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Noise annoyance assessment of various urban road vehicle pass-by noises in isolation and combined with industrial noise: A laboratory study

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ABSTRACT

Noise maps are diagnosis tools which represent the noise exposure situation using the energy-based index L_{den} (the day–evening–night level). Two major drawbacks may be attributed to noise maps: (1) energy-based indices only account for one acoustical factor (exposure level) that may give rise to annoyance; (2) combined exposures situations are left unframed.

In order to contribute to the overcoming of these flaws, two laboratory experiments were undertaken. Experiment 1 consists in listening tests where perceptual and cognitive categories of various urban road vehicle pass-by noises including two-wheeled vehicle pass-by noises are studied from the annoyance point of view. This experiment allows to highlight spectral and temporal features, and to propose noise annoyance indicators based on common acoustical and psychoacoustical indices in order to take these acoustical features into account.

Experiment 2 consists in assessing annoyance due to the previous urban road vehicle pass-by noises heard in the presence of a steady industrial noise. Interactions effects are found and attributed to the temporal evolution of combined noises. Perceptual total annoyance models are found to be better models than psychophysical ones. This last result highlights the necessity to continue efforts to improve the characterization of annoyance due to noise in isolation.

1. Introduction

Road traffic noise is a major environmental concern for the daily quality of life. A recent French survey showed that more than 86% of French people are annoyed by noise at home, and among noise sources, road traffic is the most elicited one [22]. George *et al.* [18] estimated that the total economic burden of disease due to environmental noise in Western Europe countries amounts to more than 80 billion € per year. The European Guideline 2002/49/EC [14] tackles this problem by obliging European major agglomerations to draw noise maps for various community noises: road traffic, railway, aircraft and industrial noises. Noise maps are then used to implement action plans in order to reduce the adverse effects of these community noises.

Noise maps are a communication tool to the public, providing an acoustical diagnosis of a given area at a given moment. The exposure situation is represented using the energy-based index L_{den} (day–evening–night level) that is constructed using the A-weighted equivalent sound pressure level L_{Aeq}. In order to assess noise impacts on health, for example in terms of annoyance or sleep disturbance, it is recommended to link noise maps to previously proposed dose–effect relationships (*cf.* [32,14,13]).

Noise maps are considered as a significant step forward concerning noise management, but their relevance can still be questioned [45]. Two major flaws can be particularly identified: (1) the mean energy-based index L_{den} accounts for only two factors (the noise level and the period of the day) that give rise to annoyance, among numerous other acoustical and non-acoustical factors [31]; (2) noise sources are only considered separately, leaving combined exposures unframed.

In the past, numerous studies have investigated specific features of road traffic flows, such as traffic composition (*e.g.* the

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percentages of the different vehicle types), traffic nature (*e.g.* the different types of driving conditions such as free-flow condition), or the spectral content of its resulting noise. Other acoustical factors different from the exposure level may influence annoyance responses. Nilsson [37] proposed a linear combination of energy-based indices using A- and C-weightings to predict annoyance due to road traffic noises containing different amounts of energy in low frequencies. Versfeld and Vos [54] have shown that a traffic flow with 75% of heavy vehicles is more annoying than a traffic flow with 10% of heavy vehicles, which in turn is more annoying than a traffic flow composed of light vehicles only. Langdon [28,29] found that when traffic did not flow freely (*i.e.* with much slowing, stopping, starting and acceleration in low gears), different percentages of heavy vehicles generate different annoyance responses. For urban road traffic with two-wheeled vehicles, Paviotti and Vogiatzis [40] showed that temporal features accounted for by the roughness index influence annoyance responses. The authors also pointed out the necessity to study annoyance due to urban road traffic noise by considering the different vehicle pass-by noises in order to enhance noise annoyance indicators.

Concerning total annoyance, the knowledge seems incomplete concerning interaction phenomena between combined noises. This leads the scientific community to a difficulty in reaching a consensus on a total annoyance model. Schulte-Fortkamp and Weber [49] have highlighted synergetic effects between combined noises (*i.e.* total annoyance is higher than the maximum specific annoyance, which is the annoyance due to one noise in isolation). Bottom [11], analyzing data from an *in situ* study, first found an inhibition effect (*i.e.* the reduction of the annoyance due to a noise in the presence of another noise). Powell [44], Izumi [24], Morel *et al.* [34] further proposed characterization of this phenomenon in laboratory conditions. According to Berglund and Nilsson [7], total annoyance models are either psychophysical (linking total annoyance to acoustical variables like L_{Aeq}) or perceptual (linking total annoyance to perceptual variables like specific annoyance). Numerous models were proposed and tested using *in situ* or laboratory data [50,31,34], but none is actually able to make a consensus among the scientific community.

There is thus a long-term need to improve noise annoyance prediction. The work presented here intends to contribute to these long-term aims (1) by proposing indicators based on common acoustical and psychoacoustical indices in order to account for acoustical factors different from the exposure level; and (2) by testing total annoyance models in order to take into account interaction effects that could be highlighted for combined industrial and urban road vehicle noises.

The work presented in this paper considers results of a previous work [35]. These authors conducted, on recorded urban road vehicle pass-by noises, a free categorization with free verbalization that resulted in the proposal of a perceptual and cognitive typology of urban road vehicle pass-by noises. The fifty-seven *in-situ*-recorded pass-by noises used in their study are stemmed into 7 perceptual categories presented in Table 1. The categories

Table 1

The perceptual and cognitive typology of urban road traffic pass-by noises proposed by Morel *et al.* [35] and the indices calculated for the pass-by noises selected for the current study [at the same L_{Aeq}: 56 dB(A)]. All indices are calculated using dBSONIC software [57]. N is loudness, S is sharpness, R is roughness, F is fluctuation strength, ΔN^{+} is the increase rate of loudness over time, ΔN^{-} is the decrease rate of loudness over time. L_{LF}, L_{MF} and L_{HF} are respectively L_{Aeq} calculated over low frequencies third octave bands (25–250 Hz), middle frequencies third octave bands (315–1250 Hz) and high frequencies third octave bands (1.6–12.5 kHz) as defined by Alayrac *et al.* [1]. The pass-by noises selected for experiment 2 are indicated in italics.

Category (cat.) of the typology	Pass-by noise	Duration (s)	N (sones)	ΔN^{+} (sones s^{-1})	ΔN^{-} (sones s^{-1})	S (acum)	R (casper)	R_{max} (casper)	F (cvacil)	F_{max} (cvacil)	L_{LF} (dB(A))	L_{MF} (dB(A))	L_{HF} (dB(A))
1st cat. Two-wheeled vehicles passing by at constant speed	*1*	*4*	*3.8*	*3.4*	*2.7*	*1.4*	*16.3*	*29*	*11.7*	*17.3*	*37.1*	*48.2*	*52.8*
	2	*4.8*	*4.6*	*2*	*1*	*1.2*	*17.7*	*25.5*	*9.9*	*11*	*42.4*	*47.8*	*53.6*
	3	4.7	4.1	1.5	2.3	1.4	18.5	28.2	8	11.1	36.3	46.4	52.5
	4	*4.4*	*4.1*	*1.1*	*2.8*	*1.3*	*15*	*21.1*	*17.1*	*25.3*	*40.2*	*47.2*	*53.8*
	5	2.7	4	3.9	3.2	1.2	17.6	24.4	12.1	13.9	39.8	47.5	53.5
2nd cat. Two wheeled vehicles in acceleration	*6*	*6*	*3.4*	*3*	*1.1*	*1.5*	*21.2*	*67.2*	*11.1*	*20.6*	*31.5*	*42.5*	*51.2*
	7	*4.5*	*4.5*	*0.8*	*0.2*	*1*	*46.5*	*98.2*	*23.2*	*32*	*41.8*	*50.2*	*54.7*
	8	4.9	3.8	1.4	4.5	1.2	21.2	33.7	5.8	14.3	39.3	46.9	52.7
	9	*3.7*	*4.2*	*2.3*	*2.3*	*1*	*24.6*	*58.6*	*7.5*	*9.4*	*41.5*	*48.5*	*52.8*
	10	5.6	3.5	1.3	1.9	1.2	28.9	73.2	10.8	17	42.2	44.4	54.6
3rd cat. Buses, light vehicles and heavy vehicles passing by at constant speed	*11*	*3*	*4*	*3.2*	*3.6*	*1.4*	*21.6*	*32*	*10.6*	*12.5*	*35.2*	*46.9*	*52.7*
	12	5.5	3.8	1.4	2.6	1.1	20	32.2	6	8	38.1	48.5	52.6
	13	5	3.7	1.7	2.8	1.2	19.7	28.2	6.8	10.6	35.4	49.1	53.5
	14	*4.2*	*3.3*	*2.1*	*2.6*	*1.2*	*20.9*	*33.8*	*7.2*	*10.6*	*30.4*	*49.5*	*52.2*
	15	*4.5*	*3.9*	*3*	*1.6*	*1*	*18.6*	*29.6*	*4.9*	*7.5*	*36.7*	*51.5*	*51.1*
4th cat. Two-wheeled vehicles in deceleration	*16*	*5.4*	*5.3*	*1.3*	*2.2*	*1*	*18.1*	*25.8*	*11*	*15.9*	*51*	*49.2*	*50.2*
	17	*3.7*	*3.9*	*0.6*	*12.1*	*1.3*	*17.2*	*20.8*	*8.8*	*16.4*	*38.8*	*44*	*54.3*
	18	*3.5*	*4.9*	*0.6*	*7.5*	*1.2*	*22.2*	*39.5*	*23.1*	*35.8*	*43.3*	*48.8*	*51*
	19	2.8	4.4	1.8	0.2	1.2	22.5	28.1	3.1	3.4	37.7	48.7	55.3
5th cat. Buses, light vehicles and heavy vehicles in deceleration	20	5.4	4.1	1.9	0.7	1.2	20.7	30.8	7.4	12.8	36.2	48.5	53.4
	21	8.7	4	0.9	0.7	1.3	22.6	37.6	7.7	15.2	37.2	48.3	52.8
	22	*5*	*3.7*	*1.8*	*0.4*	*1.6*	*23.2*	*28.3*	*12.2*	*18*	*31.2*	*43.5*	*53.8*
	23	*5.3*	*4.1*	*0.9*	*1.9*	*1.2*	*22.7*	*30.1*	*5.9*	*9.5*	*35.4*	*49.9*	*54.5*
	24	*3*	*4.5*	*0.7*	*1.1*	*1.1*	*23.1*	*28.6*	*4.5*	*6.2*	*38.9*	*49.1*	*54.3*
6th cat. Light vehicles in acceleration	25	5.5	3.7	1.6	2.7	1.2	16.8	23.8	9.6	14.5	40.8	46.8	53
	26	*5.9*	*2.9*	*1*	*1.8*	*1.3*	*22.5*	*37.9*	*6.6*	*11.3*	*29.4*	*43.1*	*53.8*
	27	*3.2*	*4.1*	*1.6*	*3*	*1.5*	*20.8*	*31.8*	*6.8*	*7.9*	*33.5*	*46.3*	*53.1*
	28	*4.7*	*4.6*	*2.4*	*0.4*	*1.3*	*22.2*	*28.4*	*7.6*	*12.9*	*35.9*	*49.8*	*53.2*
7th cat. Buses and heavy vehicles in acceleration	*29*	*7*	*3.4*	*1.1*	*1.4*	*1.2*	*19.7*	*44.5*	*11.2*	*28.1*	*35.6*	*49*	*52*
	30	*5.4*	*3.8*	*1.1*	*3.4*	*1.3*	*20.8*	*28.7*	*11.4*	*25.4*	*35.9*	*48.1*	*53.5*
	31	*6.4*	*4.1*	*0.9*	*1.5*	*1.3*	*21.2*	*28.3*	*7.5*	*13.7*	*35.8*	*46.9*	*50.6*
	32	*6*	*3.6*	*0.5*	*0.3*	*1.3*	*20.6*	*29.5*	*8.9*	*27.5*	*34.1*	*45.5*	*54*
	33	*5.5*	*3.4*	*1.9*	*1.4*	*1.3*	*20.5*	*32.5*	*7.3*	*10.3*	*31.4*	*47.1*	*53.5*