Assessing noise exposure levels along recently built cyclepaths in a Brazilian city with a mobile sensing system

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Abstract

The objective of this study was to verify if cycling facilities built in the past few years have resulted in infrastructures that are compatible with cyclists' standards, regarding noise exposure. The evaluations were based on a mobile sensing system, which registers GPS coordinates and noise levels every second. An assessment procedure was developed and applied in the city of São Carlos, Brazil. In general, the results did not indicate high levels of noise exposure, although high values were consistently found in particular points of the routes. The highest noise levels were observed in the cyclepaths located along the streets with the highest car traffic speeds.

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1. Introduction

A fast urbanization process associated with a considerable growth in the number of private cars circulating in urban areas in the latest years is now producing some pressure for improvements in the mobility conditions of many Brazilian cities. The protests observed in the major cities of the country in 2013 were only part of this process, which has different consequences. One of them is a change in the discourse of some mayors, who started to advocate in favor of more sustainable transportation modes. In some cities, the discourse never became an effective action. In other cities, new infrastructure for non-motorized modes (particularly cycling) was recently built or is now under construction. At a first sight, this would stimulate the use of bicycles as a regular transportation mode.

However, as discussed by Medeiros and Duarte (2013), in many cases the new facilities are not designed and implemented as they should be. This happens because the actual goals behind the projects are to reduce the implementation costs and to locate the facilities where they can be easily seen by the general public, even if the selected sites are not the best alternatives from the cyclists' point of view. A low use of the recently built facilities is one of the consequences of such a poor planning and design process. Unfortunately, the resulting low demand can be used as an excuse to stop expanding the infrastructures in the future. Therefore, it is important to understand what is really happening with the users (and potential users).

In this context, the objective of this study is to verify if the planning strategies adopted by some Brazilian municipalities for the construction of new cycling facilities in the past few years have resulted in infrastructures that are compatible with cyclists' standards, regarding noise exposure.

Unpleasant noise levels in the urban environment can be associated with several factors. Construction activities, transportation, industrial and commercial activities, and even public events are some of the common sources of noise pollution in urban areas. The conditions can be aggravated by the arrangement of physical elements, such as narrow and deep urban canyons, for example. Several international studies, such as those conducted by Botteldooren et al. (2011), Can and Botteldooren (2011), Dekoninck et al. (2012), and Gozalo et al. (2013) emphasize that road traffic is the major source of noise in urban areas. The topic is also discussed in studies conducted in Brazil (Calixto, 2002; Moraes et al., 2003; Paz, 2004; Guedes, 2005; Mardones, 2009; Costa et al., 2013). According to Paz (2004), these studies stimulated some public agencies to search for alternatives to mitigate the production and propagation of such a complex noise, which comes from more than a single source (traffic speed, acceleration, breaking, contact between tires and pavement, etc.).

Regarding the data collection procedures of noise levels for the elaboration of acoustic maps, which are mandatory in Europe for cities with more than 250,000 inhabitants, Dekoninck et al. (2012) highlighted the potential of mobile measurements. The authors also indicate the use of bicycles as a way to reduce the data collection times. This was the main motivation for the approach adopted in the present study. The evaluations were based on a mobile sensing system, which registers GPS (Global Positioning System) coordinates and noise levels every second. To our knowledge, this measurement strategy is not extensively used, although it is totally compatible with the reality experienced by the cyclists during the actual trips. The proposed method was applied in the city of São Carlos, Brazil, during the morning and evening traffic peak hours.

2. Methodology and Case Study

The proposed procedure started with the measurement and evaluation of noise exposure along cyclepaths. Two types of cyclepaths were considered: recently built cycleways and streets with a clear potential for the implementation of similar infrastructures, but without them yet (i.e. a context in which bicycles still have to share the street space with all motorized vehicles). Next, the registered noise levels were compared with reference values suggested by regulations and also discussed in the literature as comfort and health limits. The entire process involved the following procedures: i) data acquisition; ii) data processing; and iii) evaluation of the noise exposure levels along the routes.

2.1 Data acquisition

For the purpose of this study, noise measurements had to be compatible with the reality experienced by cyclists during their actual trips. Thus, the strategy used was based on a mobile sensing system developed at the University of Ghent. The sensor, which can be placed in a regular bicycle, registers GPS coordinates and noise levels every second. Afterwards, the raw data collected had to be uploaded through an internet connection to a server in Belgium, where it was stored and pre-processed. As the study partially focused on recently built cycling infrastructures, and the city of São Carlos, Brazil, had a reasonable extension of cyclepaths in that condition, we selected six of these new stretches for a case study. If seen together, these six stretches can be combined into a single route, named Route 1 (and labeled as a, b, c, d, e, and f). The trips were done in two directions, from North to South and from South to North. We also selected a route with a clear potential for the implementation of similar infrastructures, given the location and topography of the streets and the distribution of residences along them (as indicated by Guerreiro and Rodrigues da Silva, 2013). That one was called Route 2, which was split in two parts (labeled a and b, from West to East and from East to West, respectively).

Nine trips were done in Route 1 during the traffic peak hours, five in the morning (from 7 a.m. to 9 a.m.) and four in the evening (from 5 p.m. to 7 p.m.). For safety reasons, the number of trips conducted in Route 2 was limited to a minimum, in that case, only six trips (three per period of the day). Unfortunately, the first three records were lost due to technical problems. As these problems were solved only later on, during the field campaigns, the data available for further analysis was reduced to six trips in Route 1 (two in the morning and four in the evening) and three trips in Route 2 (all in the evening).

2.2 Data processing

After the raw data was uploaded to the server in Belgium, it was processed, stored in a user-friendlier format, and subsequently sent back to Brazil for the analyses. The format adopted for the intended analyses was essentially a Geographic Information System (GIS) file with the GPS locations associated to the points where the noise measurements were taken, every one second. These measurements were then aggregated in points distributed every 20 meters along the routes. This procedure allowed comparisons of the different trips conducted in the same routes, given that the points where the noise levels were aggregated have always remained the same.

2.3 Evaluation of noise exposure levels

The evaluation of the noise exposure levels was conducted in two ways. In the first one, we calculated an equivalent noise value, based on the presence and duration of values above a pre-established threshold. The approach is inspired in a directive issued by the Brazilian Ministry of Labor and Employment, which establishes a criterion level, i.e. noise exposure limits for workers based on the steady noise level permitted for a full eight-hour work shift. In the case of the Brazilian directive, the noise exposure levels should not exceed 85 dB(A). In addition, workers can never be exposed to values above 115 dB(A). As the trips last only a fraction of a full work shift, the limits were adjusted accordingly, as in the two examples shown in Table 1 (28 and 10 minutes).

Table 1. Comparison of noise exposure limits for a criterion level equal to 85 dB(A) based on the values indicated for a workday in the regulation NR-15 of the Brazilian Ministry of Labor and Employment

Noise levels (in dB(A))	Noise exposure limits for a criterion level = 85 dB(A) (in minutes)		
	For an entire work shift (8 hours)	**For a trip of 28 minutes**	**For a trip of 10 minutes**
85	480,0	28,0	10,0
90	240,0	14,0	5,0
95	120,0	7,0	2,5
100	58,0	3,4	1,3

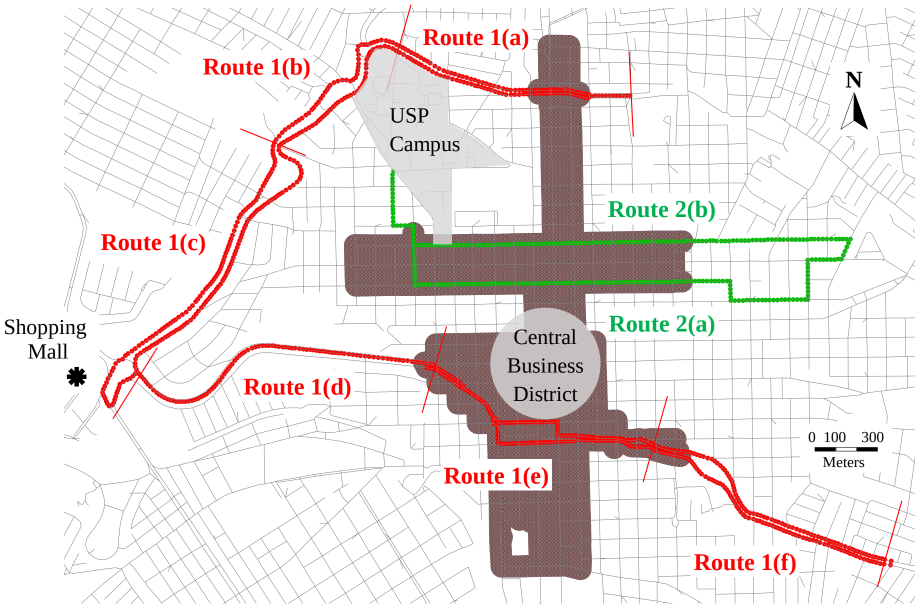
With the adjusted values, the evaluation takes into account the combination of the different noise levels and the time they last. According to the directive, the sum of the fractions of Equation 1 can never exceed the unity. These fractions are obtained by the division of the total exposure time to a certain noise level C_n by the maximum acceptable exposure time to the level T_n (obtained as is the examples of Table 1). If the result of Equation 1 is larger than one, the overall noise exposure level is above the limit. It is, therefore, unacceptable.

$$\frac{C_1}{T_1}+\frac{C_2}{T_2}+\ldots+\frac{C_n}{T_n} \quad (1)$$

The second part of the evaluation of the noise exposure levels focused in the analysis of the locations with the highest frequencies of values above the noise exposure limits. In that case, we built graphs with all noise levels registered in the points along the different routes. The results were grouped by time of the day and compared with the 85 dB(A) threshold. Every time we had values above the limit, that point was selected and saved for further analyses. Our interest was to identify the number and location of hot spots, i.e. places where the noise levels were above the pre-established limit.

3. Results

For a better understanding of the outcomes of the data acquisition phase, a map of the entire study area is first presented (Figure 1). The two considered routes are represented in distinct colors and the different parts of each route are identified in the map of Figure 1.



Areas with mixed land use, in which non-residential activities are predominant

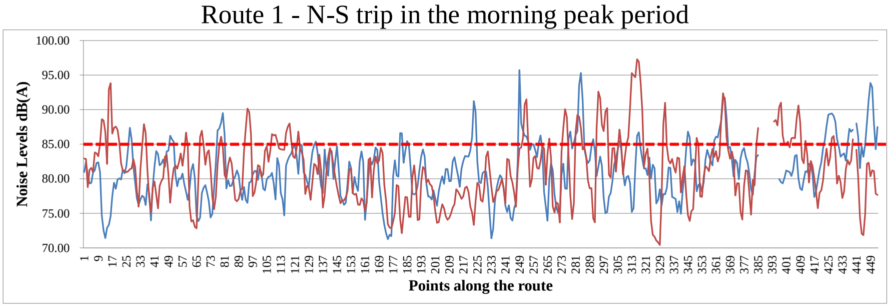
Figure 1. Representation of the cycling routes followed for noise level measurements in the city of São Carlos, Brazil

After the data processing phase, the noise levels were associated to regularly spaced points along the routes. The values obtained in the different peak periods (morning and evening), as well as in the different directions (North-South and South-North or West-East and East-West) were grouped in four sets of data, as in the two examples displayed in Figure 2, both related to Route 1.

A visual analysis of the second graph in Figure 2 indicates that we might have had problems during one of the measurement campaigns. The noise levels registered in one of the trips, in both directions, were well above the values of the other trips and also well above the limit of 85 db(A). Also, the perception of the person in charge of the data collection was not that the noise levels were significantly different from the other trips. As a consequence, we decided to eliminate that trip from the following analyses.

The evaluation of the results was therefore limited, in the case of Route 1, to three trips in the evening period and two trips in the morning period, in both N-S and S-N directions, whereas we had three trips in Route 2, in both W-E and E-W directions. The equivalent noise values found are displayed in Table 2. In general, we observed only a few equivalent values higher than or even close to one, which was considered the acceptable limit. The worst overall condition was found in one of the trips conducted in Route 2, as confirmed by the values shown in Table 2. Even in the cases with acceptable values, however, we have found places along the routes where high noise levels where consistently registered. Those were the cases of section (c) (and, to some extent, also section (e)), of the South-North trips of Route 1. The explanation for high noise levels along section (c) is certainly associated with the high speed limit (60 km/h) set for the vehicular traffic in that part of the street.

Route 1 - N-S trip in the morning peak period



Route 1 - N-S trip in the evening peak period

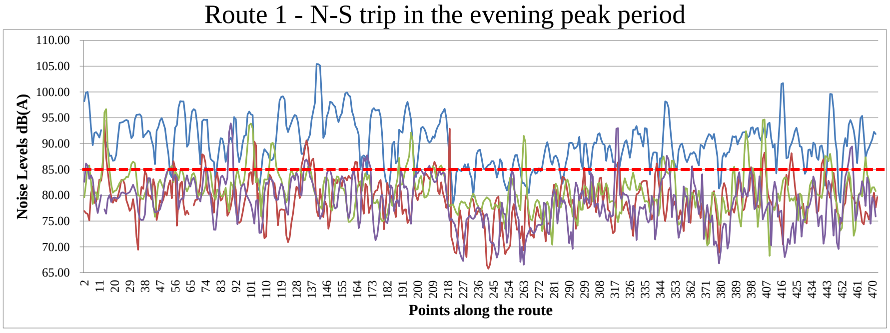


Figure 2. Noise levels registered along cycling Route 1 in the same direction (N-S) but in different periods of the day (morning and evening peaks periods)

Table 2. Equivalent noise exposure levels found in the cycling routes studied in São Carlos, Brazil for a criterion level equal to 85 dB(A)

Period of the day	Route 1											
	N-S Direction						S-N Direction					
	a	b	c	d	e	F	f	e	d	c	b	a
Evening	0.07	0.15	0.17	-	0.12	0.08	0.11	0.54	0.05	0.39	0.08	0.27
Evening	0.12	0.15	0.19	0.01	0.04	0.13	0.05	0.10	0.07	0.20	0.08	0.12
Evening	0.36	0.41	0.19	0.06	0.14	0.28	0.05	0.37	0.01	0.50	0.09	0.05
Morning	0.17	0.16	0.32	0.01	0.19	0.10	0.11	0.08	0.10	0.46	0.26	0.11
Morning	0.96	0.29	1.46	-	0.34	0.29	0.22	0.25	-	0.76	0.52	0.29
	Route 2											
	W-E Direction						E-W Direction					
Evening	1.03						0.97					
Evening	0.18						0.26					
Evening	0.06						0.25					

In the final part of the analysis we tried to evaluate the proportion of analysis points where high noise values were found several times. The results are summarized in Figure 3. The identification of these 'hot spots" regarding noise exposure is an important information if mitigation measures are planned. More than simply the number of occurrences above a certain threshold, the data collected allows the production of detailed maps with the noise distribution along the routes, as shown in Figure 4 for the case of one of the W-E trips conducted in Route 2

The orientation of the routes has, in this case, some influence on the levels of noise exposure, given that the streets along which the cycle paths are located connect important traffic generators. This explains, for example, why the results for Route 1(d) in Figure 3 vary more than for all the other routes, both for the directions and peak periods. Part of the trip (South-North in the morning and North-South in the evening) was always coincident with the peaks of vehicular traffic generated around the CBD. On the other hand, the opposite movements were exposed to the same conditions, due to the duration of the trips.

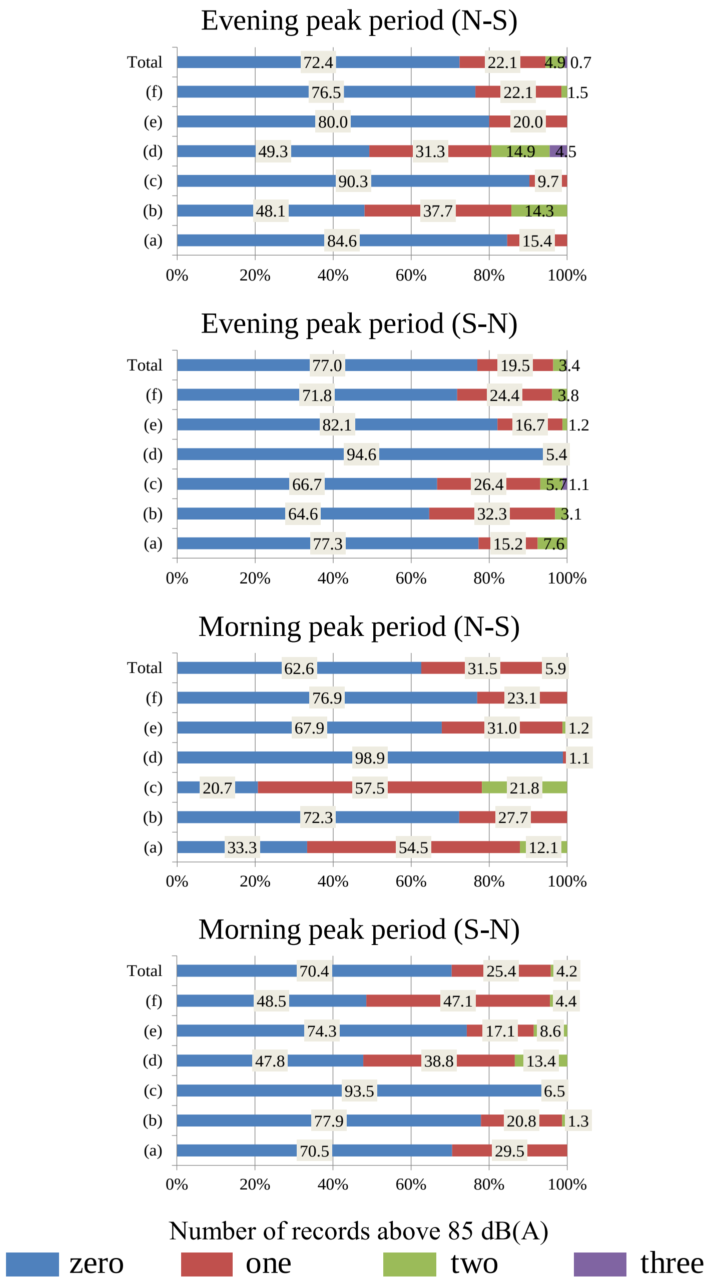


Figure 3. Percentage of points along cycling Route 1 in both directions (N-S and S-N) and in different periods of the day (morning and evening peaks periods) with noise levels above 85dB(A)

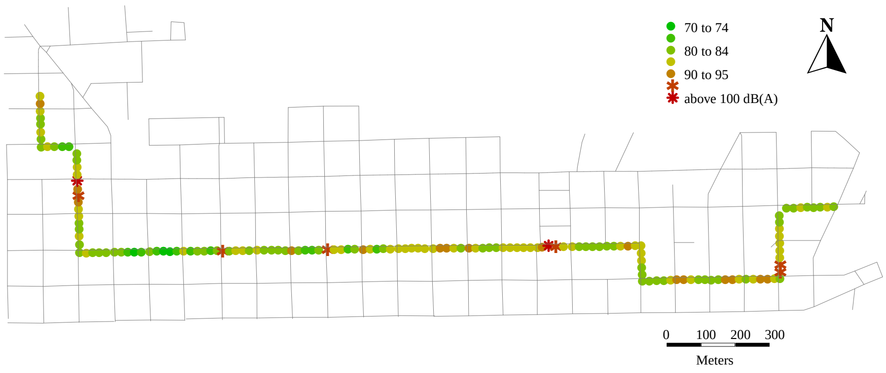


Figure 4. Noise level measurements along one of the cycling routes studied in the city of São Carlos, Brazil

4. Conclusions

Even considering that the main objective of this study was to verify if new cycling facilities have resulted in infrastructures that are compatible with cyclists' standards regarding noise exposure, we have to highlight, as a first general conclusion, the suitability of the measurement strategy for the study aim. The evaluations, conducted during the morning and evening traffic peak hours in the city of São Carlos, Brazil, were based on a mobile sensing system that registers GPS coordinates and noise levels every second. This system, developed at the University of Ghent, proved to be compatible with the experiment design. Although a comparison was not shown in this paper, the noise levels found along one of the routes are similar to the values registered with fixed sensors in the same area by Suriano et al. (2015). We must call the attention, however, to the fact that the measurements were extremely high in one of the campaigns. This is an indication that the procedures and the equipment must be thoroughly checked, in order to identify the cause of the problem.

In general, the results do not indicate a high level of noise exposure along the entire paths, although we have found high values concentrated in particular points of the routes. As expected, the highest noise levels were observed in the cyclepaths that are located along the streets in which the adjacent car traffic speed is higher. Other urban elements, such as signalized crossings and narrow street canyons were also responsible for peaks of noise exposure, as evidenced in graphs and maps by the proposed approach. Finally, it is also worth registering that measurement strategies like this one are not yet extensively used, although they are totally compatible with the reality experienced by the cyclists during actual trips.

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