Influence of tonality on the annoyance of tyre exterior noise

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Motivation of the study

- The Leon-T project (www.leont-project.eu)
  - Low particle Emissions and lOw Noise Tyres (H2020 2021-2024, project n° 955387)
  - Investigates particles and noise emissions of tyres (focus on HGV tyres)
  - Development of an airless tyre
  - Partners : Applus+ Idiada, Ford, AUDI, TNO, VTI, RIVM, Univ. Gothenburg, INSA-Lyon, JRC, EuroTurbine

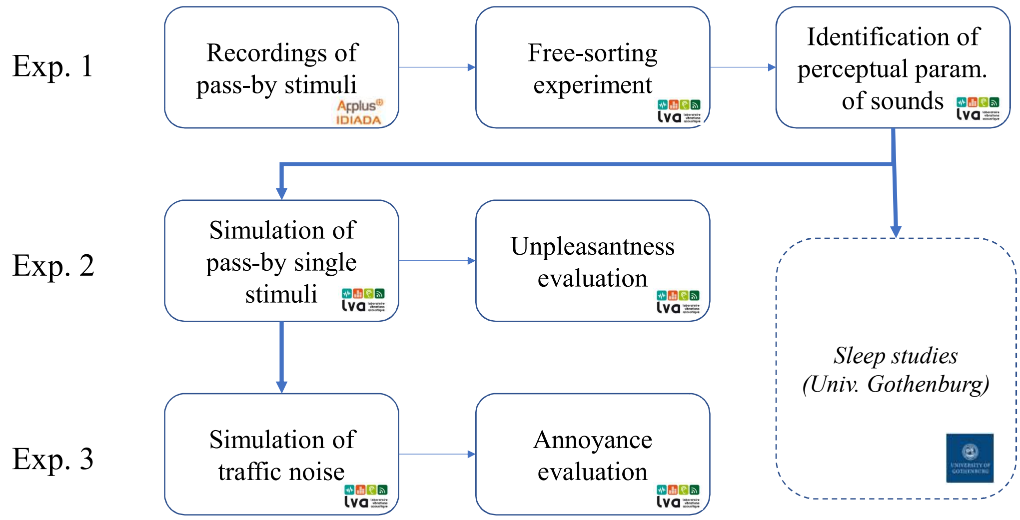
Tyre noise perception

- Interior tyre noise : a very few number of studies
  - description of sounds by professional drivers (*drumming, booming, pattern noise*….) [*Buss et al., 2001*]
  - Important sound characteristics (*loudness, spectral balance, tonal component*) [*Franck et al., 2007*]
  - Contribution of sound characteristics (*amplitude modulation, tonality*) to sound quality [*Bekke et al., 2014*]
- Exterior tyre noise : even fewer studies
  - Listeners can perceive differences in sharpness and roughness [*Hoffman et al., 2016*]
- No studies about HGV tyres

The Leon-T project

- Regarding noise emissions, the project aims to :
  - Identify the important perceptual parameters of external pass-by tyre noise
  - Evaluate the contribution of these parameters to annoyance (for residents living near an expressway)
  - Evaluate the effect of tyre noise on sleep quality

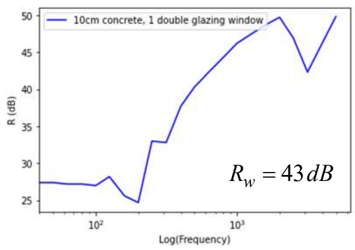
Overview of the presentation : 3 experiments



Experiment 1 : important parameters of tyre sound

- Recordings of pass-by tyre sounds (Idiada)
  - Procedure compliant with UN/ECE R 117
  - Constant speed : 70 kph
  - 3 vehicles, C1, C2 and C3 tires
  - C3 tires : steering and traction tyres

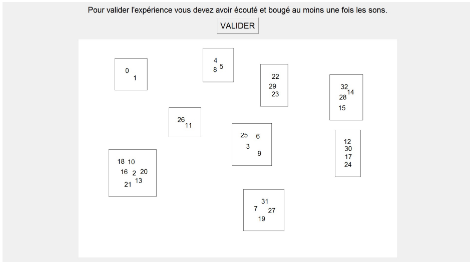
- Filtering of stimuli to create "indoor stimuli)



Experiment 1 : important parameters of tyre sound

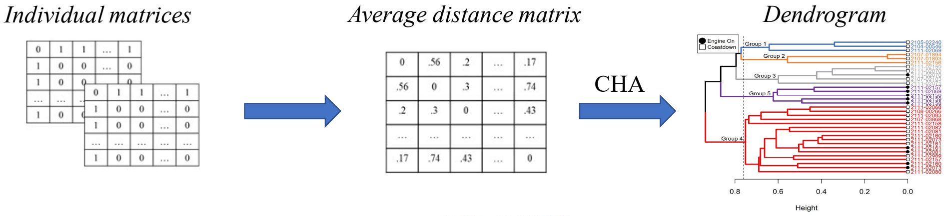
- 2 sets of 33 recordings (outdoor / indoor condition)
  - Short stimuli (2.6 s., i.e. $\pm 25\ m$. from the microphone)

- 2 listening tests (outdoor / indoor condition)
  - Participants : 53 normal-hearing students
  - Presentation : headphones (Sennheiser HD650) in a soundproof booth
  - Procedure : free sorting of similar sounds (*Koehl et al., 2007*)



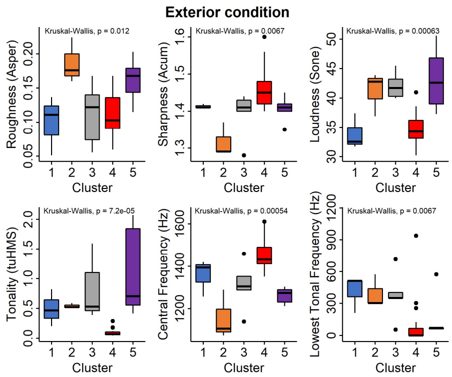
Experiment 1 : results

- Results of the free sorting experiment : individual co-ocurrence matrices (0/1) of stimuli
- Averaging of individual matrices leads to a mean distance matrix
- Clustering of this matrix (CHA, mean aggregation rule) allows to define groups of similar sounds.
  - Outdoor condition : 5 groups
  - Indoor condition : 2 groups

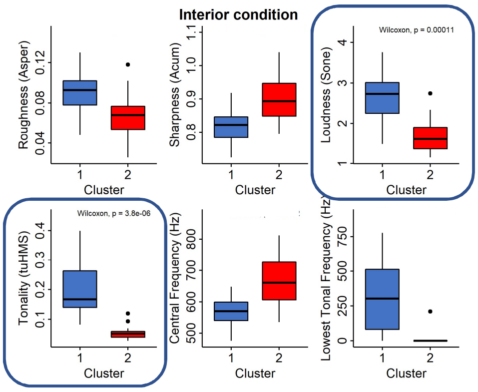


Important perceptual parameters

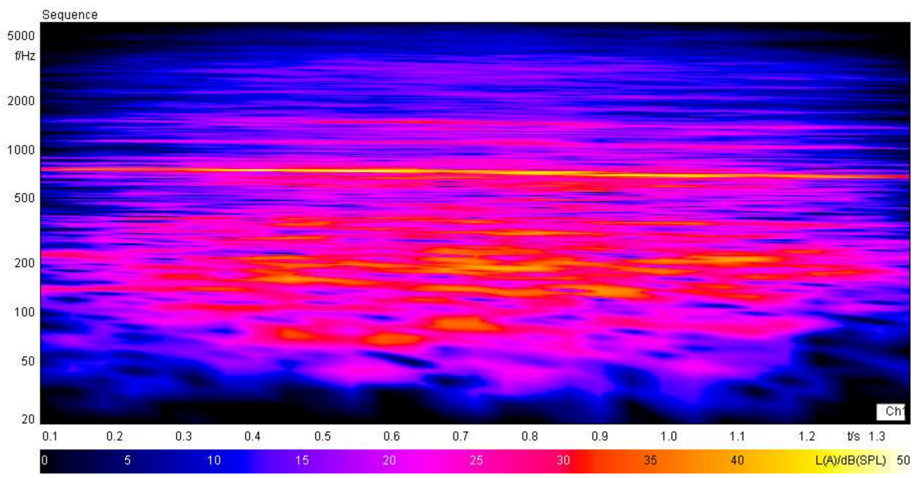
- Outdoor condition : differences in loudness, sharpness, roughness, tonality…



- Indoor condition : differences in loudness and tonality

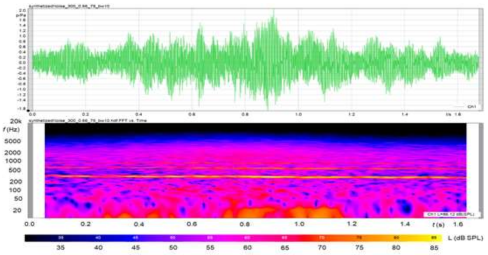


Tonality for indoor tyre sound ?



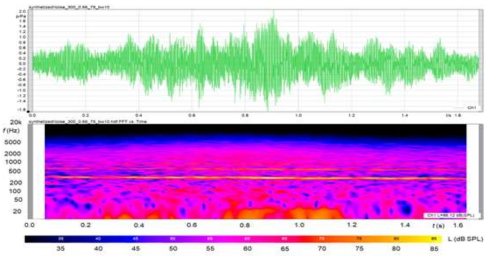
Experiment 2

- Evaluation of the contribution of sound pressure level and tonality on the unpleasantness of tyre sounds
- Procedure : experimental design (sound synthesis)
  - $s(t) = (1 - TF).Noise(t) + TF.Tonal(t)$
  - $Noise(t)$: averaged spectrum of noisy parts of all recorded sounds
  - $Tonal(t)$: combination of 3 tones $(f_0, 2.f_0, 3.f_0)$
  - TF : tonal factor $(0 \leq TF \leq 1)$
  - Application of a Doppler effect and a distance effect.
  - Filtering to simulate the facade attenuation.



Experiment 2

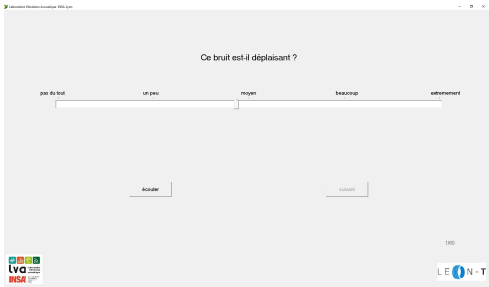
- Evaluation of the contribution of sound pressure level and tonality on the unpleasantness of tyre sounds
- Procedure : experimental design (sound synthesis)
  - $s(t) = (1 - TF).Noise(t) + TF.Tonal(t)$
- Factors :
  - Tonal Factor TF : 0, 0.25, 0.5
  - Pitch f_0 : 300, 500 Hz
  - Bandwidth of tones : 2 levels
  - Sound pressure level : 40, 46, 52 dB(A)
- 30 stimuli $(f_s = 44.1\ kHz, 1.6\ s.)$



Experiment 2

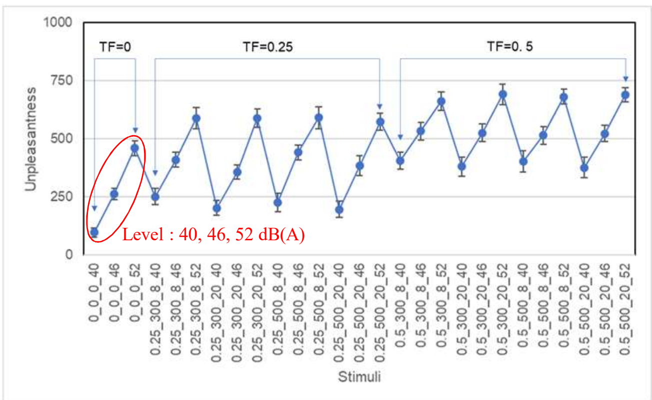
- Sound presentation : headphones (Sennheiser HD650)
- Participants : 31 normal-hearing students
- Question : *how unpleasant is that sound ?*

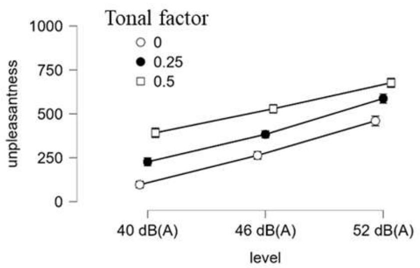
- Random presentation of sounds



Experiment 2 : results

- Sound pressure level and tonality equally contribute to unpleasantness.





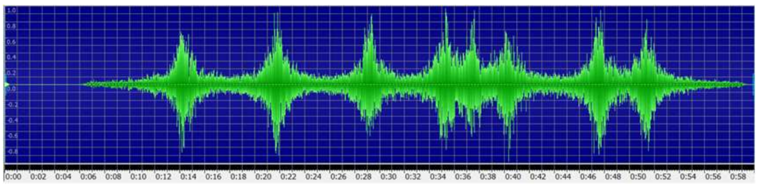
Marin-Cudraz et al., Applied Acoustics (accepted)

Experiment 3

- Limitations of experiment 2 :
  - Participants focused on the sounds (unpleasantness evaluation)
  - Very short stimuli
  - Young participants
- Goal of experiment 3 :
  - Evaluation of traffic noise annoyance for people involved in a relaxing activity
  - Considering older participants also

Experiment 3 : procedure

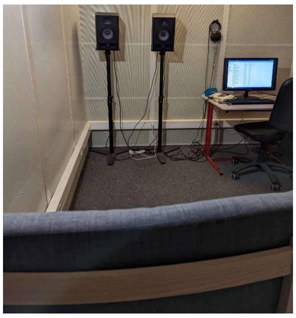
- Synthesis of a traffic flow (all vehicles drive at 70 km/h) during 10 minutes.
  - Traffic flow representing the one on Paris ring road, late evening (https://opendata.paris.fr)



- For each vehicle, noise synthesized as in experiment 2, with 2 factors only
  - Level (LeqA) : 40 – 52 dB(A)
  - Tonality (ratio tone/noise levels) : 0 – 0.5
    - f_0 randomly selected between 300 and 500 Hz

Experiment 3 : procedure

- 47 normal-hearing participants
  - 24 students (< 31), 23 people between 41 and 60.
- Relaxing activity (reading a magazine, playing crosswords…) in a comfortable chair.



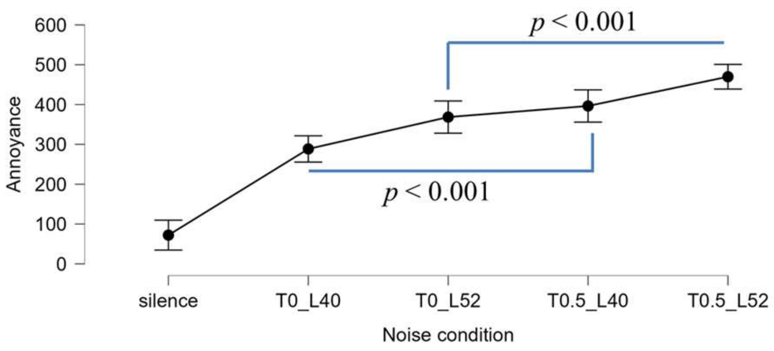
- Exposure time : 10 mn for each noise condition.

Experiment 3 : procedure

- 5 noise conditions (10 *mn*, randomized order)
  - Silence, 2 tonality values, 2 SPL values
  - For each participant, each condition is synthesized using random selections of pitch (in the "tonal" conditions) and arrival times of vehicles.
- Measurement :
  - After each condition :
    - Noise annoyance : continuous scale between "not at all annoying" to "extremely annoying"
    - Fatigue : MFI questionnaire (*Fillon et al., Cancer Nurs. 2003*)
  - Permanently : physiological parameters (Empatica E4) :
    - Temperature, electro-dermal activity, heart rate

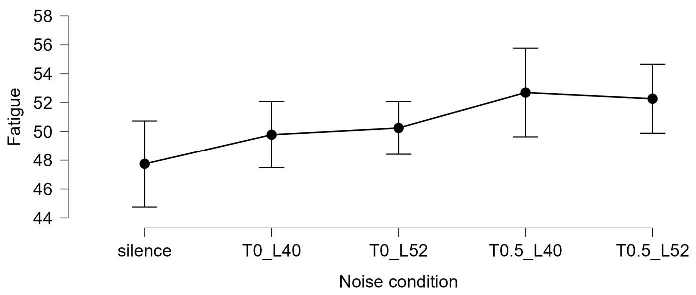
Results : Annoyance

- No order effect
- Significant effect of noise level and tonality



Other results

- No effect could be obeserved on self-assessed fatigue or physiological parameters.



- The task was not demanding, and the exposure time rather short…

Conclusion

- The filtering of a facade reduces the set of perceptual parameters of pass-by tyre sounds
- For indoor sounds, tonality and sound pressure level both contribute to unpleasantness and annoyance
- Current regulations only take account of sound pressure level: introducing tonality could be an improvement.

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