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Relationship between Urban Noise and the Health of Users of Public Spaces—A Case Study in Vitoria, ES, Brazil

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Abstract

Urban populations today are exposed to high levels of noise, which may cause discomfort and lead to health problems. Most of these noises are traffic-generated; therefore, this study focuses on evaluating the soundscapes of urban open spaces to determine its importance for the health of the citizen, since such spaces can function as noise attenuators. The methodology of this study involved a literature review, computer simulations and interviews with users of the aforementioned open spaces. The case study was conducted in an urban area in the city of Vitória, state of Espírito Santo, Brazil. The results indicate that, in the period of this study, traffic noise dissipated through open spaces but noise levels still exceeded the maximum allowable levels established by regulations. Nevertheless, the population proved to be largely unaware of the noise. It should be pointed out that the areas under study are used predominantly as recreational spaces for health and wellbeing activities. The findings of this study may serve to underpin urban planning policies that encourage the inclusion of open spaces, especially in areas of high urban density where the transport system consists of motor vehicles, in order to help control urban noise.

Keywords

Urban Noise, Simulation, Public Areas, Noise Mapping

1. Introduction

One of the most democratic ways in which urban space is used for health and well-being related activities in cities takes place in public areas. Such areas—in the form of squares or simply open spaces—have been used since ancient times for meetings and discussions of matters of interest to the community. Over time, their function has undergone modifications and their shapes have been adapted to reflect sociocultural evolution and economic relations. However, questions have been raised about whether these areas really fulfill the purpose for which they are intended, especially with regard to environmental quality, which can be a two-way street insofar as the health of their users is concerned. Wooded areas and public facilities, for example, can provide opportunities for recreation, but they are not necessarily accessible to all social groups. Agenda 21, a document that emerged from the United Nations Conference on Environment and Development-also known as the ECO-92, Earth Summit or Rio Summit which "*recognized the need to adopt a balanced and integrated approach to issues related to the environment and development*," noted some action programs that address the issues of air pollution, water pollution, pesticide use, solid waste, noise, radiation, and others [1]. Among the various types of pollution cited, some are clearly perceptible through sight or smell while others are difficult to discern. Urban noise, for example, which is one of the types of pollution produced by human activities through the routine use of maintenance equipment, loudspeakers, aircraft, automobiles, etc., is one of the types of pollution least perceived by people, possibly because they get used to it (due to a phenomenon called auditory habituation).Another reason for the difficulty in perceiving noise pollution is that it is invisible. On the other hand, water pollution is easily perceived by smell and vision, as well as air pollution by gaseous emissions.

Despite the gradual changes in mindsets and technological conditions towards more evolved and less harmful ones, machinery from the industrial age is still widely used even in today's so-called information age. One of the main legacies of the previous age, characterized by the use of fossil fuels, is represented by the most popular means of transportation-motor vehicles, which are an example of the problems arising from noise emissions.

High sound levels, associated with long periods of exposure and the long duration of the sound event, can cause health problems. These problems can manifest themselves in mild discomfort, irritability, headaches, and can affect the nervous system and cardiovascular system. For sound levels around 100 dB (A), hearing risks are imminent.

In this context, this study aimed to evaluate the overall behavior of sound in specific open spaces, and also to determine the extent to which public areas are exposed to high levels of traffic noise, and whether the population clearly perceives this phenomenon and the health risks to which they are exposed. Thus, selected areas of the city of Vitória, capital of the state of Espírito Santo, Brazil, were used as a case study. It was also assumed that such areas of urban voids can serve as spaces to attenuate traffic noise, underscoring their importance in the urban network.

Studies related to the theme are intrinsically linked to the concept of sound propagation [2] [3]. Considering air as the medium of transmission, sound propagation is influenced by factors such as climate, natural topography, constructed barriers and even vegetation, which, together with the physical aspects of sound, can reduce or amplify the noise emitted by a source.

Although Brazilian standards deal with noise-related issues in different situations, there is no specific quantification of comfortable or acceptable noise levels for public living spaces. However, the standard NBR 10151 [4], which specifies noise assessment procedures in inhabited areas to ensure the comfort of the community, establishes Levels of Evaluation Criteria (LEC) for outdoor environments. Given that the main aim of this research is to determine how open spaces affect sound propagation, and the comfort of users of these spaces, the parameter proposed by the Brazilian standard that evaluates environmental quality from the standpoint of noise levels was adopted as a parameter of analysis [4]. The areas evaluated in this study fall within the scope of the standard for mixed recreational areas, whose equivalent continuous sound level, Leq, should not exceed equivalent sound pressure levels L_{Aeq} −65 dB (A) during the daytime, *i.e.*, between 7:00 a.m. and 10:00 p.m.

2. General Features of the Study Area

Vitória, the capital of the state of Espírito Santo, Brazil, has a population of approximately 327,800 [5]. The municipality covers an area of about 87,102 km^2, which includes an extensive coastline, since it is an island that covers a continental portion to the north [5]. There are several rock formations in the insular portion, which, historically, was formed largely by landfills. The continental portion is characterized by its basically flat topography.

The local government is known to control urban noise based solely on an instrument of complaint called "dial direct noise complaints," created in 1997. It should be noted that vehicle-related noise ranks as the third main reason of complaints filed by the agency between 2012 and 2016.

As can be seen in **Table 1**, the number of vehicles in circulation in the city increased by approximately 77% over the last decade (2004 to 2016) [6] [7]. This figure is lower than the national average increase of approximately 119%, according to Brazil's National Confederation of Transport [6]. However, the situation is still worrisome, especially considering the characteristics of the city, whose geographical features and road network do not allow for horizontal urban expansion, not to mention the tendency for its traffic-related noise levels to increase.

3. Materials and Methods

One of the control mechanisms established by Law No. 10,257/2001, known as the City Statute [8], specifies that the rules for the allotment and use of land must be determined by the municipal administration through its Master Plan. Specific land use and occupation guidelines, in the form of urban zoning areas, are assigned to each region according to its particularities. Thus, the guidelines and regulations proposed by the Vitória Urban Master Plan for the urban area to be analyzed were considered in the choice of simulation areas [9].

Table 1. Evolution of the vehicle fleet in Espírito Santo and Vitória from 2004 to 2016. (Source: adapted from Vitória Municipal Administration [5] and complemented by the National Traffic Department [7].

Year	Vitória	
	Vehicle Fleet	Growth (%)
2005	113,837	6.0
2006	121,347	6.6
2007	131,712	8.5
2008	142,819	8.4
2009	153,360	7.4
2010	162,194	5.8
2011	170,533	5.1
2012	178,463	4.7
2013	185,427	3.9
2014	191,413	3.2
2015	192,897	0.7
2016	193,091	0.1

a. Data from 2014 to 2016 (up to march) obtained from the national traffic department (http://www.denatran.gov.br/frota.htm on 9 Apr. 2016).

This study involved an analysis of noise levels in public spaces, including traffic-related noise, so it was spatially demarcated considering the following criteria: 1) the study area had to be located in the continental portion of the island of Vitoria; 2) close to or within an area defined as a Controlled Occupation Zone of mixed residential and non-residential use, with complete basic sanitation infrastructure, water supply, and sewage collection and treatment services; 3) it had to be a public place with free spaces, preferably destined for squares, parks and green areas, according to art.189 §4 of Law 6705/2006 [9]; 4) it had to be more than 200 m^2 in size; and 5) it had to be located approximately 250 meters from collector or arterial roads with a traffic flow.

The areas that meet these mentioned requirements are shown in **Figure 1** and described in **Table 2**. Since the research was aimed at assessing the user's acoustic comfort, areas widely used for recreation and sports activities, which require pleasant and healthy spaces, were selected as preferred areas.

After these 10 points were selected, field data were collected for the simulations, such as digitized maps of the evaluated neighborhoods, demographic data, and vehicle counts and classification, to establish the volume of motor traffic. These data were grouped and input in the software program to perform the simulations, which were then validated by means of field measurements using specific devices, according to the Brazilian technical standard NBR 10151 [4].

The next step consisted of a subjective noise level assessment, *i.e.*, the user's perception of the problem. This perception was determined based on interviews with users in five of the ten aforementioned selected areas. A questionnaire was

Figure 1. Map of an urban part of the city of Vitória, showing the location of the points selected for the measurements (Source: Adapted from Vitoria Municipal Administration) [9].

then prepared and a pilot experiment was carried out to test this form of addressing the population, as well as the number and relevance of the questions and the time spent in conducting the interviews. Having defined the questions, the interviews were conducted.

The third step of this study was then carried out, which involved a statistical evaluation of the data collected in the interviews. Each item of the questionnaire was transformed into a variable and inserted into a database. These data, in turn, were inserted into a statistical analysis software program and subsequently evaluated.

4. Simulations

In order to evaluate the effects of the built environment in terms of traffic noise emissions, simulations were made of the noise immission levels at the evaluation points, as shown in Table 3, which were later validated based on in situ noise level measurements.

The simulations were performed, with Brüel & Kjær's Predictor version 8.11 software package, or Predictor-Lim A Software Suite Type 7810, which is based

Table 2. Characterization of the points selected for simulation.

Point	Identification	Neighborhood	Description
1	Camburiseashore	Jardim da Penha	Public seafront area of mixed use containing multi-family residential buildings of up to 7 floorsand local stores
2	Philogomiro Lannes Square	Jardim da Penha	A square surrounded mostly by multi-family residential buildings of up to 7 floors and local stores
3	Regina Frigeri Furno Square	Jardim da Penha	A square surrounded mostly by multi-family residential buildings of up to 4 floors and local stores
4	Fernando Ferrari Avenue	Mata da Praia	This avenue passes along the edge of Pedra da Cebola Park andis of mixed use, with multi-family residential buildings of up to 10 floors and local stores
5	Des. Dermerval Lírio Avenue	Mata da Praia	This avenue passes along the edge of Pedra da Cebola Park and is of mixed use, with multi-family residential buildings of up to 3 floors, single family homes and local stores
6	Jacob Suaid Square	Mata da Praia	A square surrounded mostly by single family homes with up to 2 floors
7	Camburi seashore	Jardim Camburi	Public seafront area of mixed use containing multi-family residential buildings of up to 12 floors and local stores
8	Alcino Pereira Neto Street	Jardim Camburi	A square surrounded mostly by multi-family residential buildings of up to 4 floors and local stores
9	Issac Lopes Rubim Avenue	Jardim Camburi	This avenue of mixed use is characterized predominantly by multi-family residential buildings of up to 7 floors and local stores
10	Fazendinha Municipal Park	Jardim Camburi	This park along the highway is bordered by a scattering of multi-family residential buildings of up to 10 floors

on the ISO 9613 standard [10] [11].

The simulations required access to the city's cartographic database, made available by the Vitória Municipal Administration, as well as the definition of the parameters of use of the software. The traffic flow attributes were obtained based on vehicle counts at the 10 points of the area under analysis. Vehicle counts were made between 5:30 p.m. and 7:00 p.m., characterizing the daytime period as determined by the Brazilian standard NBR 10151 [4].

The counting of the flow of vehicles was done for 15 minutes without interruptions, and the counts were extrapolated to one hour and inserted into the software. Predictor software works with the parameter "vehicles per hour".

Vehicles were counted into two categories: light and heavy. For the reader's clarification, in accordance with resolution No. 15 of 1985 of CONAMA-National Environment Council of Brazil, light vehicles are vehicles for the transport

Table 3. Comparison of simulated and measured sound pressure levels.

Point	Description	Neighborhood	Simulated sound pressure level in dB (A)	Measured sound ressure level in dB (A)	Difference
1	Camburi seashore	Jardim da Penha	75 - 80	78.0	0
2	Philogomiro Lannes Square	Jardim da Penha	65 - 70	68.2	0
3	Regina Frigeri Furno Square	Jardim da Penha	65 - 70	67.0	0
4	Fernando Ferrari Ave.	Mata da Praia	75 - 80	78.2	0
5	Desembargador Dermerval Lírio Ave.	Mata da Praia	70 - 75	69.2	0.8
6	Jacob Suaid Square	Mata da Praia	65 - 70	71.2	1.2
7	Camburi seashore	Jardim Camburi	75 - 80	72.2	0
8	Alcino Pereira Street	Jardim Camburi	70 - 75	69.2	0.8
9	Isaac Lopes Rubim Ave.	Jardim Camburi	65 - 70	64.5	0.5
10	Fazendinha Municipal Park	Jardim Camburi	65 - 70	72.8	2.8

of passengers or cargo or of mixed use, with mass less than 3856 kg, and heavy vehicles have with a mass above 3856 kg. The acoustic maps were calculated using a 10-by-10-meter grid, positioned four meters above ground level, as recommended by several studies published in the current literature on noise mapping [12] [14] [15] [16]. Sound pressure levels were measured concomitantly with the vehicle count. The measurements were taken in situ using a properly calibrated Extech 407,780 sound level meter. All these measurements were taken at the same time, following the procedures recommended by the Brazilian standard NBR 10151 [4]. The measurements were carried out under suitable conditions, *i.e.* without strong winds and without rain. The type of flooring is also considered, according to the database present in the software. A pavement is defined in the software according to the characteristics of the actual pavement.

To validate the simulated sound levels relative to the measured sound levels, the difference between these data was assumed to fall within the range of (±) 4.6 dB (A), as indicated by Licitra and Memoli [17] and by the European Directive 2002/49/EC-Relating to the Assessment and Management of Environmental Noise [18]. Bies and Hansen assume a difference of (±) 5 dB (A) between measured and simulated sound levels [19].

Figure 2 represents the result of the simulation, that is, the noise mapping calculated for the daytime period. Noise mapping is calculated according to the guidelines of ISO 1996-2-Description and measurement of environmental noise, Part 2: Acquisition of data pertinent to land use. The ISO 1996-2 standard also states that the boundaries of the zones represent the difference in results in multiples of 5 dB. The standard includes two tables to represent these results by means of colors or crosshatching. The first table uses multiples of 5 dB and the

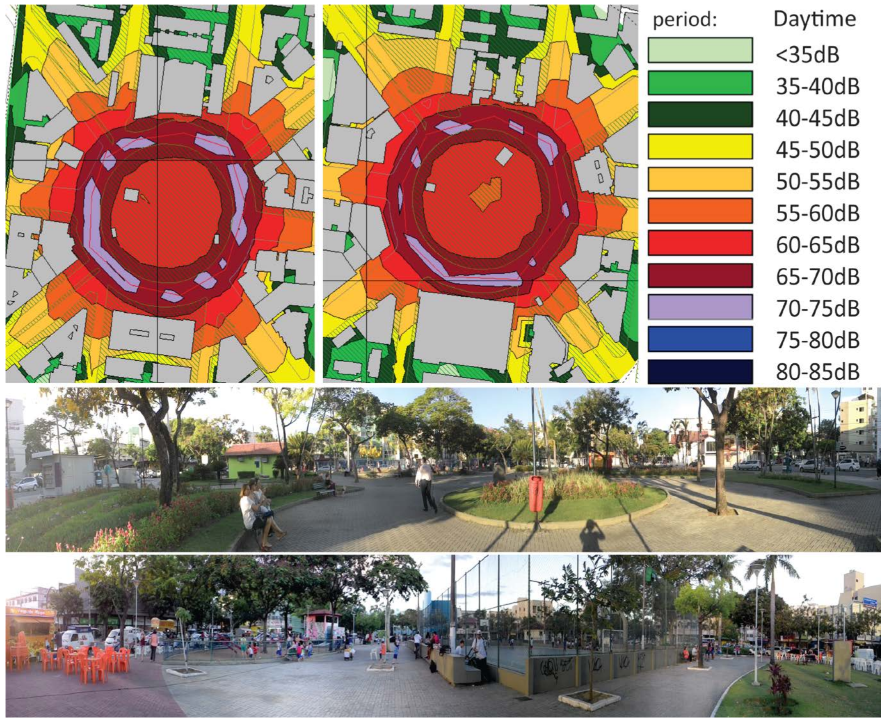

Figure 2. Simulated stretch of areas 02 and 03 and illustrative images. Equivalent sound pressure levels L_{Aeq} in dB.

second multiples of 10 dB. According to ISO 1996-2, the details and scale of the map depend on: 1) the size, structure and use of the area in question; 2) the purpose of planning (large scale decisions at sites for new sources and receivers, changes in land use, final decision for new receivers); and 3) the phase of the planning procedure. ISO 1996-2 indicates that a noise map can be established as an official map on a given scale, describing relevant details of buildings, traffic, industrial areas, vegetation and contour lines.

5. Interviews

A questionnaire was applied at the study site as the main instrument to collect data about the users' perceptions of noise levels exceeding those considered healthy. The questions were based on the studies of Zannin *et al.* [16] and Szeremeta and Zannin [20], and were drawn up in partnership with the Statistics Laboratory of the Federal University of Espírito Santo. After running a pilot experiment, the final version of the questionnaire contained with 10 questions and its application was foreseen to last about 10 minutes. In general, the questions included the characterization of the user of the areas, how often they visit them and the length of time the user stays in these areas, activities performed and the motivations to attend them. In addition, the questions also addressed how the user perceives the sounds around them, how often he/she listens to the various types of sounds and whether that bothers them. The sample size was scaled to 375 respondents and a sampling error of 5%. The interviews were conducted between 5:30 p.m. and 7:00 p.m., Monday through Friday, for ten weeks. This time frame was chosen because it corresponds to one of the peak daytime rush hours.

The questionnaires were applied to respondents at five of the 10 (ten) points under study to facilitate the logistics of the interviews. The points were selected by drawing lots, considering the largest urban park, Pedra da Cebola Park, as the control area. The points selected for interviews were points 01, 02, 03 and 09, plus the control area, which are described in **Table 1**.

The respondents' answers to the questionnaire were transformed into variables that were inserted into a database, which was then inserted into the SPSS software for statistical treatment of the data, using the Chi-square test at a 5% level of significance.

6. Results and Discussion

Table 3 compares the simulated and measured sound pressure levels of the ten evaluated areas.

Table 3 shows a compilation of the resulting data, enabling comparisons of the simulated sound pressure levels and those measured in situ. As the simulated level appears in the form of an interval and the field level indicates a unitary result, we sought to ascertain if the field level fell within the range of the simulated level. If so, any difference found was considered null, and if not, the difference found was considered by subtracting the limit value of the interval of the simulated sound levels to the highest or lowest value. In this scenario, all the simulated points can be considered valid, since the degree of uncertainty, or acceptable error, in this research was assumed to fall within the range of (±) 4.6 dB (A), as indicated by Licitra and Memoli [17] and by the European Directive 2002/49/EC-Relating to the Assessment and Management of Environmental Noise, published in the Official Journal of the European Communities; 2002. No. L 189 [18], to (±) 5 dB (A), as indicated by Bies and Hansen [19].

An evaluation of each of the simulated areas where the interviews took place revealed the incidence of vehicle-related noise sources and the sound levels reaching passersby.

Figure 2 illustrates the simulations of areas 02 and 03, which are squares of similar shape and size located in the Jardim da Penha neighborhood. Although they are located in the vicinity of traffic routes of different scales (one near a collector road and the other near a local street), the results are similar, with noise levels of L_{Aeq}60 to 65 dB (A) reaching the user, as observed in the emission scaling parameters of the software. Moreover, the noise is found to be blocked, to a certain extent, when it reaches the built mass, and to penetrate the free space between buildings and adjacent streets in the urban network.

In this scenario, all the simulated points can be considered valid, since the degree of uncertainty, or acceptable error, in this research was considered to be ± 4.6 and/or (±)5 dB (A), as recommended by current literature on noise mapping [17] [18] [19]. Therefore, all the points fell within the acceptable limit. In addition, considering the level of 65 dB (A) established as acceptable by the NBR

10151 standard for mixed areas used for daytime recreation, it was inferred that of the five areas effectively investigated, four showed noise pressure levels exceeding the recommended level.

The only age-related restriction to answer the questionnaire was that the respondents be more than 18 years old. Most of them were between 21 and 30 years old. As for the respondents' ages in relation to the interview sites, the aforementioned age bracket was observed mostly among the respondents interviewed along the seashore. In the squares, the majority age group ranged from 31 to 40 years old, while the respondents in the parks were mostly more than 61 years old. As for gender, the interviewees showed a certain equilibrium, but in absolute numbers, most of the interviewees declared they were males.

In terms of schooling, most of the respondents described themselves as high school graduates, and most of them stated that they lived in the neighborhood where they were interviewed.

The variables indicate some characteristics of the respondents' relationship with the location. For example, most of them stated that they make daily visits to the areas where the interviews were carried out, and that they frequent these areas for one to two hours, during which time they are exposed to the local traffic noise.

The respondents were asked to indicate if and how intensely they heard a series of sounds and noises emitted by people, animals and equipment (including vehicle traffic noise). Most of them stated they could distinguish these different types of noise in the surveyed areas, and traffic noise was one of the most frequently cited noise sources, followed by aircraft, children playing, conversations between people, and people talking on cell phones. They were then asked to quantify the degree of annoyance these perceived noises can cause. The overall results indicate that most of the respondents, when asked about each of the noise sources cited in the survey, stated they were not bothersome. However, traffic noise ranked among the sources that cause the most discomfort, followed by aircraft, and these responses were about equal to the number of negative responses. As for the surveyed areas, the respondents stated that the environmental noise does not exceed the expected level, that it is in harmony with the landscape, and that they are not bothered by the ambient sounds.

The statistical analysis revealed an association between some of the variables, e.g., the length of time spent in the public area relative to its location. As for mechanical noise, it should also be noted, that some show an association when related to the annoyance they cause, these being traffic and airplane-related noise sources.

This survey confirmed the importance of public spaces in lowering urban traffic noise. The simulations indicated that traffic-related noise is dissipated in open spaces and decreases in intensity with increasing distance. They also showed that noise is blocked when it reaches built masses and penetrates through free space between buildings and adjacent streets in the urban network.

In addition, the simulations and field measurements indicated that vehicle traffic noise can be considered high for the areas under study, despite the presence of other types of urban noise in the environment which may affect the users' comfort and health, such as other mechanical, natural, or human sounds.

The results of this study led to the conclusion that the areas can be classified as acoustically polluted, and that most of the respondents perceive the existence of noise but do not seem to be bothered by it and have adapted to the resulting discomfort. This conclusion is worrisome, given that constant noise actually poses a public health risk which the affected population is often unaware of. The findings of this research will hopefully serve to underpin public policies for the management of public space, aiming at the wide dissemination of the acoustic reality of cities as measures to raise the population's awareness, as is the case in several countries, especially in Europe. Moreover, since Vitória is not one of Brazil's largest capitals, we believe this problem occurs in numerous other larger cities, which underscores the need to publicize these findings. Urban noise measurements were also performed, in Brazil, in cities larger than Vitória, such as Curitiba [20] [21] [22] [23], Rio de Janeiro [13] and São Paulo [24]. In all these other cities, traffic noise of vehicles was pointed out as the main source of annoyance for the population. In Curitiba, 860 people were interviewed [21] [22]. The main noise sources found as disturbing were motor vehicle traffic (73%) and neighbors (38%), which were rated as producing the most disturbing noise. All respondents pointed out at least one of the following as noise sources: neighbors, animals, sirens, civil construction, religious worship temples, nightclubs, toys, and domestic electric appliances. The main reactions to noise exposure were: irritability (58%), difficulty to concentrate (42%), sleeping disorders (20%), and headaches (20%).

Other possible measures to mitigate urban noise include planning vehicle flows, reducing vehicle traffic speed, improving street pavement conditions, inspecting vehicles to determine their noise emissions, and establishing permits for heavy vehicles to circulate in the vicinity of leisure areas at preset times. In addition, interventions could be carried out to favor pedestrians, such as the construction of acoustic barriers at strategic locations, and the zoning of squares and parks, to render these public environments healthier.

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