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Title: Noise source analyses in the acoustical environment of the medieval centre of Cáceres (Spain).

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A large number and a variety of noise sources were identified during fieldwork. Different source groups were defined based on the types and origins of the sources; noise sources with appearance frequencies lower than 10% were put in a unique group.

Descriptive and interferential analyses of the groups were performed to study the relative importance of the various sources. The analyses revealed that vehicles, passers-by, and people made a major contribution to the sound energy of the area. In addition, a masking effect by vehicles on other sound sources was detected.

Noise source analyses in the acoustical environment of the medieval centre of Cáceres (Spain).

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Abstract

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1. Introduction

Traffic noise can be considered the major noise source disturbing the quality of urban life (Miedema, 2004; Lam et al., 2009). Although train and airplane noise sources can become more annoying than those produced by road traffic, as analyzed by different authors (Griefahn et al., 2006, Hong et al., 2010), in the major parts of our cities, noise sources are related mainly to road traffic (U.S. Department of Transportation, 1995; WHO, 1999; EEA, 2009; WHO, 2009). In previous studies, the Authors' research group confirmed that road traffic is the main cause of the spatial variability of noise in towns for the range of size of the cities studied (Barrigón et al., 2005a, 2005b, 2010, 2011, Carmona et al 2011). For the case of a large city with a major noise source, a reasonable option for noise mapping is calculation methods, which are recommended instead of measurement methods (WG-AEN, 2007) although the accuracies of the estimates of the two methods can be considered equivalent (Ausejo, 2009).

However, there are wide areas and environments inside cities where, due to diverse causes, road traffic is controlled or is not the principal source of noise (Barrigón et al., 2005c). These areas are of great interest for carrying out different types of acoustic study (Cepeda et al., 2008; Brambilla and Maffei, 2010).

If traffic is not the major noise source, the application of prediction models might not be useful for noise mapping or might require great effort for the characterisation of the noise sources. In this case, a measurement strategy for noise sampling might be reasonable for obtaining complete knowledge of the acoustical state of an area (Brown and Lam, 1987). In this type of study, it is necessary to establish an adequate sampling strategy, both spatial and temporal, to determine the acoustical situation (Gómez-Escobar et al., 2012) and to acquire further knowledge of other aspects of acoustical pollution.

Besides, the control of road traffic implies an increase in the importance of other noise sources that could achieve, objectively or subjectively, an importance equal to or greater than that of traffic. To apply a noise control strategy in this case, previous identification of the noise sources and evaluation of their relative importance, both locally in the streets and globally over the whole area, are necessary.

Finally, if the studied area has a low level of noise pollution, in the sense indicated in several international references (OECD 1986; WHO 1999 and 2009) it is an ideal environment for noise studies. Thus, the effect of low noise pollution on citizens with respect to their perception of noise as a contamination factor, the intensity of the noise disturbance that they are subjected to and the influence of noise in their daily activities could be studied and quantified (Gómez-Escobar et al., 2012).

In this paper, a study of the historical part of the city of Cáceres is presented. The city of Cáceres, with approximately 90,000 inhabitants, 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 due especially to its historic centre, which is a UNESCO World Heritage site (World Heritage, 1986). This part of the city, surrounded by an ancient wall and with limited traffic and high cultural and touristic value, was the subject of this study. Traffic is limited by means of bollards to taxis and to the cars of the people who live in the old part of the city or who are staying in the state-run hotel that is located there. Moreover, there are assigned hours for goods delivery to the restaurants and pubs and for free access in the morning. Maintenance and cleaning services are also allowed.

The main objective of the present study is the identification of the main noise sources which are present in the area, the evaluation of their absolute and relative influences on the noise level of the area and the study of the possible existence of interferences between these sources.

The second section of this paper presents the noise source analyses, the third present proposals for improvement and the last section presents the conclusions.

2. Noise source analyses

2.1. Introduction

The studied area has elements that make it a special environment with acoustical characteristics essentially different from those of locations where noise impact studies are usually performed.

The urban design and architectural characteristics of the area are exceptional due to the extraordinary conservational grade of the historic centre. As mentioned, this part of the city is walled, and for this reason, a reduced number of entrances and exits are present. It is located on the top of a hill, and the streets are short and narrow, some with steep slopes and stairs, and thus vehicles cannot transit through them. Throughout the old part of the city, squares with palaces and other ancient buildings are present. This area can be considered an acoustical island inside a modern city [although not officially delimited for noise protection but for preservation of the heritage, similar to the concept of ‘‘quiet area in an agglomeration’ given by the 2002/49/EC European Directive (Directive 2002/49/EC)]; photographs and maps of the area can be found in a previous work (Gómez-Escobar et al., 2012).

The kinds of noise source present in this area (section 2.2), are very specific and variable with respect to their geometric characteristics, mobility, spatial distribution, temporal characteristics and relative intensity. Moreover, the noise sources are not generally isolated, and different combinations of them (with different emission powers and distances to the receiver) can be observed throughout the area.

All of these characteristics imply a high acoustical complexity in the area and, as a consequence, in its analysis. However, they increase the interest in the study of the area using an adequate method and in the results of this study. Different works have been done in the field of automatic recognition of sources (Couvreur et al., 1998; Barkana and Uzkent, 2011; Mato-Mendez and Sobreira-Seoane, 2011). It is not the aim of this study to propose a working method for the recognition of sources, but once identified by a technician, to use a systematic method to assess the importance of each source in the environment.

To obtain adequate information about the spatial and temporal acoustical situation of the area, forty sampling points were chosen. These covered all the representative locations of the historic centre of Cáceres. After a detailed analysis of the uses of the area, we concluded that there was a temporal structure associated with four time intervals. Thus, in each sampling point, ten 15-minute measurements were performed at the following time intervals: 7:00 to 14:00, 14:00 to 17:00, 17:00 to 21:00, and 21:00 to 7:00. More information about sampling methodology can be found in a previous work (Gómez-Escobar et al., 2012).

2.2. Description of the noise source study method

From the noise levels measured and from the annotations written for each measurement, the influences of the sources on the sound environment of this part of the city were studied. The following procedure was used:

First, considering the high variability of the noise sources and the different circumstances in which they were present, the noise sources were grouped according to their types of sound and their characteristics. The groups established for the study were:

Vehicles: cars, motorcycles and vans passing opposite the sampling point.

Passers-by: passers-by walking opposite the sampling point.

Birds: white storks (*Ciconia ciconia*) generally, but also pigeons, jackdaws, blackbirds, thrushes, swifts, sparrows, etc. (*Columba livia, Corvus monedula, Turdus merula, Turdus philomelos, Apus apus, Passer domesticus,* etc.).

Bells: bells of the churches of the old part indicating time for mass or the just the time.

Works: temporary works to improve the street pavement or rehabilitation on the houses.

People: people not just passing by; for example, groups of persons talking, people playing music, or laughing, etc.

Animals: animals not considered previously, such as cats, dogs, and crickets.

Other: other noise sources not having a sufficient number of samples to be grouped independently (appearing in less than 10% of the measurements). Included in this group were sources such as refrigerator devices, stopped delivery trucks, vehicles passing by other streets near the sampling points, and door slams.

In Table 1, the results from these source groups are presented. Also in this table, the results for the absences of these source groups are presented. A measurement that was not included for a particular noise source group was considered as being in the absence group for this noise source.

Complementary to these groups, noise sources were also grouped as countable sources (e.g., *vehicles* and *passers-by*) and uncountable sources (those that were impossible or very difficult to count, such as *birds*, and those with small variations in number, such as *animals* and *works*). For countable sources, the variability of noise levels as a function of the number of noise sources was analysed.

2.3. Preliminary analysis

Once the noise sources were grouped, statistical variables of the measured sound levels (L_{eq} for this analysis) for each group were calculated (Table 1) and the appearance frequency of each noise source was determined (Table 2).

The appearance frequency of each noise source was considered first. *Vehicles* and *passers-by* appeared in more than the half of the measurements (53% and 80%, respectively), independently of the analysed noise source (Table 2).

These results provided relevant initial information about the importance of the presence of noise sources. According to the sampling strategy, they indicated that both passers-by and vehicles had a wide presence in this part of the city, both spatially and temporally. Because both sources were countable, the influence of source number on measured noise levels could be studied. The proportions of samples with these noise sources were grouped according to the number of sources (in steps of two for vehicles (Figure 1a) and steps of 20 (except the first step, which was 10) for passers-by (Figure 1b)).

In approximately 90% of the measurements where vehicles were present, the number of vehicles was lower than 8 for the 15 minutes of sampling (giving a traffic flow under 32 vehicles/hour), as can be seen in Figure 1a. Thus, although the transit of vehicles was present in the area, the number of vehicles was small, as could be expected for an area with traffic restrictions. Could this have been indicative of a small acoustical importance of this noise source?

In almost half of the measurements (48.2%) where *passers-by* were present, the number of *passers-by* was greater than 10, and in nearly 15%, this number was greater than 40 for the 15 minutes of measurement (Figure 1b). This demonstrated the importance of this noise source in the area with respect to both its presence and its number. An analysis of its influence on the measured noise level follows this section.

This preliminary analysis enabled numerical confirmation of the hypothesis about the importance of this zone of the city as a tourist and leisure place. This hypothesis is supported by Table 2, which shows that *passers-by* had the second greatest appearance frequency.

From these preliminary results, a method of analysis that enabled evaluation of the relative influence of each noise source on the measured sound level is proposed and developed in the next subsection.

2.4. Descriptive statistical analysis

First, the sound levels of each noise source were analysed, as shown in Table 1. As can be seen, the behaviours of the mean and median values of the groups were very similar. For this reason, only one of these parameters was analysed: the mean value.

Source groups characterised by the presence of a certain source had equivalent noise values of 55 dBA or higher, and although higher values corresponded to the presence of vehicles or passers-by, all of the values were within a range of only 3 dBA. In the groups characterised by the absence of a source, the range of variation was also small (3.2 dBA), and only the means of the two groups (*absence of vehicles* and *absence of passers-by*) had values clearly lower than 55 dBA (approximately 53 dBA in both cases).

With respect to the rest of the indicators presented in Table 1, it can be seen that the standard deviations of all the source groups were quite high and that no relevant information for the analysis could be derived from the maximum and minimum data; on the contrary, this information could be considered contradictory. This was probably due to the simultaneity of the noise sources present in the samples (Table 2).

Therefore, from the analysis of the global sound levels, the obtained information did not lead to conclusions about the relative importance of the noise sources. Nevertheless, vehicles, passers-by, and people seemed to be the noise sources with the greatest importance.

Next, the mean value obtained for the presence of a certain source group and the mean value obtained for its absence were compared. Unlike for the previous analysis, groups without common data were analysed, and each pair included all the measurements. Consequently, behaviour over the whole area in both time and space was analysed in this case. As can be observed in Table 1, the greatest difference (approximately 4 dBA) between the mean values corresponded to *vehicles* and *passers-by*. In the rest of comparisons, the differences were clearly lower. The differences were positive for *people* and *works* (2.6 and 1.4 dBA, respectively), negative for *birds*, *bells* and *animals* and equal for the rest of the source groups.

From this second analysis, it seemed that vehicles and passers-by and possibly people and works made great contributions to the total sound level of the area. Birds, bells, animals, and the rest of the sources seemed irrelevant.

Finally, the sound level range that included 90% of the measurements (90% was chosen to eliminate extreme values that were probably due to exceptional behaviour of the source or to sources other than those of the group) was analyzed (Table 3).

In the first step, the *presence of* groups was considered. For these groups, the simultaneity of the sources in each group had to be taken into account to properly interpret the information provided by the values of the lower and upper limits. As can be seen in Table 3, there were clear differences between the groups. Moreover, the limits of the groups were consistent with the median and mean values. The same was not true for the maximum and minimum levels, as discussed previously.

The lower limit obtained for the *presence of* group was associated with the lowest value of sound level that the source generated in the area, although the submitted value did not necessarily correspond to the lowest. Thus, a low value of this lower limit indicated that the source was not very noisy, and a high value indicated that the source significantly disturbed the sound environment. It can be seen in Table 3 that the range of variation of the lower limits was wide (9.4 dBA) and that, for *vehicles*, *passers-by*, *people*, and *works*, the lower limits were higher than 45 dBA (49.4 dBA for *vehicles*) and lower than 44 dBA for *birds*, *animals*, and the rest of the sources (40.0 dBA for *animals*).

Considering the upper limit for the *presence of* groups (which had a range of 5.6 dBA), double information could be obtained. Higher values indicated the maximum values that the sources could produce (e.g., more than 67 dBA for *vehicles*, *passers-by*, *people*, and *works*), and lower values indicated the maximum values over which the source was absent (physically or masked). For example, for *birds* and *animals*, whose upper limits were under 65 dBA, it could be concluded that if a noise level over this value was registered then these sources were not present or their noise was not perceived.

Therefore, vehicles, passers-by, and works were the sources that caused major disturbances to the environment and their presences could have been the cause of the absences or masking of sources having lower powers, such as birds or animals. These last sound sources must be considered the origin of a quieter and peaceful soundscape.

In the second step, the *absence of* groups was considered. Low limit values indicated a large perturbation of the sound environment by the absent sources. As can be seen in Table 4, the lower limits had a range of 3.3 dBA for these groups (note that the minimum values of the equivalent levels were the same for all the groups, as can be seen in Table 1). The lowest values of this limit were found for *passers-by*, *vehicles*, *people*, and *works*. Analysing the upper limits, the lowest values were observed for *passers-by* and *people*.

In the last step, the differences between the lower and upper limits were considered (Table 3). The presence and absence of *vehicles* and *passers-by* had differences of approximately 6 dBA in their lower limits. These differences were lower for *works* (3.7 dBA) and *people* (2.9 dBA). The difference was -4.1 dBA for *animals*, indicating that the presence of other sources masked the sound from animals. With respect to the differences in the upper limits, it is emphasised here that the differences found for *people* and *passers-by* (approximately 3 dBA) and for *animals* (-3.6 dBA) indicated the importance of the first two source groups and corroborated the previous results for the third.

This analysis allowed us to identify two facts: a) *Vehicles, passers-by, people,* and *works* were the source groups that made major contributions to the total acoustic energy of the area; and b) The existence of a masking effect from these sources on other less important such as *birds* and *animals*.

Despite the previous conclusions, it was necessary to analyse in greater detail the sound structure of the area. This was done by analysing the results of the inferential analyses of the differences between the groups (first, between *presence of* groups; second, between *absence of* groups; and finally, between each pair of *presence of* and *absence of* groups).

2.5. Group structure statistical analysis

To analyse the source groups that represented independent sonorous realities, a pairwise comparison analysis was made by means of the Mann-Whitney-Wilcoxon test with Holm corrections (Holm, 1979). The results are shown in Table 4. This is a reliable test, and the differences found are indisputable.

As can be seen in Table 4a, there was a significant difference (*) only between *birds* and *vehicles*; therefore, *vehicles* made a greater net contribution to the sound level than did *birds* (note that birds was not the source group with the lowest mean or median values (Table 1) and that thanks to the applied tests, it could be differentiated from vehicles). This significant difference was probably due to the disturbance that vehicles caused to the perception of birds.

It can be seen in Table 4b that the *absence of vehicles* group was statistically distinct (**) from the *absence of birds*, *bells*, *works*, *animals and others* groups. The *absence of passers-by* and *birds*, *bells* and *animals* groups was also statistically distinct (*). Therefore, it seemed clear that the *absence of vehicles* group created an acoustical state clearly distinct from the rest of groups (except the *absence of people* and *passers-by* groups). Besides, we can suppose that the *absence of passers-by* group also creates an acoustical state clearly distinct from three groups: *birds*, *bells* and *animals* groups.

The results of the inferential analysis of the differences between the *presence of* and *absence of* groups are presented in Table 5. The Mann-Whitney U test was used for the inferential analysis (Mann and Whitney, 1947). As it can be seen, there were three pairs of statistically distinct *presence of* and *absence o*f groups (*vehicles*, *passers-by*, and *people*), indicating that only the presence of these sources created different acoustical situations as compared with the situations of absence of them.

Therefore, according to the previous results, we can conclude that while four sound sources seemed to cause a significant contribution to the sound energy of the area, for three of them (*vehicles*, *passers-by* and *people* groups) we found that these contribution to the acoustic environment is statistically different. Moreover, noise control strategies could be suggested on the basis of the principal noise sources in the environment.

2.6. Regression sources analyses

In this section we analyze the degree of explanation of the variability of the sound level that can be explained from the variability of the sources. This kind of studies is usually done by considering only countable sources, but we also included some uncountable ones.

First, the relation between the measured equivalent level and the logarithm of the vehicle flow (Figure 2) was studied. For the measurements for traffic (Figure 2a), the correlation was highly significant ($p < 0.001$), showing that 20% of the variability of the equivalent level could be explained by traffic flow.

Considering the intrinsic variability of the source and the urban design and architectural characteristics of the squares and streets of the area, the determination of a regression equation averaging the variability was considered. The average noise level for all the measurements for the same traffic flow was obtained, and the regression line was calculated (Figure 2b). As can be seen, the correlation was highly significant ($p < 0.001$), and the variability of the equivalent level that could be explained by traffic flow increased to 55%. This result indicated that despite the traffic restrictions in the area, globally the presence of vehicles explained more than half of the equivalent noise level variability (at least for the range of traffic flow in this study), and therefore, it might be necessary to tighten the restrictions on the use of vehicles in the area. But it seemed clear that other noise sources influenced the measured sound levels, even with presence of vehicles.

The obtained regression line equation showed that 55 dBA was obtained easily with a small number of vehicles. Only 24 vehicles per hour would be necessary to obtain 60 dBA and that 94 vehicles per hour would be necessary to obtain 65 dBA (the limit for daytime according to the OCDE (OCDE, 1986)).

Second, the relation between the measured equivalent level and the logarithm of the passer-by flow (Figure 3) was studied. In this case, noise came mainly from the conversations of passers-by, and for this reason, only measurements with more than two passers-by were considered. For these measurements (Figure 3a), the correlation was highly significant ($p < 0.001$), and it can be seen that 20% of the variability of the equivalent level could be explained by passer-by flow. This interesting result shows the importance of this noise source in the area.

According to the regression line equation, a reduced number of passers-by could produce an equivalent noise level of 55 dBA. To obtain 60 dBA, more than 200 passers-by per hour would be necessary. Moreover, 1,500 passers-by per hour would be necessary to obtain 65 dBA.

For passer-by, the average noise level was obtained for all the measurements for the same flow, and the new regression line were calculated (Figure 3b). The correlation was highly significant ($p < 0.001$), and the explained variability increased to 27%.

After averaging the measurements for the same flow (traffic or passers-by) and thus minimising the variability attributed to people and to urban design and architectural characteristics, it was found that, when traffic was present (53% of all the measurements), 55% of the variability of the equivalent noise level was explained by traffic flow and that, when passers-by were present (80% of the measurements), 27% of the variability of the equivalent noise level was explained by passer-by flow. Therefore, a great percentage of the variability of the equivalent noise level was successfully explained by two sources that were present in most of measurements. There were other measurements in which these two sources were not present and the variability of the equivalent sound level might be explained by other noise sources (works or people, probably).

Finally, we considered it interesting to carry out the analysis simultaneously on all those sources whose previous results showed a significant influence on the sound levels of environment (*vehicle*s, *passers-by*, *people* and *works* groups). In addition, we considered that the analysis might include all measurements. Since there were countable sources (*vehicle* and *passer-by*) and uncountable ones (*people* and *works*), and taking into account that even if all the sources were countable in most of the measurements they were not simultaneously present, we decided to group the measurement in ten groups with equal number of samples and with an increasing value of the measured equivalent level. In each of these groups we obtained the mean value of the equivalent level and we averaged out the values of the countable sources present. For the *people* and *works* sources, we obtained the proportion of samples of the group in which this noise source was present. Thus, all the sources have a numeric value assigned to each average of the equivalent level. The results obtained for the groups are shown in Table 6.

With this procedure, we obtained statistically significant relationships of noise level against the logarithm of the value assigned for three sound sources groups, *vehicles*, *passers-by* and *people*, but no for *works* group. Then, a multiple regression analysis of noise level against the logarithm of the value assigned to these three sources was carry out. The result of this analysis is shown in Table 7. A highly significant relationship ($p < 0.001$) was obtained. We can see that the explained variability analysis was 97%. That is, if we consider the area and the different noise sources present in it, and we average out the measured sound levels, we can explain almost all the variability of these sound levels from the *vehicles*, *passers-by* and *people* noise groups. It should be noted that these three noise groups were those that presented significant differences between pairs of *presence of* and *absence of groups*, in the inferential analysis. In addition, we observe in the table that the obtained background noise in the area was near 39 dBA. This value is consistent with our measurements (the lower L_{eq} measured in the environment was 38.2 dBA).

3. Improvement proposals

Based on the analysis of the area, the focus must be on the four major sources observed, i.e., passers-by, vehicles, people, and works, to improve the noise state. Thus, the following are proposed:

1. An improvement in the control of vehicle access to the area is necessary. This can be done by joining the present system (the raising of bollards and use of vigilance cameras) with the requesting of identification for access to the zone. Thus, only authorised vehicles would be allowed to circulate in the area.

2. Restrictions on the access of passers-by to the area are not considered necessary (or even possible) because their present use of the area seems to produce an acceptable acoustical situation.
3. Surveillance of works in the area is necessary. Thus, all the possible noise control measures would be recommended.
4. Control of the leisure places of the area and of the people who use them is necessary.
5. A change in the hours of rubbish collection, avoiding making them at night is necessary. Moreover, considering the size of the area and the density of the population, smaller vehicles could be used.

4. Conclusions

The proposed method of identifying and quantifying the effects of noise sources was applied to an area of the city with traffic restrictions used mainly for walks and tourist visits.

Vehicles and passers-by were identified as the noise sources with the highest frequencies of appearance; although the traffic flow was not very important.

Descriptive statistical analyses of the defined groups enabled identification of the four major noise sources contributing to the mean sound levels of the area.

Despite the restriction on traffic in the area, this noise source was very important, making a greater contribution to the global acoustic energy than the other noise sources. People were an important noise source in the area, both as passers-by and as emitters when stopped in squares or streets (*passers-by* and *people* groups). Their contribution to the global acoustical situation of the historic part of Cáceres was similar to that of vehicles. *Works* was the next most important noise source, but its importance in the whole area was not significant, having a punctual nature. The rest of the noise sources did not cause major problems of acoustical pollution.

The inferential statistical analysis proved the existence of differences between the measured values for the source groups. This allowed us to conclude that the acoustic environment of the area is statistically different when the two most important noise sources are present (vehicles and passers-by) on respect to the soundscape existing when sources as birds, bells or animals are perceived. This analysis also allows us to conclude the existence of significant differences between the existing acoustic environment when vehicles, passers-by and people are present and the scenario where they are absent.

Precisely, these three sources groups considered in a multivariate correlation analysis allowed explaining the variability of the average noise level in the area in a 97%.

Any noise control measure in the area would have to include a stricter control of vehicle traffic.

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Table Captions

Table 1. Statistical indicators of the noise results (L_{eq}) for the source groups.

Table 2. Appearance frequencies of the source groups (%).

Table 3. Lower and upper limits of the sound values that delimited the range that included 90% of the measurements and the differences between them for the source groups.

Table 4. P value of Pairwise comparisons using Mann-Whitney-Wilcoxon test with Holm corrections for the different source groups. a) Groups characterized by the presence of a source; b) groups characterized by the absence of the source. (*) P-value < 0.05 and (**) p-value < 0.01.

Table 5. Inferential analysis results for the differences between *presence of* and *absence of* groups. (***) P-value < 0.001, (**) p-value < 0.01, and (n.s) p-value > 0.05.

Table 6. Means values obtained for the main four groups of noise sources in the area, by grouping all measurements in 10 groups with equal numbers of samples.

Table 7. Results of the multiple regression analysis. (***) P-value < 0.001

Table 1

	Presence of							
L_{eq} (dBA)	***Vehicles***	***Passers-by***	***Birds***	***Bells***	***Works***	***People***	***Animals***	***Other***
Mean	57.6	56.3	55.0	54.6	56.9	57.2	54.9	55.5
Standard deviation	5.6	6.6	6.2	6.6	7.1	7.3	7.6	6.9
Median	57.4	56.0	54.8	54.3	55.5	57.1	56.1	55.9
Maximum	75.2	81.7	73.7	68.4	81.7	81.7	72.4	73.7
Minimum	41.3	38.4	39.4	40.8	46.7	40.6	38.4	38.4
	Absence of							
	Vehicles	***Passers-by***	***Birds***	***Bells***	***Works***	***People***	***Animals***	***Other***
Mean	53.3	52.6	55.8	55.7	55.4	54.6	55.6	55.6
Standard deviation	7.9	8.1	7.4	7.2	7.1	6.8	7.0	7.1
Median	52.8	53.1	55.8	55.8	55.5	54.8	55.5	55.4
Maximum	81.7	76.3	81.7	81.7	76.3	75.2	81.7	81.7
Minimum	38.2	38.2	38.2	38.2	38.2	38.2	38.2	38.2

Table 2

	Presence of								
Frequency (%)	**All sources**	***Vehicles***	***Passers-by***	***Birds***	***Bells***	***Works***	***People***	***Animals***	***Other***
Vehicles	53	-	85	22	16	11	34	9	27
Passers-by	80	56	-	27	16	13	39	11	28
Birds	27	43	79	-	29	20	41	13	26
Bells	15	55	84	52	-	7	40	12	33
Works	13	47	83	45	9	-	19	9	30
People	36	50	86	31	17	7	-	10	33
Animals	11	45	76	31	17	10	33	-	33
Other	27	53	82	26	18	14	44	14	-

Table 3

	Presence of							
Limits	***Vehicles***	***Passers-by***	***Birds***	***Bells***	***Works***	***People***	***Animals***	***Other***
Lower (dBA)	49.4	46.8	43.8	44.5	46.9	45.4	40.0	43.3
Upper (dBA)	67.0	68.4	63.6	65.4	69.0	69.0	64.4	65.4
	Absence of							
	Vehicles	***Passers-by***	***Birds***	***Bells***	***Works***	***People***	***Animals***	***Other***
Lower (dBA)	41.2	40.8	43.5	43.5	43.2	42.5	44.1	43.8
Upper (dBA)	68.0	65.2	68.4	68.5	67.5	66.0	68.0	68.4
	Difference between the limits of *presence of* and *absence of*							
	Vehicles	***Passers-by***	***Birds***	***Bells***	***Works***	***People***	***Animals***	***Other***
Lower (dBA)	6.3	6.0	0.3	1.0	3.7	2.9	- 4.1	- 0.5
Upper (dBA)	- 1.0	3.2	- 4.8	-3.1	1.5	3.0	- 3.6	- 3.0

Table 4

a)

Presence of	*Vehicles*	*Passers-by*	*Birds*	*Bells*	*Works*	*People*	*Animals*
Passers-by	0.332	-	-	-	-	-	-
Birds	0.026 (*)	1.000	-	-	-	-	-
Bells	0.073	1.000	1.000	-	-	-	-
Works	1.000	1.000	1.000	1.000	-	-	-
People	1.000	1.000	0.656	0.656	1.000	-	-
Animals	1.000	1.000	1.000	1.000	1.000	1.000	-
Other	0.425	1.000	1.000	1.000	1.000	1.000	1.000

b)

Absence of	*Vehicles*	*Passers-by*	*Birds*	*Bells*	*Works*	*People*	*Animals*
Passers-by	1.000	-	-	-	-	-	-
Birds	0.003 (**)	0.047(*)	-	-	-	-	-
Bells	0.001 (**)	0.040 (*)	1.000	-	-	-	-
Works	0.006 (**)	0.078	1.000	1.000	-	-	-
People	0.207	0.592	1.000	1.000	1.000	-	-
Animals	0.003 (**)	0.047(*)	1.000	1.000	1.000	1.000	-
Other	0.006 (**)	0.070	1.000	1.000	1.000	1.000	1.000

Table 5

	Vehicles	*Passers-by*	*Birds*	*Bells*	*Works*	*People*	*Animals*	*Other*
Mean difference	4.3	3.7	-0.8	-1.1	1.4	2.6	-0.7	-0.1
Median difference	4.6	2.9	-1.0	-1.6	0.0	2.2	0.7	0.5
U de Mann-Whitney	6.8×10^{-11} (***)	1.9×10^{-4} (***)	0.5	0.3	0.4	1.6×10^{-3} (***)	0.9	0.8

Table 6

Average L_{eq} (dB)	Vehicles flow (Veh/h)	Passers-by flow (Pass/h)	People (%)	Works (%)
68.9	17.6	186.7	55.3	15.8
62.5	13.6	96.5	50.0	7.9
59.6	17.1	95.4	34.2	18.4
57.8	12.0	63.8	39.5	13.2
56.4	10.0	115.8	31.6	5.3
54.7	6.0	52.6	28.9	21.1
52.9	4.5	55.9	36.8	7.9
51.1	3.7	33.8	31.6	18.4
48.6	1.9	20.9	34.2	7.9
43.2	1.3	7.4	21.1	7.9

Table 7

		Critical F value
Multiple correlation coefficient	0.982	9.05E-05(***)
Determination coefficient (R^2)	0.965	
	Coefficients	**Typical error**
Interception	38.9	2.4
Variable X 1 (Vehicles)	2.0	0.7
Variable X 2 (Trans)	0.16	0.09
Variable X 3 (Personas)	25.6	8.7

Figure Captions

Figure 1. Cumulative distribution of the number of noise sources: a) vehicles and b) passers-by.

Figure 2. Relation between the measured equivalent level and the logarithm of the vehicle flow: a) all measurements and b) average equivalent noise level measurements for the same vehicle flow.

Figure 3. Relation between the measured equivalent level and the logarithm of the passer-by flow: a) all measurements and b) average equivalent noise level measurements for the same passer-by flow.

Figure 1

Figure 2

Figure 3

Noise source analyses in the acoustical environment of the medieval centre of Cáceres (Spain).

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Abstract

A study of the sound and noise sources was realized in the medieval historic centre of the city of Cáceres (Spain), which is a major site for tourism and has important restrictions on the use of vehicles. It was declared as World Heritage Site by UNESCO in 1986 and it is the third best-preserved monument in Europe.

A large number and a variety of noise sources were identified during fieldwork. Different source groups were defined based on the types and origins of the sources; noise sources with appearance frequencies lower than 10% were put in a unique group.

Descriptive and interferential analyses of the groups were performed to study the relative importance of the various sources. The analyses revealed that vehicles, passers-by, and people made a major contribution to the sound energy of the area. In addition, a masking effect by vehicles on other sound sources was detected.

Keywords: urban noise, architectural heritage, soundscape, noise sources, urbanism.

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1. Introduction

In the major parts of cities, noise sources are related mainly to traffic, particularly road traffic (U.S. Department of Transportation, 1995; WHO, 1999; EEA, 2009; WHO, 2009). In previous studies, the Authors' research group confirmed that road traffic is the main cause of the spatial variability of noise in towns for the range of size of the cities studied (Barrigón et al., 2005a, 2005b, 2010, 2011, Carmona et al 2011). For the case of a large city with a major noise source, a reasonable option for noise mapping is calculation methods, which are recommended instead of measurement methods (WG-AEN, 2007) although the accuracies of the estimates of the two methods can be considered equivalent (Ausejo, 2009).

However, there are wide areas and environments inside cities where, due to diverse causes, road traffic is controlled or is not the principal source of noise (Barrigón et al., 2005c). These areas are of great interest for carrying out different types of acoustic study (Cepeda et al., 2008; Brambilla and Maffei, 2010).

If traffic is not the major noise source, the application of prediction models might not be useful for noise mapping or might require great effort for the characterisation of the noise sources. In this case, a measurement strategy for noise sampling might be reasonable for obtaining complete knowledge of the acoustical state of an area (Brown and Lam, 1987). In this type of study, it is necessary to establish an adequate sampling strategy, both spatial and temporal, to determine the acoustical situation (Gómez-Escobar et al., 2012) and to acquire further knowledge of other aspects of acoustical pollution.

Besides, the control of road traffic implies an increase in the importance of other noise sources that could achieve, objectively or subjectively, an importance equal to or greater than that of traffic. To apply a noise control strategy in this case, previous identification of the noise sources and evaluation of their relative importance, both locally in the streets and globally over the whole area, are necessary.

Finally, if the studied area has a low degree of noise pollution, it is an ideal environment for noise studies. Thus, the effect of low noise pollution on citizens with respect to their perception of noise as a contamination factor, the intensity of the noise disturbance that they are subjected to and the influence of noise in their daily activities could be studied and quantified (Gómez-Escobar et al., 2012).

In this paper, a study of the historical part of the city of Cáceres is presented. The city of Cáceres, with approximately 90,000 inhabitants, 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 due especially to its historic centre, which is a UNESCO World Heritage site (World Heritage, 1986). This part of the city, surrounded by an ancient wall and with limited traffic and high cultural and touristic value, was the subject of this study. Traffic is limited by means of bollards to taxis and to the cars of the people who live in the old part of the city or who are staying in the state-run hotel that is located there. Moreover, there are assigned hours for goods delivery to the restaurants and pubs and for free access in the morning. Maintenance and cleaning services are also allowed.

The main objective of the present study is the identification of the main noise sources which are present in the area, the evaluation of their absolute and relative influences on the noise level of the area and the study of the possible existence of interferences between these sources.

The second section of this paper presents the noise source analyses, the third present proposals for improvement and the last section presents the conclusions.

2. Noise source analyses

2.1. Introduction

The studied area has elements that make it a special environment with acoustical characteristics essentially different from those of locations where noise impact studies are usually performed.

The urban design and architectural characteristics of the area are exceptional due to the extraordinary conservational grade of the historic centre. As mentioned, this part of the city is walled, and for this reason, a reduced number of entrances and exits are present. It is located on the top of a hill, and the streets are short and narrow, some with steep slopes and stairs, and thus vehicles cannot transit through them. Throughout the old part of the city, squares with palaces and other ancient buildings are present. This area can be considered an acoustical island inside a modern city; photographs and maps of the area can be found in a previous work (Gómez-Escobar et al., 2012).

The kinds of noise source present in this area are very specific and variable with respect to their geometric characteristics, mobility, spatial distribution, temporal characteristics and relative intensity. Moreover, the noise sources are not generally isolated, and different combinations of them (with different emission powers and distances to the receiver) can be observed throughout the area.

All of these characteristics imply a high acoustical complexity in the area and, as a consequence, in its analysis. However, they increase the interest in the study of the area using an adequate method and in the results of this study. Different works have been done in the field of automatic recognition of sources (Couvreur et al., 1998; Barkana and Uzkent, 2011; Mato-Mendez and Sobreira-Seoane, 2011). It is not the aim of this study to propose a working method for the recognition of sources, but once identified by a technician, to use a systematic method to assess the importance of each source in the environment.

To obtain adequate information about the spatial and temporal acoustical situation of the area, forty sampling points were chosen. These covered all the representative locations of the historic centre of Cáceres. For each sampling point, ten 15-minute measurements were performed at the following time intervals: 7:00 to 14:00, 14:00 to 17:00, 17:00 to 21:00, and 21:00 to 7:00. More information about sampling methodology can be found in a previous work (Gómez-Escobar et al., 2012).

2.2. Description of the noise source study method

From the noise levels measured and from the annotations written for each measurement, the influences of the sources on the sound environment of this part of the city were studied. The following procedure was used:

First, considering the high variability of the noise sources and the different circumstances in which they were present, the noise sources were grouped according to their types of sound and their characteristics. The groups established for the study were:

Vehicles: vehicles passing by the sampling point.

Passers-by: passers-by walking in the street where the sampling point was located.

Birds: white storks (*Ciconia ciconia*) generally, but also pigeons, jackdaws, blackbirds, thrushes, swifts, sparrows, etc. (*Columba livia, Corvus monedula, Turdus merula, Turdus philomelos, Apus apus, Passer domesticus,* etc.).

Bells: bells of the churches of the old part indicating time for mass or the just the time.

Works: street works to improve the pavement or rehabilitation works on the houses.

People: people not just passing by; for example, groups of persons talking, people playing music, or laughing, etc.

Animals: animals not considered previously, such as cats, dogs, and crickets.

Other: other noise sources not having a sufficient number of samples to be grouped independently (appearing in less than 10% of the measurements). Included in this group were sources such as refrigerator devices, stopped delivery trucks, vehicles passing by other streets near the sampling points, and door slams.

In Table 1, the results from these source groups are presented. Also in this table, the results for the absences of these source groups are presented. A measurement that was not included for a particular noise source group was considered as being in the absence group for this noise source.

Complementary to these groups, noise sources were also grouped as countable sources (e.g., *vehicles* and *passers-by*) and uncountable sources (those that were impossible or very difficult to count, such as *birds*, and those with small variations in number, such as *animals* and *works*). For countable sources, the variability of noise levels as a function of the number of noise sources was analysed.

2.3. Preliminary analysis

Once the noise sources were grouped, statistical variables of the measured sound levels (L_{eq} for this analysis) for each group were calculated (Table 1) and the appearance frequency of each noise source was determined (Table 2).

The appearance frequency of each noise source was considered first. *Vehicles* and *passers-by* appeared in more than the half of the measurements (53% and 80%, respectively), independently of the analysed noise source (Table 2).

These results provided relevant initial information about the importance of the noise sources. According to the sampling strategy, they indicated that both passers-by and vehicles had a wide presence in this part of the city, both spatially and temporally. Because both sources were countable, the influence of source number on measured noise levels could be studied. The proportions of samples with these noise sources were grouped according to the number of sources (in steps of two for vehicles (Figure 1a) and steps of 20 (except the first step, which was 10) for passers-by (Figure 1b)).

In approximately 90% of the measurements where vehicles were present, the number of vehicles was lower than 8 for the 15 minutes of sampling (giving a traffic flow under 32 vehicles/hour), as can be seen in Figure 1a. Thus, although the transit of vehicles was present in the area, the number of vehicles was small, as could be expected for an area with traffic restrictions. Could this have been indicative of a small acoustical importance of this noise source?

In almost half of the measurements (48.2%) where *passers-by* were present, the number of *passers-by* was greater than 10, and in nearly 15%, this number was greater than 40 for the 15 minutes of measurement (Figure 1b). This demonstrated the importance of this noise source in the area with respect to both its presence and its number. An analysis of its influence on the measured noise level follows this section.

This preliminary analysis enabled numerical confirmation of the hypothesis about the importance of this zone of the city as a tourist and leisure place. This hypothesis is supported by Table 2, which shows that *passers-by* had the second greatest appearance frequency.

From these preliminary results, a method of analysis that enabled evaluation of the relative influence of each noise source on the measured sound level is proposed and developed in the next subsection.

2.4. Descriptive statistical analysis

First, the sound levels of each noise source were analysed, as shown in Table 1. As can be seen, the behaviours of the mean and median values of the groups were very similar. For this reason, only one of these parameters was analysed: the mean value.

Source groups characterised by the presence of a certain source had equivalent noise values of 55 dBA or higher, and although higher values corresponded to the presence of vehicles or passers-by, all of the values were within a range of only 3 dBA. In the groups characterised by the absence of a source, the range of variation was also small (3.2 dBA), and only the means of the two groups (*absence of vehicles* and *absence of passers-by*) had values clearly lower than 55 dBA (approximately 53 dBA in both cases).

With respect to the rest of the indicators presented in Table 1, it can be seen that the standard deviations of all the source groups were quite high and that no relevant information for the analysis could be derived from the maximum and minimum data; on the contrary, this information could be considered contradictory. This was probably due to the simultaneity of the noise sources present in the samples (Table 2).

Therefore, from the analysis of the global sound levels, the obtained information did not lead to conclusions about the relative importance of the noise sources. Nevertheless, vehicles, passers-by, and people seemed to be the noise sources with the greatest importance.

Next, the mean value obtained for the presence of a certain source group and the mean value obtained for its absence were compared. Unlike for the previous analysis, groups without common data were analysed, and each pair included all the measurements. Consequently, behaviour over the whole area in both time and space was analysed in this case. As can be observed in Table 1, the greatest difference (approximately 4 dBA) between the mean values corresponded to *vehicles* and *passers-by*. In the rest of comparisons, the differences were clearly lower. The differences were positive for *people* and *works* (2.6 and 1.4 dBA, respectively), negative for *birds*, *bells* and *animals* and equal for the rest of the source groups.

From this second analysis, it seemed that vehicles and passers-by and possibly people and works made great contributions to the total sound level of the area. Birds, bells, animals, and the rest of the sources seemed irrelevant.

Finally, the sound level range that included 90% of the measurements (90% was chosen to eliminate extreme values that were probably due to exceptional behaviour of the source or to sources other than those of the group) was analyzed (Table 3).

In the first step, the *presence of* groups was considered. For these groups, the simultaneity of the sources in each group had to be taken into account to properly interpret the information provided by the values of the lower and upper limits. As can be seen in Table 3, there were clear differences between the groups. Moreover, the limits of the groups were consistent with the median and mean values. The same was not true for the maximum and minimum levels, as discussed previously.

The lower limit obtained for the *presence of* group was associated with the lowest value of sound level that the source generated in the area, although the submitted value did not necessarily correspond to the lowest. Thus, a low value of this lower limit indicated that the source was not very noisy, and a high value indicated that the source significantly disturbed the sound environment. It can be seen in Table 3 that the range of variation of the lower limits was wide (9.4 dBA) and that, for *vehicles*, *passers-by*, *people*, and *works*, the lower limits were higher than 45 dBA (49.4 dBA for *vehicles*) and lower than 44 dBA for *birds*, *animals*, and the rest of the sources (40.0 dBA for *animals*).

Considering the upper limit for the *presence of* groups (which had a range of 5.6 dBA), double information could be obtained. Higher values indicated the maximum values that the sources could produce (e.g., more than 67 dBA for *vehicles*, *passers-by*, *people*, and *works*), and lower values indicated the maximum values over which the source was absent (physically or masked). For example, for *birds* and *animals*, whose upper limits were under 65 dBA, it could be concluded that if a noise level over this value was registered then these sources were not present or their noise was not perceived.

Therefore, vehicles, passers-by, and works were the sources that caused major disturbances to the environment and their presences could have been the cause of the absences or masking of sources having lower powers, such as birds or animals. These last sound sources must be considered the origin of a quieter and peaceful soundscape.

In the second step, the *absence of* groups was considered. Low limit values indicated a large perturbation of the sound environment by the absent sources. As can be seen in Table 4, the lower limits had a range of 3.3 dBA for these groups (note that the minimum values of the equivalent levels were the same for all the groups, as can be seen in Table 1). The lowest values of this limit were found for *passers-by*, *vehicles*, *people*, and *works*. Analysing the upper limits, the lowest values were observed for *passers-by* and *people*.

In the last step, the differences between the lower and upper limits were considered (Table 3). The presence and absence of *vehicles* and *passers-by* had differences of approximately 6 dBA in their lower limits. These differences were lower for *works* (3.7 dBA) and *people* (2.9 dBA). The difference was -4.1 dBA for *animals*, indicating that the presence of other sources masked the sound from animals. With respect to the differences in the upper limits, it is emphasised here that the differences found for *people* and *passers-by* (approximately 3 dBA) and for *animals* (-3.6 dBA) indicated the importance of the first two source groups and corroborated the previous results for the third.

This analysis allowed us to identify two facts: a) *Vehicles*, *passers-by*, *people*, and *works* were the source groups that made major contributions to the total acoustic energy of the area; and b) The existence of a masking effect from these sources on other less important such as *birds* and *animals*.

Despite the previous conclusions, it was necessary to analyse in greater detail the sound structure of the area. This was done by analysing the results of the inferential analyses of the differences between the groups (first, between *presence of* groups; second, between *absence of* groups; and finally, between each pair of *presence of* and *absence of* groups).

2.5. Group structure statistical analysis

To analyse the source groups that represented independent sonorous realities, a pairwise comparison analysis was made by means of the Mann-Whitney-Wilcoxon test with Holm corrections (Holm, 1979). The results are shown in Table 4. This is a reliable test, and the differences found are indisputable.

As can be seen in Table 4a, there was a significant difference (*) only between *birds* and *vehicles*; therefore, *vehicles* made a greater net contribution to the sound level than did *birds* (note that birds was not the source group with the lowest mean or median values (Table 1) and that thanks to the applied tests, it could be differentiated from vehicles). This significant difference was probably due to the disturbance that vehicles caused to the perception of birds.

It can be seen in Table 4b that the *absence of vehicles* group was statistically distinct (**) from the *absence of birds*, *bells*, *works, animals and others* groups. The *absence of passers-by* and *birds*, *bells* and *animals* groups was also statistically distinct (*). Therefore, it seemed clear that the *absence of vehicles* group created an acoustical state clearly distinct from the rest of groups (except the *absence of people* and *passers-by* groups). Besides, we can suppose that the *absence of passers-by* group also creates an acoustical state clearly distinct from three groups: *birds*, *bells* and *animals* groups.

The results of the inferential analysis of the differences between the *presence of* and *absence of* groups are presented in Table 5. The Mann-Whitney U test was used for the inferential analysis (Mann and Whitney, 1947). As it can be seen, there were three pairs of statistically distinct *presence of* and *absence o*f groups (*vehicles*, *passers-by,* and *people*), indicating that only the presence of these sources created different acoustical situations as compared with the situations of absence of them.

Therefore, according to the previous results, we can conclude that while four sound sources seemed to cause a significant contribution to the sound energy of the area, for three of them (*vehicles*, *passers-by* and *people* groups) we found that these contribution to the acoustic environment is statistically different. Moreover, noise control strategies could be suggested on the basis of the principal noise sources in the environment.

2.6. Regression sources analyses

In this section we analyze the degree of explanation of the variability of the sound level that can be explained from the variability of the sources. This kind of studies is usually done by considering only countable sources, but we also included some uncountable ones.

First, the relation between the measured equivalent level and the logarithm of the vehicle flow (Figure 2) was studied. For the measurements for traffic (Figure 2a), the correlation was highly significant ($p < 0.001$), showing that 20% of the variability of the equivalent level could be explained by traffic flow.

Considering the intrinsic variability of the source and the urban design and architectural characteristics of the squares and streets of the area, the determination of a regression equation averaging the variability was considered. The average noise level for all the measurements for the same traffic flow was obtained, and the regression line was calculated (Figure 2b). As can be seen, the correlation was highly significant ($p < 0.001$), and the variability of the equivalent level that could be explained by traffic flow increased to 55%. This result indicated that despite the traffic restrictions in the area, globally the presence of vehicles explained more than half of the equivalent noise level variability (at least for the range of traffic flow in this study), and therefore, it might be necessary to tighten the restrictions on the use of vehicles in the area. But it seemed clear that other noise sources influenced the measured sound levels, even with presence of vehicles.

The obtained regression line equation showed that 55 dBA was obtained easily with a small number of vehicles. Only 24 vehicles per hour would be necessary to obtain 60 dBA and that 94 vehicles per hour would be necessary to obtain 65 dBA (the limit for daytime according to the OCDE (OCDE, 1986)).

Second, the relation between the measured equivalent level and the logarithm of the passer-by flow (Figure 3) was studied. In this case, noise came mainly from the conversations of passers-by, and for this reason, only measurements with more than two passers-by were considered. For these measurements (Figure 3a), the correlation was highly significant ($p < 0.001$), and it can be seen that 20% of the variability of the equivalent level could be explained by passer-by flow. This interesting result shows the importance of this noise source in the area.

According to the regression line equation, a reduced number of passers-by could produce an equivalent noise level of 55 dBA. To obtain 60 dBA, more than 200 passers-by per hour would be necessary. Moreover, 1,500 passers-by per hour would be necessary to obtain 65 dBA.

For passer-by, the average noise level was obtained for all the measurements for the same flow, and the new regression line were calculated (Figure 3b). The correlation was highly significant ($p < 0.001$), and the explained variability increased to 27%.

After averaging the measurements for the same flow (traffic or passers-by) and thus minimising the variability attributed to people and to urban design and architectural characteristics, it was found that, when traffic was present (53% of all the measurements), 55% of the variability of the equivalent noise level was explained by traffic flow and that, when passers-by were present (80% of the measurements), 27% of the variability of the equivalent noise level was explained by passer-by flow. Therefore, a great percentage of the variability of the equivalent noise level was successfully explained by two sources that were present in most of measurements. There were other measurements in which these two sources were not present and the variability of the equivalent sound level might be explained by other noise sources (works or people, probably).

Finally, we considered it interesting to carry out the analysis simultaneously on all those sources whose previous results showed a significant influence on the sound levels of environment (*vehicle*s, *passers-by*, *people* and *works* groups). In addition, we considered that the analysis might include all measurements. Since there were countable sources (*vehicle* and *passer-by*) and uncountable ones (*people* and *works*), and taking into account that even if all the sources were countable in most of the measurements they were not simultaneously present, we decided to group the measurement in ten groups with equal number of samples and with an increasing value of the measured equivalent level. In each of these groups we obtained the mean value of the equivalent level and we averaged out the values of the countable sources present. For the *people* and *works* sources, we obtained the proportion of samples of the group in which this noise source was present. Thus, all the sources have a numeric value assigned to each average of the equivalent level. The results obtained for the groups are shown in Table 6.

With this procedure, we obtained statistically significant relationships of noise level against the logarithm of the value assigned for three sound sources groups, *vehicles*, *passers-by* and *people,* but no for *works* group. Then, a multiple regression analysis of noise level against the logarithm of the value assigned to these three sources was carry out. The result of this analysis is shown in Table 7. A highly significant relationship ($p < 0.001$) was obtained. We can see that the explained variability analysis was 97%. That is, if we consider the area and the different noise sources present in it, and we average out the measured sound levels, we can explain almost all the variability of these sound levels from the *vehicles*, *passers-by* and *people* noise groups. It should be noted that these three noise groups were those that presented significant differences between pairs of *presence of* and *absence of groups*, in the inferential analysis. In addition, we observe in the table that the obtained background noise in the area was near 39 dBA. This value is consistent with our measurements (the lower L_{eq} measured in the environment was 38.2 dBA).

3. Improvement proposals

Based on the analysis of the area, the focus must be on the four major sources observed, i.e., passers-by, vehicles, people, and works, to improve the noise state. Thus, the following are proposed:

1. An improvement in the control of vehicle access to the area is necessary. This can be done by joining the present system (the raising of bollards and use of vigilance cameras) with the requesting of identification for access to the zone. Thus, only authorised vehicles would be allowed to circulate in the area.
2. Restrictions on the access of passers-by to the area are not considered necessary (or even possible) because their present use of the area seems to produce an acceptable acoustical situation.
3. Surveillance of works in the area is necessary. Thus, all the possible noise control measures would be recommended.
4. Control of the leisure places of the area and of the people who use them is necessary.

5. A change in the hours of rubbish collection, avoiding making them at night is necessary. Moreover, considering the size of the area and the density of the population, smaller vehicles could be used.

4. Conclusions

The proposed method of identifying and quantifying the effects of noise sources was applied to an area of the city with traffic restrictions used mainly for walks and tourist visits.

Vehicles and passers-by were identified as the noise sources with the highest frequencies of appearance; although the traffic flow was not very important (less than 10% of the measurements were greater than 32 vehicles per hour).

Descriptive statistical analyses of the defined groups enabled identification of the four major noise sources contributing to the mean sound levels of the area.

Despite the restriction on traffic in the area, this noise source was very important, making a greater contribution to the global acoustic energy than the other noise sources. People were an important noise source in the area, both as passers-by and as emitters when stopped in squares or streets (*passers-by* and *people* groups). Their contribution to the global acoustical situation of the historic part of Cáceres was similar to that of vehicles. *Works* was the next most important noise source, but its importance in the whole area was not significant, having a punctual nature. The rest of the noise sources did not cause major problems of acoustical pollution.

The inferential statistical analysis proved the existence of differences between the measured values for the source groups. This allowed us to conclude that the acoustic environment of the area is statistically different when the two most important noise sources are present (vehicles and passers-by) on respect to the soundscape existing when sources as birds, bells or animals are perceived. This analysis also allows us to conclude the existence of significant differences between the existing acoustic environment when vehicles, passers-by and people are present and the scenario where they are absent.

Precisely, these three sources groups considered in a multivariate correlation analysis allowed explaining the variability of the average noise level in the area in a 97%.

Any noise control measure in the area would have to include a stricter control of vehicle traffic.

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Table Captions

Table 1. Statistical indicators of the noise results (L_{eq}) for the source groups.

Table 2. Appearance frequencies of the source groups (%).

Table 3. Lower and upper limits of the sound values that delimited the range that included 90% of the measurements and the differences between them for the source groups.

Table 4. P value of Pairwise comparisons using Mann-Whitney-Wilcoxon test with Holm corrections for the different source groups. a) Groups characterized by the presence of a source; b) groups characterized by the absence of the source. (*) P-value < 0.05 and (**) p-value < 0.01.

Table 5. Inferential analysis results for the differences between *presence of* and *absence of* groups. (***) P-value < 0.001, (**) p-value < 0.01, and (n.s) p-value > 0.05.

Table 6. Means values obtained for the main four groups of noise sources in the area, by grouping all measurements in 10 groups with equal numbers of samples.

Table 7. Results of the multiple regression analysis. (***) P-value < 0.001

Table 1

	Presence of							
L_{eq} (dBA)	***Vehicles***	***Passers-by***	***Birds***	***Bells***	***Works***	***People***	***Animals***	***Other***
Mean	57.6	56.3	55.0	54.6	56.9	57.2	54.9	55.5
Standard deviation	5.6	6.6	6.2	6.6	7.1	7.3	7.6	6.9
Median	57.4	56.0	54.8	54.3	55.5	57.1	56.1	55.9
Maximum	75.2	81.7	73.7	68.4	81.7	81.7	72.4	73.7
Minimum	41.3	38.4	39.4	40.8	46.7	40.6	38.4	38.4
	Absence of							
	Vehicles	***Passers-by***	***Birds***	***Bells***	***Works***	***People***	***Animals***	***Other***
Mean	53.3	52.6	55.8	55.7	55.4	54.6	55.6	55.6
Standard deviation	7.9	8.1	7.4	7.2	7.1	6.8	7.0	7.1
Median	52.8	53.1	55.8	55.8	55.5	54.8	55.5	55.4
Maximum	81.7	76.3	81.7	81.7	76.3	75.2	81.7	81.7
Minimum	38.2	38.2	38.2	38.2	38.2	38.2	38.2	38.2

Table 2

	Presence of								
Frequency (%)	**All sources**	***Vehicles***	***Passers-by***	***Birds***	***Bells***	***Works***	***People***	***Animals***	***Other***
Vehicles	53	-	85	22	16	11	34	9	27
Passers-by	80	56	-	27	16	13	39	11	28
Birds	27	43	79	-	29	20	41	13	26
Bells	15	55	84	52	-	7	40	12	33
Works	13	47	83	45	9	-	19	9	30
People	36	50	86	31	17	7	-	10	33
Animals	11	45	76	31	17	10	33	-	33
Other	27	53	82	26	18	14	44	14	-

Table 3

	Presence of							
Limits	***Vehicles***	***Passers-by***	***Birds***	***Bells***	***Works***	***People***	***Animals***	***Other***
Lower (dBA)	49.4	46.8	43.8	44.5	46.9	45.4	40.0	43.3
Upper (dBA)	67.0	68.4	63.6	65.4	69.0	69.0	64.4	65.4
	Absence of							
	Vehicles	***Passers-by***	***Birds***	***Bells***	***Works***	***People***	***Animals***	***Other***
Lower (dBA)	41.2	40.8	43.5	43.5	43.2	42.5	44.1	43.8
Upper (dBA)	68.0	65.2	68.4	68.5	67.5	66.0	68.0	68.4
	Difference between the limits of *presence of* and *absence of*							
	Vehicles	***Passers-by***	***Birds***	***Bells***	***Works***	***People***	***Animals***	***Other***
Lower (dBA)	6.3	6.0	0.3	1.0	3.7	2.9	- 4.1	- 0.5
Upper (dBA)	- 1.0	3.2	- 4.8	-3.1	1.5	3.0	- 3.6	- 3.0

Table 4

a)

Presence of	*Vehicles*	*Passers-by*	*Birds*	*Bells*	*Works*	*People*	*Animals*
Passers-by	0.332	-	-	-	-	-	-
Birds	0.026 (*)	1.000	-	-	-	-	-
Bells	0.073	1.000	1.000	-	-	-	-
Works	1.000	1.000	1.000	1.000	-	-	-
People	1.000	1.000	0.656	0.656	1.000	-	-
Animals	1.000	1.000	1.000	1.000	1.000	1.000	-
Other	0.425	1.000	1.000	1.000	1.000	1.000	1.000

b)

Absence of	*Vehicles*	*Passers-by*	*Birds*	*Bells*	*Works*	*People*	*Animals*
Passers-by	1.000	-	-	-	-	-	-
Birds	0.003 (**)	0.047(*)	-	-	-	-	-
Bells	0.001 (**)	0.040 (*)	1.000	-	-	-	-
Works	0.006 (**)	0.078	1.000	1.000	-	-	-
People	0.207	0.592	1.000	1.000	1.000	-	-
Animals	0.003 (**)	0.047(*)	1.000	1.000	1.000	1.000	-
Other	0.006 (**)	0.070	1.000	1.000	1.000	1.000	1.000

Table 5

	Vehicles	*Passers-by*	*Birds*	*Bells*	*Works*	*People*	*Animals*	*Other*
Mean difference	4.3	3.7	-0.8	-1.1	1.4	2.6	-0.7	-0.1
Median difference	4.6	2.9	-1.0	-1.6	0.0	2.2	0.7	0.5
U de Mann-Whitney	6.8×10^{-11} (***)	1.9×10^{-4} (***)	0.5	0.3	0.4	1.6×10^{-3} (***)	0.9	0.8

Table 6

Average L_{eq} (dB)	**Vehicles flow (Veh/h)**	**Passers-by flow (Pass/h)**	**People (%)**	**Works (%)**
68.9	17.6	186.7	55.3	15.8
62.5	13.6	96.5	50.0	7.9
59.6	17.1	95.4	34.2	18.4
57.8	12.0	63.8	39.5	13.2
56.4	10.0	115.8	31.6	5.3
54.7	6.0	52.6	28.9	21.1
52.9	4.5	55.9	36.8	7.9
51.1	3.7	33.8	31.6	18.4
48.6	1.9	20.9	34.2	7.9
43.2	1.3	7.4	21.1	7.9

Table 7

		Critical F value
Multiple correlation coefficient	0.982	9.05E-05(***)
Determination coefficient (R^2)	0.965	
	Coefficients	**Typical error**
Interception	38.9	2.4
Variable X 1 (Vehicles)	2.0	0.7
Variable X 2 (Trans)	0.16	0.09
Variable X 3 (Personas)	25.6	8.7

Figure Captions

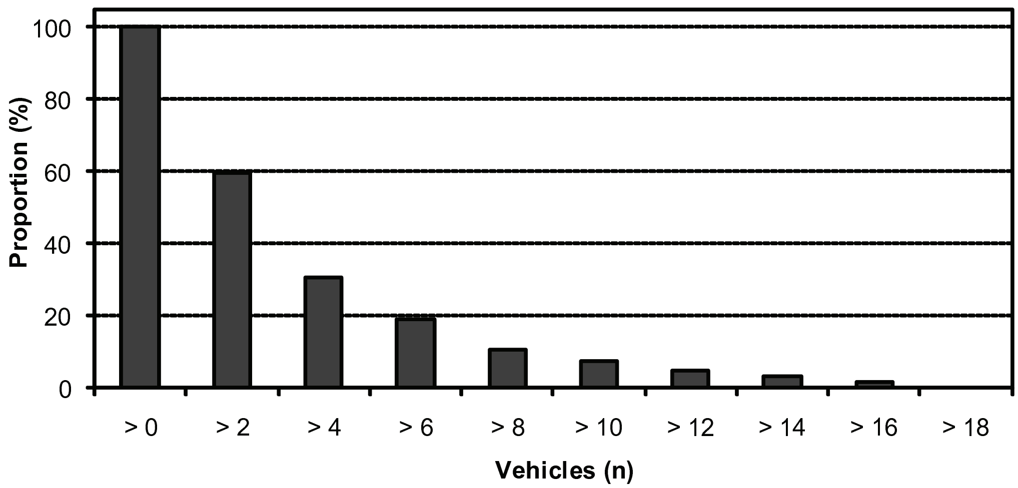
Figure 1. Cumulative distribution of the number of noise sources: a) vehicles and b) passers-by.

Figure 2. Relation between the measured equivalent level and the logarithm of the vehicle flow: a) all measurements and b) average equivalent noise level measurements for the same vehicle flow.

Figure 3. Relation between the measured equivalent level and the logarithm of the passer-by flow: a) all measurements and b) average equivalent noise level measurements for the same passer-by flow.

Figure 1

a)


100
80
60
40
20
0
Proportion (%)
> 0
> 2
> 4
> 6
> 8
> 10
> 12
> 14
> 16
> 18
Vehicles (n)

b)

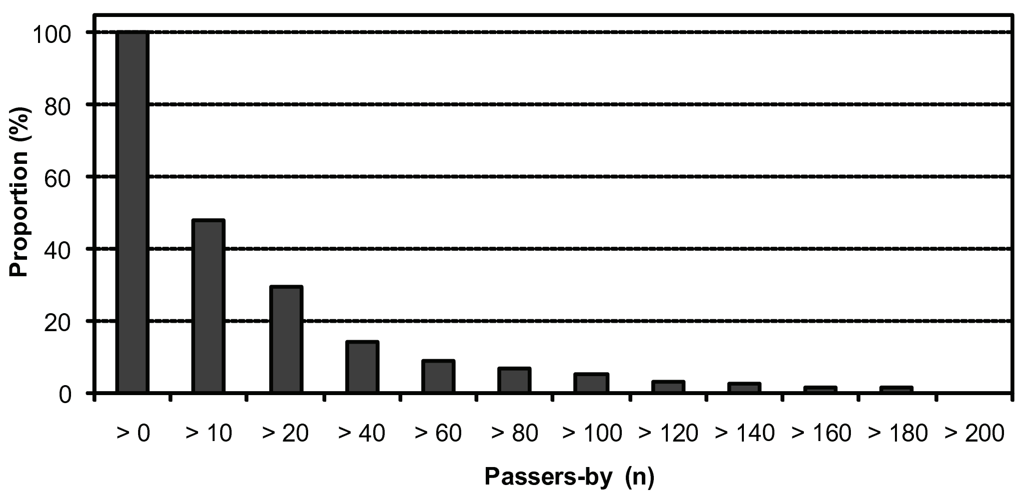
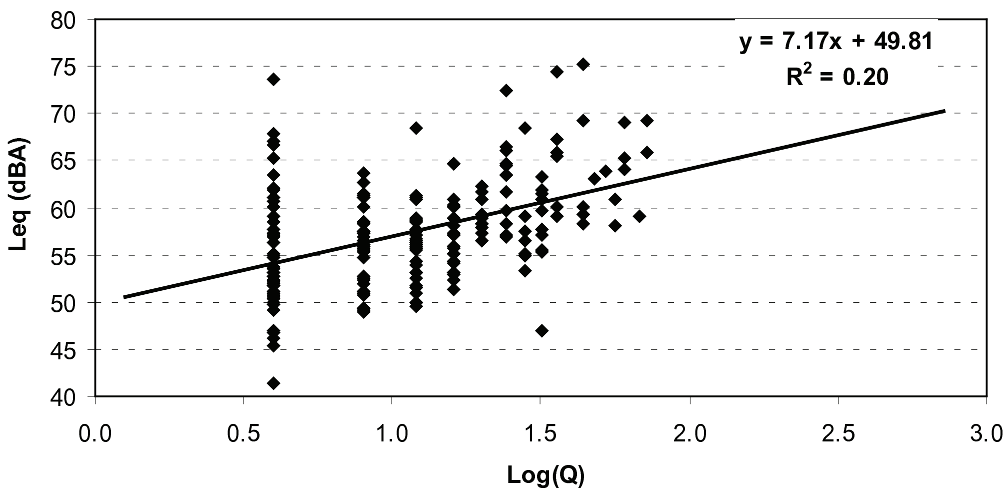

100
80
60
40
20
0
Proportion (%)
> 0
> 10
> 20
> 40
> 60
> 80
> 100
> 120
> 140
> 160
> 180
> 200
Passers-by (n)

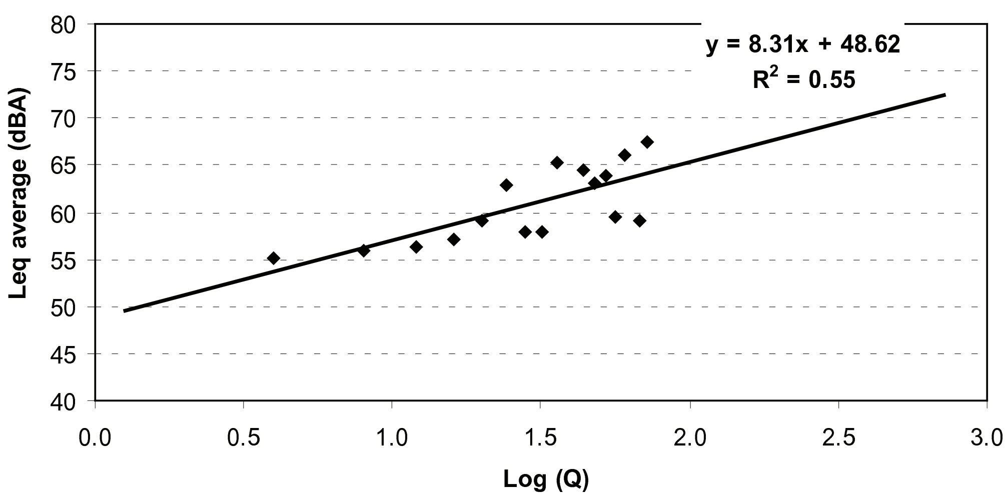
Figure 2

a)



y = 7.17x + 49.81
R^2 = 0.20
Leq (dBA)
Log(Q)
80
75
70
65
60
55
50
45
40
0.0
0.5
1.0
1.5
2.0
2.5
3.0

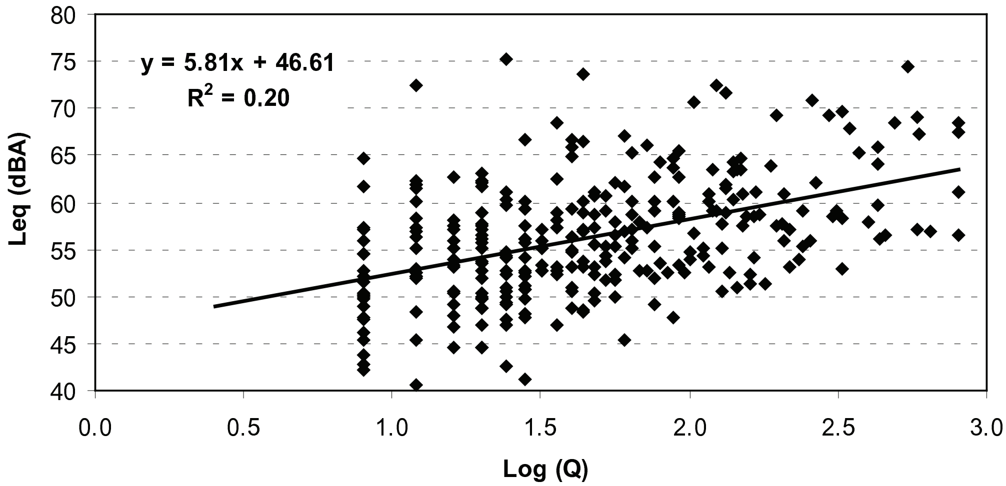
b)



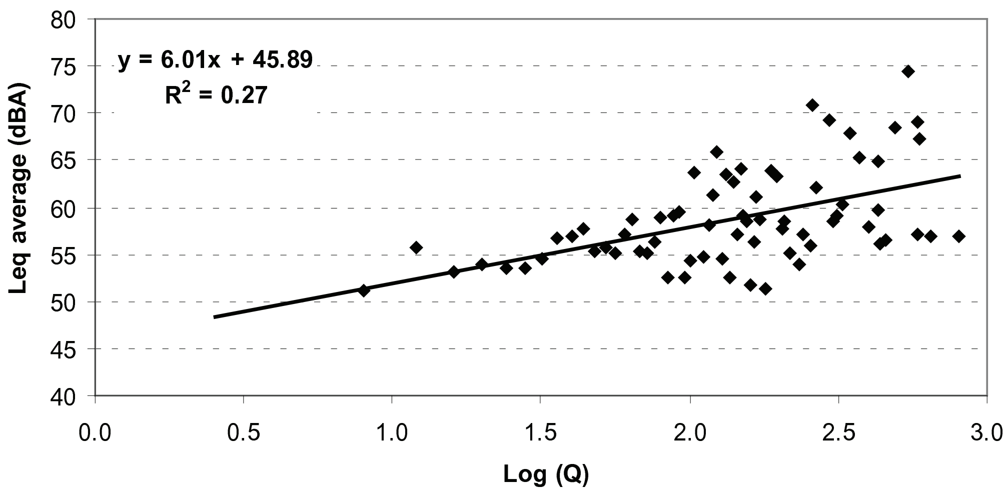
y = 8.31x + 48.62
R^2 = 0.55
Leq average (dBA)
Log (Q)
80
75
70
65
60
55
50
45
40
0.0
0.5
1.0
1.5
2.0
2.5
3.0

Figure 3

a)


y = 5.81x + 46.61
R2 = 0.20
Leq (dBA)
Log (Q)
80
75
70
65
60
55
50
45
40
0.0
0.5
1.0
1.5
2.0
2.5
3.0

b)


y = 6.01x + 45.89
R2 = 0.27
Leq average (dBA)
Log (Q)
80
75
70
65
60
55
50
45
40
0.0
0.5
1.0
1.5
2.0
2.5
3.0