out from a balcony of the second floor of a residential building located on the corner of Tres de Febrero and Valentin Gomez streets. Thousands of cars, motorcycles and busses circulate daily by Tres de Febrero Street at just 11 meters from the measurement point. Moreover, at just 50 meters away circulating over one hundred and fifty (150) passenger trains and two (2) freight trains per day by San Martin railroad.
2 Subjective attributes

Some definitions were explained to the audience before performing the subjective test:

**Loudness** was defined as the perceptual aspect of the sound stimulus that changes by turning the volume knob on a radio set. Increasing or decreasing the gain will enhance or reduce loudness, respectively.

The term "noisiness" refers to the specific quality of sound. So, two different sounds, include at the same level, may not be equally noisy. For example, the sound emitted by a jackhammer may be more or less noisy than a motorbike noise, even if they are considered equally loud. Also, some industrial noises (like the noise of machinery, tools and engines) could be considered very noisy and, by the other hand, a piece of classical music or the singing of a bird could be qualified as absolutely nothing noisy. However, certain sounds of nature like a thunder or a waterfall could be considered extremely noisy.

Moreover, it is necessary to distinguish between loudness and noisiness: For example, the sound of a knife rubbing against a glass may be absolutely nothing loud but noisier than a bus braking.

**Annoyance** was defined as the nuisance aspect of the noise experienced in an imaginary situation phrased as: "After a hard day’s work, you have just been comfortably seated in your chair and intend to read your newspaper" [4]. Then the observer was questioned how annoyed he would feel when exposed to the given noises.

3 Method

In this section, the equipment used for the environmental noise measurements and for recording audio signals will be detailed. Moreover, the measurement procedure and the selection and editing method for the sound stimulus evaluated will be described. Finally, the results of the objective analysis will be presented and the acoustic environment will be studied by calculating the compost level of full journey.

3.1 Measurement equipment

The following list presents the measurement equipment used:

- DPA - Measurement microphone
- Svantek 959 – Sound level meter
- Svantek SV30A - Calibrator
- M-Audio FW 410 – sound interface
- Laptop computer
- KRK “Rokit 8” loudspeaker

3.2 Measurement Procedure

First, a know calibration signal was recorded using a class 1 calibrator SVANTEK-SV30A (which emits a sinusoidal tone signal centred on 1000Hz and 94dB) to get a reference level at the digital scale. The recorded reference signal, aims to establish an objective relationship between sound
pressure levels at the measuring point and the digital audio signals. For example, if the calibration audio file has a root mean square (RMS) amplitude of -10 dBFS (dB Full Scale), then the audio of a particular noise that has a RMS level of -15 dBFS is equivalent to a sound level 94 dB - (-10 dBFS) + (-15 dBFS) = 89 dB.

The sound events selected correspond to: a train pass-by honking its horn, a train pass-by noise (no honking), a car passing by with an audio car system, a car pass-by with pulleys and timing belts noise, a motorcycle accelerating and a bus honking its horn. It is worth mentioning that sound events were selected from those sounds recorded that more discomfort cause in people who live or pass through the area, according to the results of a pilot survey.

The sound stimulus “honking train pass by noise”, corresponds to a passenger train arriving to Caseros Station, decelerating and using its horn to announce the arrival to the platform. The train consists of six (6) wagons powered by a diesel-electric RDS-16 model provided by the American Locomotive Company (ALCO) in 1956.

The sound stimulus “train pass by noise”, corresponds to a passenger train of six (6) wagons and a locomotive ALCO RDS-16. The train was in deceleration while arrive to the platform of Caseros Station, but in this case without using his horn.

Another sound stimulus corresponds to a car reproducing music through its audio-car system while circulate through Tres de Febrero Street.

The next sound stimulus corresponds to a car passing by through Tres de Febrero Street at low speed with pulleys and timing belts noise. Its high frequencies noise, type "chirp", produced by the transmission system of pulleys and belts. Note that this type of noise is very common in the Greater Buenos Aires soundscape, due to the large number of out maintenance vehicles which circulate daily through the streets.

The other sound event corresponds to a 125 cc motorcycle, detained, but accelerating in vacuum.

The bus honking sound stimulus corresponds to a bus transiting in deceleration by Tres de Febrero Street and blows the horn when meeting an illegally parked vehicle obstructing its path.

### 3.3 Subjective descriptors

A series of subjective descriptors were adapted and used to assess the sound events more annoying, noisy and loud.

The percentage of highly annoying (%HA), noisy (%HN) and loud (%HL) were calculated as the sum of the percentages of people who qualified every stimulus as very and extremely annoying/noisy/loud.
4 Objective results

4.1 Objective Acoustic Parameters

Objectives acoustic parameters of each sound event were analysed; among these, the $L_{Aeq}$, $SEL$, $L_{pk}$, $L_{max}$, $L_{min}$ and percentiles $L_{10}$ and $L_{90}$. In addition, although these levels are not typically used for sound events of such short time duration, noise climate (NC) was calculated according to the difference of level between $L_{10}$ and $L_{90}$. The above acoustic parameters are presented in Table 1.

Table 1: Objective acoustic measurements results.

<table>
<thead>
<tr>
<th></th>
<th>$L_{Aeq}$</th>
<th>$SEL$</th>
<th>$L_{pk}$</th>
<th>$L_{max}$</th>
<th>$L_{min}$</th>
<th>$L_{10}$</th>
<th>$L_{90}$</th>
<th>NC $(L_{10}-L_{90})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Train pass-by honking its horn</td>
<td>83.3</td>
<td>94.0</td>
<td>98.5</td>
<td>90.7</td>
<td>42.1</td>
<td>88.7</td>
<td>68.8</td>
<td>19.9</td>
</tr>
<tr>
<td>Train pass-by noise</td>
<td>81.1</td>
<td>91.7</td>
<td>85.6</td>
<td>82.7</td>
<td>45.5</td>
<td>82.3</td>
<td>74.8</td>
<td>7.6</td>
</tr>
<tr>
<td>Car passing by with an Audio-Car System</td>
<td>81.5</td>
<td>92.2</td>
<td>86.8</td>
<td>84.0</td>
<td>46.2</td>
<td>83.6</td>
<td>75.1</td>
<td>8.6</td>
</tr>
<tr>
<td>Car passing by with pulley noise</td>
<td>75.5</td>
<td>86.2</td>
<td>80.8</td>
<td>78.5</td>
<td>38.0</td>
<td>78.4</td>
<td>66.4</td>
<td>12.0</td>
</tr>
<tr>
<td>Motorcycle accelerating</td>
<td>79.8</td>
<td>90.5</td>
<td>90.8</td>
<td>84.8</td>
<td>50.9</td>
<td>83.1</td>
<td>71.6</td>
<td>11.5</td>
</tr>
<tr>
<td>Bus honking its horn</td>
<td>80.8</td>
<td>91.4</td>
<td>94.4</td>
<td>88.4</td>
<td>38.5</td>
<td>86.9</td>
<td>66.8</td>
<td>20.1</td>
</tr>
</tbody>
</table>

The higher Equivalent Continuous Sound Level ($L_{Aeq}$) was the train pass-by honking its horn, reaching 83.3 dBA; followed by the car pass-by with an audio car system that reaches 81.5 dBA and the train pass-by noise (no honking) in 81.1 dBA.

Also, if the concentrated energy is analysed in a second through the Sound Exposure Level ($SEL$) parameter, it can be seen that the train pass-by honking its horn reaches 94.0 dB, followed by the car pass-by with an audio car system valued at 92.2 dB and then the train pass-by reaches 91.7 dB.

The maximum peak level ($L_{pk}$) recorded was 98.5 dB and corresponds to the sound stimulus train pass-by honking its horn. Then, the bus honking its horn stimulus indicated 94.4 dB and subsequently the motorcycle accelerating shown 90.8 dB.

It should be noted that higher noise climate (NC) had been obtained for those stimuli which honking their horns as the train and the bus. Followed by the car pass-by with pulleys noise and motorcycle accelerating. Slightly below follows the noise climate of the car pass-by with its audio car system and finally the sound event that has less jitter is the train pass-by (no honking).
4.2 Whole-day noise evaluation

In addition, noise measurements integrated in periods of 15 minutes per hour were evaluated for a whole-day of 24 hours. In order to do this, a Class 1 Svantek sound level meter mounted on a tripod at 1.5 meters above the floor of the balcony on the second floor of the building located at the intersection of Valentin Gomez and Tres de Febrero streets was used. It is worth mentioning that all measurements were carried out using the microphone windscreen and under favourable weather conditions for the propagation of sound as suggested by ISO 1996-2 [7], precisely, relative humidity above 30% and wind speed lower than 5 km/h. Also, the audio of each measurement was recorded in order to evaluate the origin of the most important sound events and to analyse the temporal noise behaviour.

In Figure 1, can be seen a graphical representation of the evolution of the “A” weighted equivalent continuous sound level for a complete journey of 24 hours. As can be seen, noise in Caseros’ downtown has two noise peaks at 09:00 pm, reaching 70.2 dBA and then at 20:00 and 21:00, reaching 69.3 dBA.

Also, the composite whole-day rating levels were calculated during different periods: $L_{Rdn} = 69.1$ dB (day/night) and $L_{Rden} = 69.3$ dB (day/evening/night).

![Figure 1: Equivalent continuous sound level registered at 24 hours full-journey period.](image)

4.3 Sound Events Spectral Analysis

Frequency spectrum of each sound event were evaluated. In Figure 2, it can be seen that the frequency spectrum of the train pass-by honking its horn has a tonal component of 99.0 dB in the fundamental frequency centred on 250 Hz, a first harmonic of 84 dB in the one-third octave band centred on 500 Hz and a predominant third harmonic of 97 dB in the spectral component centred on 800 Hz. The train pass-by noise spectrum do not show tonal components for this sound stimulus.
The car passing by with an audio-car system has a frequency spectrum with predominance of low-frequencies in the order of 50 Hz reaching up to 92 dB. However, it can't be distinguished any particular tonal component.

The spectrum of the car passing by with pulley and timing belt has a fundamental tonal component of 77 dB centred on 5 kHz and first harmonic of 74 dB centred on 10 kHz.

The frequency spectrum in one-third octave band of the motorcycle accelerating shown that there is no tonal component that stand out in the audible spectrum.

The frequency spectrum of a bus honking its horn is characterized as a broadband noise with a single tonal component of 81 dB centred on 400 Hz caused by the horn.

5 Subjective Evaluation

In this research, three surveys were conducted: an online pilot survey and two hearing surveys conducted in laboratory conditions based on verbal rating scale and by the method of pairwise comparison.

5.1 Online Pilot Survey

A online pilot survey was designed and carry out in order to relieve those noise sources that most annoy or disturb people in the area of Caseros Downtown.

For this pilot survey were interviewed 63 people, of both sexes and normal hearing, whose ages are between 18 and 28 years. The interview was conducted via online forms, and was designed to be answered in no longer than 3 minutes.

5.2 Verbal rating scale survey

In order to design the Verbal Rating Scale (VRS) survey the ISO/TS 15666 standard was taken into account [8]. So, people were asked to imagine being resting at home and scale the annoyance, noisiness and loudness caused by each sound stimulus according to: not at all, slightly, moderately, very or extremely annoying/noisy/loud (as applicable).
As a result, the most annoying stimulus was the train pass-by honking its horn with %HA of 78%, followed by the accelerating motorcycle noise (67%) and by the car passing by with pulley and timing belt noise and the bus horn (64%). Conversely, the least annoying sound event had been the train pass-by noise (without honking its horn) with HA 25%. Also, the car passing by with an audio car system reaches a %HA of 58%.

Also, the noisiest sound event had been the motorcycle with HN% of 75%, followed by the train pass-by honking its horn (58%) and the bus horn, along with the car passing by with pulleys noise (56%). Then, the car passing by with an audio car system and the train pass-by reach 42% of noisiness %HN qualifications.

Results of loudness rating scale survey indicate that the louder sound event was the train pass-by noise honking its horn with an HL% of 78%, followed by the bus horn (75%) and the noise of the accelerating motorcycle (69%). The least loud sound events had been the car passing by with an audio-car system (39%), the car with pulleys noise (36%) and train pass-by noise with a %HL of 31%.

5.3 Pairwise comparison test

Another hearing survey was conducted by mean of pairwise comparison method. Listeners were questioned about which sound event they found most annoying, noisy and loud, when hear the fifteen (15) pair combinations for the six (6) sound stimuli.

The most annoying sound event was the train pass-by honking its horn, followed by the bus horn. Then was rated the car with pulleys noise and slightly below the car passing by with an audio-car system. After that the accelerating motorcycle were qualified. According to the results, the least annoying sound event was the train pass-by (without honking its horn).

The noisier sound events were the train pass-by noise honking its horn and accelerating motorcycle. Below these, follows the bus horn and the car passing by with pulleys noise. The less noisy sound events were the car passing by with an audio-car system and the train pass-by noise.

The loudest sound events were the train pass-by honking its horn and accelerating motorcycle. Below these, follows the bus horn and the car passing by with pulleys noise. The less loud sound events were the car passing by with an audio-car system and the train pass-by noise.

6 Correlation coefficients

The correlation between objective acoustic descriptors and the scale values of each subjective attribute was evaluated. In order to do this, correlation coefficients were calculated and those values equal or greater than 0.6 were considered as good correlation indicators (highlighted in bold values).

First, the correlation between scale values of annoyance, noisiness and loudness, obtained from pairwise comparison test were analysed. There was found a good correlation between the three subjective attributes studied throughout this investigation.
In table 2, the correlation coefficients between the scale values of the pairwise comparison test and verbal rating scale classification were analysed. Results indicate a good correlation between both surveys. Results of both surveys regarding to same subjective attribute show an excellent correlation coefficient (greater than 0.87). So, it could be used either methods to assess the perception of people regarding annoyance, noisiness and loudness from individual sound events.

Table 2: Correlation coefficient for both survey methods.

<table>
<thead>
<tr>
<th></th>
<th>ANNOYANCE (Verbal rating scale)</th>
<th>NOISINESS (Verbal rating scale)</th>
<th>LOUDNESS (Verbal rating scale)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANNOYANCE (pairwise comparison)</td>
<td>0.98</td>
<td>0.64</td>
<td>0.60</td>
</tr>
<tr>
<td>NOISINESS (pairwise comparison)</td>
<td>0.66</td>
<td>0.87</td>
<td>0.87</td>
</tr>
<tr>
<td>LOUDNESS (pairwise comparison)</td>
<td>0.62</td>
<td>0.57</td>
<td>0.93</td>
</tr>
</tbody>
</table>

Then, correlation coefficients between the acoustic parameters of each sound event were calculated. The highest correlation values were found between LA_{eq} and SEL, then between L_{pk} and L_{max}, follow by L_{pk} and L_{10} and between L_{max} and L_{10}.

Also, a correlation analysis between the results of the objective acoustic parameters and the three subjective attributes were conducted. Results indicate a good correlation between loudness and the acoustic parameters L_{eq}, SEL, L_{pk}, L_{max}, and L_{10}. In turn, the noisiness has a good correlation with the L_{pk} parameter and the annoyance with the percentile L_{90}.

7 Conclusions

- It was showed that people are able to distinguish and scale the annoyance, noisiness and loudness of sound events if carefully designed experiments in laboratory conditions are made.

- The most annoying sound event was the train pass-by honking its noise, followed by the bus honking its horn and the car passing by with pulleys and timing belts noise. Instead, the least annoying sound stimulus is the train pass-by (without honking its horn).

- It can be concluded that the most annoying sound events were those that shown tonal characteristics and present the higher levels of noise climate (NC).

- The noisiest sound events were the train pass-by honking its horn and the accelerating motorcycle. Conversely, the least noisy sound events were the train pass-by (without honking its horn) and the car passing by with an audio car system.
The louder sound events were the train and the bus honking its horns (matching results with the most annoying sound events). However, the car passing by with pulley and timing belt noises had been rated as the least loud. Therefore, it is possible to say that some slightly loud sound events could be very annoying.

The train pass-by honking its horn get the highest acoustic parameters (Leq=83.3 dB, SEL=94.0 dB). Also, this sound stimulus has been indicated as the most annoying and the loudest. Then continues the car passing by with an audio-car system with slightly lower acoustic parameters (Leq=81.5 dB, SEL=91.7 dB). However, such sound event has not been considered among the most annoying, noisy and / or loud sound events. That results indicates that there are high sound pressure levels noise sources that are not annoying, noisy or loud (in comparison with lower level sound events).

There is a good correlation between the three subjective attributes evaluated (annoyance, noisiness and loudness). Moreover, loudness is the only subjective attribute that shown a good correlation with various objective parameters (LA_{eq}, SEL, L_{pk}, L_{max} and L_{10}).

It was found that verbal rating surveys and pairwise comparison test show an excellent correlation for the same subjective attribute. Therefore, it can be concluded that both methods are valid to evaluate the subjective perception of people with regard to sound events obtained from community noise and under laboratory conditions. It is worth mentioning that pairwise comparison test requires 50% more time than verbal classification method to be completed.

Those Ordinances, Laws and Regulations which simplify the problem of noise pollution only to the qualification of noise as "Annoying" or "Not Annoying" when a sound level is exceeded, as well as those purely objective studies for assessing community noise, do not take into account the "quality" of noise. So, to assess the existence of annoyance in an exposed population is necessary to carry out subjective studies in order to complement objective evaluations.

References