Contribution au design de sons pour véhicules électrique

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Journées Techniques Acoustique et Vibrations 2024

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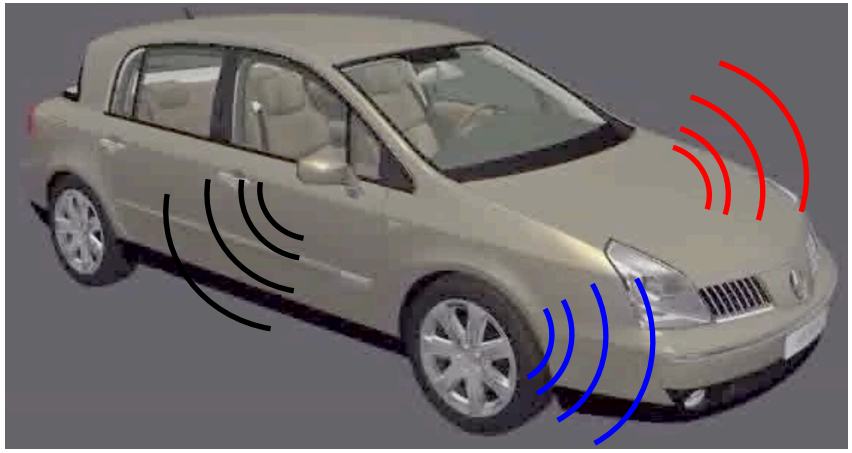
CONTEXT

3 main sources of noise in a vehicle

- Engine sound
- Tire/road interaction: V > 30 km/h
- Aerodynamical noises: V > 30km/h



Motivations

- Electric vehicles (EVs) are silent and dangerous at low speed (V<50km/h)
  - Pedestrians
  - Visually impaired people
- Adding sounds is compulsory in EU, Japan and US
  - Regulations (2019) still under study

- => Design of artificial sounds for EVs
- AVAS (Acoustic Vehicle Alerting System)

DESIGN PROBLEM

- Many conflicting requirements
  - Improve the detectability of EV
  - Control the unpleasantness (…if not pleasant…)
  - Improve the values of the brand
  - Reinforce the vehicle character (sporty, funny, …)
  - Improve the driving experience
  - …

=> Focus on the tradeoff detectability/unpleasantness in the point of view of a pedestrian

- Research objective
  - Set up users tests to assist the design of sounds for EV
  - Demonstrate the potential of Interactive Genetic Algorithm (IGA) to propose relevant designs

Optimization of a parametric sound synthesis based on hearing tests with a panel of users [1]

[1] Ava Souaille, Conception Interactive en Design Sonore. Thèse de Doctorat de l'Ecole Centrale de Nantes, 22/03/23.

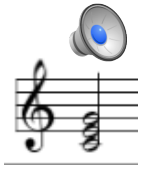
OUTLINE

- Parametric sound synthesis
- Optimization with IGA
- Perceptual experiment
- Results
- Conclusions

SYNTHESIS OF EV SOUNDS

- Additive synthesis technique
- Mix of 4 components C1, C2, C3, C4

- Component C1 ‘A combustion engine sound’
  - the first harmonics of a classical 4-cylinders internal combustion engine (harmonics H0.5, H1, H1.5, H2, H4, H6).



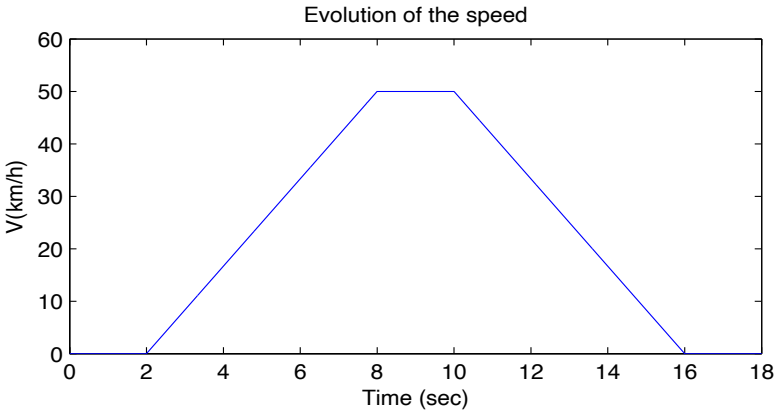
- Component C2 ‘A Harmonic Sound’
  - different musical ‘notes’ that constitute a chord (chord with 2, 3, or 4 notes)

- Component C3 ‘A broad band Noise’
  - filtered noise

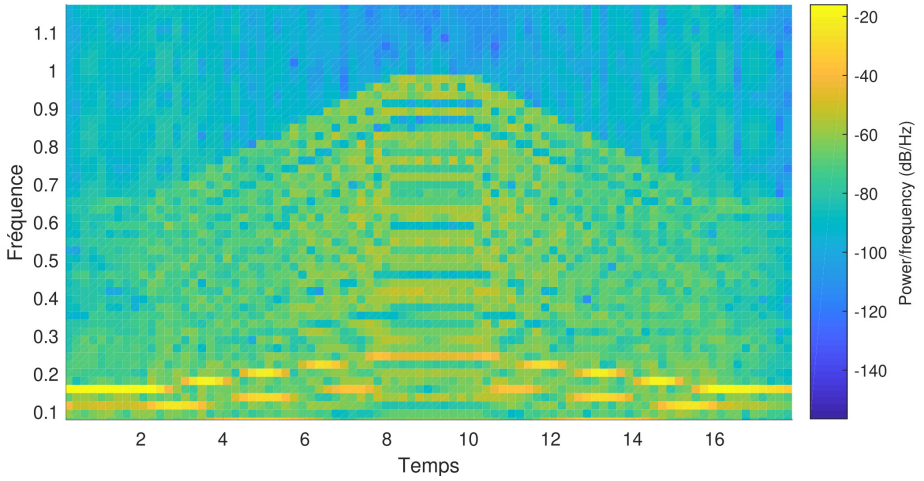
- Component C4: ‘A narrow band noise’
  - + “temporal events” in the sounds

SYNTHESIS OF EV SOUNDS

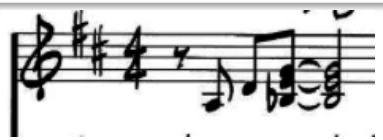
- All frequencies and amplitudes are adjustable (more than 70 parameters to define a sound)
- The sound is played by control parameters of the car
  - Mapping (frequency-speed) – (intensity-load)



Spectrogram



Speed pattern = musical score
Sound synthesis = instrument



DESIGN VARIABLES OF THE SYNTHESIS

Among the 70 independent variables to define a sound

- Choice of 6 design variables (and their levels) for the optimization

Factor	*Variable*	*Level 1*	*Level 2*	*Level 3*	*Level 4*
C1	Fundamental frequency of C1	70Hz	100Hz	130Hz	160Hz
C2	Fundamental frequency of C2	100Hz	150Hz	200Hz	250Hz
C3	Central frequency of C3	100Hz	200Hz	300Hz	400Hz
C4	Central frequency of C4	500Hz	600Hz	700Hz	800Hz
Amp	Amplitude of C1, C2, C3, C4	$a_{C1} = 2$ $a_{C2} = 1$ $a_{C3} = 0.75$ $a_{C4} = 0$	$a_{C1} = 0.5$ $a_{C2} = 0.75$ $a_{C3} = 1.5$ $a_{C4} = 0.33$	$a_{C1} = 0.25$ $a_{C2} = 0.5$ $a_{C3} = 0.1$ $a_{C4} = 0.25$	$a_{C1} = 0$ $a_{C2} = 0.1$ $a_{C3} = 0.1$ $a_{C4} = 0.5$
Filter	Type of filter	None	Sweeping filter	Flanger	Sweep+flanger

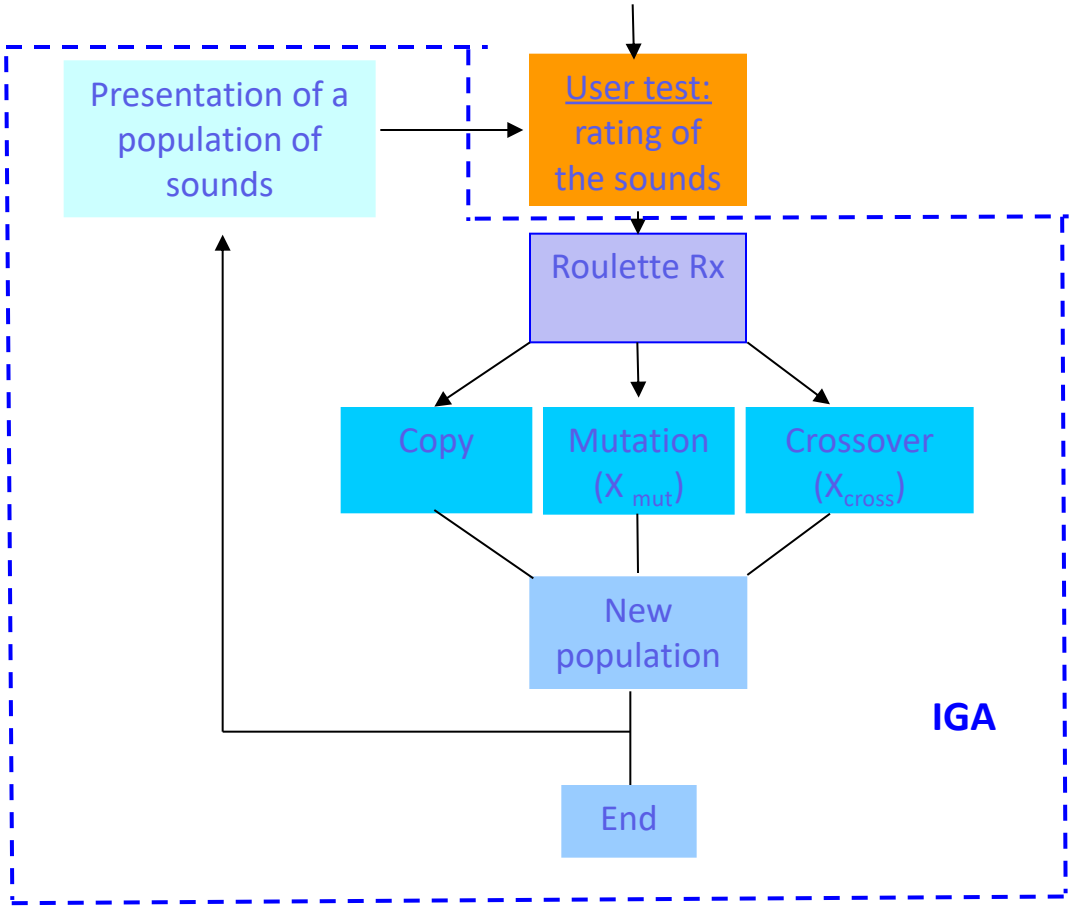
Examples

Low pitched 

High pitched 

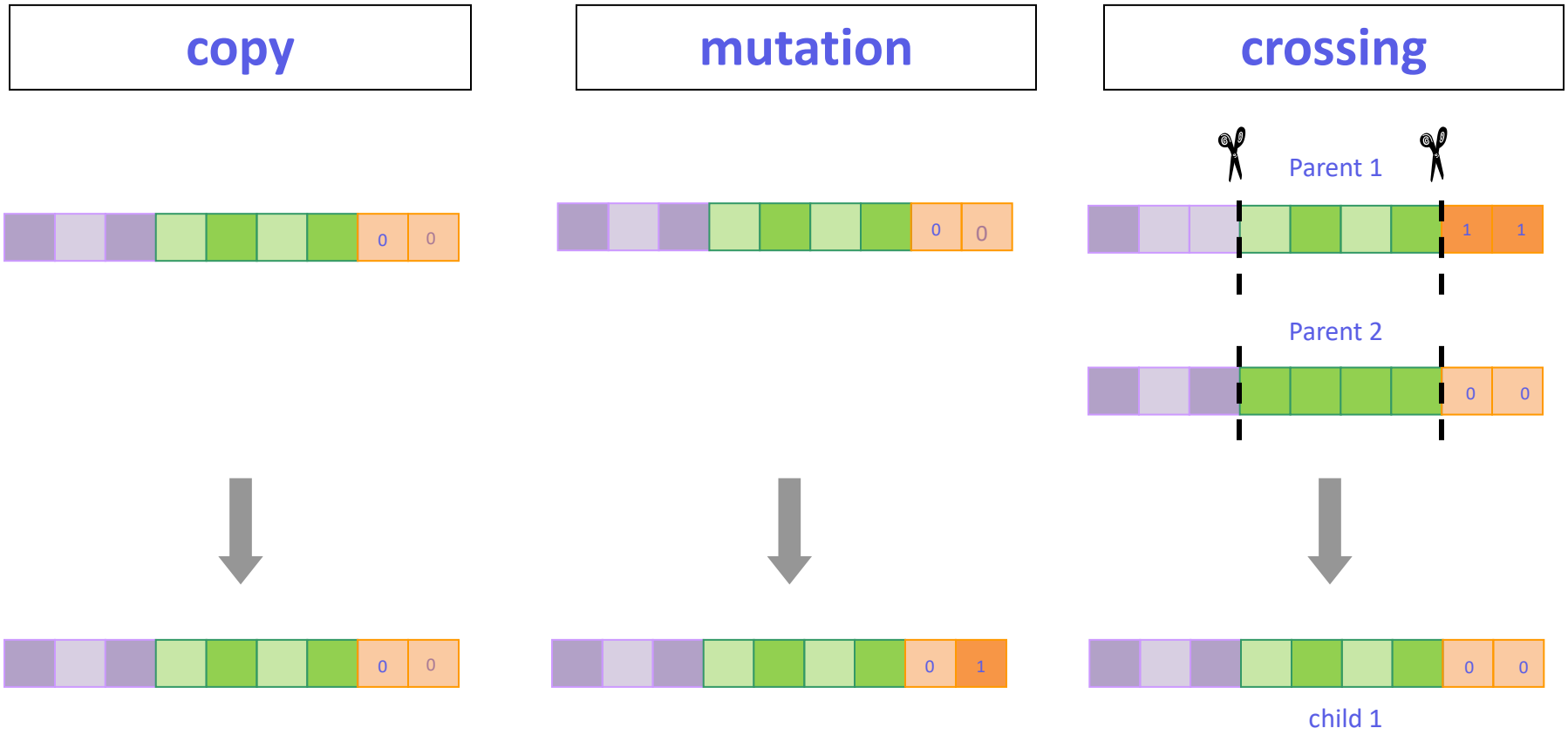
BACKGROUND ON IGA

- Evolutionary optimization methods
- Improvement of the fitness of a population of designs (defined by the user)
- Increase the reproduction of the best solutions (roulette wheel)



3 parameters of IGA
- Roulette wheel Rx
- Mutation X_{mut}
- Crossover X_{cross}

Principles of Interactive genetic algorithms (IGA)



[1] Poirson E., Petiot J-F., Boivin L., Blumenthal D. Eliciting User Perceptions Using Assessment tests based on an Interactive Genetic Algorithm. Journal of Mechanical Design, Vol. 135, Issue3, 031004 -1-16 March 2013

PERCEPTUAL EXPERIMENT

Aim

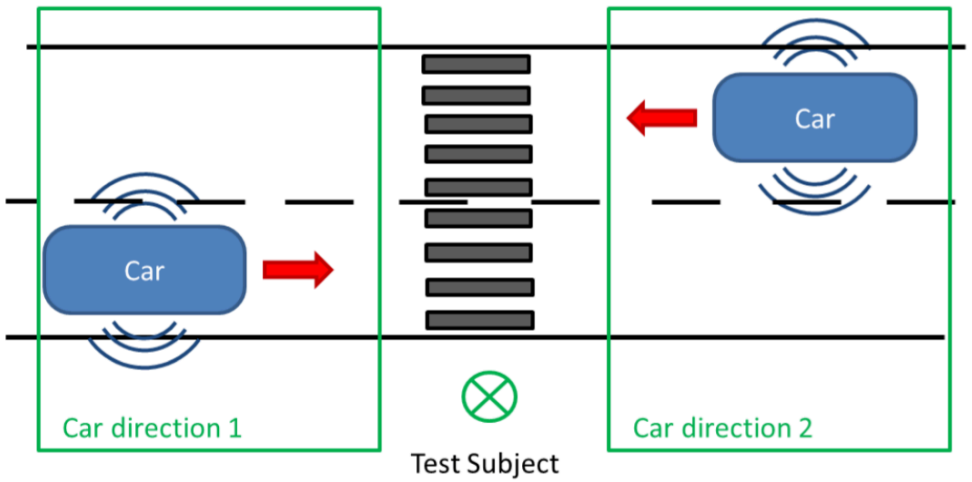
Setting up of a listening test to assess detectability and unpleasantness

Set up: 32 participants, Hearing with headphones

Method

1. Integration of the EV sound in a urban soundscape
2. Definition of a passing by scenario (sound stimuli)
   1. The pedestrian stays still
   2. The EV car may come from the left, or the right

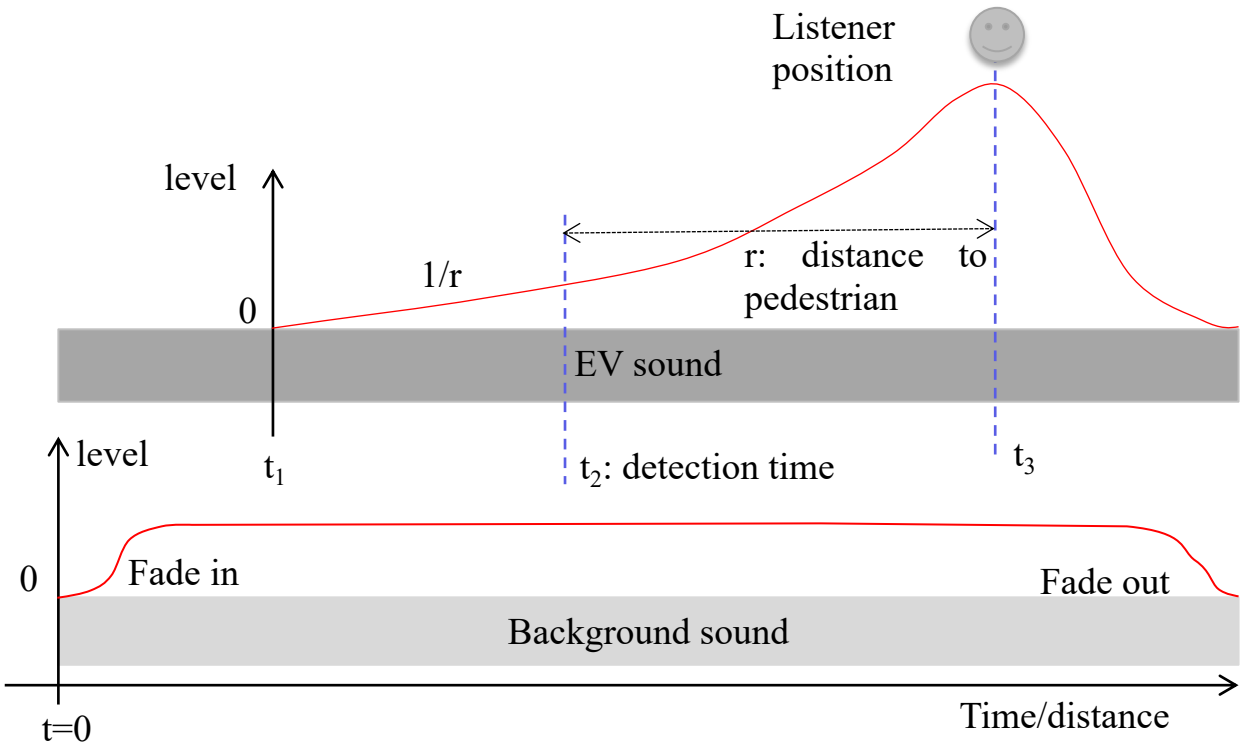
Passing by scenario



DESIGN OF THE STIMULI

Method:

1. Integration of the EV in a urban soundscape
2. Simulation of the « passage » of the car on the road
   - Panning (left/right)
   - Level increase/decrease
   - Doppler effect
   - The car may come from the « left » or the « right »



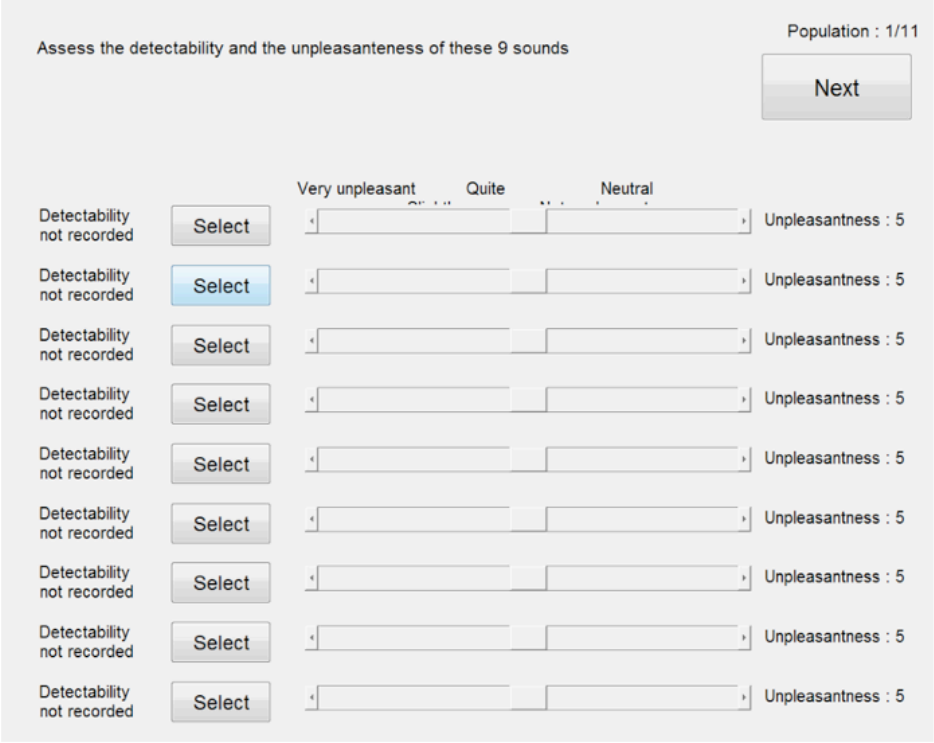
[1] Tom Souaille, Jean-François Petiot, Nicolas Misdariis, and Mathieu Lagrange. An interactive bi-objective optimization process to guide the design of electric vehicle warning sounds. *Design Science*, Volume 8, 2022 , e26

Task of the participants

1) IGA test

11 populations of 9 sounds

1. Detect the direction of the car => strike the « A » or the « P » key
   Computation of the detection time
2. Rate the unpleasantness
   Continuous scale



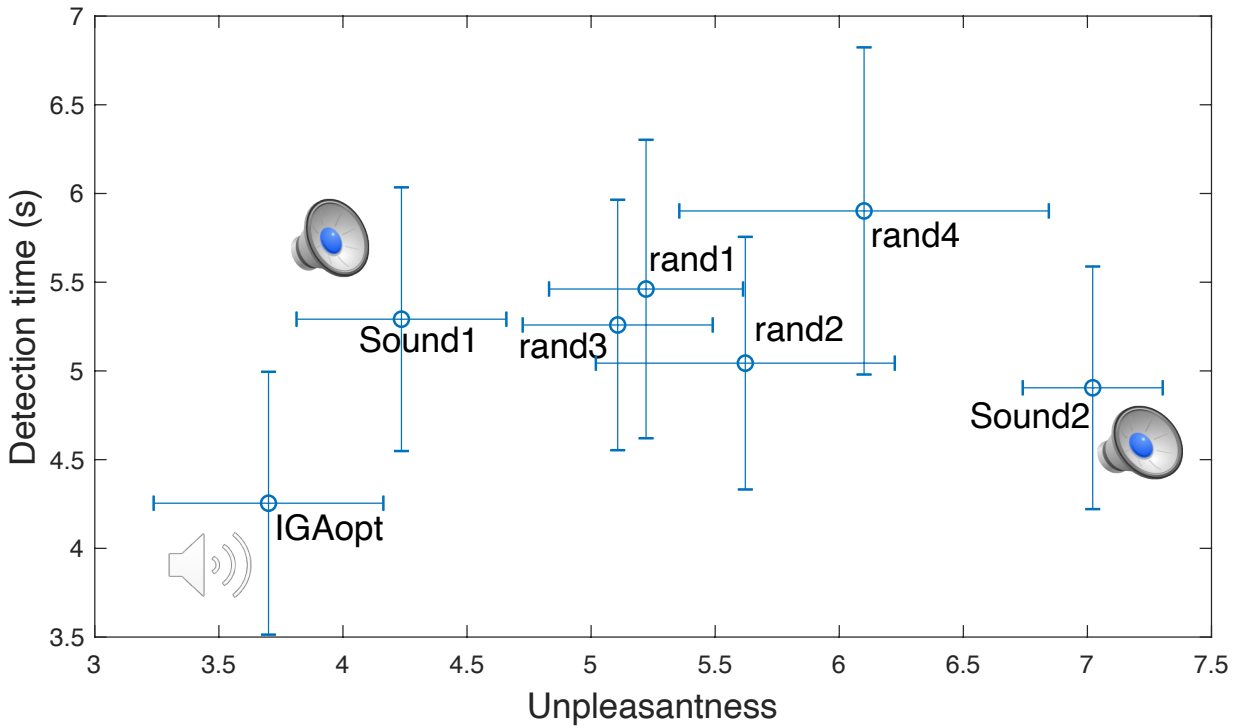
2) Assessment test

IGAopt sound + 2 sounds proposed by a designer (sound1 , sound2) + 4 sounds chosen randomly in the design space (rand 1, rand2, rand3, rand4)

1. Detect the direction of the car => strike the key => detection time
2. Rate the unpleasantness

RESULTS (1)

Performances of the different EV sounds

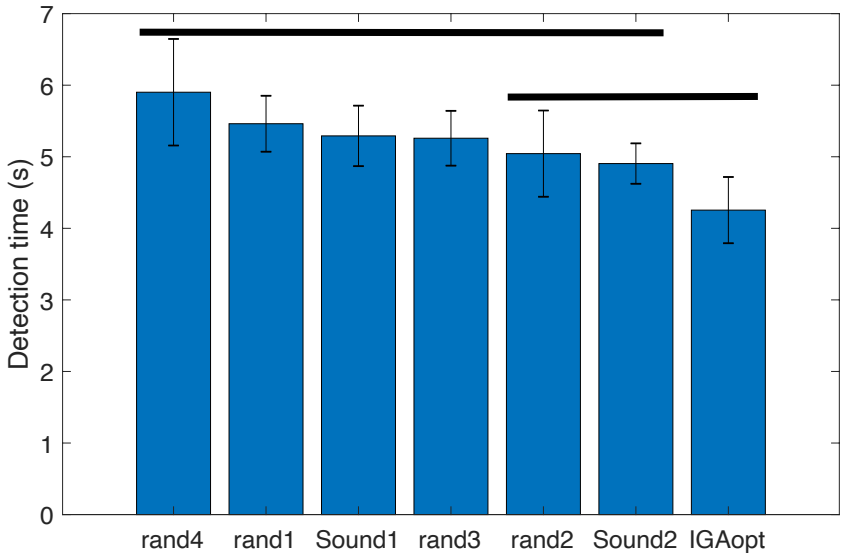


=> IGAopt is Pareto efficient

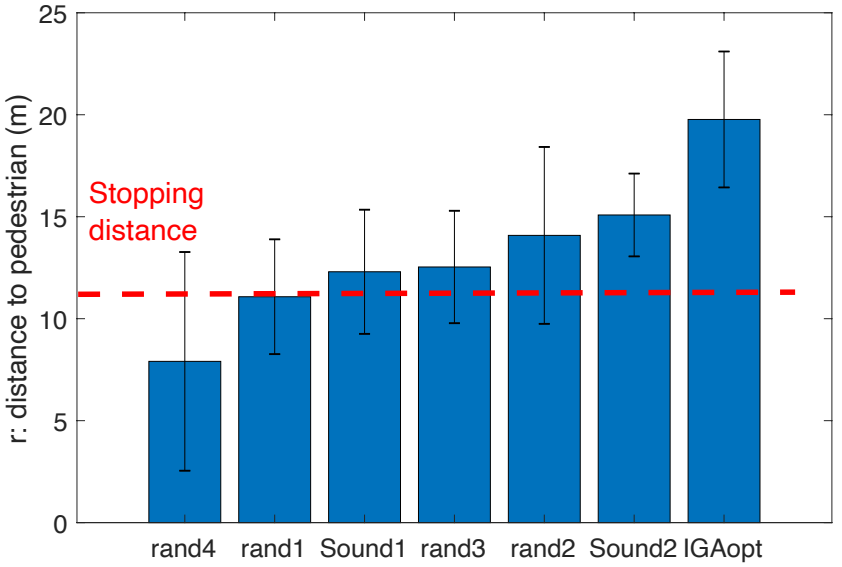
RESULTS (2)

Detection time/distance to pedestrian:

Detection time



Distance to pedestrian



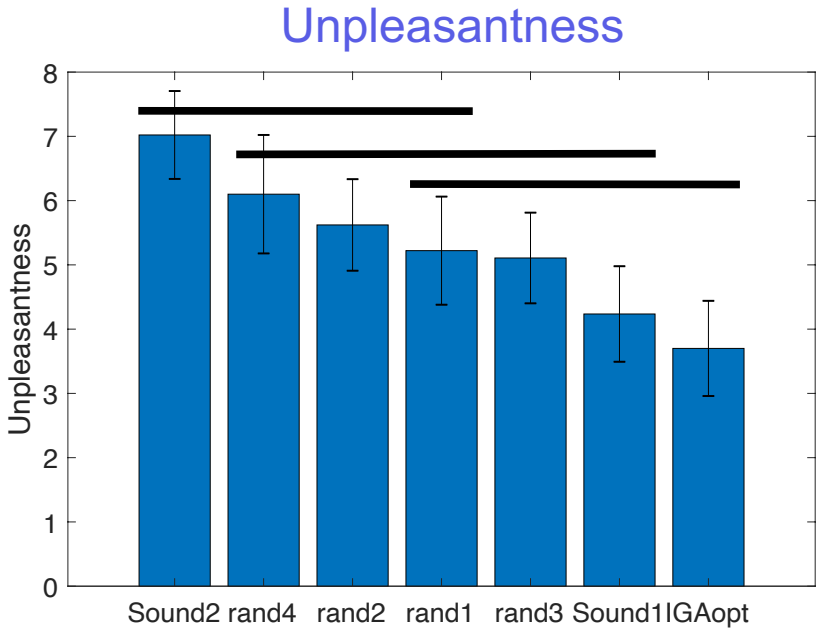
IGAopt: the smallest detection time

Sound2 has also a low detection time

Risk for sound rand4 and rand1:
Detection time is too long,
distance to pedestrian is lower than the stopping distance (11m)

Paired t-test with Bonferroni correction ($p<.05$)

RESULTS (3)



IGAopt: the lowest unpleasantness
Sound 1 is also not unpleasant

Paired t-test with Bonferroni correction ($p<.05$)

CONCLUSIONS

- The perceptual experiment + the IGA allows the improvement of the fitness of sounds
  - Decrease of the detection time, and of the unpleasantness
- No noticeable fatigue of the user, the test is short enough
- The sounds proposed by IGA are better compromises than the 2 designer's proposals (sound 1 and sound 2).

- Additional works
  - Comparison of IGA with classical DOE approach [1] (coll. Peugeot Citroen SA)
  - Definition of a method for the selection of design variables
- Perspectives
  - Test other Interactive algorithms
  - Take into account several outputs (sound quality, brand image, …)

[1] **Petiot J-F**., Villa S., Denjean S., Diaz E. Design of warning sounds using an interactive genetic algorithm. Proceedings of Forum Acusticum 2020, December 2020, Lyon, France, pp.107-114

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