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!

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**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).

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<th>L1</th>
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<tbody>
<tr>
<td>F1 Nb of frequency components</td>
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<td>6</td>
<td>9</td>
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<tr>
<td>F2 Frequency mod.</td>
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<td>Sinusoidal</td>
<td>Sawtooth</td>
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<tr>
<td>F3 Temporal mod.</td>
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<td>Irregular</td>
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- 3 levels for each factor.
- Fractional experimental design: 9 combinations.
- All sounds have the same A-weighted level.

Sound levels

- A-weighted level vs. time (fast)

  - Diesel car
  - Electric car
  - EV + warning sound (111)

- EV + warning sound
**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: 45 dBA
- 9 components: 51.5 dBA
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…..

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<tr>
<th>3rd octave band</th>
<th>Table 1</th>
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(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.

- 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

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.