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Relationship between tyre-road noise and temperature under noncontrolled traffic flow conditions

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Abstract
The influence of temperature on tire-road noise level is a topic on which many investigations have been carried out on controlled road traffic flow conditions based on international standards. Its practical application under uncontrolled vehicle flow conditions may be of interest for the assessment and management of road traffic noise through strategic noise maps. This paper presents the results of an investigation carried out by means of in situ measurements of road traffic noise levels and environmental temperature and a discussion is conducted with respect to those findings available in the scientific literature. A negative and highly significant dependence relationship of the road traffic noise level with both pavement and air temperature was found on the two days of measurement, with similar explanations for variability in the range 59-75% for both temperatures but with differences of around 12-14% between the two sets of measurements. When the slope coefficient is compared, increases of approximately 40% for pavement temperature and 36% for air temperature are found from day 2 to day 1. While the values of the coefficient of variation of noise level with temperature range from -0.05 to -0.07 dBA/◦C for pavement temperature, they are in the range of -0.14 to -0.19 dBA/◦C for air temperature. These values are similar to those published in the scientific literature for pavement temperature, but higher than those reported for air temperature under controlled traffic flow conditions. The followed methodology could be applicable in different conditions.

Keywords: road traffic noise, temperature correction, strategic noise map, on-site measurements.

1 Introduction

Environmental noise from road infrastructure is a topic widely addressed in the scientific literature due to its impact on the surrounding environment, including both people and wildlife [1,2]. The noise level generated by vehicle traffic depends on different aspects related to road and vehicle characteristics as well as weather conditions.

In connection with the characteristics of this type of infrastructure, Freitas et al. [3] point out the relevance of road surface conservation. Based on a study carried out in Guimarães (Portugal), they found that pavement maintenance in the early stages of problem development is, especially on low-speed roads, very important to reduce the environmental noise. The type of pavement is another relevant point in relation to tyre/road noise. For example, from a study carried out in Brazil, Mendes Knabben et al. [4] indicated that the porous friction layer (PFL) was the surface with the lowest noise index (CPXI) when compared to other pavements. But the characteristics of the vehicles driving on the road are also important in the generation of noise. The role of the kind of tyres on the sound pressure level generated on low-noise road surfaces was showed by Licitra et al.

[5], while other studies have shown the influence of factors such as the speed and type of vehicle on road traffic noise [6].

Concerning the meteorological conditions, different authors conducted investigations following international standards such as ISO 11819-1, ISO 11819-2 and ISO/PAS 11819-4 [7,8,9] that found linear relationships between the temperature and the tyre/road noise with coefficients varying between −0.03 and −0.11 dBA/ºC [10,11,12,13,14,15]. Jaben [16] conducted a study on a road with non-controlled traffic circulation, obtaining values of the temperature correction between -0.03 and -0.12 dBA/ºC for light vehicles depending on the speed (50-140 km/h) and -0.04 dB/ºC for middleweight trucks in the range 70-100 km/h. A coefficient for temperature correction is proposed in the ISO/TS 13471-1 standard [17] for two specific tires under controlled traffic conditions, that ranges between −0.04 and −0.11 dBA/ºC depending on the pavement and the vehicles speed. But other values independent of speed are also proposed in this standard ranging between −0.05 and −0.10 dBA/ºC. CNOSSOS-EU method [18] also suggest a correction to the sound power emitted by road traffic to show its reduction as temperature rises: −0.08 dB/°C for light vehicles (category 1) and −0.04 dB/°C for heavy vehicles (categories 2 and 3). If the tyre/road noise is analysed in frequency bands, CNOSSOS-EU method [18] and the ISO/TS 13471-1 standard [17] point out that the same correction should be applied in all bands. In this line, some investigations reported a higher linear relationship between temperature and tyre/road noise in the ranges of 31.5–630 Hz and 1.6–5 kHz [10,11,13].

Considering that this dependence of tyre/road noise on temperature may have a practical application under uncontrolled vehicle flow conditions in the assessment and management of road traffic noise, a paper is presented where an experimental test of the relationships between temperature and road traffic noise on a main road under free traffic flow conditions.

2 Methods

To conduct the present study, in situ measurements were carried out on the section between Cáceres and Malpartida de Cáceres of the national road N-521 in Extremadura (Spain). As can be seen in Figure 1, this is a two-way road with one lane of traffic for each direction. The pavement is seven years old and can be considered as porous asphalt [17] and NL01 class [18]. More specific details of the pavement composition can be found in the paper by Sanchez et al. [19]. The area around the measurement point is flat and can be considered as acoustically absorbent (Figure 1).

The official data from the Ministry of Transport of the Spanish National Government for vehicle flow on the stretch of road under study over the last ten years indicate that the average daily traffic (ADT) is 7,658 vehicles/day, where 95.1% are light vehicles and 4.9% are heavy vehicles. Estimates made from this data indicate that this section of the road can be considered as a major road [20] and that a flow of 600 vehicles per hour during the day can be predicted.

Figure 1. Location of the measurement site (by Google Maps)

The aim of this study was to analyse the dependence of road traffic noise on temperature under actual traffic conditions, which means considering simultaneously a large variability in terms of vehicle model and tyre type and maintenance condition in the experimental test. For this purpose, taking into account the ADT value, a measurement period of 10 minutes was selected to ensure a vehicle flow of at least 100 vehicles. A class 1 sound level meter/analyser was used during the measurements, whose microphone was placed 15 m from the centre of the road [21] and 1.5 m above the ground [22]. No obstacles were present between the microphone and the road that could generate acoustic shielding effects [23] and no reflective surfaces were in the vicinity that could cause reflections of sound [24,25]. Eighteen 10-minute measurements were carried out in each of the two campaigns, recording the equivalent sound pressure level in broadband ($L_{eq,A}$) and 1/3 octave bands (L_{Xeq}). A verification of the calibration of the sound level meter/analyser was performed before and after of each series of measurements.

Simultaneously, the air and pavement temperature, the relative humidity and the wind speed were recorded for each measurement. In the case of air temperature, it was monitored at a height of 1.5 m above the ground [8,10,11,13] avoiding direct exposure of the thermohygrometer to sunlight, while the pavement temperature was taken with a thermal camera on the nearest lane. The wind speed was zero or negligible during the tests. Vehicle flow and class were also monitored according to the vehicle categories indicated in the CNOSSOS-EU method (European Directive, 2015). A speed camera with a 100 km/h limit was in the vicinity of the monitoring point and some measurements showed that vehicles drive on this stretch at an average speed slightly below the limit (most of them in the range of ± 5 km/h). In this concern, Institute for Vehicle Technology estimated a maximum variation of about 1 dBA for variations in speed of ±5 km/h [6].
A period of 10 minutes was considered to ensure the passage of at least 100 vehicles in each measurement, but it is assumed that the number of vehicles will not be exactly the same in all measurements. A normalisation with respect to a reference flow of 780 vehicles/hour (in situ monitored average) was therefore proposed to deal with this aspect [19]. Given that the sound power emitted by categories of vehicles 2, 3 and 4 [18] can be considered different from that of category 1 (light vehicles) [6], a second normalisation was employed by considering the equivalence between the noise level emitted by category 1 vehicles and the rest of the vehicle categories [19]. The coefficients for vehicle categories 2, 3 and 4 in this normalisation were obtained by Sandberg [21].

Since the total equivalent number of light vehicles (category 1) is again likely not to be the same for each measurement, an additional normalisation was performed to study the relationship between measured noise level and temperature. The equivalent vehicle value V_{eq1} derived from the second normalisation was again normalised considering the 930 category 1 vehicles/hour obtained as the average total equivalent category 1 vehicle flow in the measurements. Then, the category 1 equivalent normalised sound pressure level L_{Neq1} was derived from Equation (1) [19]:

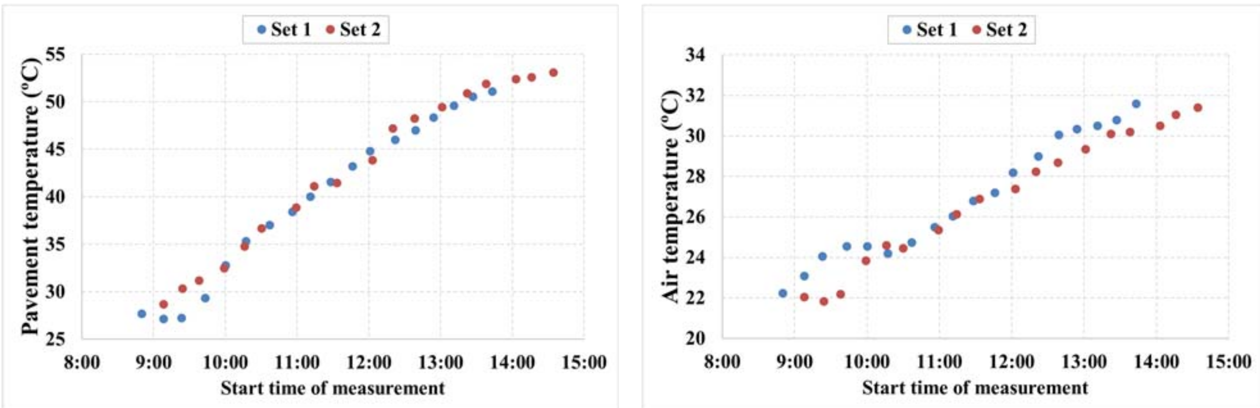
$$L_{Neq1} = L_0 - 10 * log_{10}\left(\frac{V_{eq1}}{930}\right) \quad (1)$$

where L_0 is the recorded sound pressure level; V_{eq1} is the total number of equivalent vehicles in category 1.

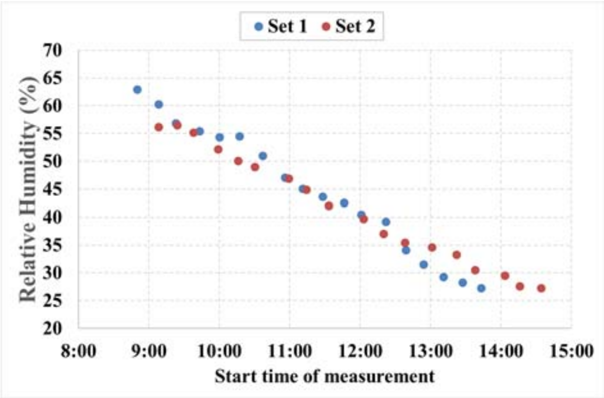
3 Results and discussion

3.1 General conditions

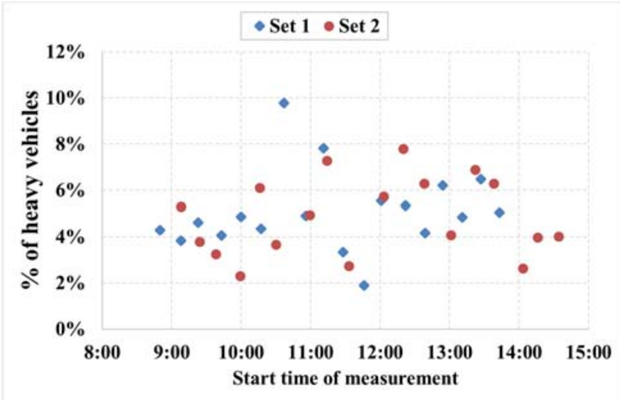
Two sets of 18 on-site measurements were made on consecutive days and at similar hours to try to reduce the variability related to traffic flow and weather conditions. Figure 2 shows the evolution of air (Figure 2a) and pavement temperature (Figure 2b) in relation to the start time of each of the measurements for the two sets. The time-related evolution of the pavement temperature in the two sets is very similar, with some differences in the temperatures recorded in the early morning (between 9:00 and 10:00 a.m.). In the case of air temperature, the differences observed in the early hours are greater than those for pavement temperature. Moreover, from 12.00 onwards, the temperatures recorded in the two surveys also show differences of up to 1ºC. These slight differences between the two sets of measurements in the early morning and from 12:00 onwards are also reflected for relative humidity (Figure 2c). Regarding the percentage of heavy vehicles obtained in each measurement (Figure 2d), it is generally in the range of approximately 2% to 8% and is similar for both sets. No trend is observed in the distribution of the percentage of heavy vehicles in relation to the time of day.



a) b)



c)



d)

Figure 2. Time evolution during measurement sets 1 and 2 of: a) pavement temperature, b) air temperature, c) relative humidity and d) percentage of heavy vehicles.

More detailed information on the maximum, minimum and average values of the measurement conditions regarding temperature, relative humidity and percentage of heavy vehicles for each set of measurements is shown in Table 1. As can be seen, there are no relevant differences in terms of averages in the measurement conditions of both sets. One aspect that is worth to be pointed out is that, although the average air temperature coincides on both measurement days, the average pavement temperature is approximately 2.6 ºC higher in measurement set 2. The average percentage of heavy vehicles recorded in both measurement campaigns was similar and around 5%, although a maximum value of 9.7% was recorded in set 1, higher than the maximum value in set 2.

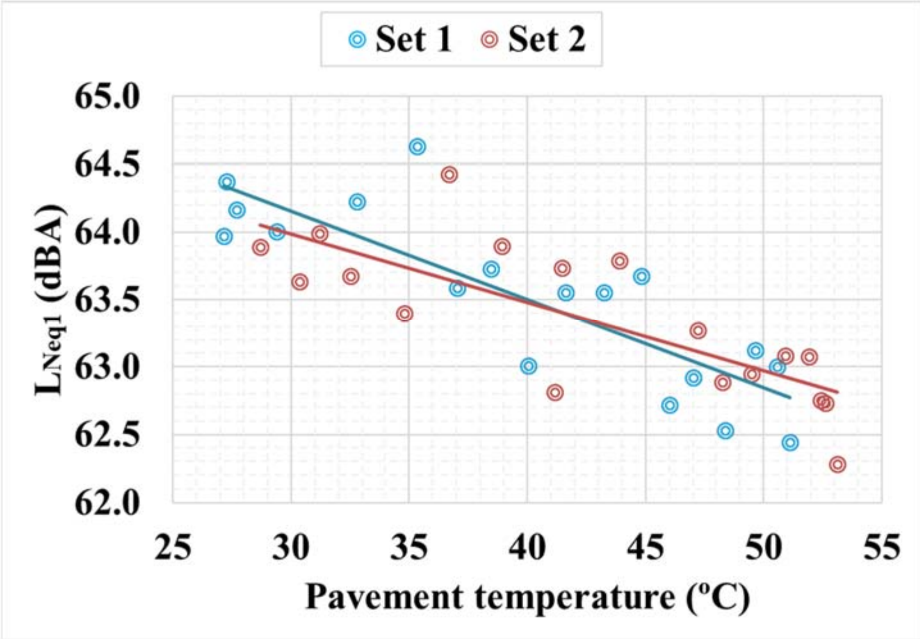
Table 1. Summary of temperature and vehicle data

		Pavement Temperature (ºC)	**Air Temperature (ºC)**	**Relative humidity (%)**	**% of heavy vehicles**
Set 1	Maximum	51.1	31.6	63	9.7
	Minimum	27.2	22.3	27	1.9
	Average	39.9	26.9	45	5.1
Set 2	Maximum	53.1	31.4	57	7.8
	Minimum	28.7	21.9	27	2.3
	Average	42.5	26.9	42	4.8

3.2 Broadband analysis

As mentioned in the methodology section, taking into account the variability in the total number of vehicles and in the percentage of heavy vehicles in each measurement, some normalisations were applied to obtain the category 1 equivalent normalised sound pressure level L_{Neq1}. This allowed to more accurately study the effect of temperature on the sound pressure level from road traffic. Figure 3 shows a diagram of the relationship between the category 1 equivalent normalised sound pressure level L_{Neq1} and the pavement and air temperature for each of the measurements sets 1 and 2, as well as their corresponding linear regression. As can be seen, a negative dependence relationship of the road traffic noise level with both pavement and air temperature is obtained on the two days of measurement, which means that the measured noise level decreases with increasing temperature.

a)



b)

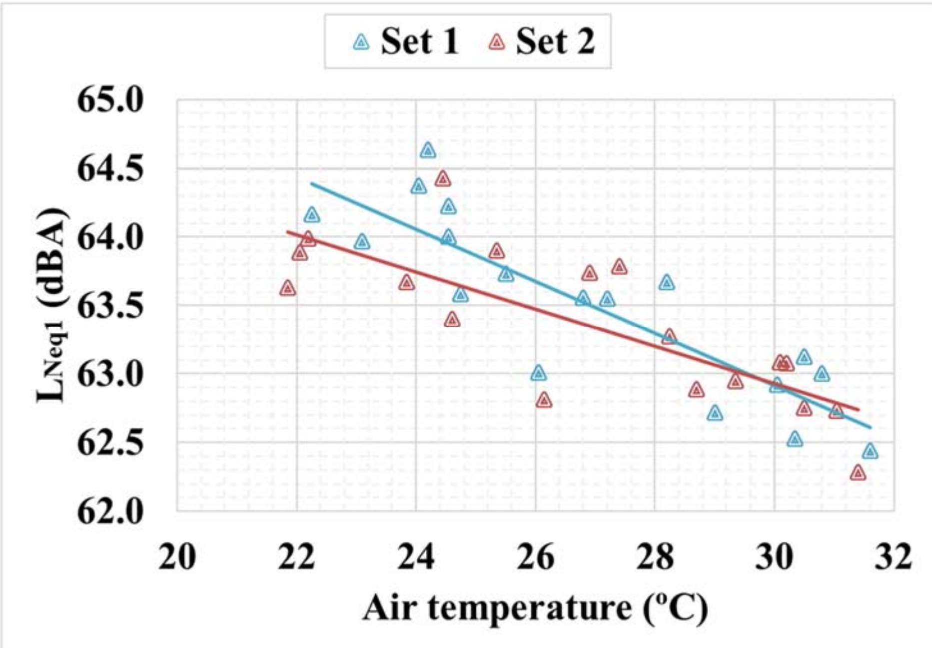


Figure 3. Variation of the category 1 equivalent normalised sound pressure level (L_{Neq1}) with pavement (a) and air temperature (b).

To analyse the results in more detail, Table 2 shows the values of the linear regression parameters as the slope (βi) and its standard error, the coefficient of determination (R^2), the intercept coefficient and the significance, for each set of measurements and for each of the temperatures considered. First, it seems interesting to highlight that all the relationships shown are highly significant (>99.9%), which implies that there is a very low probability that these relationships occur randomly. If the explanation of the variability of the noise level from temperature is studied, it is quite similar for both pavement temperature (59-71%) and air temperature (61-75%). It is also interesting to note an increase in the explanation of variability of 12% for pavement temperature and 14% for air temperature from day 2 to day 1, even though all relationships are highly significant and have a similar intercept coefficient. When comparing the slope of the regression lines, increases of approximately 40% for pavement temperature and 36% for air temperature are found from set 2 to set 1. A larger number of measurement series would be useful to analyse in depth variations of this nature under similar measurement conditions. It is worth pointing out that while the values of the coefficient of variation of noise level with temperature range from -0.05 to -0.07 dBA/◦C for pavement temperature, they are in the range of -0.14 to -0.19 dBA/◦C for air temperature. This difference between the two temperatures is mainly due to the fact that, for the same range of noise level variation in both cases, the range of variation of the pavement temperature (approximately 24 ºC) is considerably larger than in the case of the air temperature (approximately 9.5 ºC). The findings of these experimental tests for the coefficient of variation of road traffic noise level with pavement temperature are similar to those obtained in previous investigations [10, 11] for tyre/road noise level under controlled traffic flow conditions using a Controlled Pass-By (CPB) method [26] and a Close-Proximity method (CPX) [8] respectively. However, the slope values found in the case of air temperature are higher than those reported so far in the scientific literature under controlled conditions. In this regard, values between approximately -0.08 and -0.11 were determined in previous studies [10,13,27,28] under controlled traffic conditions following procedures such as Statistical Pass-By method (SPB) [7], Close-Proximity method [8] and On-Board Sound Intensity (OBSI) Method [29].

Table 2. Linear regression parameters between the the category 1 equivalent normalised sound pressure level (L_{Neq1}) and the air and pavement temperatures.

	Independent variable	βi (dBA/◦C)	Standard error βi (dBA/◦C)	R^2	Intercept coefficient (dBA)	Sig.
Set 1	T_P	-0.07	0.01	0.71	66.12	< 0.001
Set 2	T_P	-0.05	0.01	0.59	65.50	< 0.001
Set 1	T_A	-0.19	0.03	0.75	68.64	< 0.001
Set 2	T_A	-0.14	0.03	0.61	67.02	< 0.001

4 Conclusions

This paper presents an experimental test of the relationships between temperature and road traffic noise on a main road under free traffic flow conditions. Two sets of 18 in situ measurements were performed at the same point on two successive days to carry out a comparison of the results, considering also the findings reported in the scientific literature which have mainly been performed under controlled conditions. A normalisation was applied to consider the variability in the total number of vehicles and in the percentage of heavy vehicles in each measurement.

A negative and highly significant dependence relationship of the road traffic noise level with both pavement and air temperature was found on the two days of measurement. Similar explanations for variability in the range 59-75% were reported for both temperatures, but with differences of up to 14% between sets of measurements. If the slope coefficient is compared, increases of up to 40% are found from set 2 to set 1. A larger number of measurement series would be useful to analyse in depth variations of this nature under similar measurement conditions.

While the values of the coefficient of variation of noise level with temperature range from -0.05 to -0.07 dBA/◦C for pavement temperature, they are in the range of -0.14 to -0.19 dBA/◦C for air temperature. These values are similar to those published in the scientific literature for pavement temperature, but higher than those reported for air temperature under controlled traffic flow conditions.

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