Listening test experiments

Etienne Parizet
Laboratoire Vibrations Acoustique
INSA-Lyon, Villeurbanne

Introduction

- Electric vehicles are very quiet at low speeds (below 30 km/h).
- This can prevent pedestrians from detecting an approaching car (Garay-Vega *et al.* 2010, Grosse *et al.* 2013, Altinsoy 2013, Glaeser *et al.* 2012).
- This may increase the number of pedestrians' injuries (Wu *et al.* 2011).
- Using warning sound is necessary (in spite of Sandberg 2012 !).
- The efficiency depends on the sound features (Yamauchi *et al.* 2011, Wall Emerson *et al.* 2013, Misdariis *et al.* 2013).

- Some sound characteristics are mandatory (NHTSA, European regulations).

INSA contribution to eVADER

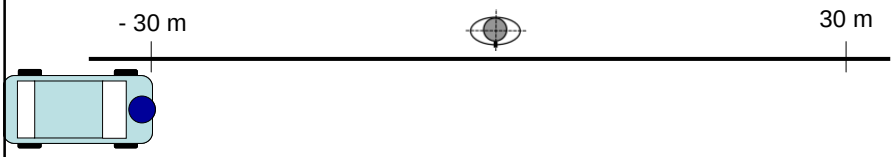
- Requirements for an optimized warning sound :
  - it can easily be detected but with a low level;
  - it helps in localizing the car;
  - it does not contribute to noise annoyance in cities.
- INSA contribution : evaluation of the contribution of some timbre parameters :
  - frequency bandwidth;
  - frequency and amplitude variation (increased urgency, see Edworthy et al. 1991, Sueid et al. 2011, …).
- This *does not* mean to define the warning sound to be used on the prototype !

3 experiments have been conducted

- Detectability and source localization.
- Sound meaning (can a sound provide useful information about the speed and the distance of the car ?);
- Annoyance.
- In a collaborative way :
  - definition of the experiment : Insa;
  - sound synthesis : Insa, Lms (auralization);
  - vehicle recordings : Renault, Idiada;
  - conduction of the experiments : Insa, Tud, Renault, Psa, Nissan, Ait, Lms.

"Waiting-to-cross" scenario

- Passing-by car (20 km/h)



- Recording of an electric vehicle (Renault, Idiada).
- Synthesis of each warning sound (Insa-Lyon).
- Binaural simulation of a moving source (Lms).
- Mixing with EV recording (Insa-Lyon).

Experiment 1 : sound detectability

- Goal : evaluate the influence of 3 timbre parameters on detectability
  - frequency bandwidth;
  - frequency modulation;
  - temporal modulation.

- All sounds have harmonic content (f_0 = 300 Hz).

		L1	L2	L3
F1	Nb of frequency components	3	6	9
F2	Frequency mod.	None	Sinusoïdal	Sawtooth
F3	Temporal mod.	None	Sinusoïdal	Irregular

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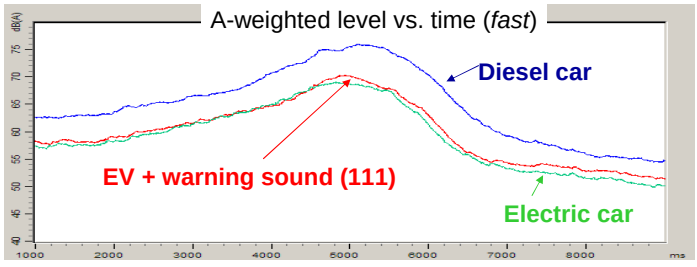
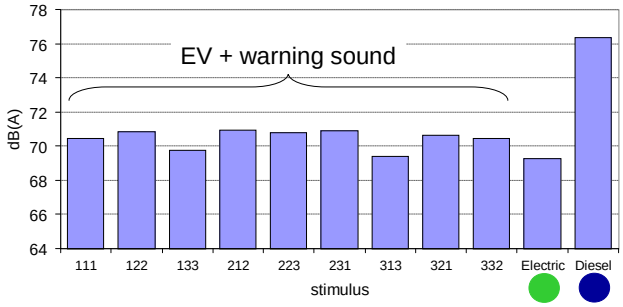
- 3 levels for each factor.
- Fractional experimental design : 9 combinations.
- All sounds have the same A-weighted level.

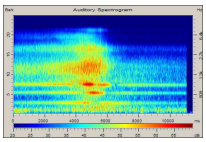
Sound levels

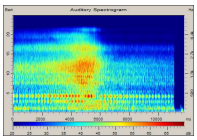




Procedure

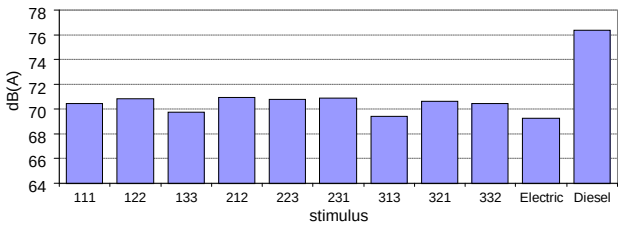
- 11 stimuli (EV, EV+warning sound, diesel car).
- 8 repetitions for each stimuli (left-right or vice-versa).
- Two background noises (69 dB(A)) : with or without rain.
- Headphone presentation (Stax Lambda Pro).
- Task :
  - detect the car as soon as possible, identify the direction of the car (left/right).
- 162 participants :
  - "wet" background noise : 116 Ss (37 VI, 79 sighted);
  - "dry" background noise : 46 Ss (20 VI, 26 sighted).



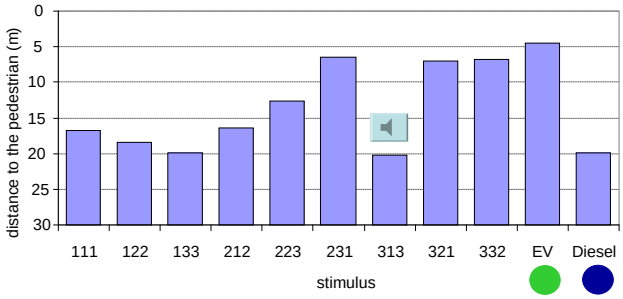


Main results (e.g. : "wet" background noise)

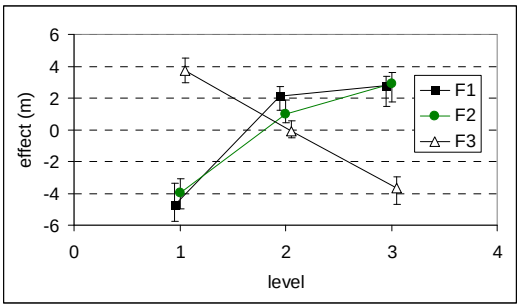
Maximum of A-weighted level



Detectability



Factors effects



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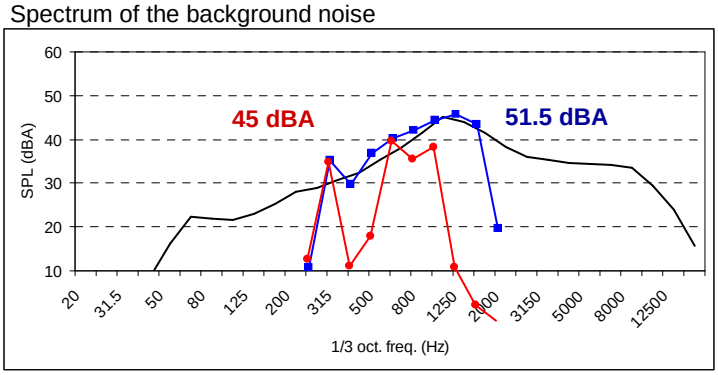
Benefit of a limited bandwidth

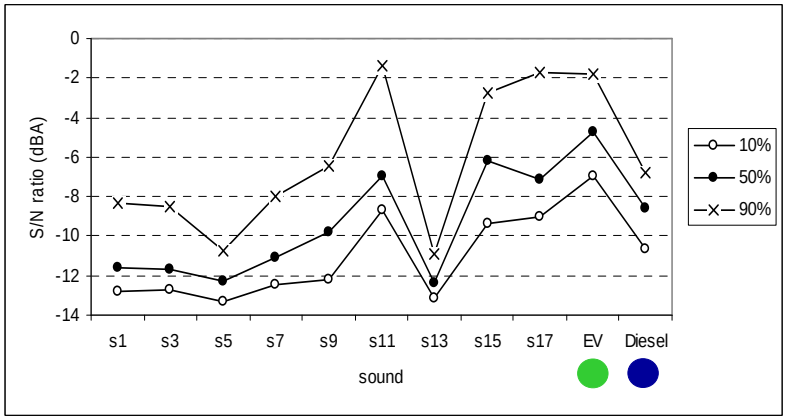
Spectrum of the background noise



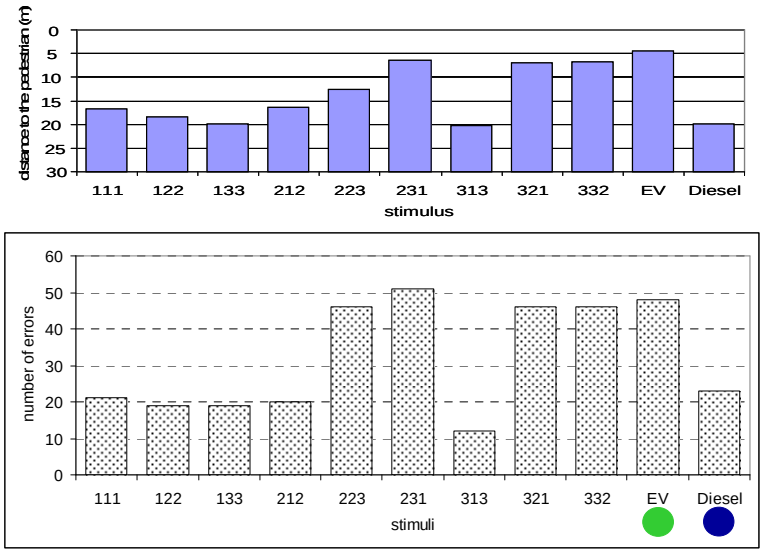
3 components **9 components**

Signal-to-noise ratios at detection

- The response time for 90% of trial was converted to SNR.



Localization errors



Conclusion of the detectability experiment

- temporal irregularity helps detectability;
- a warning sound should have a limited bandwidth !

- In contradiction to current regulations…..

3rd octave band	Table 1 STAT ACT	Table 2 BACKING	Table 3 CRS 10	Table 4 CRS 20	Table 5 CRS 30
	49	52	55	62	66
Hz	dB(A)	dB(A)	dB(A)	dB(A)	dB(A)
315	42	45	48	54	59
400	43	46	49	55	59
500	43	46	49	56	60
2000	42	45	48	54	58
2500	39	42	45	51	56
3150	37	40	43	49	53
4000	34	36	39	46	50
5000	31	34	37	43	48

(NHTSA)

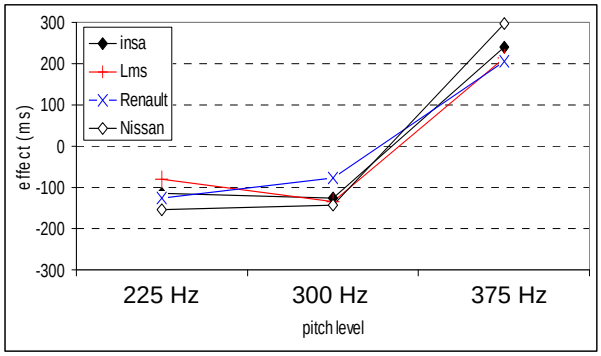
Experiment 2 : sound meaning

- Can pedestrian get some information about the speed and the distance of the car from the warning sound, and without any training ?

- Procedure :
  - approaching cars, 20 or 30 km/h;
  - quieter background noise (the car was clearly detected);
  - different warning sounds (pitch, speed of the amplitude irregularity);
  - Question : when do you think it is too late for you to cross the road safely ?
  - 125 participants (40 VI, 85 sighted).

Results

- Significant factors :
  - speed : the difference between 20 and 30 km/h is about - 400 ms;
  - pitch, in an unexpected way.



Results

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  - speed : the difference between 20 and 30 km/h is about - 400 ms;
  - pitch, in an unexpected way.

- At low speeds, perception of distance is mainly based on the motion-induced rate of change of intensity (Lutfi and Wang 1999, Kaczmarek 2005).

- Of course, pitch variation gives information about the speed variation of the car.

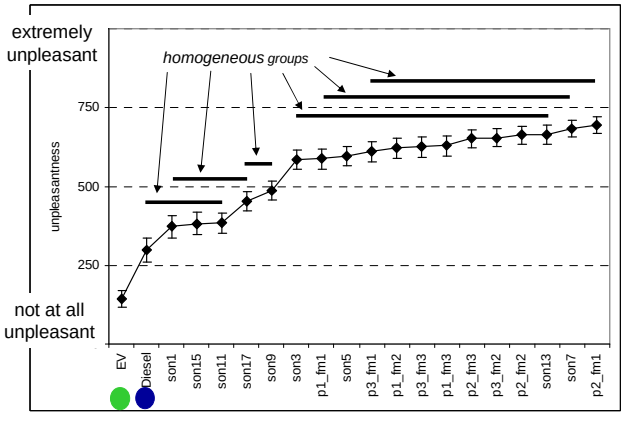
Experiment 3 : unpleasantness

- 20 sounds (20 km/h, already used in previous experiments);
- each sound is presented twice (random order);
- subject's task : to evaluate the unpleasantness of the sound;
- 145 participants :
  - 56 : no background noise;
  - 89 : low-level background noise (57 dBA).

- 56 reliable subjects (based on individual consistency, i.e. mean difference between the two evaluations of each sound).

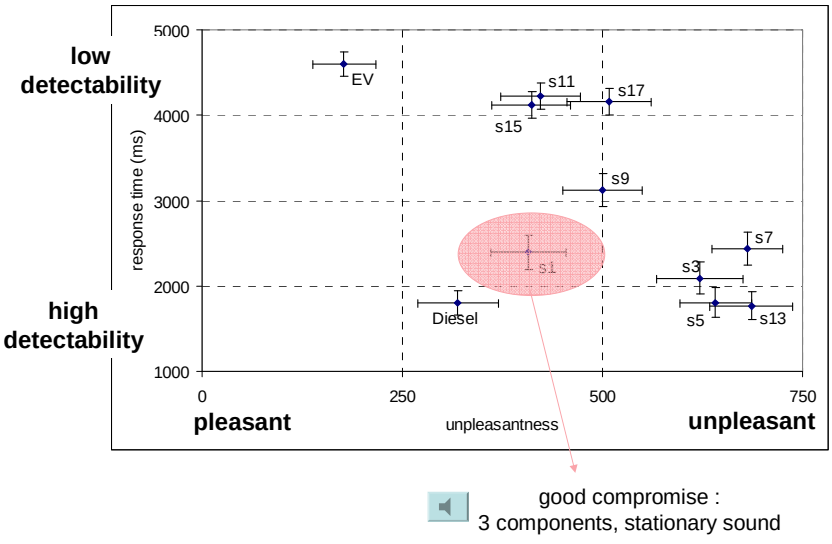
Results

- Unfortunately, people did not like our warning sounds !



- because they are not used to such sounds ?

Detectability vs. unpleasantness



good compromise :
3 components, stationary sound

Conclusion

- Some guidelines for an increased detectability of low-level warning sounds could be established.
- On-going regulations may not be optimized.
- Difficult compromise between detectability and unpleasantness.