Research and Innovation action

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LEON-T

Low particle Emissions and lOw Noise Tyres

Deliverable No.	D4.1	
Deliverable Title	Definition of the acoustic perceptual space of tyre noise and creation and synthesis of tyre sound stimuli for health studies.	
Dissemination	PU	
Written by	Thibaut Marin-Cudraz (INSA Lyon)	03/03/2022
Checked by	Etienne Parizet (INSA Lyon)	11/03/2022
Approved by	J.J. Garcia (IDIADA)	04/04/2022
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Revision history

REVISION	DATE	DESCRIPTION	AUTHOR (ORGANIZATION)
1	31/03/2022	First complete version of the deliverable	Thibaut Marin-Cudraz (INSA Lyon)

List of abbreviations and acronyms

Abbreviation	**Meaning**
HGV	Heavy Goods Vehicles
M/S	Mountain/Snowflake

Content

1 – Public Executive Summary

This document presents the first set of listening test experiments conducted at INSA Lyon. The goal of these experiments was to allow the knowledge of the acoustic perceptual space of tyre noise and the definition of the sound parameters to be considered in the evaluation of noise annoyance (to be done in the next experiment) and in the sleep studies to be conducted at UGOT.

Thirty-four passing-by noises were recorded by Applus+ IDIADA on an ISO track. These sounds have been filtered in order to simulate the isolation of a typical building façade. The two sets of sounds (exterior and interior ones) were presented to listeners (through high quality headphones) in two different experiments. For each condition, a free sorting task procedure was used: the listener was asked to group together stimuli which sounded similar. Fifty-three people participated to these experiments.

Individual results were used to build two distance matrices, related to the similarity of sounds, in each possible pair. Then a clustering algorithm was used, using these mean accordance matrices as inputs. It appeared that 5 groups could be built in the "exterior" condition, whereas 2 groups only defined the perceptual space in the "interior" condition.

The relationship between the composition of each group and some technical features of tyres (or vehicles) as well as some acoustical features of sounds could be established. More precisely, for the outdoor condition, important acoustical dimensions proved to be loudness, roughness, spectral balance of the noisy part (the part of the signal that is not a tone) and tonality. For the indoor condition, which is the most important one for the other studies to be conducted in the project, loudness and tonality were the key features.

Following those results, stimuli have been synthesized in order to generate sounds with specific values of these important parameters, i.e., loudness, tonality (amplitude and frequency of an emerging tone) and the frequency balance of the noisy part. These artificial sounds will be used in an experiment to assess their short-term unpleasantness, which will be reported in D4.2. Results will allow to evaluate the relative contribution of the above-mentioned parameters, which will help UGOT in the selection of the stimuli to be used in the sleep experiments.

Then, annoyance will be evaluated in another experiment in which exposure duration will be greater. This annoyance will be evaluated through assessment given by the participants and physiological data measured while participants will be asked to do a simple task (e.g. reading a book). This activity will be reported in D4.2 and D4.3.

2 – Definition of the acoustic perceptual space

2.1 – Sound stimuli

2.1.1 – Exterior listening condition

The sound stimuli were taken from the set of recordings made by Idiada on the ISO track (for more details see Annex 1 and Support deliverable D1.1: Tyre rolling sound emission test). As the microphone was 7.5 meters from the recording track, the resulting recordings were ideal for simulating a listening condition where the listener would be close to the road, i.e. the 'Exterior' condition.

The recordings were made at different speeds (50, 70 and 90 km/h). However, preliminary listening has shown that vehicle speed modifies the timbre of the sound in only two aspects: an increase in onset rate, sound level and in the frequency of the emerging tone (if any). Therefore, to reduce the duration of the experiment, only recordings made at 70 km/h were used.

One recording was removed from those 34 recordings, as an additional metallic noise could be clearly heard (in addition to the vehicle noise). Thus, the dataset for this exterior condition was made of 33 sounds. The global level of sounds ranged from 67.5 dB(A) to 80 dB(A) (computed with the "fast" time constant).

2.1.2 – Interior listening condition

The 'interior' condition aims to simulate a condition in which the listener is in a bedroom. Using a software specialized in building acoustics (AcouBAT by Cype: https://info.cype.com/fr/software/acoubat-by-cype/), we computed the isolation of a facade with the following properties:

- a 10cm thick concrete wall (21.32 m^2);
- a double-glazing window (1.44 m^2), equipped with an air intake and a rolling shutter box.

The volume of the bedroom was fixed to 50 m^3. These parameters represent a configuration that can be found throughout Europe while allowing for a global sound reduction of 43 dB (Fig.1), which satisfies all the current minimum regulations regarding outdoor noise in Europe [1].

The software computed the sound insulation index R'_w in dB (SPL) for frequencies ranging from 50 Hz to 5000 Hz. R'_w is the difference between the incident level (L_{pi}) and the transmitted level (L_{pt}) modulated by the surface of the wall (S), the volume of the room (V) and the reverberation time of the sound in the room (T):

$$(1)\ R'_W = L_{pi} - L_{pt} + 10 \times \log_{10} \frac{S}{0.161 \times \frac{V}{T}}$$

To simplify the process, no walls other than the one exposed to exterior noise was defined. The software thus neglect the last term of Eq.(1) to calculate only the simplest expression of R'w, R: the difference between the incident level (L_{pi}) and the transmitted level (L_{pt}):

$$(2)\ R = L_{pi} - L_{pt}$$

This can be written as an expression of the sound pressure for the incident sound (P_i), the transmitted sound (P_t) and the reference sound pressure in the air (P_{ref}):

$$(3)\ R = 10 \times \log_{10} \frac{P_i^2}{P_{ref}^2} - 10 \times \log_{10} \frac{P_t^2}{P_{ref}^2}$$

Which resulted in:

$$(4)\ R = 20 \times \log_{10} \frac{P_i}{P_t}$$

And finally:

$$(5)\ \frac{P_t}{P_i} = 10^{\frac{-R}{20}}$$

Thus, the quantity $10^{\frac{-R}{20}}$ can be considered as the frequency response of a filter. P_i corresponds to the sound recorded close to the ISO track.

Using the frequency response (Fig.1), the finite impulse response (FIR) filter of the corresponding was calculated with python (function firwin2 of the scipy library, see Fig.2). The number of taps (length of the impulse response) was fixed to 40000. The advantage of FIR filters is their linear phase and easy implementation: the filtering is applied using a simple convolution of the filter with the targeted signal. Thirty-three sounds were then obtained by application of this filtering to the 33 sounds of the exterior condition. The global level of sounds ranged from 26.7 dB(A) to 39 dB(A) (computed with the "fast" time constant).

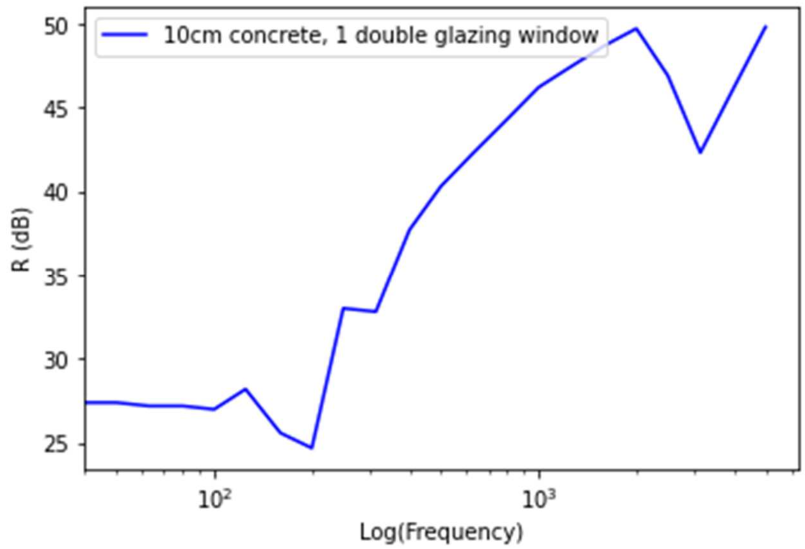

Figure 1: Frequency response of the filter for each 1/3 octave, corresponding to a global sound reduction of 43 dB.

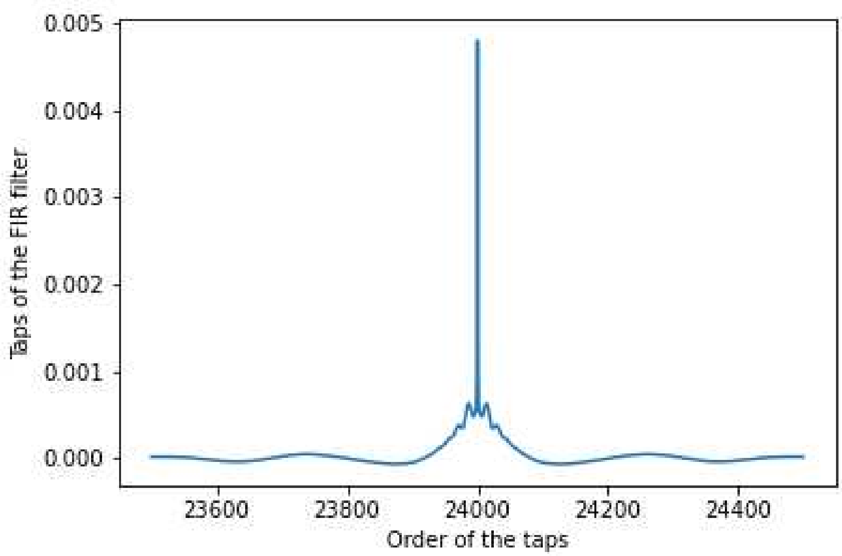

Figure 2: Finite impulse response (FIR) obtain from the frequency response of the filter. The figure is zoomed in for taps with an order around 24000, where the tap values are the most variable.

2.2 – Participants

Fifty-three students (18 women, 35 men) participated in the listening test. They were between 19 and 27 years old (mean age: 21.17 ± 1.78 years). Their hearing threshold was measured using a computer (Dell optiplex 9020) the Eolys Piston XP software, and 3M PELTOR Optime II headphones, in the sound proof booth of the Laboratoire Vibrations Acoustique at INSA Lyon (Fig.3). The audiometry was measured according to the ISO 8253-1:1989 standard (tonal audiometry, 7 frequencies between 125 and 8000

Hz) and showed that all participants had normal hearing (i.e. their hearing threshold was below 20 dB HL at all tested frequencies).

Figure 3: The soundproof booth during the experiment.

2.3 - Listening test protocol

The experiment took place in the same sound proof booth. It used the same DELL computer, linked to an USB audio interface (RME Fireface UC) and headphones (Sennheiser HD650). It was separated in two steps: a questionnaire to measure the participant's noise sensitivity and then the free sorting task of sounds. The questionnaire is the NoiSeQ-R [2], composed of 12 questions about noise tolerance at work, at home and during sleep. It gives a noise sensitivity score between 0 (not sensitive) and 3 (very sensitive).

The second phase, the free sorting task, used a graphical interface developed in-house (using Python [3] and tKinter [4]) where participants could freely move and listen to the sounds (converted in 16 bits rate WAVs with a sampling frequency of 44100 Hz), represented by numbers (Fig.4; Appendix 3 for the given instructions). The experimental setup was calibrated beforehand, with a binaural recording head combined with measuring microphones (Neutrik-Cortex Instruments 'MANIKIN MK1') linked to an OROS OR38 system, so that the levels heard by the participants would match the reality of the recordings.

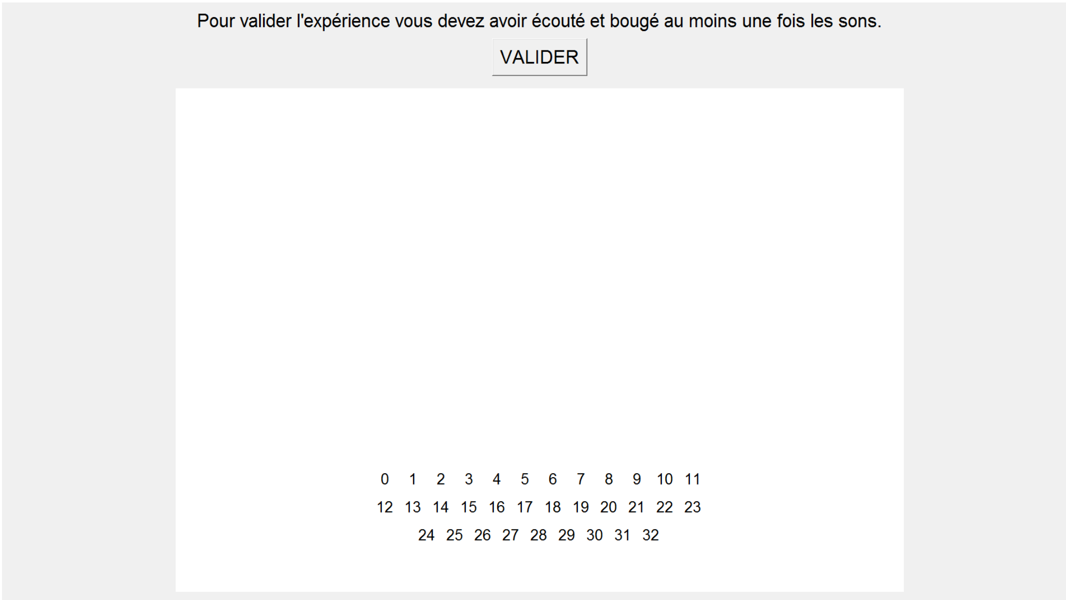

Figure 4: Interface for the free sorting task. Each tyre noise is represented by a number. Users can move the numbers freely inside the white rectangle. Whenever a number is moved, black rectangles will highlight the current groups.

For each listening condition (exterior and interior), the participant had to sort the sounds according to their similarity: each group represents sounds that seemed similar, homogenous based on their perception and sufficiently different from the rest (see Fig.5 for the state of the interface when the grouping is over). When the first sorting task was completed, the participant had to repeat the task for the other listening condition. The order of the two listening conditions and also the attribution of the sounds to each number in each particular condition were randomized. The duration of the completion of each sorting task was measured, as well as the number of times the sounds were listened to. At the end of the experiment, the participant was briefly interviewed (Appendix 3) to know how difficult the task was. Verbal responses were translated into a numeric score: 1 ('not difficult'), 2 ('difficult') and 3 ('very difficult'). It was also asked if he/she felt that the task was more difficult for one of the two listening conditions. Finally, the participant had to explain with their own words which criteria he/she used to group the sounds.

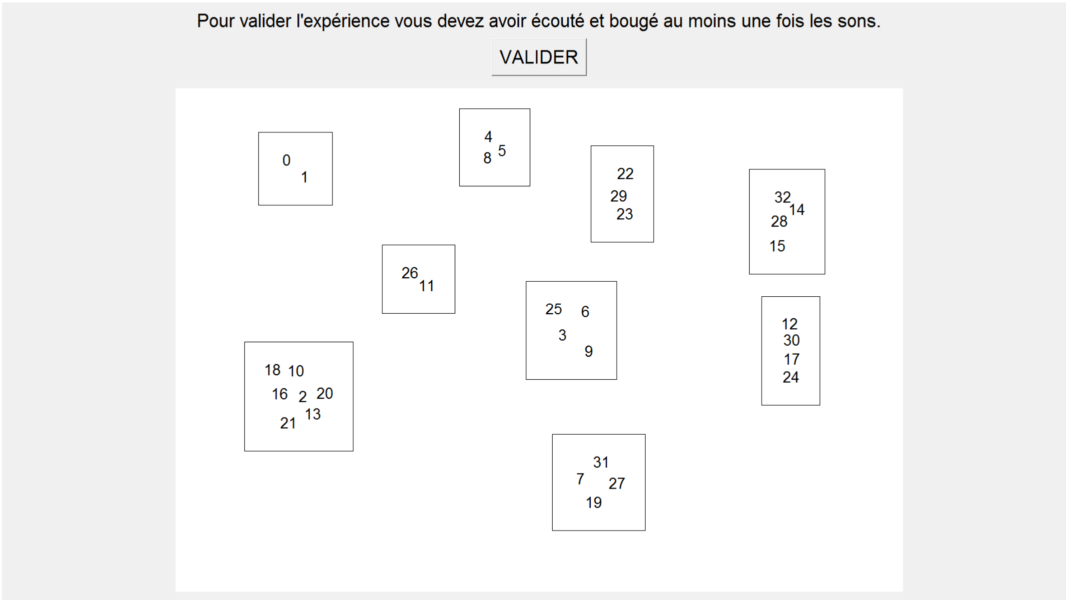

Figure 5: An achieved sorting task. The different sounds are grouped according to the black rectangles. To validate the task, each sound had to be moved and listened to at least one time.

2.4 – Ethics

The only personal data collected were the participant's age, gender and hearing threshold. Their personal information was treated to respect their privacy: in the computer running the experiment, participants are referred to as numbers only. The table relating numbers to participants' names and personal information is stored as one file, recorded in the experimenter's personal computer and will be erased at the end of Leon-T project.

Sound stimuli were presented through headphones, with a level lower than 80 dB(A), i.e. the level of a busy road. Long exposure of sounds with level superior to 70 dB(A) can cause hearing damage but our exposure time is short as all sounds last 1.54s and the listening part of the experiment does not last more than 30 minutes. Thus, the combination of a short exposure time and the relatively low level of the stimuli ensures no risk of hearing damage. Particular care was taken in consideration of the current Covid-19 situation: the sound booth was disinfected and ventilated for at least 5 minutes between participants.

The interior dimensions of the booth were large enough so that participants would feel at ease (3.4 m long, 2.4 m large and 2.2 m high). A window allowed the experimenter to check that everything was fine with the participant. Participants signed a consent form before starting the experiment (Appendix 2) and were informed that they could stop at any time (see the instructions in Appendix 3).

2.4 – Results

In general, the participants had a rather high noise sensitivity (mean NoiSeQ-R score: 1.92 ± 0.38) and found the sorting task difficult (mean difficulty score: 2.38 ± 0.66). Most of them (60 %) said that the interior condition was more difficult than the exterior one, while 23 % reported the opposite (and 17% of the participants said both conditions were equally difficult).

On average, participants spent the same time for each listening condition and listened to the noises the same number of times. But the number of groups was significantly lower in the interior condition (mean number of groups for exterior: 8.13 ± 3.77, for interior: 6.85 ± 2.97, $p<0.0003$), see Fig.6. Positive correlations were found between those 3 variables (Appendix 4).

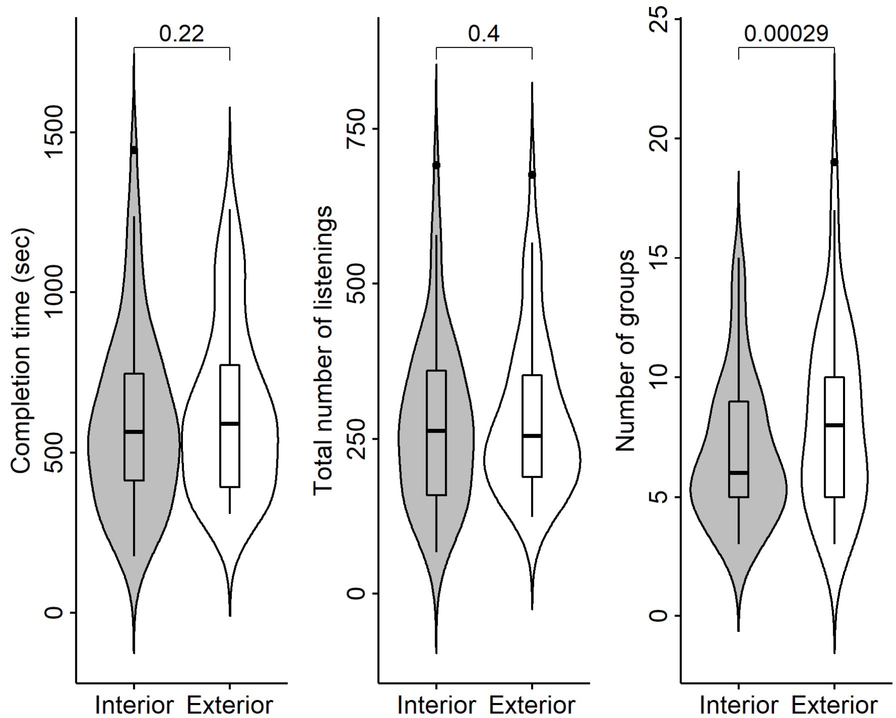

Figure 6: Boxplot and violin plot of the comparison of the completion time, number of listening (sum of the number of times a participant listened to a noise) and number of groups between each listening condition. The p-values shown are the result of paired Wilcoxon tests.

At the end of the experiments, individual accordance matrices were built from the participants' results of the free sorting tasks for each condition. The matrices were calculated using the following rule: if the participant grouped two noises together, then the value in the matrix for this pair is 0, if the noises are in different groups, the value is 1. We then obtained 106 triangular matrices. For each condition, we averaged the corresponding 53 matrices, resulting in two mean accordance matrices, with values inside representing the number of times two sounds were grouped together: the closer to 0, the more often they were together.

The two mean accordance matrices were used as distance matrices to perform hierarchical agglomerative clustering [5], an algorithm that organizes data into groups (clusters) by merging them according to their similarity using the mean distance aggregation criterion (the mean distance of the different cluster is compared). This resulted into classification trees (Fig.7-8). In our case, the more the noises were grouped together by the participants, the more likely they belong to the same cluster. The number of clusters, i.e. the place to where the trees could be cut, was found using the maximum mean silhouette criterion [6] for each possible cut of the tree (Fig.9): it ranges from -1 (all clusters are poorly separated) to 1 (all clusters are well defined and homogenous). We found that the maximum silhouette criterion was attained when cutting the tree in 5 clusters for the exterior condition and 2 clusters for the interior condition (Fig.7-8-9).

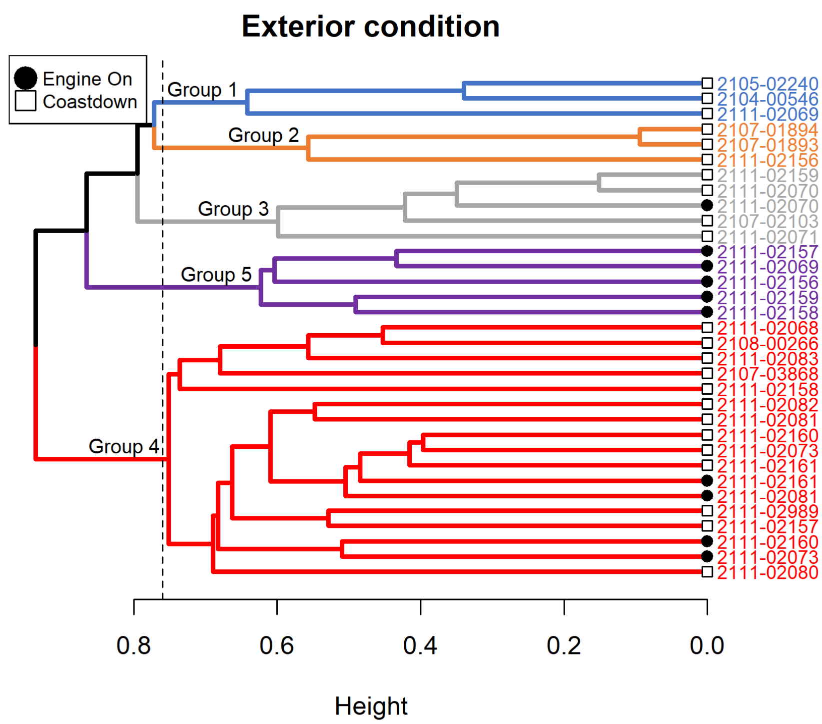

Figure 7: Classification tree of the tyre noises for the exterior condition. The identification number of the noise as well as the engine status (Engine On or Off (Coastdown)) is indicated at the end of each branch (the leaves). The lower the height between two noises, the more they were grouped together during the experiment. The dashed line shows the cut of the tree selected using the silhouette criterion, resulting in 5 clusters, whose names are indicated on the tree and are also designated by different colors.

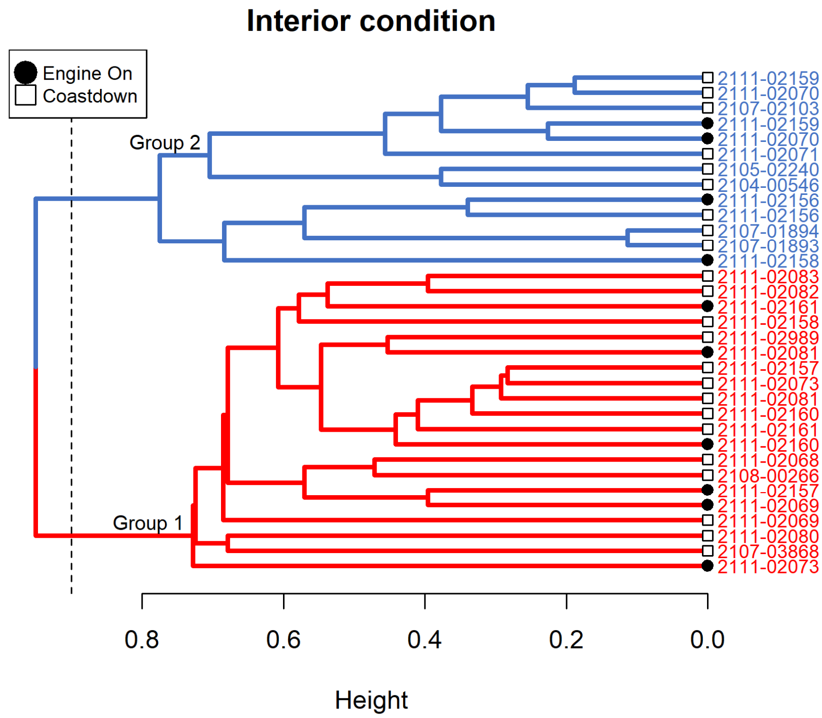

Figure 8: Classification tree of the tyre noises for the interior condition. The identification number of the noise as well as the engine status (Engine On or Off (Coastdown)) are indicated at the end of each branch (the leaves). The lower the height between two noises, the more they were grouped together during the experiment. The dashed line shows the cut of the tree selected using the silhouette criterion, resulting in 2 clusters, whose names are indicated on the tree and they also are designated by different colors.

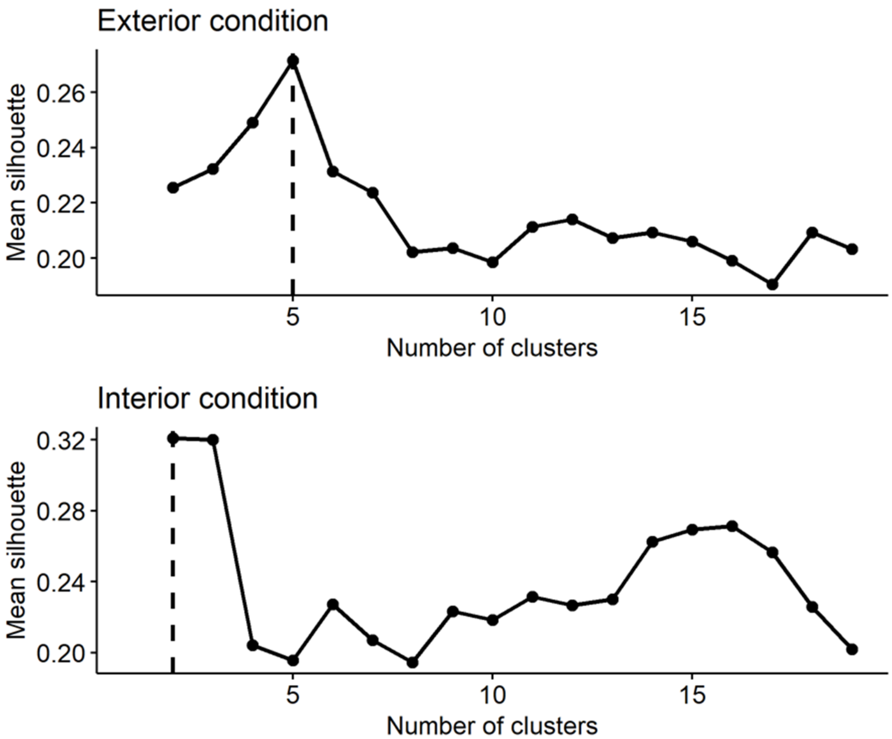

Figure 9: Mean silhouette criterion according to the different number of clusters for each listening condition. The clusters are obtained by cutting the classification tree in different places.

2.5 –Properties of the different groups of tyre noises

2.5.1 – Selected psychoacoustics parameters and physical characteristics

Different psychoacoustics parameters were measured with Artemis 13.2 (Head acoustics) in order to identify the common features of sounds within a same group. We used roughness, sharpness, loudness, tonality, central frequency and lowest tonal frequency. The relevance of these parameters was confirmed by the free descriptions of sounds participants made after the experiment: the participants used criteria that were closely related or analogous to the ones these metrics are supposed to describe (Appendix 5).

The following parameters were used:

- Loudness (in Sone), computed according to the American ANSI S3.4-2007 standard [7], defined by Glasberg & Moore in 2006 [8] for frequencies ranging from 20 to 5000 Hz to evaluate the perceived intensity of the sound in 3rd octaves with the following parameters (soundfield: free, window length: 1024 samples, window type: Hanning, 50% overlap).

- Sharpness (in Acum) is related to the balance between high frequencies and low frequencies. The method described by von Bismarck (Appendix 6) with the standard ANSI S3.4-2007 [7] was used with the following parameters (soundfield: free, window length: 1024 samples, window type: Hanning, 50% overlap).
- Roughness (in Asper) can be induced by modulation amplitude of sounds. It was computed according to the first edition of ECMA-418-2.
- Tonality (in tuHMS) represents the audibility of one or several tones in the noise. The ECMA-74 procedure proposed was used (see Appendix G of ECMA-74 15th edition [9]) for frequencies ranging from 20 to 5000 Hz. We also measured the frequency of the lowest emerging tone (if any) using the specific tonality, i.e. the tonality calculated for each frequency.
- The spectral centroid frequency is the center of mass, i.e. weighted mean, of a frequency spectrum (window length: 1024 samples, window type: Hanning, 90% overlap).

All computed metrics have also been compared to the technical characteristics of recordings (Appendix 1), namely the type of tyres (C1, C2 or C3), the position used for HGVs (steering or traction), the use category (summer (normal), winter (M&S) and alpine (M&S Severe) tyres) and if the engine was on or off during the recording.

2.5.2 – Properties of tyre noise groups for the exterior listening condition

In the case of outdoor sounds, the 5 clusters are acoustically different (Fig.10) and correspond to different tyre configurations (Fig.11).

The first group is only composed of C3 summer and winter tyres, in steering position and during coastdown (engine off). From an acoustic point of view, the group is mainly characterized by low loudness, mid to high center frequency and medium tonal frequency. It corresponds well when the sound is listened through headphones: the sounds have a rather low level but some tones can be clearly heard.

The second group also contains only C3 summer and winter tyres in coastdown, but in traction position. These sounds exhibit the highest roughness values. Their frequency spectrum is more balanced towards low frequencies (the lowest sharpness and centroid frequency) and they have a medium tonality and tonal frequency. When listening through headphones, tonality is indeed quite present and there is a rather unpleasant amplitude modulation, as described by roughness.

The third group is made of C3 alpine tyres only (M&S severe) in steering position. These sounds have a high tonality, which can be clearly perceived when listened through headphones.

The fourth group contains all the smaller tyres (C1 and C2) as well as some C3 alpine tyres in steering position. They have a very specific timbre: high sharpness and central frequency), one of the lowest loudness and the lowest tonality. This group is very different when listened through headphones, the noises are very similar to a passing car, with no prominent frequencies. However, if the listener pays close attention, the weight of the vehicles could be distinguished.

The fifth group contains only recordings of C3 tyres the engine being switched. They are loud, relatively rough but, most importantly, highly tonal, with very low tonal frequencies, highlighting the effect of the engine on the measured tonality. When listening through headphones, the engine is really prominent, with a low frequency hum.

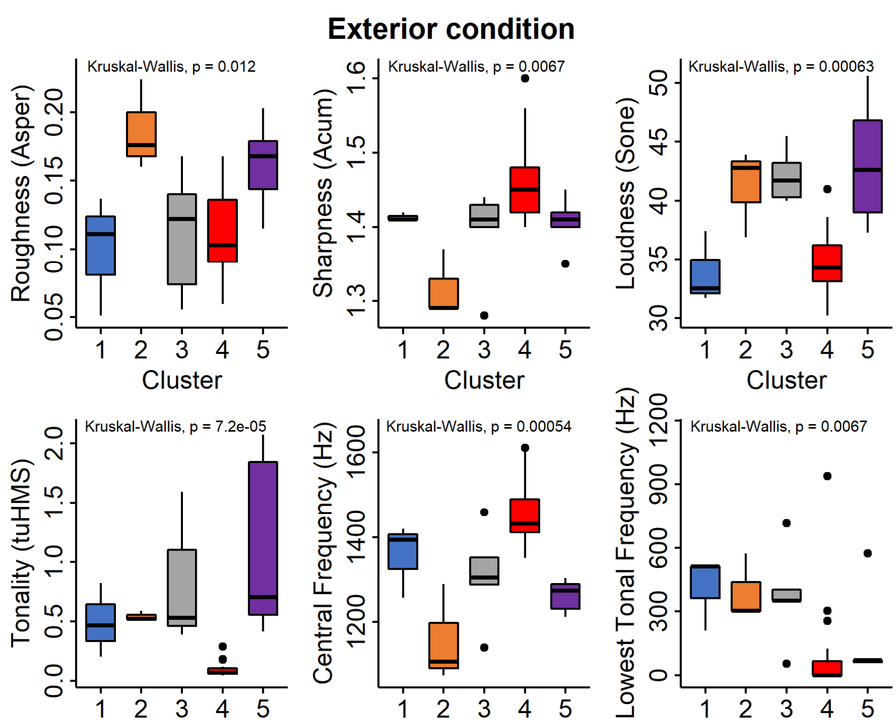

Figure 10: Repartition of the psychoacoustics parameters in each cluster found for the exterior listening condition. The p-values on top of each boxplot are the result of a non-parametric ANOVA (Kruskal-Wallis test) to test the main of each parameter, i.e. it indicates that each parameter is affected by the cluster.

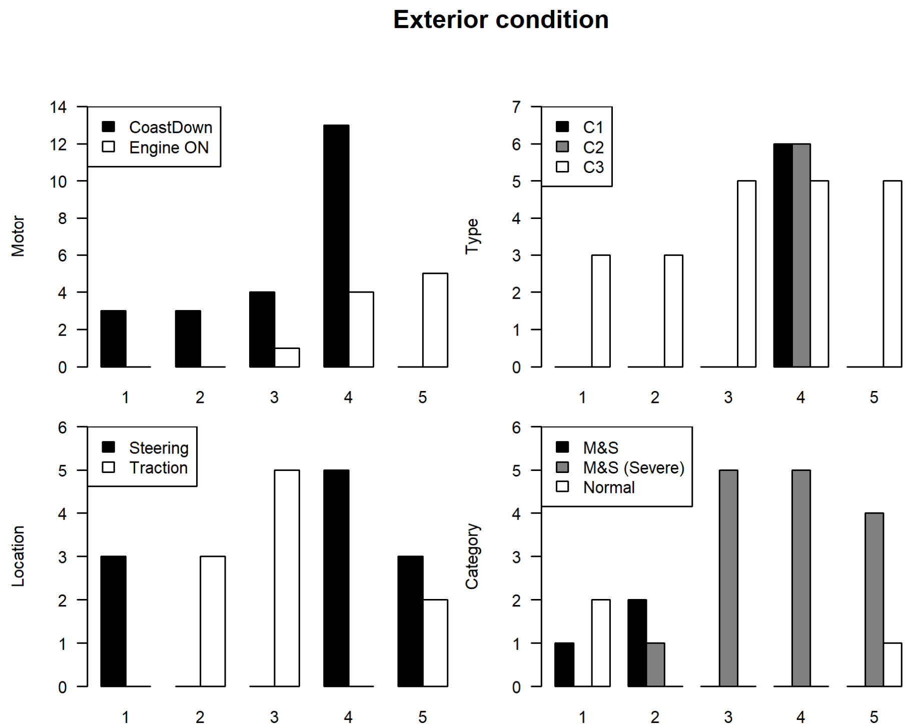

Figure 11: Repartition of the different tyre characteristics and engine status in the different groups of the exterior listening condition.

2.5.3 – Properties of tyre noise groups for the interior listening condition

In the case of the interior listening condition, two groups only could be built. The second group roughly corresponds to the fourth group in the exterior listening condition. Sounds from groups 1, 2, 3 and 5 in the outdoor condition can all be found in group 1 after the façade filtering (Fig.12). Thus, the first group is composed of C3 tyres only and the second is a mix of C1, C2 and steering C3 tyres (Fig.13).

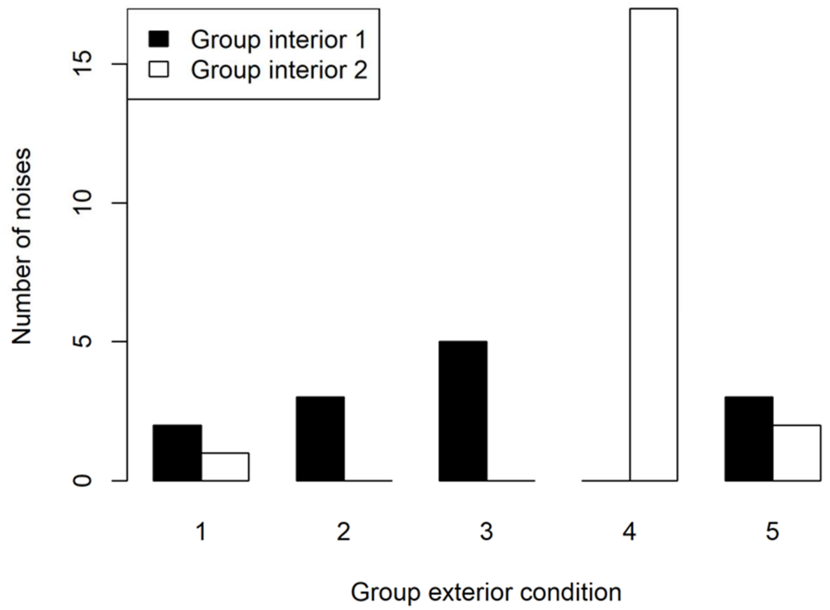

Figure 12: Repartition of the two groups of tyre noises found for the interior listening condition according to the group they were in for the exterior listening condition.

The two groups mostly differ by their loudness and tonality (Fig.14), which has highest values for sounds of group 1. The tonality is close to 0 for sounds in group 2. Besides, roughness and sharpness are also slightly different (but these differences are less easily detected when listening).

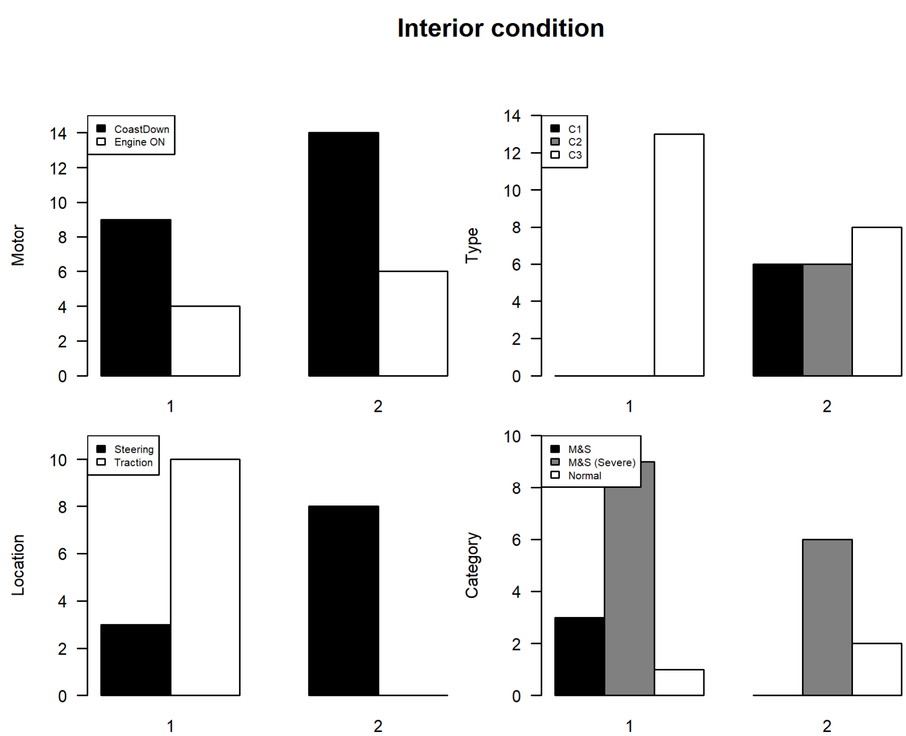

Figure 13: Repartition of the different tyre characteristics and engine status in the different groups of the interior listening condition.

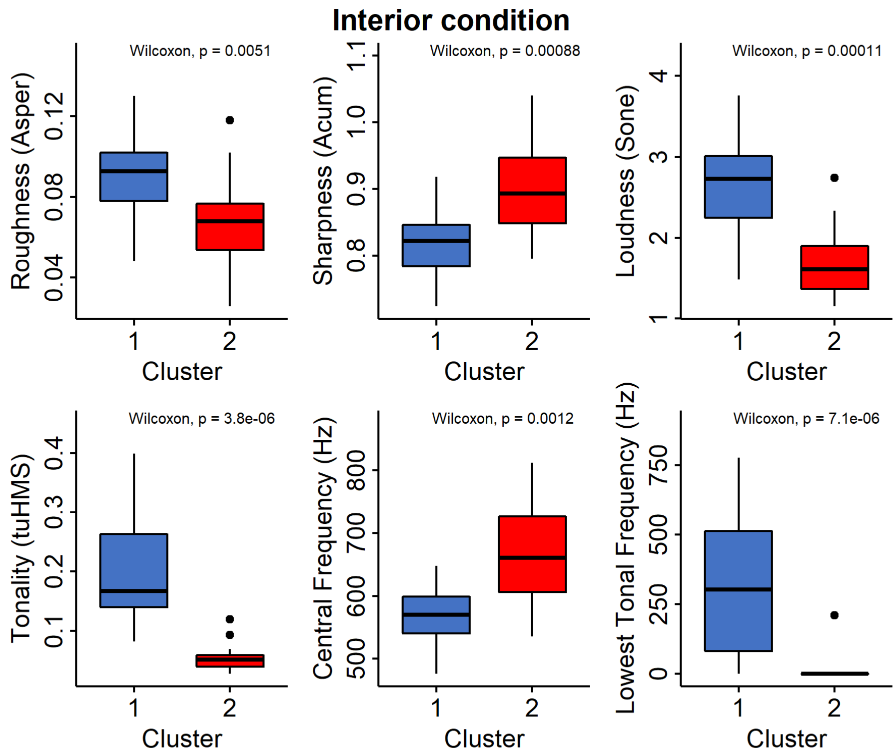

Figure 14: Repartition of the psychoacoustics parameters in each cluster found for the interior listening condition. The values on top of each boxplot are the result of a non-parametric comparison test (Wicoxon test) and indicates that each parameter is different between the two clusters.

3 – Creation and synthesis of tyre sound stimuli for health studies

As of the redaction of this deliverable, the stimuli are currently synthetized. The following parameters are modified to create the stimuli:

- Loudness;
- Tonality (amplitude and frequency of an emerging tone);
- Frequency balance of the noisy part.

Listening tests will be organized to validate the similarity of the synthesized stimuli with real tyre sounds. Experts (NVH experts and acousticians) will participate to guarantee the validity of our stimuli.

4 – Conclusion

The two experiments showed that the façade modifications of sounds strongly reduce the diversity of acoustic parameters that allow listeners to group signals in a free sorting task. The relevant differences seem to be related to the tonality (perception of an emergent frequency) and the perceived intensity and, to a lesser extent, to the frequency balance.

These results will be used for further study: firstly, the effect of intensity, pitch and frequency balance on the unpleasantness of noise (as perceived in the home) will be investigated. A complete experimental design (in which these factors will take different levels) will be used. The aim is to gain a better understanding of the relative importance of these sound parameters, which will allow for a better choice of stimuli for the study of sleep effects.

5 – Bibliography

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Appendicies

Appendix 1: Summary of tyres and tests

			Type			Files					
						Microphone: *.hdf Vehicle speed: *.xlsx					
	Trade Mark	Size	Steering	Traction	Category	Coast Down (km/h)			Engine ON (km/h)		
						50	70	90	50	70	90
C3	Michelin	315/80R/22.5		X	M&S (Severe)	X	X	X	X	X	X
	Michelin	315/80R/22.5	X		Normal	X	X	X	X	X	X
	Bridgestone	315/80R/22.5		X	M&S	X	X	X			
	Bridgestone	315/80R/22.5	X		M&S (Severe)	X	X	X			
	Goodyear	315/80R/22.5		X	M&S (Severe)	X	X	X			
	Goodyear	315/80R/22.5	X		M&S (Severe)	X	X	X			
	MAXXIS	315/80R/22.5	X		Normal	X	X	X			
	MAXXIS	315/80R/22.5		X	M&S (Severe)	X	X	X			
	LEAO	315/80R/22.5	X		M&S (Severe)	X	X	X			
	BRIDGESTONE	315/80R/22.5		X	M&S	X	X	X			
	LLG	315/80R/22.5		X	M&S (Severe)	X	X	X	X	X	X
	LLG	315/80R/22.5	X		M&S (Severe)	X	X	X	X	X	X
	PETLAS	285/70R 19.5 (Ref CW)	X		M&S	X	X	X			
	LLG	285/70R 19.5 (Ref CW)		X	M&S (Severe)	X	X	X	X	X	X
	LLG	285/70R 19.5 (Ref CW)	X		M&S (Severe)	X	X	X	X	X	X
C2	Michelin	235/65R 16				X	X	X	X	X	X
	Bridgestone	235/65R 16				X	X	X			
	THUNDERER	235/65R 16C				X	X	X			
	(LLG) **ATLAS**	235/65R 16C				X	X	X	X	X	X
C1	Michelin	225/55R 17				X	X	X	X	X	X
	Bridgestone	225/55R 17				X	X	X			
	Goodyear	225/55R 17				X	X	X			
	LLG	225/55R 17				X	X	X	X	X	X

Appendix 2: Consent form signed before the listening test (Originally in French)

Laboratoire Vibrations Acoustique

INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES LYON

Consent form

Last name :
First name :
Address :
Tel. number:

I declare that I do not have any hearing problem that could alter the tests or have an impact on my health.

I agree to participate freely with the help and assistance of the INSA Lyon vibration and acoustics laboratory in a listening test experiment.

This experiment is safe and has no consequences for hearing.

The noise level is controlled by the laboratory and does not exceed that experienced in everyday life or in the vicinity of certain common appliances.

The duration of the tests is also controlled by the laboratory.

This experiment takes place in specially equipped booths or in the presence of everyday sound objects.

I have been informed that I am free to stop the experiment at any time, temporarily (to rest) or permanently.

I agree to assist without remuneration and to answer the questionnaire at the end of the experiment.

The questionnaire and the results of the experiment are the exclusive property of the laboratory, which is free to use them as it wishes, provided that it does not reveal the identity of the person involved.

As a compensation, the laboratory will give me the sum of 15 Euros (fifteen Euros) corresponding to travel expenses, loss of time, etc. (please attach a bank details form).

Date :

Signature of the participant | Signature of the experimenter

Appendix 3: Instruction given during the listening test (Originally in French)

“You are participating in a European project, LEONT, aiming to understand and measure the emissions of micro-particles and - in our case here - noise from vehicle tyres.”

Bring the participant into the booth.

“I will ask you to keep your mask on for health safety, and you should know that all the accessories have been disinfected before your arrival.”

Have the participant sit in the booth.

“During the experiment, you are allowed to signal me if you have any questions. I am on the other side of the booth if you need help. You can leave the booth at any time: if you need to get some fresh air or don't feel well, need a break. If all is clear for the moment, we can continue.”

Show the audiometry interface.

“The first phase of this experiment is an audiometric measurement. I'm going to ask you to take this button and put on these headphones (*Shows the test button and associated headphones*). The task is as follows, this is an audiometry test. As soon as I step out of the booth and you click this button (*Show button*), sounds in the form of 'beeps' will be played to you. As soon as you hear one, press the button. Do you have any questions at this time?”

Repeat and explain again if necessary.

“I'm going to leave the booth. You can start as soon as I leave. I'll be back when you're done.”

Go out, let the experiment run. Come back in when it is done.

“Did everything go well?”

Wait for an answer.

“Well, we can continue then. The rest of the experiment is in two main phases. The first one consists of a questionnaire; twelve sentences will be presented to you. For each sentence, you must agree or disagree by clicking on one of the four boxes presented.

The selected box will appear in blue. As long as you have not clicked on Next, you can modify your choice. The choice is final once you click on Next.
The second phase is a free sorting phase: You will have a screen with numbers. Each number represents a sound, a noise of a vehicle passing. When you move the mouse over a number, it turns red, which means that it is active. By clicking the right mouse button, you can play the sound in your headphones. By holding the left mouse button and moving the mouse, you can move the number in space. You will see that squares will form around the numbers. Each square represents a group. The squares change automatically as you move a sound. Your task will be to sort the sounds according to their similarity: each group represents sounds that seem similar, homogenous to you and sufficiently different from the rest. You can make as many groups as you want, arranging them as you like: the distances do not have to represent the dissimilarities between these groups and it is quite possible for a group to contain only one sound if it seems very different from the rest. Some sounds will be very faint, so don't worry, this is not a problem. Once you are satisfied, you can validate this sorting. You can only validate if you have listened and moved each sound at least once. Once the button is clicked, you will have to start the same sorting task again. The experiment will end once you have validated this last sorting phase. Do you have any questions?”

Answer and repeat the explanations as needed.

“Please type in your assigned number, wait until I am out to begin.”

Upon participant exit:
“- Was it hard? Was one set harder than the other? If so, why?
- How did you sort out the sounds? Were there any sounds that stood out from each other?”

Appendix 4: Difficulty of the free sorting task

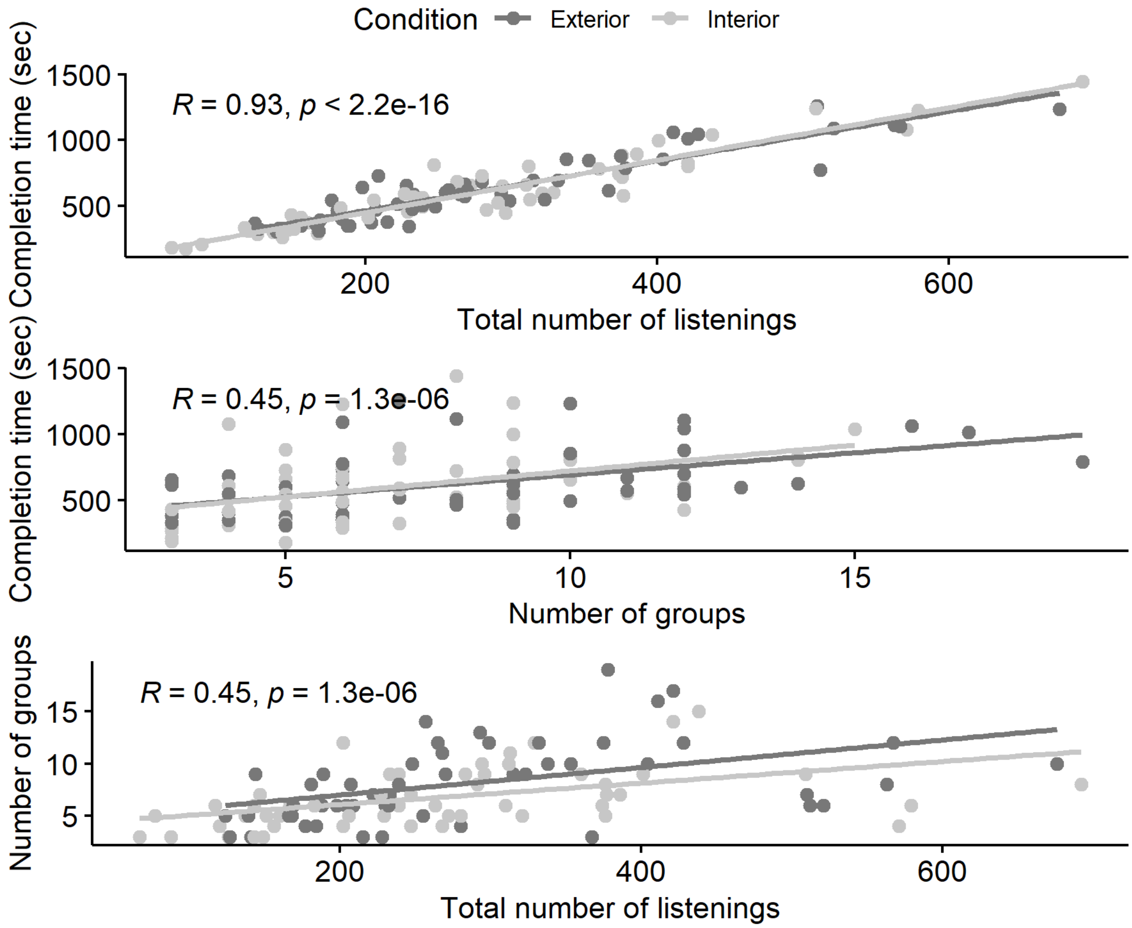

Figure A4.1: Positive correlations between the completion time, number of groups and total number of listening. All relationships are significant, i.e. the more the participant listened to noises, the longer it took him to finish the task but also the more groups he/she did. The linear regression lines are displayed as well as Pearson's correlation coefficient with the associated p-value.

Appendix 5: Criteria used by the participants to differentiate the noises in groups

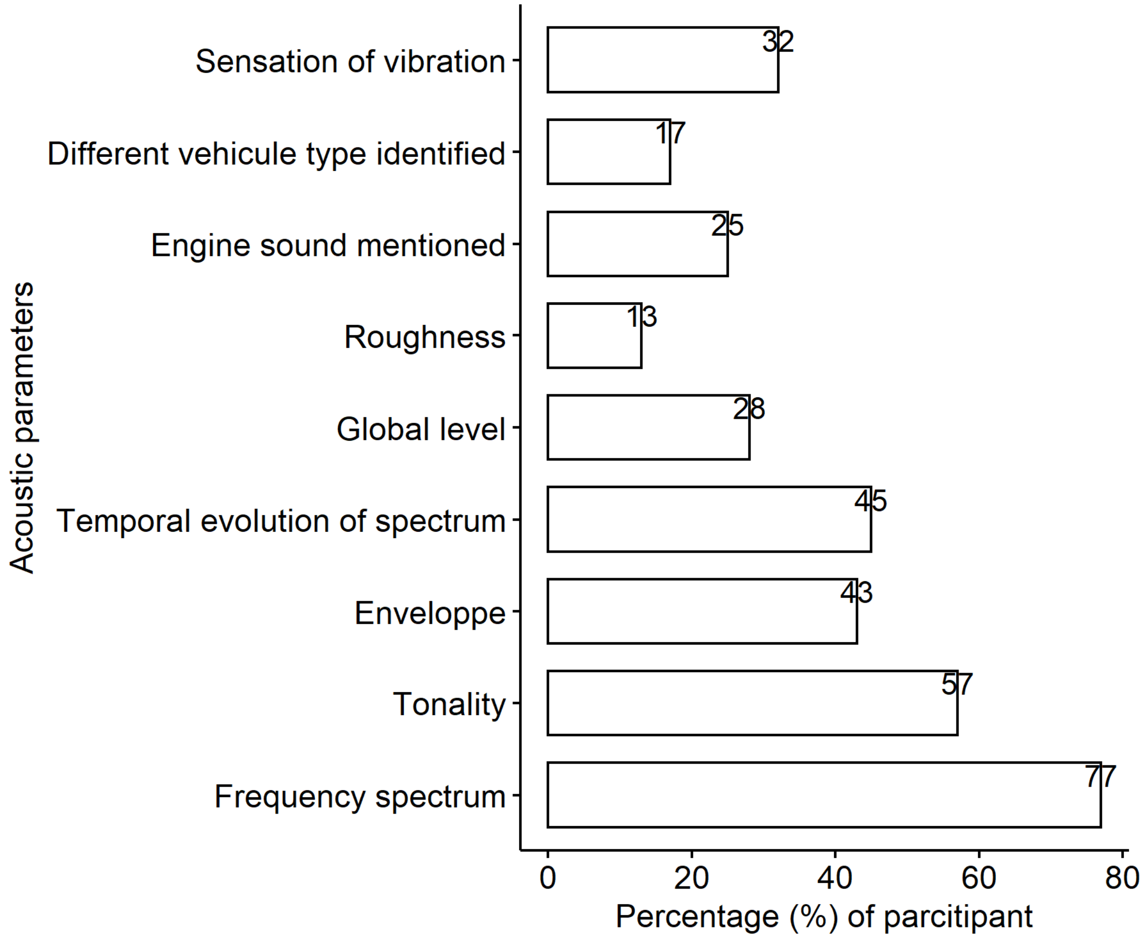

Figure A5.1: Percentage of participants mentioning particular acoustic parameter used to differentiate the noise groups. As participants used their own words, the experimenter attributed them to the corresponding category.

Appendix 6: Adaptation of the von Bismarck method by Artemis to calculate sharpness

n'(z): Specific Loudness [sone/Bark]
z: Critical Band Rate [Bark]
N: Total Loudness [sone]
K_n: Scaling factors

$$S = K_2 \cdot \frac{\int_0^{24\,Bark} n'(z) \cdot z \cdot g(z) \cdot dz}{N}$$

$$g(z) = \begin{cases} 1 & , \quad z < 14\,Bark \\ 1 + 0.003 \cdot (z - 14\,Bark)^3 & , \quad z \geq 14\,Bark \end{cases}$$