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Original Research

Effects of Singular Noisy Events on Long-Term Environmental Noise Measurements

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Abstract

One important question to solve is if singular noisy events can affect noise levels in the short, medium, and long term. If the answer is yes and these singular noisy events are present or absent during the monitoring of a place, then long-term noise indices can be overestimating or underestimating, respectively, the noise impact. Therefore, it is necessary to observe and quantify the contribution of these singular noisy events to the annual indices established by the European directive [night level (L_n) and day-evening-night level (L_{den})]. As an example of this situation, for a whole year this study quantified in 24 measurement points how some representative sound indices were affected during the FIFA World Cup celebrated in South Africa during summer 2010 in three Spanish cities (Cáceres, Málaga, and Madrid). It is shown how very short singular events lasting only a few hours can alter appreciably the values of annual noise indices.

Keywords: long-term environmental noise monitoring, anomalous events, temporal variability, prediction models, FIFA World Cup

Introduction

The European Commission refers to environmental noise as one of the main environmental problems in Europe, and the Commission emphasizes the need for specific measures and initiatives to reduce environmental noise [1]. Indeed, considering the total exposure to road traffic noise, it can be calculated that approximately half of all Europeans live in areas of high noise pollution, and over 30% of the population is exposed to sound pressure levels exceeding 55 dBA (A-weighting, International Standard IEC 61672:2003) at night.

European Noise Directive 2002/49/EC introduces two key indices for environmental noise assessment, L_{den} (day, evening, and night) to assess noise annoyance and L_n (night) to assess sleep disturbance. According to this directive, it is recommended that noise assessments for the estimation of the community response to disturbances caused by noise pollution are made for a long-term time interval, usually one year. State members must use these indices to prepare and revise strategic noise maps.

Sound level measurements are required either to contrast the results of the strategic noise maps (obtained by prediction software) or to realize the noise map directly through position measurements[1)] (very rare). In both cases, due to the costs and time needed for long-term measurements it is common practice to obtain short-term data, vary-

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[1)] Working Group Assessment of Exposure to Noise recognizes that some noise measurement is essential to the development and validation of computation methods. It also has a role to play in other aspects of the implementation of the European Noise Directive.

ing from minutes to hours [2-6], to a whole day [7-10], longer periods of time are rarely used [11-14]. To obtain the long-term time indicated in the European Noise Directive 2002/49/EC, these results are extrapolated to longer periods (primarily months or years).

By considering the typical method of using an extrapolation of the measurements taken for periods of less than a month, the fact that singular events may occur during the measurement period can seriously affect the estimates, because extrapolated values can present a non-representative value; if these singular events are present and measured, then the long-term index will overestimate the noise, but if they are not, then the long-term index will underestimate the noise. Therefore, there is a need to observe and quantify the contributions of these singular events to the annual indices established by the European directive (L_{den} and L_n).

We have sought, in the time interval for which we have data from long-term measurements in a large number of sampling points, some kind of events that could potentially

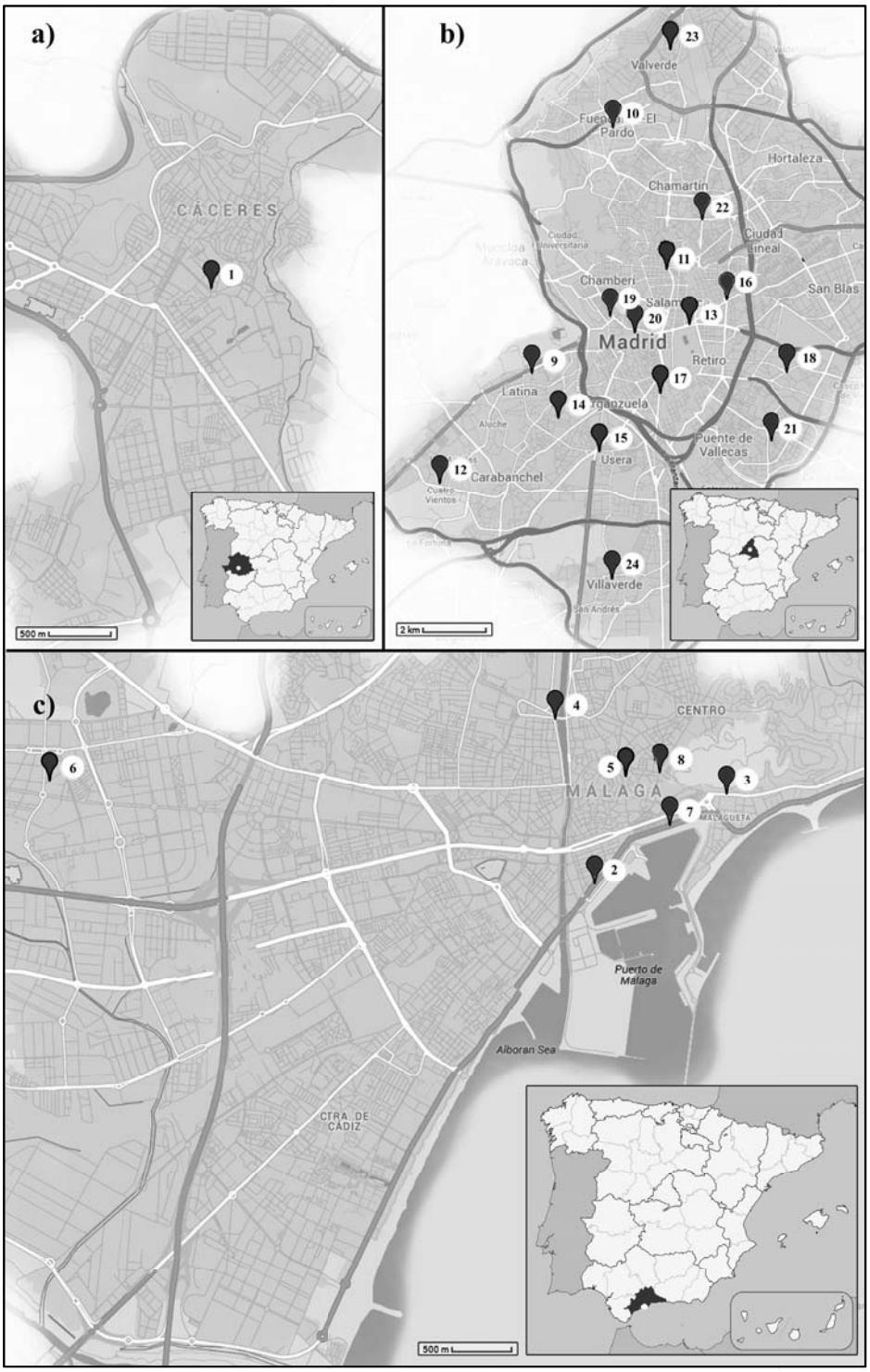

Fig. 1. Location of the different stations in each city.

Table 1. Main features of the environmental sound monitoring stations.

City Population Area Density	Measurement point	Street Category*	Coordinates GPS Latitude-Longitude	
CÁCERES (Cc) 93.131 inhabit. 1750.33 km^2 53.21 inhabit./km^2	Cáceres (1)	3	39.469633	-6.373886
MÁLAGA (Ma) 568.305 inhabit. 395.13 km^2 1438.26 inhabit./km^2	Agustín Heredia (2)	2	36.714328	-4.423072
	Alcazabilla (3)	4	36.722522	-4.416997
	Fátima/Martiricos (4)	3	36.726908	-4.427008
	Granada (5)	6	36.721814	-4.420633
	Hermes (6)	5	36.722064	-4.473908
	Paseo de los curas (7)	2	36.718453	-4.417339
	Uncibay (8)	5	36.722394	-4.420161
MADRID (M) 3.255.944 inhabit. 605.77 km^2 5374.86 inhabit./km^2	Alto de Extremadura (9)	3	40.406947	-3.742517
	Barrio del Pilar (10)	2	40.478228	-3.711542
	Castellana (11)	1	40.439722	-3.690278
	Cuatro Vientos (12)	3	40.376111	-3.776639
	Escuelas Aguirre (13)	1	40.421564	-3.682319
	Farolillo (14)	4	40.394778	-3.731833
	Plz. Fdez. Ladreda (15)	2	40.384722	-3.718611
	Manuel Becerra (16)	2	40.428753	-3.668833
	Méndez Álvaro (17)	4	40.398056	-3.686667
	Moratalaz (18)	3	40.407956	-3.645294
	Plaza de España (19)	2	40.423992	-3.712333
	Plaza del Carmen (20)	3	40.419208	-3.703172
	Puente de Vallecas (21)	3	40.388150	-3.651522
	Ramón y Cajal (22)	2	40.451472	-3.677353
	Tres olivos (23)	4	40.500556	-3.689722
	Villaverde (24)	3	40.347100	-3.713328

*Street categories go from 1 'Main city roads' to 6 'pedestrian roads'. The definitions for the different categories can be found in [17, 18]

affect noise levels in the different measuring stations. We have found an example of a singular event that affects the sound levels in the 19th FIFA World Cup held in South Africa between 11 June and 11 July 2010.

This work analyzed the influence of this singular event on the L_{den} and L_n sound indices for hourly, monthly, and yearly time periods in three important Spanish cities (Madrid, Málaga, and Cáceres). The measurements were taken throughout 2010 at 24 different sampling points. That is, we have collected and analyzed as much data as possible from 24 measurement stations that collect a full year of noise levels at each station. The main objectives are the following:

- To analyze the levels obtained during the competition period and to evaluate its effect on the noise indices recommended in European Directive 2002/49/EC, L_{den} and L_n, with measurements taken for a full year.
- To separately evaluate (hourly, monthly, and yearly) increases in the L_{den} and L_n indices resulting from the celebrations of the three final matches of the Spanish team (quarter-finals, semi-finals, and final) in the World Cup.

Table 2. Calendar of the matches played by the Spanish team during 2010 FIFA World Cup in South Africa.

Round	Day	Month	Start time	End time	Match		Results
Group stage	Wednesday 16	June	16:00	17:50	Spain	Switzerland	0-1
Group stage	Monday 21	June	20:30	22:20	Spain	Honduras	2-0
Group stage	Friday 25	June	20:30	22:20	Chile	Spain	1-2
Round of 16	Tuesday 29	June	20:30	22:20	Spain	Portugal	1-0
Quarter-finals	**Saturday 3**	**July**	**20:30**	**22:20**	**Paraguay**	**Spain**	**0-1**
Semi-finals	**Wednesday 7**	**July**	**20:30**	**22:20**	**Germany**	**Spain**	**0-1**
Final	**Sunday 11**	**July**	**20:30**	**23:10**	**Netherlands**	**Spain**	**0-1**

The importance of our study was to assess the extent to which singular events can affect the sound levels obtained from measurements with duration clearly greater than the event itself. If this effect were detected, it could have important consequences on estimates of the appropriate extent of the noise measurements as well as for the preparation of noise maps using software.

Characterization and Location of Measurement Stations

For this study, three Spanish cities with different characteristics were chosen. Measurements were taken throughout 2010, with integration intervals of 1 minute, in 24 different locations (according to city inhabitants and size (Table 1)): one in Cáceres (small town), seven in Málaga (medium town), and 16 in Madrid (large town) (see Fig. 1 for the locations of the different stations). Table 1 contains the geographical locations of the sampling points and the street category.

Different authors consider that the values for the environmental noise from the streets may depend on different factors [10, 15], the type of road considered [16-19], social activities and socioeconomic factors [20], weather, and the intrinsic attributes of the street itself, such as the geometry, the presence of obstacles to the propagation of sound, the type of pavement [13, 21, 22], and the time of day [23]. For this reason, we have considered a wide variety of locations for the different measurement stations.

Temporary Location of Singular Events

To evaluate the noise contribution of a singular event, we must know which days and at what times it occurs. Table 2 shows the schedule of the latest qualifying rounds played by the Spanish team. After a preliminary analysis we found that the development and success of the Spanish team from the previous games did not result in the different stations used in this study, where such an increase could impact the annual or monthly noise levels. For this reason, only those events occurring after the last three matches in July (bolded rows in Table 2) were used in this study. As shown in Table 2, the sound levels that will be most affected due to the victory celebrations are those that incorporate the night period of the next day, i.e., L_n and L_{den}.

Fig. 2 shows the profile of the sound equivalent level in July for integration intervals of one hour together with the values of L_{den}, L_e, and L_n for each day of the month in three different locations. We should note that the index for the evening period, L_e, for all 24 stations considered in this study was mostly unaffected by the development of the matches. During this period (7-10:59 p.m.), matches took place and the fans were usually found indoors. However, in some locations (see Cáceres (Cc) and Méndez Álvaro (M) – Fig. 2), the evening level (L_e) was also affected notably, although the overall increase in noise pollution began when the fans of the Spanish team celebrated in the streets after a win. This is the peak event under study here.

Experimental Procedure

Statistical noise analyzers running continuously (Oper@ by 01dB-Metravid (Cáceres), SDR-500 by PD de Audio, S.L. (Málaga) and Noise Monitoring Terminal type 3639 by Brüel & Kjær (Madrid)) were used as the environmental sound monitoring equipment (class 0 and 1 sound level meter according to IEC 61672-1:2002). The parameter measured to evaluate the noise level was the continuous equivalent A-weighted level integrated every minute ($L_{Aeq,1min}$) for all of 2010. However, to calculate the noise indices that consider both the WHO [24] and the European Union [1], it is necessary to consider the parameter $L_{Aeq,1h}$, i.e., L_{Aeq} integrating within one hour. Once the hourly L_{Aeq} was estimated, the L_{den} and L_n indices were calculated and averaged.

Analysis and Discussion of Results

On the basis of the situation of the environmental sound monitoring stations (Table 1) and the specific times for the singular events mentioned above (Table 2), we proceeded to evaluate and analyze the noise level changes caused during the celebration of these peak events.

Increase over the Daily Average Noise Level

When evaluating and identifying the time slots when each single event developed, it is interesting to note that the increases in the sound indices (L_{den} and L_n) occurred only at night (from 11 p.m.-6:59 a.m.) after the days when victory celebrations occurred after the different matches in the final stages (Table 2), i.e., during the nights of the 4 (quarter-finals), 8 (semi-final), and 12 (final) of July 2010 (Fig. 2).

To understand and evaluate this impact, the values of L_{den} and L_n for all of the measurement stations for the day in July when the final celebration occurred are presented in Table 3, along with the monthly and annual averages. It can be observed that the percentage of stations measuring 5 dB above the annual average was approximately 96% for the night of 12 July (46% for 8 July and 30% for 4 July). Furthermore, 83% of the stations had values 10 dB above the L_n annual average for 12 July (25% of the stations were 10 dB above on 8 July; and approximately 9% of the stations were 10 dB above for 4 July).

Given the very significant effect observed on the sound levels on the days of celebration, especially on 12 July, we decided to perform a more detailed analysis of what happened that night. Table 4 shows a comparison of the equivalent levels for the first hours (11 p.m.-2:59 a.m.) of the night of 12 July together with the average value of the night period for the remaining days of 2010. Differences at or above 10 dB for the 24 measurement stations are shaded in Table 4. Empty fields indicate that during that time the station failed to capture more than 45 minutes and, therefore, as noted above, this hour was omitted. Clearly there is an important increase in the noise level at that time for the vast majority of the stations studied. The duration of these events was estimated to be at least three hours; however, some stations had events lasting throughout the night (11 p.m.-6:59 a.m.). We can see that the hourly noise difference for most of the 24 stations remained very close to or above 10 dB for four hours in some locations, and this difference was greater than 20 dB for three hours. This difference was greater than or approximately equal to 5 dB for six hours.

Increase over the Monthly Average Noise Level

As established in the Introduction of the present paper, it is necessary to know the noise increase percentage during the month in which the World Cup celebration occurred to better assess the impact of this event on the main acoustic indices collected in European Directive 2002/49/EC.

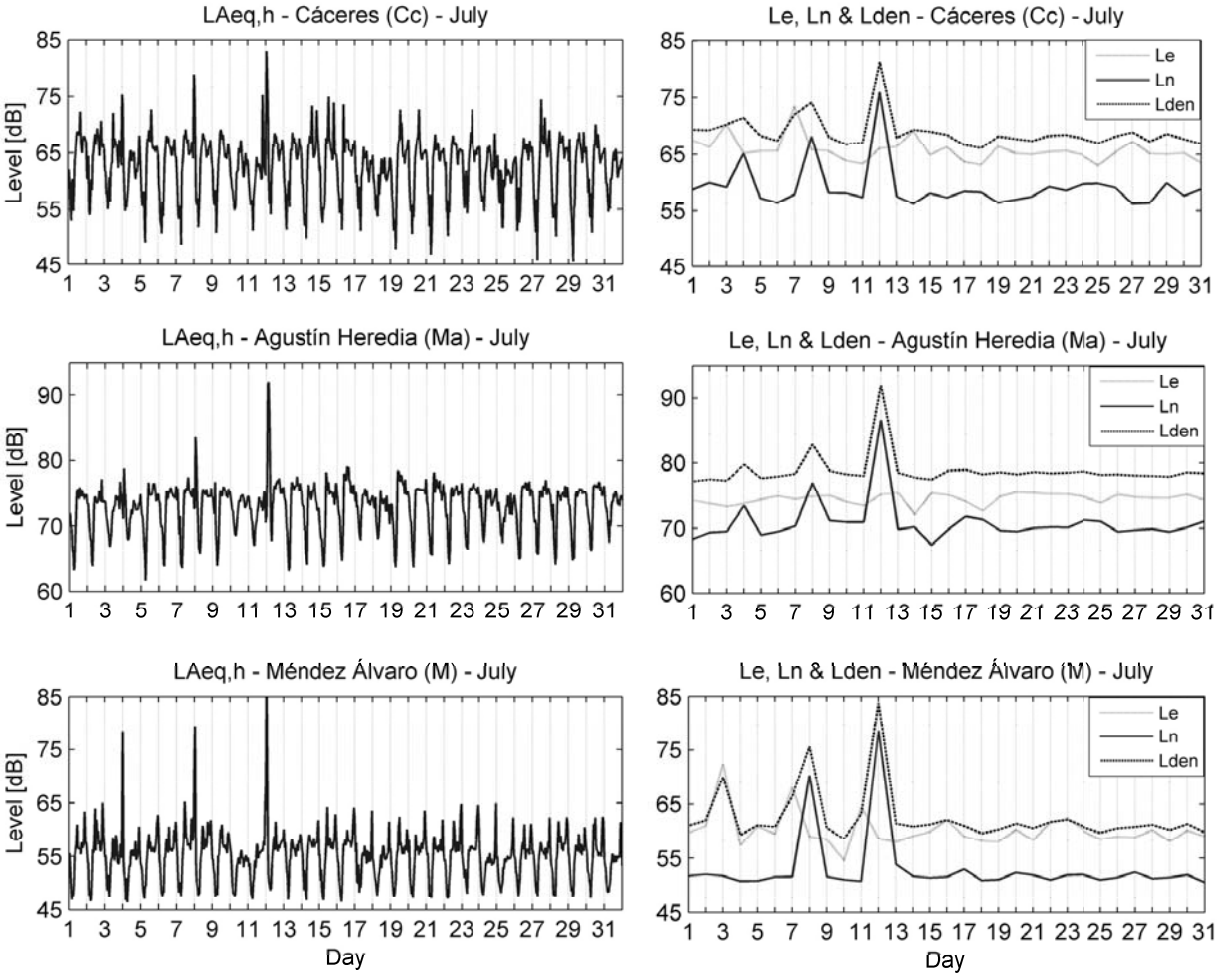

Fig. 2. $L_{Aeq,h}$, L_e, L_n, and L_{den} measurements for July in Cáceres and at one of the Málaga and Madrid stations.

Table 3. Annual, monthly, and daily averages for the different stations.

Measurement points	Annual average		July average		July 12	
	Ln	LDEN	Ln	LDEN	Ln	LDEN
Cáceres (Cc)	59.4	68.9	63.3	70.7	75.9	81.2
Agustín Heredia (Ma)	70.6	78.6	74.2	80.7	86.6	91.9
Alcazabilla (Ma)	69.1	76.4	73.4	79.5	84.4	89.7
Fátima/Martiricos (Ma)	67.8	76.2	70.1	77.2	80.9	86.3
Granada (Ma)	70.6	77.1	77.2	82.6	90.4	95.7
Hermes (Ma)	60.1	66.4	66.9	68.1	79.3	---
Paseo de los curas (Ma)	69.4	77.7	71.5	78.8	82.2	87.6
Uncibay (Ma)	71.8	76.0	77.6	74.6	90.5	---
Alto de Extremadura (M)	58.4	66.2	59.4	66.8	68.1	73.7
Barrio del Pilar (M)	58.5	66.6	61.0	68.0	72.8	78.2
Castellana (M)	61.3	68.3	62.8	69.3	72.7	78.1
Cuatro Vientos (M)	61.4	69.7	61.5	69.4	71.8	77.3
Escuelas Aguirre (M)	66.3	73.7	67.5	74.2	77.7	83.1
Farolillo (M)	60.1	66.1	60.2	66.4	72.1	77.4
Plz. Fdez. Ladreda (M)	62.2	69.8	64.3	70.9	75.8	81.1
Manuel Becerra (M)	61.6	69.4	63.7	70.4	75.9	81.2
Méndez Álvaro (M)	55.7	63.0	64.4	70.2	78.5	83.7
Moratalaz (M)	58.4	66.9	62.9	69.4	75.7	81.0
Plaza de España (M)	66.9	74.0	73.2	79.1	78.5	84.2
Plaza del Carmen (M)	62.3	68.7	62.8	69.7	71.5	77.5
Puente de Vallecas (M)	63.8	70.7	73.4	79.4	68.8	74.2
Ramón y Cajal (M)	64.4	72.7	65.4	72.9	75.7	81.3
Tres olivos (M)	52.0	61.1	55.7	62.9	65.1	70.6
Villaverde (M)	61.6	67.8	60.6	67.2	69.4	74.8
% of Measurements points exceeding 5/10 [dB]			25/0	18.2/0	95.8/83.3	95.5/54.5

Cc – Cáceres, Ma – Málaga, and M – Madrid

The first two columns of Table 5 show the monthly noise increases (in dB and per cent) caused from the development and subsequent celebration of the World Cup matches played by the Spanish team. That is, the differences in the L_{den} and L_n between the average monthly value and the averaged value we would have obtained if we had averaged July without the days corresponding to the matches and the celebrations (3, 4, 7, 8, 11, and 12 July) are shown in these two columns. In the next two columns, the increases due solely to the celebrations (days 4, 8, and 12 July) are shown. Finally, in the last two columns the increases due solely to the celebration of the final victory of the Spanish team are shown.

For the first two columns the events discarded (days 3, 4, 7, 8, 11, and 12, July 2010) would imply a 15% maximum increase in the L_{den}. In the case of the L_n, the maximum percentage increase is greater than 24%. These two maxima were measured at the Méndez Álvaro station (Madrid). In the next columns, from which 4, 8, and 12 July were omitted, we can see how the magnitude of the increases is very similar to those obtained in the previous case for both indicators. This corroborates our claim that the noise effects of the World Cup are mainly due to the celebration of victories. For this reason, in the last two columns we studied the effects of the celebration on 12 July instead of the match day, because the final match ended after 11 p.m. on 11 July (Table 2). Comparing the last two columns to the previous two in Table 5, we can deduce that although the most important effect is concentrated from the celebration after the final, the effects of the quarter and semi-finals are

Table 4. Hourly equivalent levels at night for all of 2010 and for 12 July 2010, together with the differences between them.

Meas. points	23:00			00:00			01:00			02:00		
	July 11	Annual	Dif.	July 12	Annual	Dif.	July 12	Annual	Dif.	July 12	Annual	Dif.
Cáceres (Cc)	83.0	62.6	**20.5**	79.1	60.1	**19.1**	73.3	57.2	**16.2**	60.7	56.0	4.7
Agustín Heredia (Ma)	77.2	72.5	4.7	91.6	71.6	**20.1**	91.9	70.5	**21.4**	86.9	69.1	**17.8**
Alcazabilla (Ma)	78.6	70.0	8.6	88.9	69.7	**19.2**	88.9	68.9	**20.1**	85.4	68.1	**17.3**
Fátima/Martiricos (Ma)	74.9	71.0	3.8	87.1	69.6	**17.6**	84.5	68.0	**16.5**	80.9	66.4	**14.6**
Granada (Ma)	---	---	---	92.9	68.8	**24.2**	93.9	69.9	**24.0**	91.7	68.9	**22.9**
Hermes (Ma)	76.1	62.6	**13.6**	86.9	61.8	**25.1**	80.4	59.6	**20.8**	75.9	56.8	**19.1**
Paseo de los curas (Ma)	74.5	72.1	2.4	87.4	71.1	**16.3**	87.3	69.6	**17.6**	82.9	67.8	**15.1**
Uncibay (Ma)	79.3	70.2	9.2	92.4	70.6	**21.8**	94.6	70.9	**23.6**	94.2	70.5	**23.7**
Alto de Ext. (M)	74.2	60.1	**14.1**	72.9	59.5	**13.4**	62.7	58.0	4.7	61.4	57.9	3.5
Barrio del Pilar (M)	78.4	60.5	**17.9**	76.5	60.7	**15.8**	72.0	59.1	**12.9**	69.1	56.9	**12.2**
Castellana (M)	73.8	62.0	**11.8**	75.9	62.2	**13.7**	75.4	61.7	**13.7**	74.7	61.4	**13.3**
Cuatro Vientos (M)	79.6	63.0	**16.6**	73.3	64.2	9.1	64.1	58.8	5.3	58.2	57.2	1.0
Escuelas Aguirre (M)	80.9	67.6	**13.3**	82.8	67.5	**15.3**	79.6	66.5	**13.1**	76.3	65.7	**10.6**
Farolillo (M)	81.0	54.2	**26.8**	63.8	67.6	-3.8	63.5	58.9	4.6	50.1	52.8	-2.7
Pl. Fdez. Ladreda (M)	80.9	64.2	**16.7**	80.8	63.0	**17.8**	77.0	61.4	**15.6**	65.8	60.4	5.4
Manuel Becerra (M)	80.4	62.3	**18.1**	82.4	63.9	**18.5**	71.9	63.4	8.5	68.0	59.9	8.1
Méndez Álvaro (M)	87.5	54.0	**33.5**	66.0	53.3	**12.7**	51.8	50.9	0.9	50.0	49.1	0.9
Moratalaz (M)	82.6	60.5	**22.1**	79.7	58.8	**20.9**	72.0	57.0	**15.0**	65.2	55.7	9.5
Plaza de España (M)	77.0	67.9	9.1	83.0	67.4	**15.6**	80.0	66.8	**13.2**	78.8	65.5	**13.3**
Plaza del Carmen (M)	77.4	61.7	**15.7**	72.5	64.8	7.7	71.3	63.1	8.2	71.5	62.9	8.6
Puente de Vallecas (M)	76.7	68.4	8.3	68.9	68.4	0.5	67.0	66.8	0.2	53.7	56.8	-3.1
Ramón y Cajal (M)	78.6	66.6	**12.0**	81.7	65.9	**15.8**	75.8	64.3	**11.5**	72.5	63.0	9.5
Tres olivos (M)	73.2	54.2	**19.0**	63.5	55.4	8.1	62.4	49.7	**12.7**	52.8	48.0	4.8
Villaverde (M)	77.3	59.8	**17.5**	70.4	69.8	0.6	64.9	55.0	9.9	53.5	50.1	3.4
Mean [dB]	79.7	66.7	14.6	85.6	67.0	14.4	85.7	65.5	12.9	83.6	64.1	9.7
Standard Deviation [dB]	3.4	5.6	7.3	8.9	5.1	7.4	11.1	6.1	6.7	13.2	6.6	7.5

Bold numbers indicate differences above 10 dB in relation with the annual average for that hour.

not negligible. Therefore, we can assume the existence of similar effects in countries where the football team won these matches and went on to the next phase of qualifying.

In Table 5 we note the existence of a station where no effect is detected from the celebrations of the World Cup: the "Puente de Vallecas" station in Madrid. The cause was not that the celebration of the World Cup poses no important increase over the normal noise values measured at this station, but rather during that month, there was another singular event whose impact masked the World Cup celebration. Fig. 3 shows that between 16 and 19 July there was a very important variation in the "Puente de Vallecas" station coinciding with another celebration in the neighborhood ("Fiestas del Carmen"). Additionally, it can be observed that there are other months in this location when other noisy events seem to have occurred and led to significant increases in the L_{den} and L_n compared to the baseline values. Table 6 shows the increases in the July and yearly values of the L_{den} and L_n due to the "Fiestas del Carmen" celebration that took place from 16 to 19 July, with and without considering the World Cup final. The inclusion or exclusion of the World Cup only affects the July values.

Table 5. Monthly noise increases due to the development of the World Cup.

Measurement points	July 3, 4, 7, 8, 11, and 12		July 4, 8, and 12		July 12	
	ΔL_n (dB/%)	ΔL_{den} (dB/%)	ΔL_n (dB/%)	ΔL_{den} (dB/%)	ΔL_n (dB/%)	ΔL_{den} (dB/%)
Cáceres (Cc)	5.1/8.8	2.7/3.9	5.1/8.8	2.4/3.5	3.6/6.0	1.9/2.7
Agustín Heredia (Ma)	4.1/5.8	2.5/3.2	4.1/5.8	2.6/3.3	3.4/4.8	2.2/2.9
Alcazabilla (Ma)	5.2/7.7	4.0/5.3	5.2/7.6	3.9/5.2	2.2/3.1	1.8/2.3
Fátima/Martiricos (Ma)	2.7/4	1.4/1.9	2.8/4.2	1.6/2.1	2.0/2.9	1.2/1.6
Granada (Ma)	10.5/15.8	9.6/13.1	10.5/15.7	9.4/12.9	4.7/6.5	4.4/5.7
Hermes (Ma)	5.8/9.5	0.1/0.1	5.8/9.6	--/--	4.7/7.5	--/--
Paseo de los curas (Ma)	2.2/3.2	1.2/1.5	2.3/3.3	1.2/1.6	2.0/2.9	1.1/1.5
Uncibay (Ma)	9.2/13.4	--/--	8.9/12.9	--/--	4.3/5.9	--/--
Alto de Ext. (M)	1.4/2.5	1.0/1.5	1.5/2.5	0.9/1.3	1.0/1.8	0.6/0.9
Barrio del Pilar (M)	3.8/6.6	2.2/3.4	3.8/6.6	2.1/3.2	2.8/4.8	1.6/2.4
Castellana (M)	2.5/4.1	1.8/2.6	2.4/4.0	1.7/2.5	1.5/2.4	1.1/1.6
Cuatro Vientos (M)	2.0/3.4	1.0/1.5	1.9/3.3	0.9/1.4	1.7/2.8	0.8/1.2
Escuelas Aguirre (M)	2.0/3.1	1.3/1.8	1.9/2.9	1.3/1.7	1.6/2.5	1.1/1.5
Farolillo (M)	7.9/15.2	5.5/9.0	7.7/14.8	4.6/7.4	2.9/5.1	2.1/3.3
Plz. Fdez. Ladreda (M)	3.0/5.0	2.0/3.0	3.0/4.9	2.0/2.9	2.5/4.0	1.6/2.4
Manuel Becerra (M)	3.5/5.9	2.3/3.4	3.5/5.9	2.2/3.2	3.2/5.3	2.0/2.9
Méndez Álvaro (M)	12.7/24.5	9.3/15.2	12.7/24.6	7.9/12.7	7.4/13.0	5.7/8.8
Moratalaz (M)	6.3/11.1	3.8/5.8	6.1/10.8	3.5/5.3	4.1/7.0	2.6/3.9
Plaza de España (M)	5.7/8.4	4.3/5.8	2.9/4.2	2.3/3.0	0.4/0.5	0.3/0.4
Plaza del Carmen (M)	1.6/2.5	1.9/2.8	1.4/2.3	1.0/1.4	1.0/1.7	0.8/1.1
Puente de Vallecas (M)	-0.9/-1.2	-0.8/-1.0	-0.4/-0.5	-0.4/-0.5	-0.1/-0.1	-0.1/-0.1
Ramón y Cajal (M)	2.3/3.6	1.3/1.7	2.1/3.4	1.1/1.6	1.7/2.7	0.9/1.3
Tres olivos (M)	5.1/10.1	2.7/4.5	5.0/9.8	2.7/4.4	3.4/6.5	2.0/3.3
Villaverde (M)	1.5/2.5	1.3/1.9	1.4/2.4	1.0/1.5	1.0/1.8	0.7/1.1
% Increase [dB] > 2.5	66.7%	37.5%	62.5%	29.2%	50.0%	12.5%

Therefore, the possibility of localized noise events at specific points, or spread over significant areas, in a city that can cause important variations in the long-term noise indices collected in the European Directive 2002/49/EC reinforces the interest of the present work.

Increase over the Annual Average Noise Level

During the 19th World Cup, the singular event under study, there were notable increases in the $L_{Aeq,1h}$ value collected by the monitoring stations due mainly to the celebration of the victory of the Spanish team. We compared the annual levels of all measurement stations (for 365 days of 2010) with the average annual levels after discarding the days when these singular events occurred, i.e., 3 and 4 July 2010 (quarter-finals), 7 and 8 July 2010 (semi-finals), and 11 and 12 July 2010 (final). The study was performed independently for each of the events to provide a reference for what might have happened in those countries that reached different classification levels throughout the occurrence of the World Cup. Table 7 shows the noise increase in the acoustic indices L_{den} and L_n (in dBA) over the annual period caused by the development and subsequent conclusion of the final match. The cells of the stations with annual increases in the L_{den} and L_n equal to or greater than 0.5 dB are shaded.

The singular events of 4, 8, and 12 July (3 days × 24 hours = 72 h), constituting less than 1% of the total hours in a year, represent an increase, in the worst case, of 4.4 dB, which is more than 8.5% over the reference value (in the case of L_n, this occurred at the Méndez Álvaro station in

Table 6. Variations in Lden and Ln due to "Fiestas del Carmen" (FC) at the "Puente de Vallecas" station.

Puente de Vallecas	Including FC – Excluding FC ΔL_n	Including FC – Excluding FC ΔL_{den}
Year 2010 with World Cup	6.1	4.1
July 2010 with World Cup	15.2	12.8
Year 2010 without World Cup	6.1	4.2
July 2010 without World Cup	16.1	13.6

Madrid). At this station, if the World Cup had not occurred, the L_n value averaged for 2010 would have been 51.3 dBA instead of the actual 55.7 dBA.

It is even more interesting to observe how only the celebration event related to the Spanish victory generated increments of 0.5 dBA or greater for the L_n levels averaged over 2010 for almost 30% of the monitoring stations: a period of only 8 hours (less than 0.3% of the number of hours in a year) for the celebration night after the Spanish team triumph, from 11 p.m.-6:59 a.m. on 12 July 2010, is able to modify the indices on an annual basis (with a night period of 2,920 hours and a combined 8,760 hours for the day, evening, and night periods) by 3.5 dB for the L_n and 1.8 dB for the L_{den} in the extreme case (the Méndez Álvaro station in Madrid).

Conclusions

In this study we analyzed the impact that specific sound events can have on standard sound indicators contained in international laws and regulations. The results obtained in this study could be extrapolated, in similar circumstances, to many countries around the world. The analyzed data proceed in 24 measurement stations located in three cities of different size, very far apart, with very different planning, over a full year.

- We detected the existence of a measurable effect on the average annual indices, L_{den} and L_n. There was only one station where no effect was detected due to the existence of another event with abnormal sound that was even greater than the event studied in this work. This is very important as it indicates that the relative importance on the year of the event under study may be affected in other stations by events that happened in them but they have not been studied. It further indicates that this event is not unique. The relationship of the importance of the event on the month and year can give us an idea of the existence of non-studied events in other months. The detailed study of the month at those stations where their relevance is smaller can make us detect anomalous sound events. In virtually all of the monitoring stations for environmental noise we measured a very important impact on the average daily and monthly noise levels after the celebrations corresponding to the quarterfinals onwards.
- The effect of the World Cup on the average annual indices was greater than 0.5 dB for the L_n indicator for nearly 40% of the measuring points, with a maximum increase of 4.4 dB. It was also greater than 0.5 dB for the L_{den} in more than 20% of the locations, with a maximum increase of 2.2 dB.

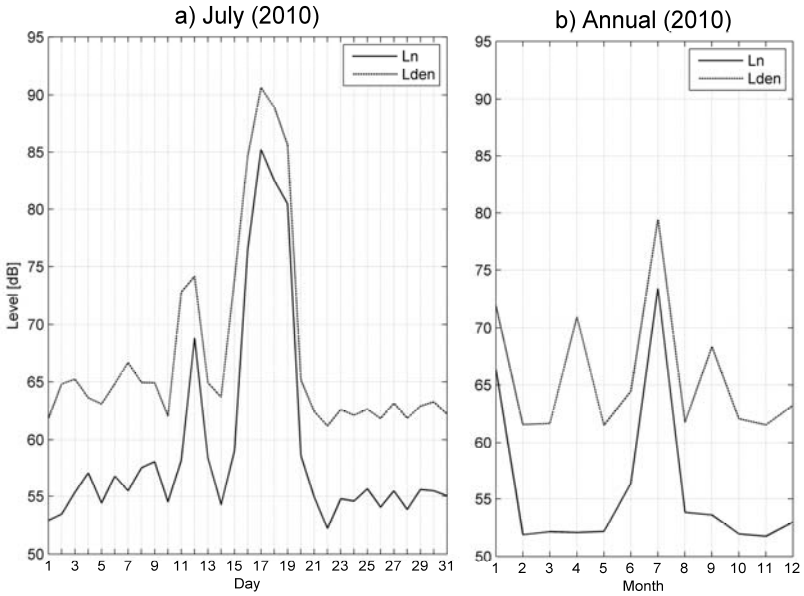

Fig. 3. July (a) and annual (b) L_{den} and L_n variations in the vicinity of the "Puente de Vallecas" station in Madrid.

Table 7. 2010 annual increases due to the development of the World Cup.

Measurement points	Including-Excluding 4, 8, and 12 July		Including-Excluding 12 July	
	ΔL_n	ΔL_{den}	ΔL_n	ΔL_{den}
Cáceres (Cc)	**0.7**	0.2	**0.6**	0.2
Agustín Heredia (Ma)	**0.6**	**0.5**	**0.5**	0.4
Alcazabilla (Ma)	**0.7**	**0.5**	0.4	0.3
Fátima/Martiricos (Ma)	0.3	0.1	0.2	0.1
Granada (Ma)	**2.0**	**1.5**	**1.4**	**1.0**
Hermes (Ma)	**1.3**	0.0	**1.2**	0.0
Paseo de los curas (Ma)	0.2	0.2	0.2	0.2
Uncibay (Ma)	**1.7**	0.0	**1.2**	0.0
Alto de Extremadura (M)	0.1	0.1	0.1	0.1
Barrio del Pilar (M)	0.4	0.2	0.3	0.2
Castellana (M)	0.3	0.2	0.2	0.2
Cuatro Vientos (M)	0.1	0.1	0.1	0.1
Escuelas Aguirre (M)	0.2	0.1	0.2	0.1
Farolillo (M)	0.3	0.2	0.2	0.2
Plz. Fdez. Ladreda (M)	0.3	0.2	0.3	0.2
Manuel Becerra (M)	0.3	0.2	0.3	0.2
Méndez Álvaro (M)	**4.4**	**2.2**	**3.5**	**1.8**
Moratalaz (M)	**0.8**	0.4	**0.7**	0.3
Plaza de España (M)	**0.9**	**0.6**	0.2	0.1
Plaza del Carmen (M)	0.1	0.1	0.1	0.1
Puente de Vallecas (M)	0.0	0.0	0.0	0.0
Ramón y Cajal (M)	0.2	0.1	0.2	0.1
Tres olivos (M)	0.4	0.1	0.3	0.1
Villaverde (M)	0.1	0.1	0.1	0.1
% increase [dB] > 0.5	37.5%	20.8%	29.2%	8.3%

Bolded cells show increases equal to or greater than 0.5 dB.

- The individual effect of the quarterfinals has been measured in more than 20% of the measurement stations for the L_n index, with a maximum increase of 0.7 dB, and 17% for the L_{den} index, with an increase up to 0.4 dB.
- The individual effect of the semi-finals has been measured at nearly 40% of the measurement stations for the L_n index, with a maximum increase of 0.4 dB, and 17% for the L_{den} index, with a maximum increase of 0.3 dB.
- The individual effect of the final has been measured at almost 100% of the measurement stations for both indices L_{den} and L_n, with a maximum increase of 3.5 dB for the first index and 1.8 dB for the second one.
- Therefore, this study suggests that there are singular noisy events that may have an appreciable effect on the mean daily, monthly, and even annual noise indices, implying that would not be adequately addressed in the noise maps that are being developed, both by measurements and by sound field propagation models. Given the type of event studied, the results can be used to remember similar situations.

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