A psychoacoustic based approach to pavement classification

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Summary

The road traffic noise is one of the major contributors to environmental noise, which can cause considerable impact on public health and quality of life of populations. However, road noise raises several questions because, if on one hand is associated with several health problems and welfare, on the other hand its lack affects the detection of the sound sources, and consequently it constitutes a risk to the safety of road users. Thus, it becomes essential to classify road pavements not only based on acoustic indicators but also based on psychoacoustic indicators. Therefore, this work aims to contribute to pavement classification from the point of view of psychoacoustics. An innovative approach leading to important methodological advantages was done by using the Close proximity Method (CPX) method to acquire tyre-road noise. This work presents the acoustic characterization of five different types of pavement by using three acoustic and psychoacoustic indicators (LAmax, LAeq and Loudness) as a function of speed. Each variable was related to the sound intensity and annoyance evaluation responses of twenty six individuals subjected to the acquired noise. As main results, loudness proved to be a more sensitive variable to vehicle speed and type of pavement than LAmax and LAeq and fits better with individual's responses.

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1. Introduction

A few years ago, several European countries tried to implement programs for noise classification of road surfaces. Most of them take a surface as reference and apply correction terms for the other surfaces types or group of surfaces. Factors such as the type of vehicle, percentage of heavy vehicles, longitudinal road gradient, noise spectrum and mean texture depth are occasionally considered as correction factors [1]. Some countries, such as France and The Netherlands, predict rolling noise levels for different types or categories of surfaces versus vehicle category and speed. Some European projects such as HARMONOISE or CNOSSOS proposed enhanced methods for predicting the influence of the road surface on vehicle noise emission. The classification problem was in that way addressed indirectly. The project SILVIA proposed a classification system for labelling a specific surfacing technology and for subsequently contractually checking the conformity of production of that technology once applied on the road [2]. The labelling procedures are based on Statistic Pass-By (SPB) and Close Proximity (CPX) measurements or SPB measurements and on measurements of intrinsic properties of the road surface. Recently, [3] developed a modified CPX-based methodology, in order to improve the usefulness of tyre/road noise measurement in the evaluation of acoustical performances of a road surface, in terms of both temporal and spatial stability and in terms of effectiveness of a mitigation action. According to the authors, the acoustical uniformity of each single surface can be evaluated in order to label or verify the installation of special pavements mainly prepared for environmental noise reduction. Also, it can be used to assess the acoustical performances of a road surface over time.

These different ways of dealing with pavement surface acoustical classification do not consider in their methodologies sound quality parameters such as loudness, roughness or sharpness.

The sound quality of road traffic noise as it is described by various psychoacoustic parameters not only determines the subjective estimation of noise-induced discomfort but in addition affects physiological parameters like heart rate [4].

Several studies showed that loudness describes the correlation with subjective estimation of noise-induced discomfort better than the A-weighted sound level [4-5].

Licitra *et al.* [6] suggested to classify surface layers based of CPX measurements using loudness-SPL behavior and the difference in loudness spectrum for new road surfaces as loudness presents a better sensibility to local differences in the pavements.

This paper examines the suitability of CPX measurements to establish a relation between subjective annoyance ratings and the traffic noise levels described by acoustic and psychoacoustic indicators (LAmax, LAeq and Loudness) as a function of speed.

When sound measurements are made by the CPX method, the propagation and absorption components are not taken into account [7]. Therefore the adequacy of the results were corroborated/validated by a panel asked to respond to annoyance and intensity tasks to check if the method adopted provide consistent results, as discussed in [5]. Furthermore, in this study several types of urban road pavements were analysed, including not only common asphalt concrete surfaces but also concrete block and cobble stone surfaces which are expected to be highly annoying.

2. Materials and methods

2.1 Pavement surfaces

The types of pavement surfaces selected for the study were (Figure 1): asphalt concrete (AC), which has been used in several situations for many years; concrete blocks (CB) and cobble stones (CS), often used in urban contexts, particularly in city centres; slurry seal (SS), used to improve friction; and open graded asphalt rubber (OGAR), which has been used among other things to reduce noise [8].

2.2 Tyre-road noise measurement

The tyre-road noise was recorded with a Brüel & Kjaer Pulse Analyzer type 3560-C and two microphones assembled according to ISO/CD 11819-2 as shown in Figure 2.

The tyre used in the vehicle was the ContiEcoContact3 195/65-R15. According to Morgan *et al.* [9] this tyre performance is acceptable when compared to other recommended reference tyres.

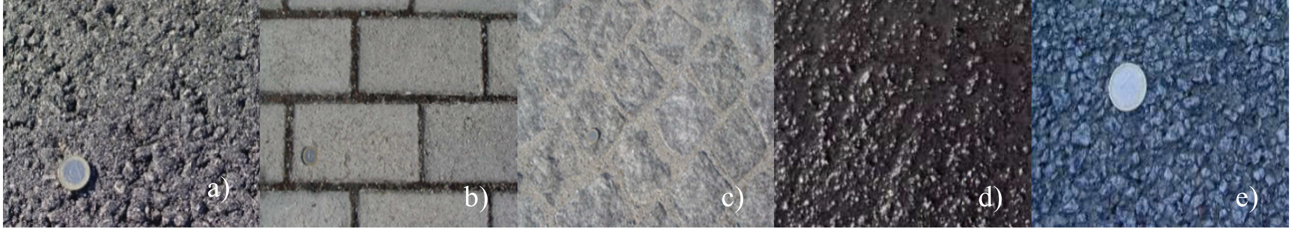

Figure 1. Pavement surfaces: a) asphalt concrete(AC); b) concrete blocks (CB); c) cobble stones (CS); d) slurry seal (SS); e) open gradded rubber asphalt (OGRA).

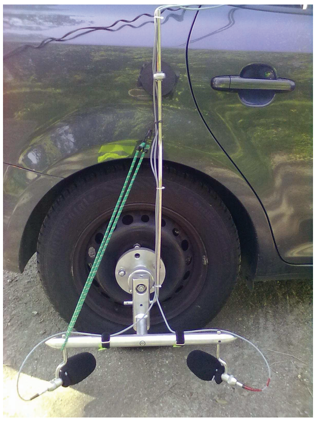

Figure 2. Tyre-road noise measurement set up.

2.3 Experiment

2.3.1 Participants

Twenty-eight voluntary listeners participated in the experiment (21-29 years old, average of 25 years old). To exclude prior major hearing deficiency all participants underwent audiometric screening tests (250, 1000 and 4000 Hz).

2.3.2 Stimuli and equipment

The single vehicle recordings produced the stimuli for the annoyance or intensity assessment, for each pavement type and vehicle speed, from 20 to 50 km/h with 10 km/h increments.
Therefore there were a total of 20 stimuli (5 pavements x 4 speeds). Each stimulus had the duration of 5 seconds. The stimuli were presented through a custom built C++ application, running in a computer with a sound card Intel 82801BA-ICH2, and AKG K 271 MKII closed headphones. This system was calibrated to achieve sound pressure levels identical to those found in the original road environments. The values of LAmax, LAeq and Loudness were extracted with the Psysound3 application [10] from sound files with 5 seconds.

2.3.3 Procedure

The annoyance assessment of each participant was performed in a quiet room. The stimuli were presented channel reversed to avoid interaural biases. The resulting 20 samples were repeated 5 times (trials). Thus each participant listened to a total of 200 noise trials (20 stimuli x 2 channel sequences x 5 trials). Trials were presented in a pseudo-random order (method of the constant stimulus) to reduce anticipation and expectation interferences. Participants were requested to assess the annoyance of each noise trial with a 10-graded interval scale from 1 (less annoying) to 10 (very annoying). The interval between trials was variable and depended on the promptness of the participant: after the answer to a given trial (by pressing a number on a keyboard) the next noise sample was presented. Each session, with the 200 trials, lasted for about 15 minutes per participant.
The same protocol was followed to assess the intensity ratings of each noise trial.

3. Results

Table I presents for each pavement and testing speed the corresponding acoustic indicators (LAeq, LAmax and Loudness) and the average annoyance and intensity ratings.
In the following subsections the acoustic indicators characterization is discussed and the assessment of annoyance and intensity is made.

3.1 Characterization of the acoustic indicators

In order to correctly compare the acoustic performance of each pavement as a function of speed described by LAeq, LAmax and Loudness, all data were normalized using a feature scaling method as shown in Figure 3.

The CS pavement reached the highest values for all indicators while the AC had the lowest ones.
Althought CB, OGRA and SS are completely different surfaces, quite close results were found for the LAeq and LAmax. On its turn, loudness was able to better distinguish the surfaces. Indicators LAeq and LAmax had a similar performance with speed, being more sensitive to changes at low speeds, while Loudness was more sensitive at higher speeds, as can be seen by the corresponding graphical representation.
To analyse in detail the effect of the type of pavement and speed, the difference between the normalized LAeq and Loudness was considered as shown in Figures 4 and 5. The most important differences were found for the OGRA surface and the opposite for CS (Figure 5). Similar relative differences between sound indicators were found for AC and CB.
Speed also affected the relative differences of sound indictors. At 40km/h were registered the highest differences. On its turn, at 20 km/h those differences were the smallest (Figure 6).

Table I. Noise indicators and average annoyance and intensity ratings.

Pavement surface	Speed (km/h)	LAeq (dB(A)SPL)	LAmax (dB(A)SPL)	Loudness (Sone)	Annoyance (1-10)	Intensity (1-10)
AC	20	71.64	72.70	25.62	2.78	2.68
	30	78.90	79.86	33.79	3.80	3.89
	40	82.63	83.67	41.53	5.00	5.10
	50	87.33	88.21	54.71	7.07	7.35
CB	20	73.76	75.50	30.68	3.83	3.72
	30	80.81	83.68	43.82	6.71	6.32
	40	87.27	89.81	56.45	7.91	7.73
	50	91.82	94.22	70.58	8.80	8.88
CS	20	78.65	81.04	40.38	6.09	5.97
	30	85.82	87.32	56.06	7.72	7.48
	40	90.93	93.33	71.48	8.85	9.05
	50	94.81	96.24	86.13	9.48	9.72
SS	20	76.38	77.84	34.45	4.21	4.18
	30	82.66	83.80	45.44	5.55	5.60
	40	86.72	87.88	55.18	7.11	7.08
	50	91.37	92.77	68.47	8.36	8.43
OGRA	20	74.52	75.58	28.06	2.96	2.88
	30	81.50	82.63	37.49	4.15	4.13
	40	85.58	86.74	46.02	5.50	5.52
	50	89.91	91.44	58.93	7.03	7.18

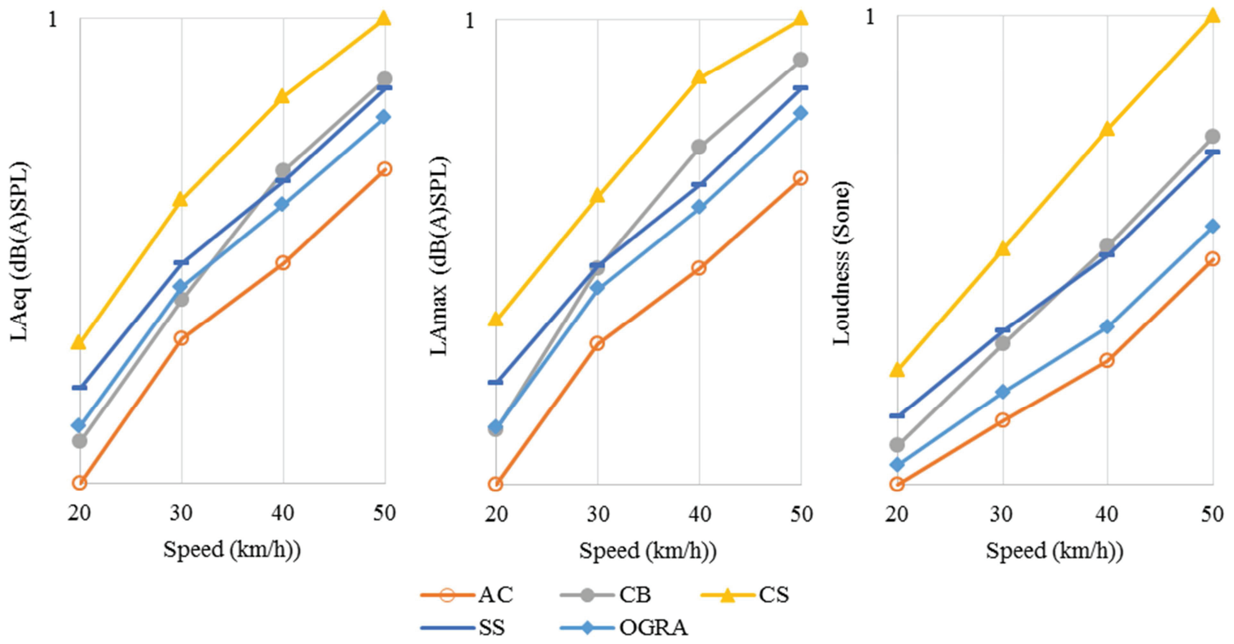

Figure 3. Normalized noise indicators for each pavement and for each speed level.

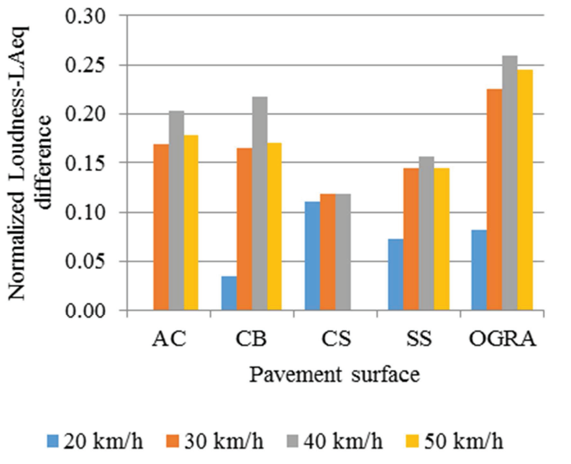

Figure 4. Normalized LAeq-Loudness difference for each pavement surface.

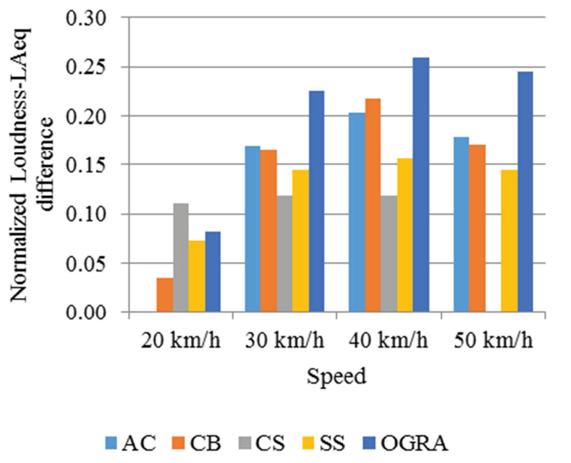

Figure 5. Normalized LAeq-Loudness difference for each speed.

3.2 Annoyance and intensity assessment

To corroborate the results discussed previously, the panel ratings will be hereafter related to noise indicators. It was found a high correlation between intensity and annoyance average ratings (pearson, 0.997). Because annoyance is often referred in literature [5], it was selected to determine which acoustic indicator predicts it better.

As expected, the effect of speed over annoyance ratings was statistically significant in a two-way ANOVA for repeated measures ($F_{3,75}$= 488.9, $p<.001$). The mean annoyance ratings increase with speed for all pavements (Figure 6). Pavement type also had a significant effect ($F_{4,100}$ = 152.9, $p<0.001$), revealing differences in the mean annoyance ratings of pavement surfaces. Even though AC and OGRA surfaces had similar performance, this can be clearly seen in Figure 6.

The analysis of the speed-pavement interactions revealed a linear increase of the mean annoyance as a function of speed ($F_{12,300}$= 18.66, $p<.001$).

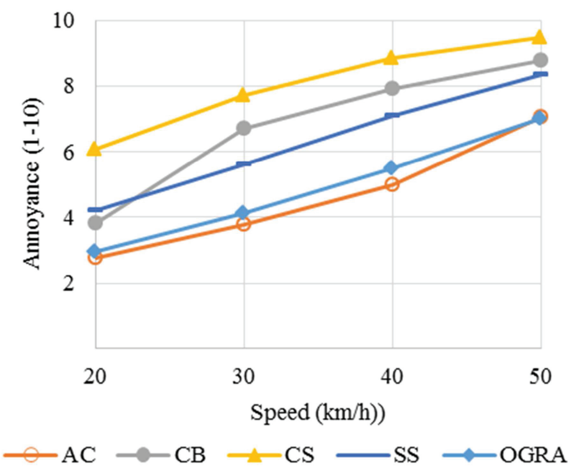

Figure 6. Average annoyance versus speed for all pavements.

3.3 Annoyance versus acoustic indicator

To determine which acoustic indicator predicts better annoyance, their trend lines and fit quality were compared (Figure 7).

The determination coefficient calculated for loudness (0.91) is better than the one for LAmax (0.89) which in its turn is better than for LAeq (0.84).

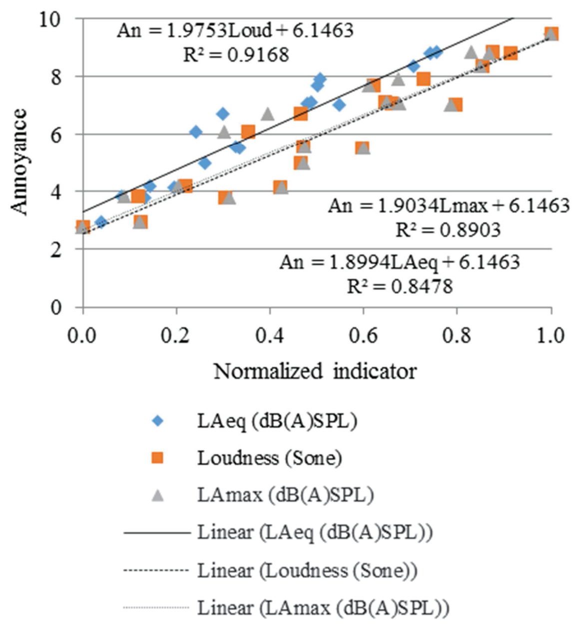

Figure 7. Average annoyance versus acoustic indicators for all pavements.

This means that loudness explains better the annoyance rated by the participants, relative to the tyre road noise measured by the CPX method for all pavements. Also, the slop annoyance-loudness is slightly higher than the others indicating more sensitivity to higher speeds.

4. Conclusions

The aim of contributing to pavement classification from the point of view of psychoacoustics, using the Close proximity Method (CPX) to acquire tyre-road noise, was achieved.

The CPX seems to be an adequate method to provide psychoacoustic indicators to be used in pavement classification. The results are consistent with previous studies based on the CPB method.

The effect of pavement over annoyance ratings was statistically significant. As a result, it was possible to distinguish the impact of each pavement as a function of speed on annoyance.

Loudness distinguishes better than LAeq and LAmax the acoustic performance of each type of pavement as a function of speed. Furthermore, Loudness describes better annoyance or intensity ratings than LAeq and LAmax. These results point towards the introduction of psychoacoustic indicators in pavement classification.

The study limitations are related to the type of tyre and measurements variability, the influence of which was not studied. Future developments should considerer these factors as well as structured comparisons with the SPB method to analyse the effect of sound propagation on annoyance ratings.

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