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Technical Note

Acoustical environment of the medieval centre of Cáceres (Spain)

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ABSTRACT

Cáceres (Extremadura, Spain) is a medium-sized city located in the west of Spain with an old part that has been considered a World Heritage Site by UNESCO since 1986 and is the third-best preserved monument in Europe. The main aim of this work was to study the acoustics of this area of the city, both spatially and temporally and also the perception of noise by its citizens. The sound results of this study have been compared with those measured in other neighborhood streets of Cáceres city and other cities of the region (Badajoz and Zafra). Along with the present work, a careful strategy based mainly on short measurements was used. The results show that the old part of Cáceres is a quiet area, though with some moderately intense sound events; indeed, 95% of the measurements presented L_{eq} values lower than 65 dBA during the day, and 79.4% presented L_{eq} values lower than 55 dBA at night. The sound levels measured were similar to those measured in the neighborhood streets of a small town (Zafra). A sociological study carried out allowing us to find some significant relationships among: (i) annoyance and measured sound levels and (ii) measured sound levels and the way residents perceive noise distribution both spatially and temporally.

1. Introduction

Noise pollution is considered a major problem with respect to human health and quality of life in urban areas all over the world [34]. Thus, in the last decades, several noise studies have been conducted in different cities regarding different aspects of noise pollution, such as noise characteristics (sampling strategies [2,4,30,31], source [38,37], contamination levels [1,21], and noise exposure [24,18,11,19]), relationship among population and noise levels [7] and psychological effects of noise [28,27,22,16].

Moreover, it is thoroughly recognized that road traffic is the main source of noise pollution [34,14,35]. However, there are some areas inside our cities where traffic is partially or totally restricted and therefore cannot possibly be considered a major component of noise pollution. Noise produced by other human activities (e.g., leisure activities) is even more important than traffic noise [6]. This fact can be very interesting for scientists, as different noise studies can be conducted, such as those related to noise sampling strategies, the development of systematic working and analysis methodologies for the evaluation of the relevance of different noise sources in different areas, the sound quality of these environments, and the effects of low sound levels on inhabitants.

The search for an adequate sampling strategy for noise studies cannot be considered a minor problem, and different studies have been recently conducted [17,25,33,8,9]. These aspects of sampling may become essential, especially in an area with the characteristics of that selected in this study. Thus, the selection of an adequate sampling strategy is basic to achieving an adequate description of the sound of an area and also as a basis for conducting other studies, such as source analysis or the study of the effect of noise pollution on the inhabitants of the area. Essentially, the challenge is to establish a good sampling methodology, both spatially and temporally, which implies an acceptable cost. This methodology might allow the evaluation of both the overall and specific situations in the different noise environments that could be present in the area. Moreover, the methodology employed might allow for the evaluation of the temporal noise variability of a certain area.

The first objective of this study was to develop and verify a noise methodology that can be used to adequately evaluate the noise in an area of a city that is considered peculiar with respect to urbanism, use, and the presence and importance of noise sources.

The second objective of this work was to carry out a sociological study in this area that allows us firstly to evaluate the citizens' perception of the area characteristics (being noise an essential one), and, secondly, to analyze the possible relationships among dose and response in this special area of the city.

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Fig. 1. Map of the old part of the city of Cáceres with the sampling point location and its situation and size with respect to the rest of the city.

Finally, as a third objective, the acoustical situation was characterized and compared (referring only to sound levels) with the acoustical situation of other residential areas of Cáceres city and other cities of the region [7].

For this work, the old part of the city of Cáceres was studied. This old part represents a small part of the city (see Fig. 1). The city of Cáceres, with about 90,000 inhabitants and an area of 12.66 km^2, is located in the west of Spain. It is one of the most important cities in the region and has a constant flow of tourists, especially due to its historic center. It has been a UNESCO World Heritage Site since 1986 [36] and is the third-most important monumental complex in Europe [12].

Section 2 of this work describes the studied area of the city. Section 3 presents the methodology, and, in Section 4, the main results, their comparison with the results of other residential areas of different cities, and the results of the sociological study are showed. Finally, in the last section, conclusions are presented.

2. Study area

In this section, a detailed description of the studied area is presented. This description is necessary to understand the study conducted and the particularities of the area.

The old part of the city has town-planning and architectonic characteristics typical of the Middle Ages (as can be observed in the photographs of Fig. 2), which are consequently very different from the characteristics of modern cities. As was common in the Middle Ages in Spain, the old part of the city is surrounded by walls; this implies that there is a limited number of entrances and exits (one of them shown in Fig. 2g). Additionally, as the city was built at the top of a hill, there are important differences in height throughout area.

The streets of the old part of Cáceres are narrow and, in some cases, are steeply sloped. As a consequence, vehicles have problems traversing a majority of them (due to the narrowness, as can be observed in Fig. 2c and g) or cannot traverse them at all due to the presence of steps in the streets (as shown in Fig. 2b, d, e and h). Another important element of the area is the presence of squares (some examples can be seen in Fig. 2a and f), although they are distributed without a defined pattern. These squares are generally associated with the presence of Catholic churches.

In analyzing the different uses of the old part of the city by inhabitants or visitors, it becomes evident that they are peculiar with respect to the typical uses of common streets in modern cities. Indeed, they are used mainly for tourism purposes, for enjoying a walking around the old part of the city, and for enjoying the architecture and the peace provided by the place.

The number of inhabitants is small, around 900, which is less than the 1% of the total number of citizens of Cáceres. The surface area is 12.6 hm^2 (also 1% of the total surface of the city).

Some of the most famous restaurants in the city and a state-run hotel are located in the old part of Cáceres. Moreover, in this area, there are several old palaces and stately homes that have been restored for administrative purposes (e.g., the rectory of the

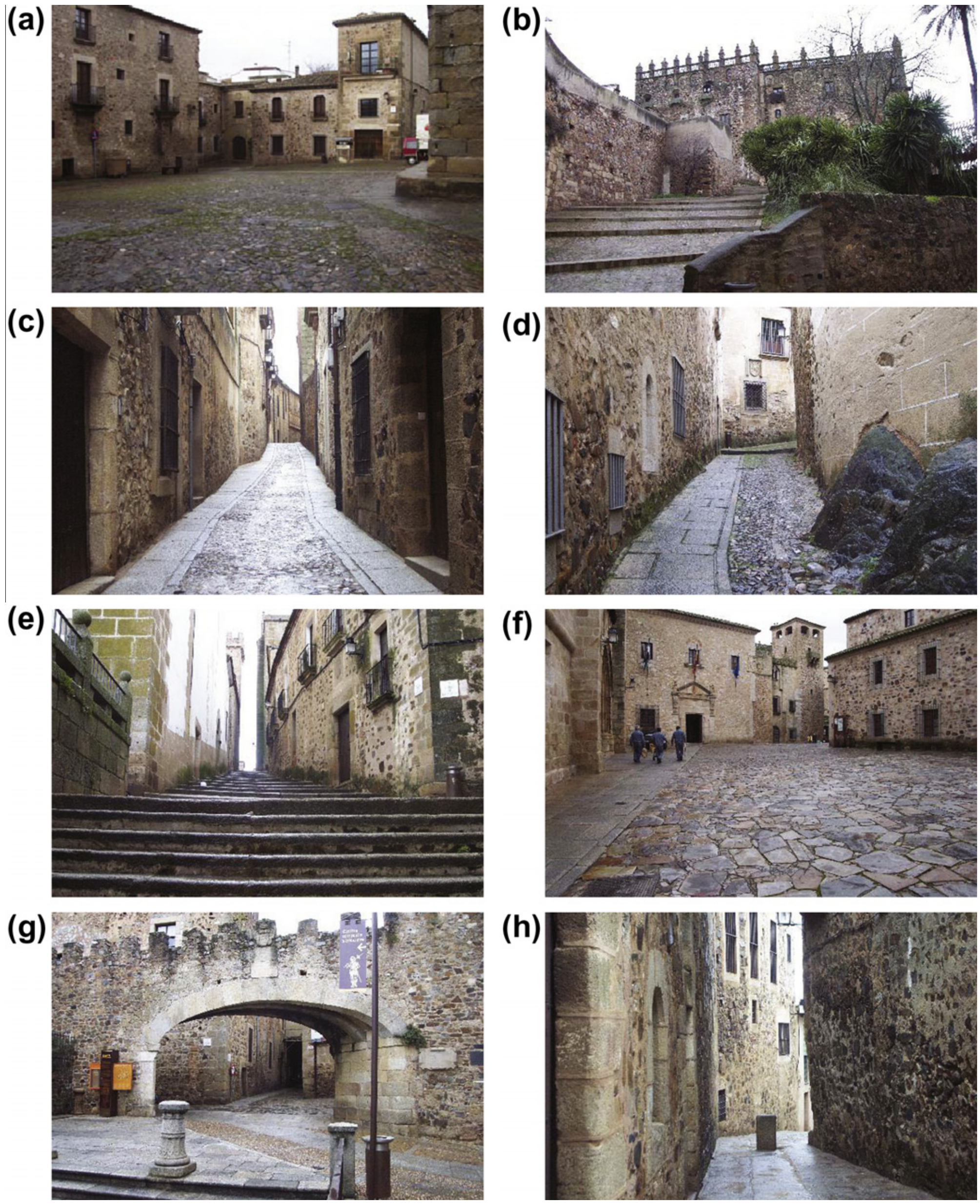

Fig. 2. Photographs of landscape representative of the studied area.

University of Extremadura), museums, and some pubs. There are several churches that have relevant architectonic importance, some convents, and other places of worship, which are usually associated with the convents.

Vehicular traffic is limited by bollards to taxis and the cars of people who live in the old part or who are staying in the state-run hotel. There are hourly intervals assigned for the delivery of goods to the restaurants and pubs, and there are also hourly intervals during the morning designated for free access. Finally, maintenance and cleaning services are also allowed. As mentioned previously, in some of streets, it is impossible to drive a vehicle.

Although there are certain noise sources, as there are in any modern city, such as vehicles (cars, mainly) and noises associated with nightly leisure activities (besides the leisure activities associated to the pubs of the area, the proximity of the 'Plaza Mayor' of Cáceres – see Fig. 1 – increase this type of noise), this area of the city also hosts other, more unusual, sources (sometimes present but masked by the rest of noise sources), such as bells, different kinds of birds (*Columba livia, Corvus monedula, Ciconia ciconia, Turdus medula, and Passer domesticus*), tourists, and people playing instruments or singing.

3. Methods

3.1. Sound measurements

This study was planned to allow for an adequate objective evaluation of the acoustical situation of the area. Special care was taken in treating the main components of this study: the spatial and temporal components.

The spatial component was analyzed by means of *in situ* short measurements, covering the studied area in detail. Thus, 40 sampling points were selected, covering all of the representative locations and all of the streets in the area. The sampling points were always in the middle of the street or location-specific. This methodology for selecting sampling points and locations allows us to perform a detailed study of the area and it is not based in a previous categorization of the streets as proposed previously by our research group [2,4] but neither is similar to the commonly used grid method [20].

With respect to the temporal component, due to the large number of requirements necessary for long time samples, the study was focused into discrete temporal intervals. The selection of these intervals was one of most important decisions made in this study. After a detailed analysis of the uses of the area, we concluded that there was a temporal structure; the selected time intervals were as follows: 7:00–14:00, 14:00–17:00, 17:00–21:00 and 21:00–7:00. Additionally, to detect variability throughout the week, measurements were taken over at least five different days (if necessary, one of them was Saturday or Sunday). For availability reasons, the measurements were taken between 10:00 am and 2:00 am. In order to get a detailed study of the temporal structure of the sonorous landscape of the area, the number of measurement per point was much higher that the usually employed. Thus, at each sampling point, ten 15-min measurements were performed.

Measurements were taken following the ISO 1996-2 [20] guidelines, using a 2238 Brüel & Kjaer type-I sound-level meter with a tripod and windshield. Calibration was performed using a 4231 Brüel & Kjaer calibrator. The volume of traffic was determined and categorized visually (cars, heavy vehicles, and motorcycles) during sampling, and other relevant information (noise sources, number of pedestrians, meteorological conditions, street dimensions, road surface type, conservation of road surface, etc.) was also noted. The sound levels recorded were the equivalent level (L_{eq}), percentile values (L_{10}, L_{50} and L_{90}) and maximum and minimum levels (L_{max} and L_{min}). The time weighting used in the sampling measurements was fast (F), and frequency weighting A was used.

Complementary to the previously mentioned measurement and to develop a better understanding of the acoustics of the area and verify the results obtained from the discrete measurements, one long-time measurement (approximately 1 week) was taken. It was performed at the Generala Palace, one of the noble palaces in the historical part of Cáceres.

In Fig. 1, sampling measurement points are presented, both the short measurements (numbered from 1 to 40) and the long-time measurement (labelled as 1c).

Finally, once the temporal and spatial acoustical situation was analyzed, and the results were compared with those previously measured in other residential areas of Cáceres city and other cities of the Extremadura region: Badajoz (Badajoz and Cáceres cities are the most populated and largest of the Extremadura region) and Zafra (small town). Noise maps of both cities were measured following the categorization methodology proposed by our research group [2,3,5,7]. This method classifies the streets of the city by taking into consideration how urban streets are used to communicate between different areas of the town or connect other cities or areas of the territory.

3.2. Sociological study

For the sociological study, 70 residents of the old part of Cáceres (approximately an 8% of all the residents of this area) were interviewed. The questionnaire used was elaborated by our research group [3] and it was used previously elsewhere [6,23]. The procedure followed was door-to-door, with the interviewer present.

4. Results

4.1. Global analysis

First, the results obtained from a general analysis of all of the measurements are presented to understand the overall acoustical situation.

Table 1
Descriptive statistical results calculated for the 400 measurements performed.

Parameter	L_{eq} (dBA)	L_{10} (dBA)	L_{50} (dBA)	L_{90} (dBA)
Mean	55.4	55.6	47.5	42.6
Median	55.3	55.6	46.8	42.1
Standard deviation	7.1	6.8	6.7	6.2
Range	43.5	45.0	39.1	38.7
Minimum	38.2	39.3	33.4	30.1
Maximum	81.7	84.3	72.6	68.8
N	400	400	400	400
Kurtosis coefficient	0.4	1.1	1.3	1.6
Asymmetry coefficient	0.3	0.5	0.8	0.8

In this analysis, descriptive statistics of the indicators L_{eq}, L_{10}, L_{50}, and L_{90} were calculated. The results are presented in Table 1. As can be seen in this table, the median and mean values are very similar (differences under 1 dB), mainly for L_{eq} and L_{10}, indicating that the distribution of sound levels is quite symmetric with respect to the central values. This is corroborated by the asymmetry coefficients, which are close to zero. This indicates that unusually high or low sound levels are not common. Indeed, this can also be seen in Fig. 3. However, because the Kurtosis coefficients are not close to zero when the normality Kolmogorov–Smirnov test [32,13] was applied to study significant differences with respect to the normal distribution, only for L_{10} were no significant differences found [results of this test were 0.019; 0.105 (not significant); 0.004 and 0.0002 for L_{eq}, L_{10}, L_{50}, and L_{90}, respectively].

With respect to the dispersion parameters, we can observe in Table 1 that the ranges of the different studied sound indicators are relatively high [varying between 39 dBA for L_{90} and L_{50}, and 45 dBA for L_{10}]. This result is logical if we take into consideration the high spatial and temporal variability of the measurements. The large standard deviations of the sound indicator [varying from 6.2 to 7.1] corroborate these results. Moreover, the low value of the range and standard deviation of the L_{90} indicator with respect to L_{eq} indicate that, in the studied area, the background level tends to be uniform.

Finally, we consider it interesting to point out the great similarity between the L_{10} and L_{eq} indicators, not only with respect to the mean and median values but also with respect to the maximum and minimum values and the range of measured sound values. This indicates that the mean sound energy of the area (evaluated with the L_{eq}) is due to sound events produced over a short time. Thus, the acoustical behavior of this area seems to be characterized by small noise moments inside a quiet environment (notice that the median of the L_{50} value was only 46.8 dBA, indicating that, in half of the measurements, during half of the measurement time, the noise level was less than 46.8 dBA).

This description of the quiet acoustical environment of the area can also be seen in the bar charts shown in Fig. 3. From the L_{10} bar chart, we can see that approximately half of the measurements present a value of this indicator that is less than 55 dBA (which indicates that, in these measurements, during 10% of the sampling time, this value was not exceeded); in more than 90% of the measurements, the L_{10} value was less than 65 dBA. We can see that, in more than 90% of the measurements, the value of the L_{50} indicator was less than 55 dBA. Finally, in only 2% of the measurements was the value of the L_{90} indicator higher than 60 dBA.

To summarize, we can affirm that the following:

- By using and analyzing four sound indicators (L_{eq}, L_{10}, L_{50} y L_{90}), we succeeded in describing and understanding the acoustical characteristics of the studied area.
- The acoustical environment can be spatially and temporally described as quiet, though with brief moments and areas where some occasional events with relevant sound intensity break the peace of the environment.

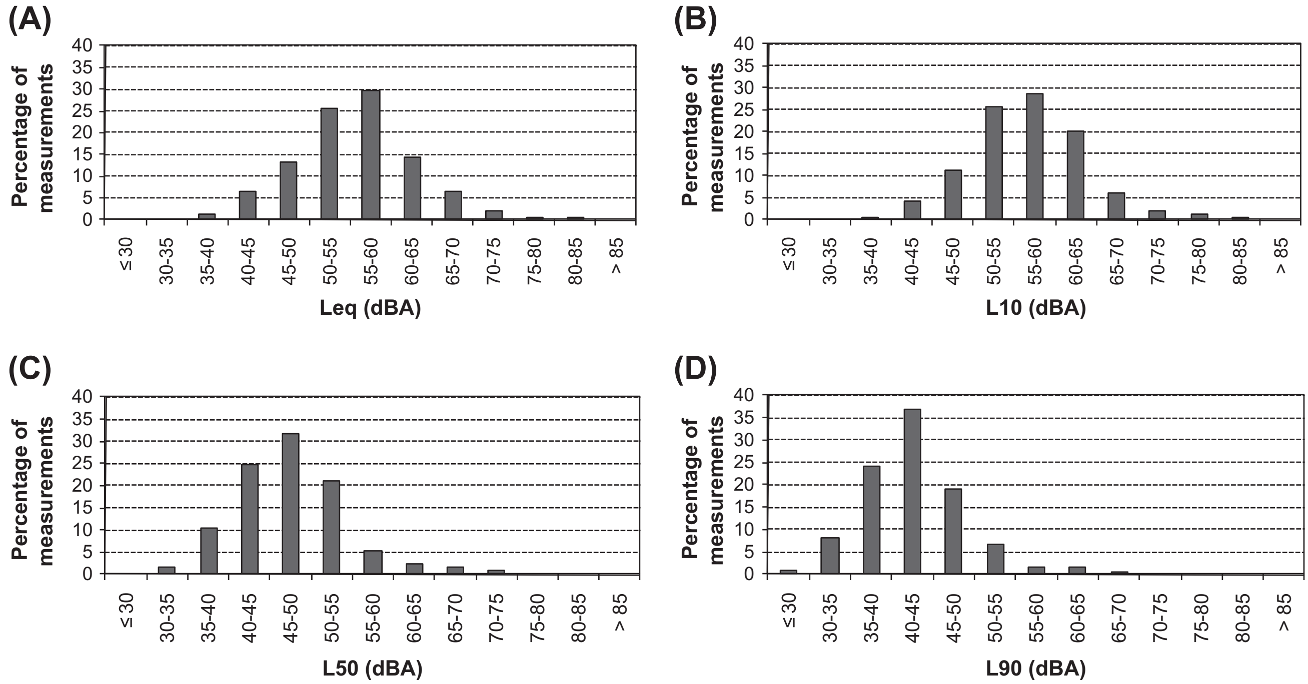

Fig. 3. Box diagrams of the measurement results for the different measured sound indicators: (A) L_{eq}, (B) L_{10}, (C) L_{50}, and (D) L_{90}.

Table 2
Descriptive statistical results calculated for the data from 40 sampling points.

Parameter	L_{eq} (dBA)	L_{10} (dBA)	L_{50} (dBA)	L_{90} (dBA)
Mean	55.4	55.6	47.5	42.6
Median	55.0	55.3	46.7	41.9
Standard deviation	3.3	3.2	3.2	2.9
Range	15.1	13.6	13.3	12.6
Minimum	49.0	50.7	42.8	38.0
Maximum	64.1	64.3	56.1	50.6
N	40	40	40	40
Kurtosis coefficient	0.4	−0.1	−0.1	0.0
Asymmetry coefficient	0.4	0.5	0.7	0.7

4.2. Spatial analysis

In this section, we try to obtain detailed knowledge of the spatial distribution of the sound levels assigned to the different selected sampling points.

As a first step, a global descriptive analysis of the 40 sampling point sound levels was performed, which is presented in Table 2. The sound level of each sampling point was obtained as the arithmetic mean of the ten measurements taken at each point. As can be seen in Table 2, the mean and median values are similar to those of Table 1; thus, in the same manner, the spatial distribution of sound levels is very balanced, without a large proportion of points with high or low sound levels with respect to the mean value. Nevertheless, in contrast to the results in the previous section, the Kurtosis and the asymmetry coefficients have values near zero (in the previous study only this last coefficient was near zero), and, thus, they did not present significant differences with respect to the normal distributions for a significant level higher than 0.05 [results of the normality Kolmogorov–Smirnov test for the data of the 40 sampling points were 0.200; 0.200; 0.117 and 0.121 for L_{eq}, L_{10}, L_{50}, and L_{90}, respectively, and were not significant in all cases].

As can be seen in Table 2, the standard deviation and range are clearly lower than those values obtained for all 400 measurements (Table 1), indicating that an important part of the variability of the measurements stems from the temporal distribution instead of the spatial distribution.

In Fig. 4, the sound levels of each sampling point (L_{eq}, L_{10}, L_{50}, and L_{90}) are presented. As can be seen, all of the sound level indicators exhibit similar behavior. Indeed, calculating the Pearson correlation coefficient of the other indicators as a function of L_{eq}, we obtained 0.93, 0.78, and 0.70 for the pairs L_{eq}–L_{10}, L_{eq}–L_{50}, and L_{eq}–L_{90}, respectively. Although the Pearson coefficients have a p-value < 0.01, L_{eq} and L_{10} are the indicators that present the greatest similarity. This similarity between L_{eq} and L_{10} gives us information about the noise characteristics. When the noise fluctuations are small, the value of L_{eq} is close to that of L_{50}; however, when noise fluctuations are large, the value of L_{eq} is close to that of L_{10} [10]. This similarity can be due to the sporadic character and relatively high power of the traffic sound source.

In analyzing the three measurement points with L_{eq} values higher than 60 dBA, it was observed that two of them correspond to streets that are typical traffic (and passer-by) entrances to the old part of the city [‘Arco de la Estrella’ (point 5) with 64.1 dBA and ‘Puerta de Mérida’ (point 15) with 62.5 dBA]. The third point (‘calle Ancha’ (point 16) with 60.9 dBA) corresponds to a street near point 5 with an elevated flow of vehicles and passers-by. In contrast, the three measurement points with lower values of L_{eq} [‘Callejón del Moral’ (point 37), ‘Callejón de Don Álvaro’ (point 30), and ‘Cuesta de Aldana’ (point 11) with 49.0, 49.3, and 49.9 dBA, respectively] were located in streets that are rarely or never used, as they are inaccessible to cars or are not included in the usual tourist routes.

Fig. 5 shows a noise map of the old part of the city. The color[1] of each street was drawn with respect to the measured L_{eq} value.

To compare the measured sound levels with those of various international recommendations, the measurements were classified by the time interval during which they were measured. Thus, samples were divided into those belonging to the day time period

[1] For interpretation of color in Fig. 5, the reader is referred to the web version of this article.

Table 3
Descriptive statistical results calculated for the different sound indicators for all the different days of the week.

Indexes	Parameters	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
L_{eq} (dBA)	Mean	55.7	55.0	54.4	55.8	57.4	56.6	53.9
	Median	55.2	54.2	55.8	56.4	58.0	56.0	53.9
	Standard deviation	7.7	6.7	6.4	7.6	5.9	6.8	7.9
	Range	33.1	41.0	26.5	34.1	29.1	35.2	36.3
L_{10} (dBA)	Mean	57.2	55.9	56.2	56.8	58.9	58.3	55.5
	Median	56.4	54.9	56.8	57.2	58.6	58.0	55.2
	Standard deviation	7.7	6.4	5.9	7.0	6.3	6.9	8.0
	Range	35.3	42.0	24.9	33.2	29.7	37.6	39.0
L_{50} (dBA)	Mean	47.5	46.3	45.7	47.0	49.8	49.9	46.4
	Median	47.1	46.3	46.4	46.9	49.2	49.7	44.0
	Standard deviation	6.3	6.1	5.3	5.8	6.3	6.9	7.8
	Range	32.6	38.5	19.3	29.5	28.8	37.7	37.5
L_{90} (dBA)	Mean	43.0	41.4	41.0	41.8	44.6	45.0	41.7
	Median	42.3	41.2	42.2	42.6	43.1	44.4	40.2
	Standard deviation	5.5	5.4	5.4	5.1	5.3	6.4	7.4
	Range	30.1	28.1	20.1	21.4	21.4	32.9	38.0

Table 4
P-values obtained by applying the *U*-Mann Whitney test with Bonferroni correction to the sound values of the different days of the week.

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
L_{eq}						
Tuesday	1.000					
Wednesday	1.000	1.000				
Thursday	1.000	1.000	1.000			
Friday	1.000	0.591	1.000	1.000		
Saturday	1.000	1.000	1.000	1.000	1.000	
Sunday	1.000	1.000	1.000	1.000	0.094	0.268
L_{10}						
Tuesday	1.000					
Wednesday	1.000	1.000				
Thursday	1.000	1.000	1.000			
Friday	1.000	0.240	1.000	1.000		
Saturday	1.000	0.180	1.000	1.000	1.000	
Sunday	1.000	1.000	1.000	1.000	0.130	0.160
L_{50}						
Tuesday	1.000					
Wednesday	1.000	1.000				
Thursday	1.000	1.000	1.000			
Friday	1.000	0.134	0.251	1.000		
Saturday	0.691	0.005**	0.030*	0.752	1.000	
Sunday	1.000	1.000	1.000	1.000	0.061	0.005**
L_{90}						
Tuesday	1.000					
Wednesday	1.000	1.000				
Thursday	1.000	1.000	1.000			
Friday	1.000	0.061	0.970	1.000		
Saturday	1.000	0.005**	0.110	0.318	1.000	
Sunday	1.000	1.000	1.000	1.000	0.055	0.003**

* *p*-Value < 0.05.
** *p*-Value < 0.01.

(from 7:00 to 23:00) and those belonging to the night period (from 23:00 to 7:00). Bar charts of both periods are shown in Fig. 6.

With respect to the diurnal period, the L_{eq} value (16 h) of 97.5% of the streets exceeded the reference value of 50 dBA. It is worth noting that although the diurnal sound levels are not very high and only two points (points 5 and 15) of the 40 measured points (5%) surpass the reference value of 65 dBA [26], there is an important percentage of the points (72.5%) that surpasses the reference value of 55 dBA, described by the WHO as serious annoyance during the daytime [34].

With respect to the night period, the L_{eq} value (8 h) of only seven points (points 2, 4, 5, 6, 7, 8, and 10) (20.5%) exceeded the value of 55 dBA, established as a reference in the OECD and in Spanish regulations [29]. Despite this small percentage, the high percentage of samples (82.4%) that surpassed the 45 dBA reference value [34] indicates that noise impact studies of the population may be necessary.

Taking now into consideration the percentile indices, in the day time, 95% of the measured points did not surpass 65 dBA during 10% of the sampling time. It was found that 93% and 100% of the values of the L_{50} and L_{90} were under 55 dBA, indicating that this noise level was not surpassed during 50% and 90% of the measurement time, respectively. During the night time, more than 70% of the measured points did not surpass the reference level of 55 dBA during 10% of the sampling time. This reference level was not surpassed by any of the measured points during 50% and 90% of the sampling time. If we consider the reference value of 45 dBA, as recommended by the WHO for night time [34], 25%

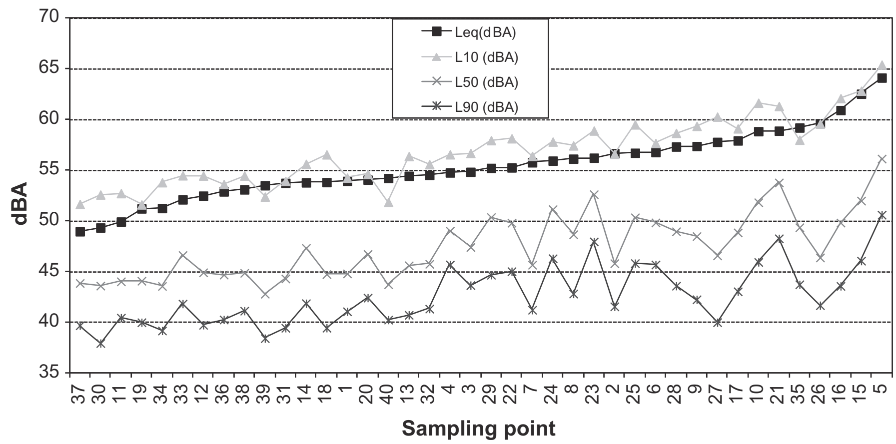

Fig. 4. Variation of the measured sound levels (L_{eq}, L_{10}, $L_{50,}$ and L_{90}) in the different sampling points.

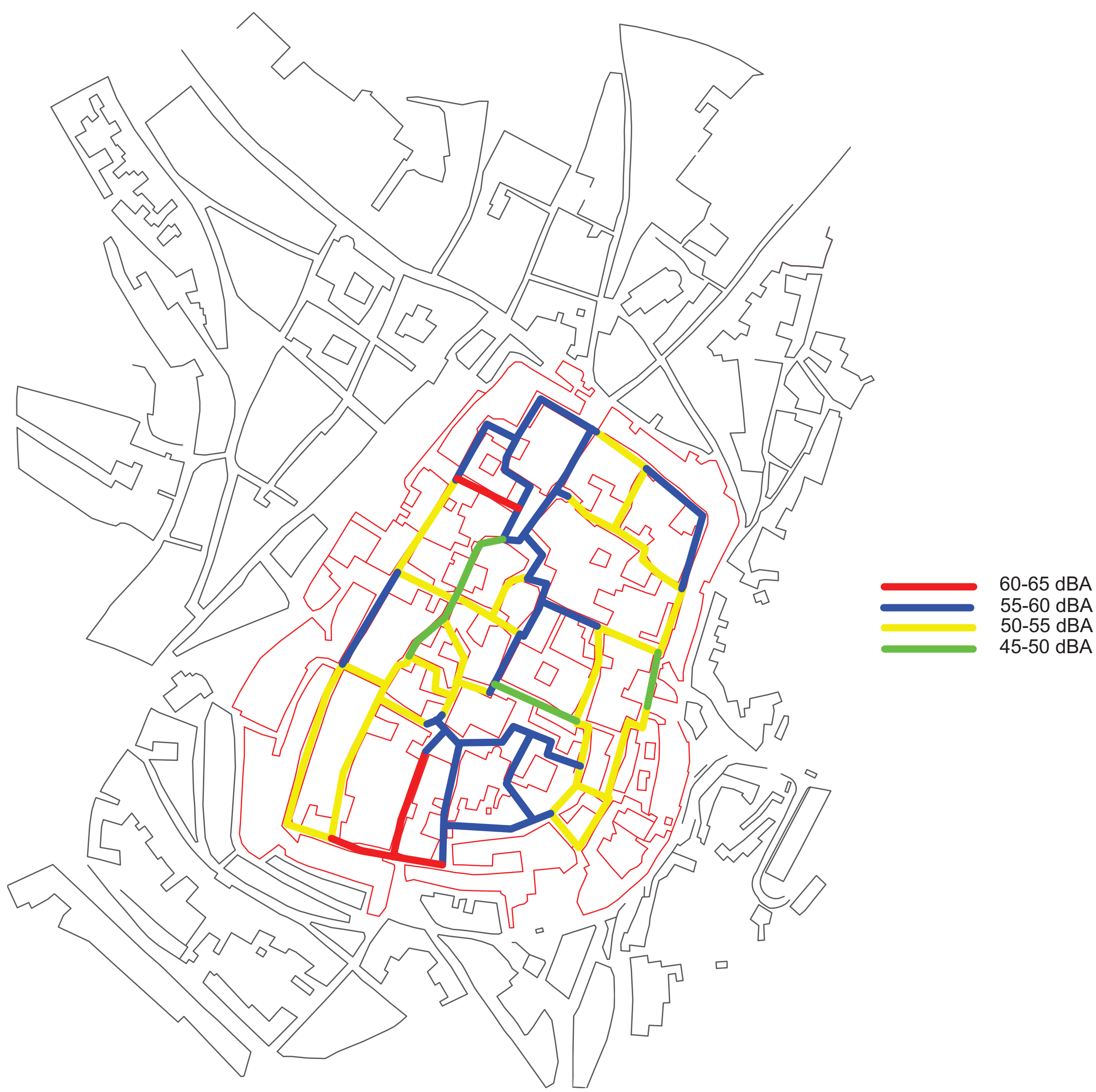

Fig. 5. Noise map of the old part of Cáceres (Spain).

and 9% of the sampled points surpassed this level during 50% and 90% of the measurement period, respectively.

From these analyses, we come to the following conclusions, which are very similar to those of the previous section:

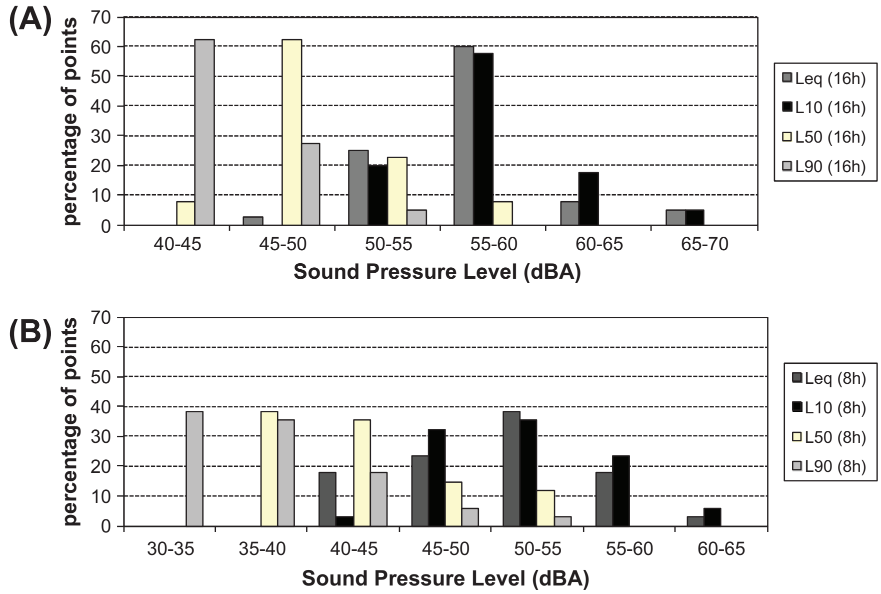

Fig. 6. Box diagrams of different noise indicators (L_{eq}, L_{10}, $L_{50,}$ and L_{90}) according to the measurement period: (A) diurnal period (16 h) and (B) night period (8 h).

- Sound levels obtained globally and for the different periods (nocturnal and diurnal) indicate that the studied area is a quiet environment with some occasional events creating relevant sound intensity, which comes mainly from vehicles or passers-by.
- With the sampling strategy used here, we were able to understand the sonorous environment present throughout different street of the studied area and, taking the measurements into account, a noise map was developed.

4.3. Temporal analysis

The strategy used for short measurements is analyzed in this section. In addition, the results of these measurements are compared with those of the continuous measurement to find similar behavior.

As mentioned, for the short measurements, 4-h intervals were chosen [7:00–14:00, 14:00–17:00, 17:00–21:00, and 21:00–7:00] and the measurements were taken on different days, including either Saturday or Sunday.

First, the chosen daily time intervals were compared with those time intervals indicated in the EU Directive 2002/49/EC [15] (7:00–19:00, 19:00–23:00, and 23:00–7:00). Tables 5 and 6 show this comparison. As can be seen in Table 5, if the time interval of the European legislation was chosen, the observed differences from the global value and those values obtained for the day and evening periods are small (near 1 dBA); the night values are, as expected, clearly lower than the global value. However, if we take into consideration the time interval chosen for this study from a previous analysis of the different uses of the studied area and the characteristics of the expected sound sources, we can see that we have successfully identified a temporal structure (with distinguish sound values) that is of clear interest to this study. Thus, between the morning and evening periods (7:00–14:00 and 17:00–21:00, respectively) we found an intermediate period (14:00–17:00) with clearly lower sound levels (under 2–3 dB on respect to the other diurnal periods and to the global value). The last period (21:00–7:00) was, as expected, different from the other three periods due to the reduction in activity in the area at night.

To better understand the information from the different selected hourly intervals, it is very interesting to analyze not only the energy aspects of the sonorous field provided by the equivalent level but also the temporal aspects provided by the percentile indi-

Table 5
Descriptive statistical results calculated for the different sound indicators, for the different hour intervals studied and for the time intervals indicated by European legislation.

Indexes	Parameters	Global	Measurement time interval				Time intervals indicated in the European legislation		
			7–14	14–17	17–21	21–7	7–19	19–23	23–7
L_{eq} (dBA)	Mean	55.4	57.4	54.9	57.1	52.1	56.5	56.1	50.4
	Median	55.3	57.2	54.2	57.0	52.5	56.2	55.9	50.2
	Standard deviation	7.1	6.0	7.8	6.1	7.4	6.7	7.0	6.9
	Range	43.5	29.6	39.4	32.0	34.2	39.4	34.2	28.0
L_{10} (dBA)	Mean	56.8	59.2	56.0	58.7	53.3	58.0	57.3	51.7
	Median	56.7	58.2	54.6	57.9	53.5	57.5	57.5	51.6
	Standard deviation	7.0	6.2	7.4	6.2	6.8	6.8	6.9	6.0
	Range	44.6	31.7	40.3	32.8	36.4	40.3	36.4	23.8
L_{50} (dBA)	Mean	47.5	49.9	47.4	49.5	43.2	49.0	47.9	41.6
	Median	46.8	49.1	46.2	48.5	42.3	47.7	47.6	40.5
	Standard deviation	6.7	5.8	6.7	5.7	6.5	6.1	6.8	5.5
	Range	39.1	34.3	32.4	24.9	34.4	34.3	33.8	26.1
L_{90} (dBA)	Mean	42.6	45.0	42.6	44.3	38.7	44.1	42.8	37.1
	Median	42.1	44.1	41.7	43.8	37.0	42.8	42.9	35.5
	Standard deviation	6.2	5.3	6.2	4.9	6.2	5.6	6.1	5.5
	Range	38.7	29.2	33.2	24.2	31.4	34.0	30.7	27.8

Table 6
P-values obtained by applying the *U*-Mann Whitney test with Bonferroni correction to the sound values of the different hour intervals studied and for the time intervals indicated by European legislation.

	Measurement time interval			Time intervals indicated in the European legislation		
	7–14	14–17	17–21		7–19	19–23
L_{eq}						
14–17	0.043*	–		19–23	1.000	–
17–21	1.000	0.044*	–	23–7	0.000**	0.000**
21–7	0.000**	0.226	0.000**			
L_{10}						
14–17	0.005**	–		19–23	1.000	–
17–21	1.000	0.022*	–	23–7	0.000**	0.000**
21–7	0.000**	0.169	0.000**			
L_{50}						
14–17	0.001**	–		19–23	0.600	–
17–21	1.000	0.013*	–	23–7	0.000**	0.000**
21–7	0.000**	0.000**	0.000**			
L_{90}						
14–17	0.000**	–		19–23	0.450	–
17–21	1.000	0.006**	–	23–7	0.000**	0.000**
21–7	0.000**	0.000**	0.000**			

* p-Value < 0.05.
** p-Value < 0.01.

ces. We observe, in the mentioned table, a great similarity between the three percentiles present during the periods 7:00–14:00 and 17:00–21:00. This indicates that not only is the average energy of both periods the same but that the average of both periods is also the same in the temporary structure.

All of the previous analyses of the time intervals are corroborated to a great extent by the results of the inferential analysis shown in Table 6. Compared with the time intervals recommended by European legislation, we did not observe significant differences between the day and evening periods, though we obtained significant differences, as it could be expected, between both periods and the night period. Thus, from these results, it can be deduced that, when the measurement strategy is based on the time intervals provided by European normative value during the entire day (day and evening periods), the sound level does not present important variations. Considering now the time intervals chosen for the present study, we note the following interesting results:

– Significant differences are found between the intermediate interval (14:00–17:00) and the morning and evening periods (7:00–14:00 and 17:00–21:00, respectively) for the different sonorous indices analyzed. This corroborates the existence of a temporal structure.
– The registered sound levels during the morning and evening periods (7:00–14:00 and 17:00–21:00, respectively) did not present significant differences in any case. As mentioned, the major activity of tourists and residents is concentrated during these time periods.
– The three diurnal periods (from 7:00 to 21:00) present significant differences from the last period (21:00–7:00), except for the L_{10} and L_{eq} indices of the intermediate interval (14:00–17:00). These last two exceptions show an important decrease in activity during the day period (due to lunch and naptime in Spain), which makes the noise in the area similar to the last period with respect to those short events with higher intensity. In the last period (21:00–7:00), these kinds of short events are usually related to nighttime leisure activities (pubs, young people gathering, etc.).

Second, the continuous measurement results were analyzed. As can be seen in Table 7, we can conclude that the location of the sampling points can be representative of the mean sound value throughout the week in the studied area, although some sound indices present important differences on some days, despite the results being obtained from the short measurements (street measurements).

If we consider now the street measurements, as they are representative of the whole area, we can see that there is high stability throughout all days of the week, expect during the night on weekends, when a slight increase is observed (probably due to the nighttime leisure activities). An increase is also observed during the evening on weekends, probably due to the important increase in the number tourists on these days. Nevertheless, the value of L_{day} did not vary significantly throughout the week; this must be due to the compensation for the reduced working and economic activities during the weekends by the increased number of tourists.

We now descriptively and inferentially compare the measurements of the different days (Tables 3 and 4). The central tendency and dispersion parameters were used in the descriptive analysis and *U*-Mann Whitney non-parametric test (with the Bonferroni correction) were employed in the inferential analysis, as the data did not present a normal distribution. As can be seen in Table 3, all of the studied sound levels (L_{eq}, L_{10}, $L_{50,}$ and L_{90}) measured were higher on Fridays and Saturdays. However, the differences are not significant (according to the *U*-Mann Whitney test) for the L_{eq} and L_{10} indices on any of the days, and they are only significant on Saturday in some cases for the L_{50} and L_{90} indices. As the former indices are related to higher-energy sonorous events and the last are related to sound levels that are present a majority of the time, these results corroborate the importance of occasional events with relevant sound intensity. Additionally, we can seen that, on weekends (statistically significant only on Saturdays), the activity of the area increases, as is reflected by the study of the used indices.

Finally, from the results discussed in this section, we can conclude that the temporal strategy chosen in the short measurements allows us to detect and quantify the temporal structure present in the entire studied area. The information obtained suggests not only the existence of a temporal structure of the sound level but also the existence of global behaviors that vary depending on the considered period.

- The daily measurement strategy has allowed us to identify two similar time periods with respect to both the average sound energy and temporal structure of the sound environment.

Table 7
L_d, L_t, L_n, L_{24h}, and L_{den} values measured during the different days of the week in the continuous measurement and in the short measurements (street measurements).

	L_{night}		L_{day}		$L_{evening}$		L_{eq} (24 h)		L_{den}	
	Continuous	Street	Continuous	Street	Continuous	Street	Continuous	Street	Continuous	Street
Tuesday	41.5	53.0	60.1	55.0	52.9	56.0	57.4	54.9	58.2	60.1
Wednesday	42.8	50.6	60.4	56.3	53.5	55.9	57.7	56.4	58.6	59.0
Thursday	52.5	47.7	66.5	57.9	56.8	58.2	63.7	57.8	64.9	59.3
Friday	50.1	53.2	58.6	56.8	57.0	60.0	56.8	56.4	59.9	61.7
Saturday	52.4	51.6	53.8	57.6	54.4	58.5	53.5	54.6	59.3	60.6
Sunday	59.7	51.1	53.2	56.1	51.7	51.5	56.4	54.7	65.2	58.5
Monday	43.2	45.7	58.0	56.5	–	53.9	–	54.7	–	56.8
Average	48.9	50.4	58.6	56.6	54.4	56.3	57.6	55.4	61.0	59.4

- The daily measurement strategy has allowed us to clearly distinguish the presence of an intermediate time period between the two daytime periods, which showed some similarities to the night period.
- The weekly measurement strategy has allowed us to verify very similar conditions between different working days of the week, except for Friday, which experiences an increase in noise level associated with the weekend.

4.4. Comparison with other urban areas of Cáceres city and other cities of the region

The sound levels measured in the old part of Cáceres were compared with results measured by our research group in other urban areas of Cáceres city and other cities of the region. For this comparison, results from the main cities of the Extremadura region were used: Cáceres (90,000 inhabitants) and Badajoz (147,000 inhabitants) and the small town of Zafra (16,200 inhabitants). For the noise studies of these cities, the categorization method was used (method developed by our research group [2,4,5,7,8,9]). Only results measured in category 4 streets [streets that clearly allow communication between the previous categories and the principal streets of the different districts of the town that were not included in the previously defined categories] and category 5 streets [neighborhood streets without any communication use] were used for the comparison, as they correspond to streets that are thought to be used in a manner similar to those studied in the old part of Cáceres.

For the comparison, only measurements between 7:00 and 19:00 were used. Tables 8 and 9 show the comparison results. In Table 8, we can see that the median and mean values measured in the old part of Cáceres are similar to those of the category 5 streets in Zafra (which, as mentioned, has fewer inhabitants than Cáceres). Despite this similarity, a certain tendency is observed if we compare the noise levels with the population of the city; this tendency has already been described [7]. Differences are clear when comparing the results from the old part of Cáceres with those obtained for categories 4 and 5 in Cáceres and Badajoz and for category 4 in Zafra (except for L_{90}). Considering now the dispersion parameters, we can observe in Table 8 that the old part of Cáceres presented high values of standard deviation and range with respect to those obtained in other urban areas of Cáceres, Zafra and Badajoz, although the differences are less important when considering only category 5. This larger dispersion in the values is due to the fact that there are very different acoustical environments in the old part of Cáceres.

In Table 9, the inferential results corroborate the conclusions reached from the descriptive ones. The results from the old part of Cáceres present significant differences with respect to categories 4 and 5 in Cáceres and Badajoz and category 4 in Zafra (except for L_{90}), but they did not present significant differences with respect to category 5 in Zafra.

From the results presented in this section, we can conclude that the results measured in the old part of Cáceres are similar to those obtained in the neighborhood streets of a small town (Zafra).

4.5. Sociological study

For this part of the study, as mentioned, a questionnaire elaborated by our research group was used. In this questionnaire [3] there were questions referring: (i) firstly, to the perception of residents about their own environment and the relation of this environment on respect to the rest of the city, (ii) secondly, about their level of satisfaction with respect to the facilities and the

Table 8
Descriptive statistical results calculated for the different sound indicators, for the measurements of this study and for categories 4 and 5 in the cities of Badajoz and Zafra.

Indexes	Parameters	This study	Cáceres cat. 4	Cáceres cat. 5	Badajoz cat. 4	Badajoz cat. 5	Zafra cat. 4	Zafra cat. 5
L_{eq} (15 min)	Mean	56.6	66.7	60.4	65.9	63.9	60.4	54.9
	Median	56.2	66.7	60.7	65.9	64.9	60.9	55.5
	Standard deviation	6.7	2.9	4.2	3.3	4.9	2.7	3.5
	Range	39.4	14.4	21.1	13.0	20.6	13.8	13.0
L_{10} (15 min)	Mean	56.8	68.6	61.7	68.5	65.5	62.9	55.6
	Median	56.6	69.3	62.5	68.0	66.5	64.2	56.0
	Standard deviation	6.4	3.0	4.7	2.9	4.5	3.8	3.7
	Range	40.1	11.0	21.5	12.8	20.5	17.8	15.4
L_{50} (15 min)	Mean	48.9	58.0	52.9	60.3	55.9	50.9	46.7
	Median	47.7	59.0	53.0	60.5	56.0	51.2	46.3
	Standard deviation	6.3	4.1	4.4	3.4	4.2	4.0	4.2
	Range	35.8	13.5	21.0	18.0	19.0	19.8	19.7
L_{90} (15 min)	Mean	44.0	52.7	48.2	54.2	50.2	44.5	42.1
	Median	42.8	53	48.5	54.0	49.8	45.1	42.0
	Standard deviation	5.7	4.7	4.3	3.9	4.2	3.3	4.8
	Range	36.2	16.5	18.5	23.0	18.0	17.5	19.1

Table 9
P-values obtained by applying the *U*-Mann Whitney test to the comparison of the sound levels measured for this study and the sound levels measured in the cities of Badajoz and Zafra.

Indexes	This study & Cáceres cat. 4	This study & Cáceres cat. 5	This study & Badajoz cat. 4	This study & Badajoz cat. 5	This study & Zafra cat. 4	This study & Zafra cat. 5
L_{eq} (15 min)	0.000**	0.000**	0.000**	0.000**	0.000**	0.158
L_{10} (15 min)	0.000**	0.000**	0.000**	0.000**	0.000**	0.376
L_{50} (15 min)	0.000**	0.000**	0.000**	0.000**	0.001**	0.087
L_{90} (15 min)	0.000**	0.000**	0.000**	0.000**	0.055	0.128

** *p*-Value < 0.01.

characteristics of the environment (being noise one of them) and (iii) thirdly, about the grade of annoyance due to noise and the relationship among noise in this part of the city and noise in the rest of the city.

Answers related to the area facilities and characteristics were in concordance with the particularity of the area, as expected. Thus, for example, citizens were not satisfied with the proximity of schools, green zones or public transports, but were satisfied with the esthetic of the zone, the relationship with neighbors, the proximity of restaurants and churches, etc.

Focusing only on those answers related to noise, we found that citizens of this area were usually satisfied ('very satisfied' or 'satisfied' answers) with the absence of diurnal and nocturnal noise (54% and 66%, respectively) whilst very few interviewed residents were unsatisfied with diurnal and nocturnal noise (only 13.5% and 14.7% respectively for the sum of the 'somewhat satisfied' or 'no satisfied' answers).

On respect to the previous years, 44% of the interviewed citizens considered their street equally noisier than in previous years, whilst 37% and 19% considered them more or less noisy than in previous years, respectively. Nevertheless, comparing noise of their streets and noise in the rest of the city, 79% of the citizens considered their street as less noisy than the rest of the city while 7% considered them as noisier.

Finally, 55% of the interviewed persons considered they were 'nothing' or 'little' annoyed by traffic noise when staying at home, while 12% were highly annoyed ['enough' and 'too much' answers]. This percentage of 12% is a value close to the percentage of unsatisfied residents ('somewhat' of 'no' satisfied' answers) with the absence of diurnal and nocturnal noise presented above. This result is in coherence with the proportion of highly annoyed citizens expected from the noise levels measured [24].

4.6. Dose–response relationships

In order to compare the noise values of the studied area and the sociological study, relationship between the noise levels measured and the results of the sociological study were analyzed.

It is important to take into consideration that the noise levels associated to each street (see Fig. 5) were very low, surpassing 60 dBA only in some streets. Besides, in the considered area of Cáceres there were only 900 inhabitants as was previously mentioned. Although both considerations seem to indicate the difficulty to establish a relationship among noise levels and the answers of the sociological study, the singularity of the area encouraged us to analyze these relationships.

Considering the great variability in the perception of noise by people and the expected low impact of noise with levels similar to those measured, we decided to group sound levels in intervals of 3 dB. This value allows a reasonable number of points for the different analysis, and, besides, represents the minimum increase of sound pressure level that persons appreciate outside the laboratory. Mean values of noise impact onto citizens was used instead of using only the proportion of annoyed persons as other authors used [24].

The statistical study carried out comparing annoyance associated to different noise sources (claxon, barking or mewing, nightlife ambient, noise from trucks, voices outside, garbage truck, noise from motorcycles, traffic, works, and other) and their sound levels showed that there were only significant relationships [$P(|r| \geqslant |r_0|) < 5\%$] among annoyance due to 'traffic' and the measured sound level and also among annoyance due to 'garbage truck' and the measured sound level. These two linear relationships are represented in Fig. 7, being the determination coefficient (r^2) 0.68 and 0.66, respectively, indicating that the variability of annoyance associated to the mentioned noise sources is explained by the measured sound level in a percentage near 67%. It should be noted that this high percentage is obtained while annoyance due to 'traffic' has values near 1 (little annoyance) and the annoyance due to 'garbage truck' has values between 0 (no annoyance) and 1 (little annoyance).

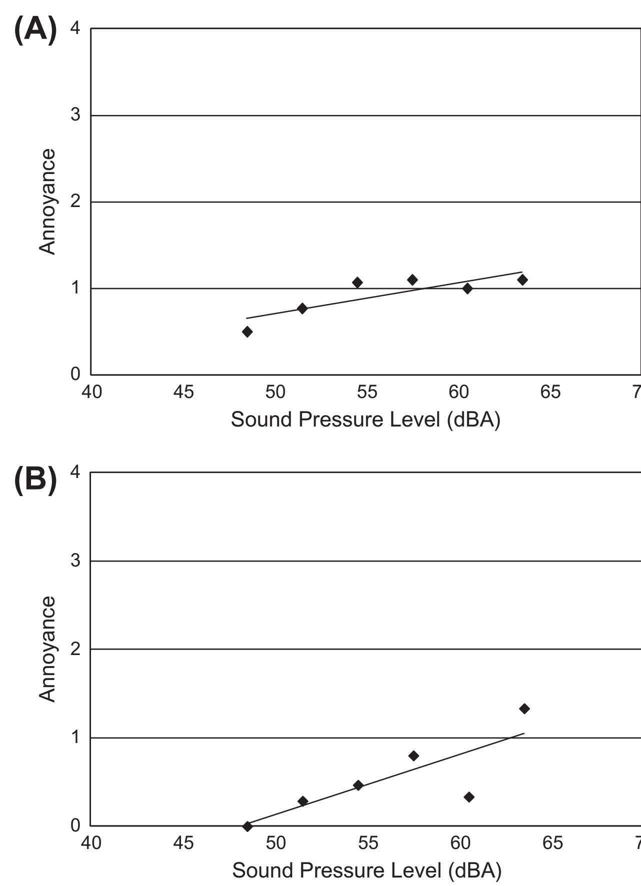

Fig. 7. Relationship between annoyance due to noise sources and the measured sound levels. In both graphics a value of 0 indicates no annoyance, 1 little annoyance, 3 much annoyance, and 4 very much annoyance. (A) Annoyance to 'traffic'. (B) Annoyance to 'garbage truck'.

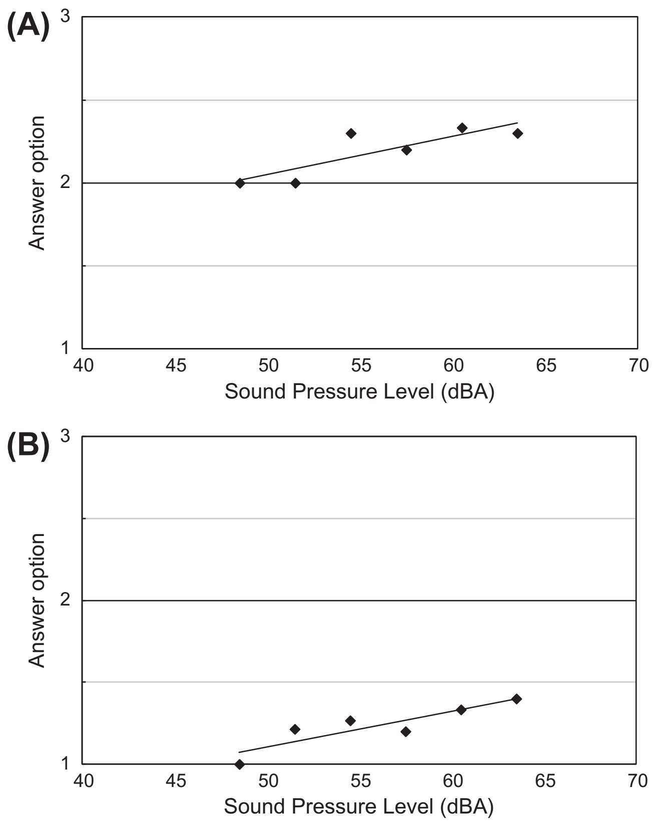

Fig. 8. Relationship between perception of noise of the street in comparison with previous years (A) or other streets of the city (B) [1 indicates less noisy; 2 equally noisy, and 3 noisier].

On the other side, there were also found significant relationships among the measured sound levels and the perception of the noise of the street on respect both to the noise in the street in previous years and to the noise of other streets of the city. These two linear relationships are shown in Fig. 8, being the determination coefficient (r^2) 0.70 and 0.79, respectively. Thus, in the case of the comparison with previous years, it can be seen that the perception of the street as noisier than in previous years increases when increasing the measured sound level, being the variability explained by sound levels 70%. In the case of the comparison with other streets of Cáceres, the perception of the street as noisier than other ones in the city increases from less noisier to equally noisy with the measured sound level, being the variability explained by sound levels 79%.

From these results, we can conclude that these considerations related with perception from residents of the noise component (both temporally and spatially) are influenced by the existing noise level.

5. Conclusions

The main conclusions that can be extracted from the present study of the old part of Cáceres are as follows:

1. The acoustical environment of the area can be globally described as quiet (90% and 96% of measurements had L_{50} and L_{90} indexes, respectively, under 55 dBA). Nevertheless, there are some brief moments and places where some occasional events with relevant sound intensity break the peace of the zone. These events influence the values of L_{eq}, which exceeded 55 dBA in 72.5% of the measurements performed during the diurnal periods (from 7:00 to 21:00) and over 45 dBA in 82.4% of the measurements performed during the night period (21:00–7:00).
2. The temporal strategy to conduct sound measurements every day of the week allowed us to observe a clear increase in night noise levels during the weekends (due to the night leisure activities), while diurnal noise levels were observed to be almost constant during all days of the week (due to the compensation for the reduction in working activities with an increase in the number of tourists).
3. The temporal strategy used to conduct sound measurements during different time periods allowed for the detection and quantification of the temporal structure of the area. Thus, there are two periods (7:00–14:00 and 17:00–21:00) with similar acoustical behavior, both energetic; moreover, in their internal temporal structure and during intermediate time interval [14:00–17:00], clearly different morning or evening intervals were characterized, which had significantly lower sound levels than the rest of the diurnal periods and, in some ways, possessed similar characteristics to the night period.
4. From the comparison of different noise indices (L_{eq}, L_{10}, L_{50}, and L_{90}), the global results of this study can be considered to be similar to those obtained from neighborhood streets of smaller cities of the region.
5. Significant relationships were found among the measured sound level in the different streets and the annoyance produced on citizens due to two typical noise sources of our cities: road traffic and garbage trucks. This was found even in this area of the city where perceived annoyance presented minimum values. Explained variability of this relationship was almost 70%.
6. Finally, significant relationships were also found among the measured sound levels and the way residents perceive noise both spatially and temporally. Thus, the perception of a noisier street on respect to previous years or on respect to other streets of the city are influenced by noise level, with a explained variability over 70%

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