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## Influence of various timbre parameters on the unpleasantness of tyre noise

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### ABSTRACT

Road traffic noise accounts for the majority of perceived urban environmental noise and has important health consequences. The rolling noise of vehicle tyres is a major contributor to perceived road noise. The tread pattern of light vehicle tyres is already designed to minimize the amplitude of the noise emitted, but this is not the case for heavy vehicles. The European LEON-T project aims to minimize the nuisance of heavy vehicle tyres, especially noise. Prior to a study of the effects of tyre noise on sleep, an experiment was conducted to determine the timbre parameters of such noise. It was determined that the loudness, tonality and the frequency balance of the noisy part were the most variable psychoacoustics parameters and were used by listener to discriminate different category of noises. According to those results, tyre noises were synthesized with different combinations of those parameters. These stimuli were presented with headphones and participants were asked to self-assess their unpleasantness.

The presentation will show the results of the experiment, i.e. which relationship of the studied parameters influence the most the unpleasantness. Those results will be correlated with future experiments on the physiological stress reaction provoked of the synthesized tyre noises.

Keywords: Psychoacoustics, Urban and Road noise, Tyre noise, Unpleasantness

### 1. INTRODUCTION

Road traffic noise has negative impacts on sleep and can generate physiological stress responses: (changes in cardiac function, blood pressure, viscosity, coagulation and lipid and carbohydrate content of blood) [1,2]. In the long term, the risk of cardiovascular diseases such as heart attacks may increase [3].

The noise of combustion engines has been reduced in the last decades [4] and will even tend to disappear with the progressive electrification of the car fleet. It is therefore necessary to study the second source of noise from vehicles: the rolling noise of tyres.

One of the objectives of the European project LEON-T (Low particle Emissions and Low Noise Tyres, <https://www.leont-project.eu/>) is to understand and minimize the impact of tyre rolling noise on sleep. The interest will be focused on the effect of the different psychoacoustic parameters of these noises on cardiovascular health during sleep according to different road traffic scenarios.

The tyres available on the market have a great diversity of uses and tread patterns, influencing the generated rolling noise [5]. Previous studies already showed that tyre noises can be differentiated by perception in an experiment simulating a listener outside [6]. A free sorting task showed that the level and the tonality (amplitude and frequency of an emerging tone) were the main factor to differentiate tyre noises when they were listened inside a room [7]. However, there are no data on the unpleasantness provoked by such psychoacoustics parameters in this scenario.

The goal of this experiment was to study the relation between noise unpleasantness and different sound parameters. We generated artificial tyre rolling noises with different combination of those parameters and asked participants to rate the unpleasantness they felt when listening to those sounds.

### 2. MATERIAL AND METHODS

We generated 36 stimuli, each one corresponding to a tyre rolling noise with a given combination

of fundamental frequency (F), bandwidth (Bw) and tonality factor (TF). Each stimulus was synthesized as the mix of a noisy part (a broadband noise) and a tonal part (a white noise filtered around precise frequencies) according to (eq. 1):

$$Stimuli_{F,TF,Bw} = (1 - TF) \times Noisy\ part + TF \times Tonal\ part_{F,Bw} \quad (1)$$

The different combinations of psychoacoustic parameters allowed to generate 2 frequencies  $\times$  3 TFs  $\times$  2 bandwidths  $\times$  3 levels for a total of 36 stimuli (Tab.1). The stimuli with a TF value of 0 do not depend on the bandwidth and fundamental frequency parameters. Some of these stimuli were removed from the dataset to avoid an over-representation of identical atonal sounds. The final dataset was thus composed of 30 stimuli.

Frequency	Tonality factor	Bandwidth	Level
300 Hz	0	[F - 8 Hz ; F + 8 Hz]	40 dB(A)
500 Hz	0.25	[F - 20 Hz ; F + 20 Hz]	46 dB(A)
	0.5		52 dB(A)

Table 1: Summary of the different parameters and their different values.

We used the stimuli in a psychoacoustics experiment where thirty-one participants (11 women, 20 men) were asked to rate the unpleasantness on a continuous scale from 0 ('not at all unpleasant') to 1000 ('extremely unpleasant'). Participants had to imagine that they were in their bed, trying to fall asleep, when suddenly, a vehicle passed nearby their bedroom. The operation was repeated for 60 sounds, i.e. two pseudorandom repetitions of the dataset described before.

The unpleasantness scores for each participant  $i$  and each evaluated sound  $j$  were corrected by mean normalization: the average of all scores given by the participant  $i$  was subtracted and the global mean of the data was added (eq. 2):

$$Centered\ score_{i,j} = score_{i,j} - \frac{1}{n_j} \sum_j score_{i,j} + \frac{1}{n_j \times n_i} \sum_{i,j} score_{i,j} \quad (2)$$

With  $n_j$ , the number of stimuli evaluated by a given participant  $i$ , i.e.  $n_j = 60$ ;  $n_i$ , the number of participants, i.e.  $n_i = 31$ .

### 3. RESULTS

The centered unpleasantness scores were used to perform a regression tree [8,9] with the psychoacoustics variables of the synthesized sounds as explanatory variables: the fundamental frequency, the tonality factor, the bandwidth and the global level. The model was fitted using the R language 4.1.2 [10] and the rpart library [11]. The resulted tree showed that the level was the most important factor driving the unpleasantness followed by the tonality factor.

An importance analysis performed in a simple linear model (vip library [12] for the R language) showed the same results (Fig.1).

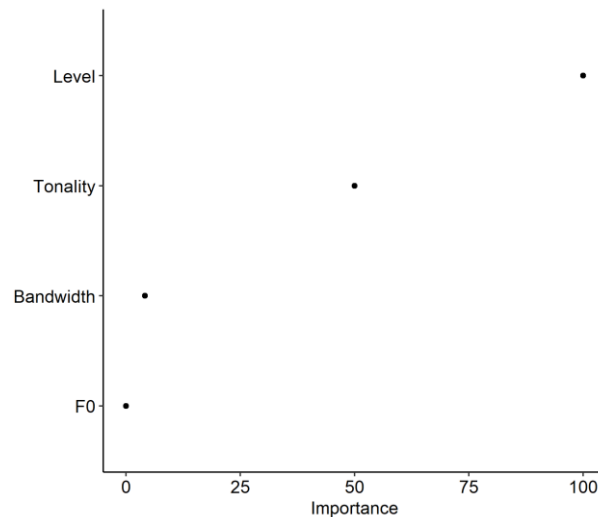


Figure 1: Importance of the different psychoacoustic parameter calculated from a linear model. The importance values are scaled so that the maximum importance equals 100.

#### 4. CONCLUSION

The experiment showed that the global level and the prominence of the tonal component of the synthesized tyre rolling noises were the most important cues for self-assessed unpleasantness of tyre noises, as heard indoors. These findings reinforce the results found before in the project where tonality and overall level were the main acoustic parameters used to differentiate tyre noises in a free sorting task.

Unpleasantness evaluations will also be compared with the results of future experiments. For example, the self-assessed unpleasantness will be correlated with physiological changes (heart rate, body temperature and skin conductivity). Such findings could also be correlated with the future study of the effect of tyre noise on sleep.

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