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Electric Vehicle Alert for Detection and Emergency Response

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Executive summary

This document presents the results of the three experiments conducted in WP2, considering data collected by all partners.

Results are very similar to partial ones which have already been published in deliverables D2.2, D2.3 and D2.4. But some further analysis could be made.

Most important conclusions are the following ones :

- In the first experiment (detectability), factors effects were similar in the two background noise conditions (wet or dry). The difference between the two conditions is that effects had greater amplitudes in the "wet" noise, indicating a higher contribution of additional warning sounds in adverse condition;
- Most warning sounds made the electric vehicle more unpleasant than the diesel car, except three of them;
- Generally speaking, a high detectability of a sound is associated to a great unpleasantness, which is in accordance with previous studies about warning sounds;
- Sound s1 from experiment 1 (three components, no temporal or frequency fluctuation), seems to offer a good compromise between detectability and unpleasantness.

Contents

1 Introduction

This report completes deliverables D2.2, D2.3 and D2.4, in which the results of the three experiments conducted in work package 2 were exposed.
At the time each deliverable was published, INSA-Lyon (coordinator of the work package) had not yet received data from all labs participating to each experiment. Therefore, results were partial ones, even if they the number of subjects used for each analysis was already large.
As all data have been received now, this document will present the final analysis of each experiment.
Please refer to the already published deliverables for any detail about the stimuli and the procedure used in each experiment.

2 Experiment 1 : detectability

Data were received from INSA-Lyon, TU Darmstadt, LMS, Nissan and PSA. Two background noises were used : the "wet" one, which included pouring rain and the "dry" one.

All together, 162 people participated to the experiment (table A).

	Wet		Dry	
	VI	Sighted	VI	Sighted
INSA-Lyon	19	27		
TUD	5	20	20	
LMS				26
Nissan		30		
PSA	13	2		
Total	*37*	*79*	*20*	*26*

Table A : number of participants for each partner.

Nine participants were excluded from further analysis, as their results were evaluated as inconsistent. This was based on the following criteria :

- the subject missed more than 20 % of the stimuli;
- he missed all presentations of one particular car (this happened once, for the Diesel car. I guess the participant thought this car was a part of the background noise);
- his mean response time was greater than 5.4 s (which was the time needed for the car to arrive in front of the pedestrian).

Some statistics about the 153 subjects remaining for the analysis are in table B. Basically, this represents 109 people for the "wet" condition (32 VI and 77 sighted) and 44 for the "dry" one (19 VI and 25 sighted).

Laboratory	Normal Vision (NV)			Visually Impaired (VI)		
	N	Median age	% fem.	N	Median age	% fem.
INSA - Lyon	27 (wet)	56	37	17 (wet)	50	47
TU Darmstadt	19 (wet)	22	79	19 (wet), 5 (dry)	46	42
LMS (Leuven)	25 (dry)	27	12	-	-	-
Nissan	29 (wet)	25	21	-	-	-
PSA	-	-	-	12 (wet)	44	17
Total	100	27	34	53	49	34

Table B : statistics about subjects

The distribution of individual subjects' mean reaction times is presented in figure 1. The averaged values are 2.3 s for the dry condition and 2.95 for the wet one. This difference is significant (KS test, p<0.001). This can be understood as the rain increased the level in the middle frequency range (above 1500 Hz), so that masking of the electric vehicle was more efficient.

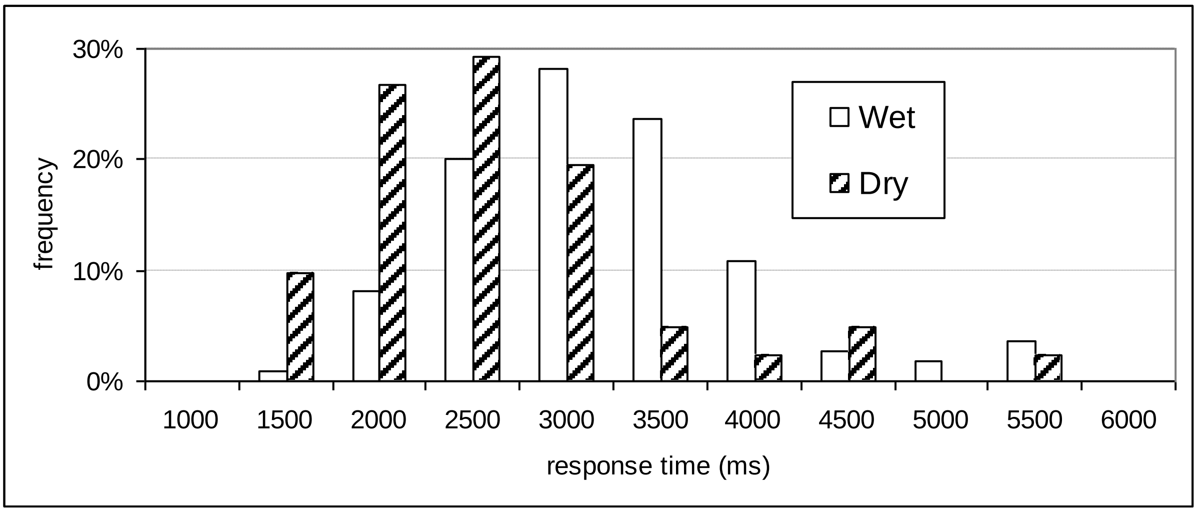

Figure 1 : averaged individuals' response times in the two conditions.

On the other hand, as noticed in deliverable D2.2, no difference between sighted and visually impaired subjects could be found, whatever the background noise (figure 2). Even if the means are smaller for visually impaired subjects, the difference with the averages computed for the sighted people group is not significant (KS test, p>0.1 in both cases).

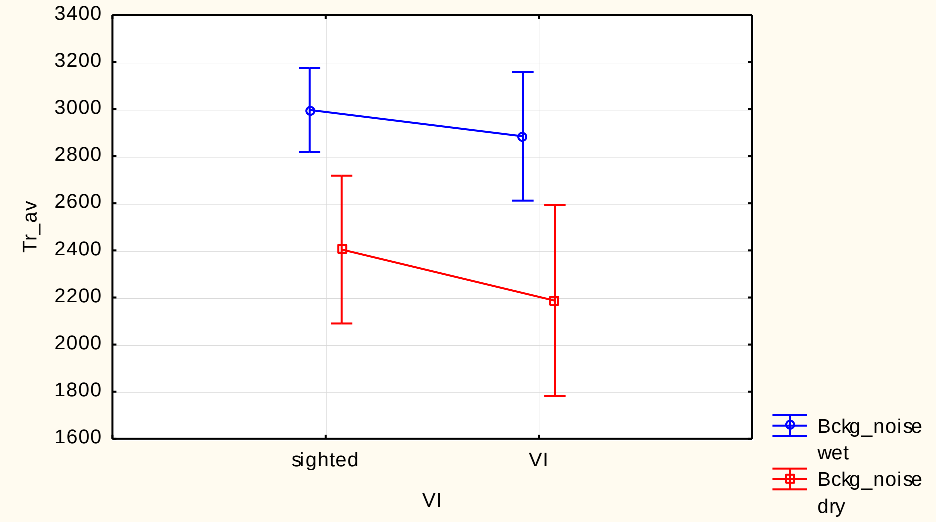

Figure 2 : averaged individuals' response time, for the two groups of subjects (sighted vs. visually impaired) and the two conditions (wet vs. dry).

In the following, the two groups of subjects (VI and sighted) will be merged into one group. The response times were averaged for each stimulus. In the two conditions, the tendency is quite similar, but the difference between minimum and maximum values is greater in the "wet" condition (figure 3). The efficiency of additional warning sounds increases in adverse conditions.

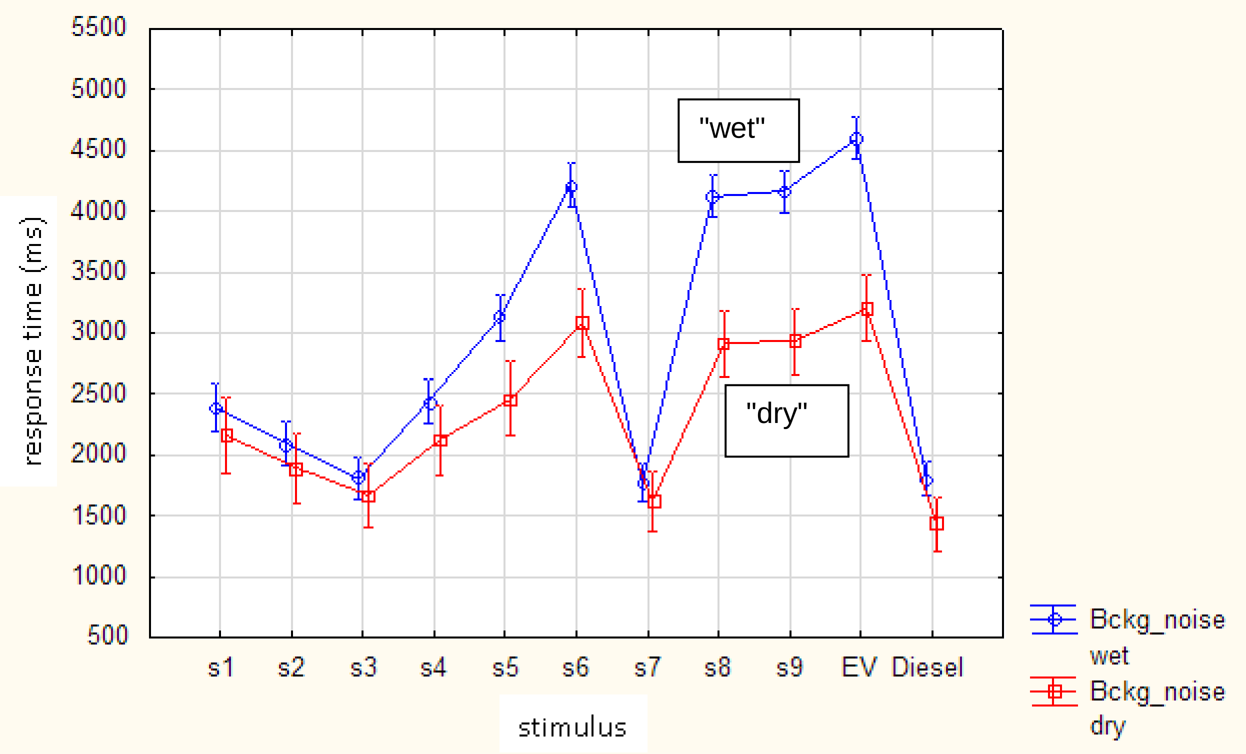

Figure 3 : averaged individuals' response times for each stimulus, in the two conditions.

The factors effects have been computed in the two conditions (figure 4). As can be expected from figure 4, effects are smaller in the "dry" conditions (right panel), but the relative contributions of factors are similar to the ones determined in the "wet" condition (left panel).

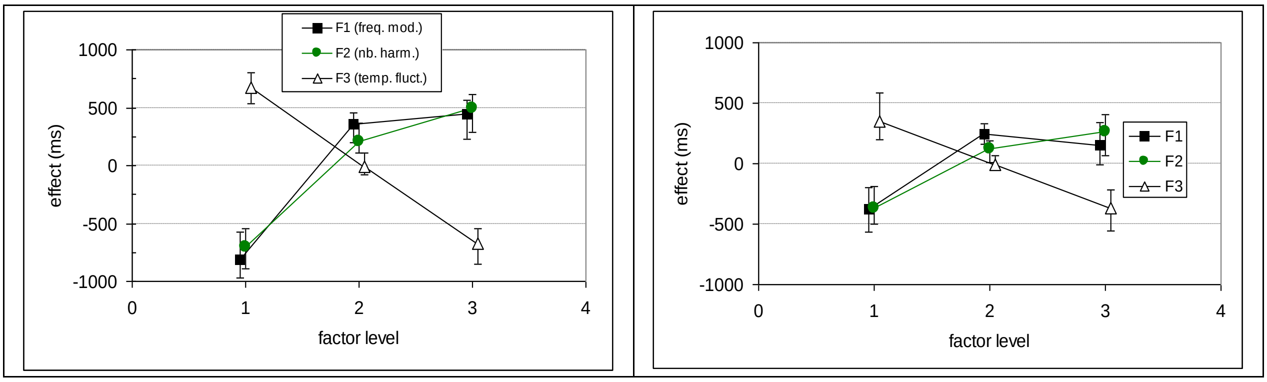

Figure 4 : factors effects. Left panel : "wet" condition; right panel : "dry" condition.

3 Experiment 2 : sound meaning

This experiment was conducted at INSA-Lyon, LMS, Renault and Nissan. We received data from 125 people (85 sighted and 40 visually-impaired, see table C).

	Visually-impaired	sighted
INSA-Lyon	28	
LMS		25
Renault	12	32
Nissan		28

Table C : number of participants for each partner

Based on the same rejection rules already used in experiment 1, 7 people were rejected from the panel (6 from Renault data and 1 from Nissan data). All of them were sighted people. So the analysis will be based on data from 118 subjects (40 VI and 78 sighted, 41 women and 77 men).

The average response time is 2.65 s, which is between values observed in the two conditions of experiment 1. As noise level was lower, each car was clearly detected and people had to respond when they thought the car was too close for them to cross the road safely. This represented a rather difficult task (even for blind people, are some of them are not ready to cross a road while hearing an approaching car), so that the range of individually averaged response times is large (between 0.9 s and 4.4 s, see figure 5).

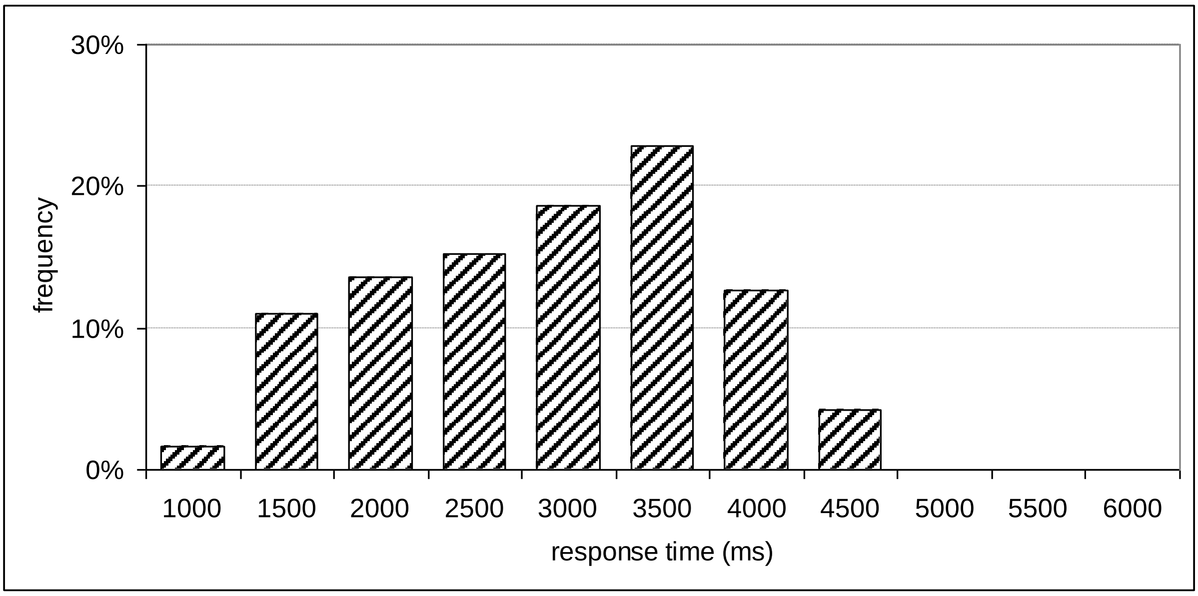

Figure 5 : mean individuals' response times.

As in experiment 1, some differences between partners appear (figure 6). The difference is significant between Lms (3.0 s) and Renault (2.3 s (KS test, $p<0.005$). This difference is not understood : I think the presentation level of was explained more clearly in this second experiment, and should have been more similar between the different labs.

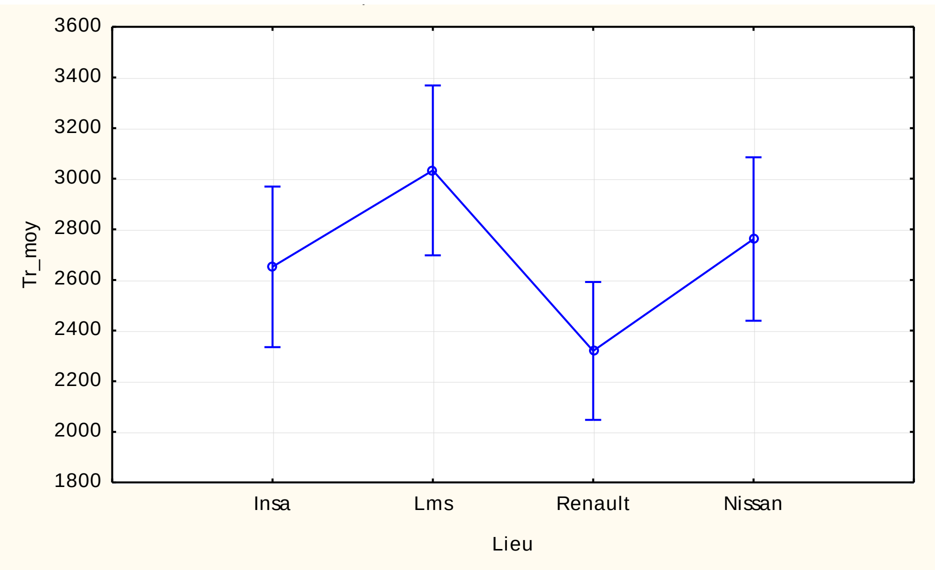

Figure 6 : individual response times for the four partners

Unlike in experiment 1, there is a significant difference between mean response times obtained from the VI subjects and the sighted ones (KS test, $p<0.025$). Mean values are 2.3 for visually-impaired subjects and 2.9 s for sighted ones (figure 7). This may be due to the "Renault" effect : if Renault data are excluded, no difference appears between Insa (VI subjects) and Lms or Nissan (sighted subjects). But the reason for this particularity remains unclear.

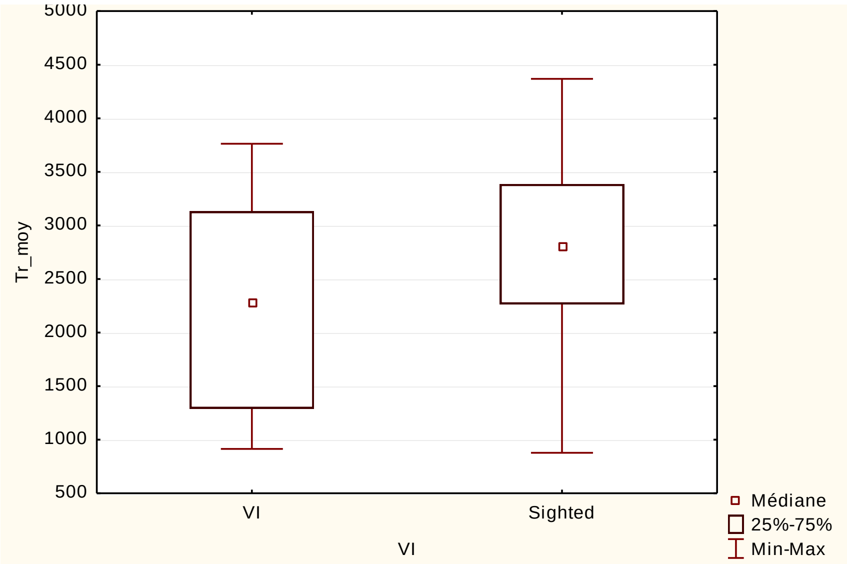

Figure 7 : mean individual response times repartition (VI vs. sighted subjects).

On the contrary, no difference could be found between male and female subjects.

Apart from this difference between mean response times, the influence of stimuli is quite similar between sighted and VI subjects (figure 8). For each subject, the averaged response time of this subject was subtracted from responses he gave for each stimulus. This set of data was averaged over the two groups so as to obtain values represented in figure 8.

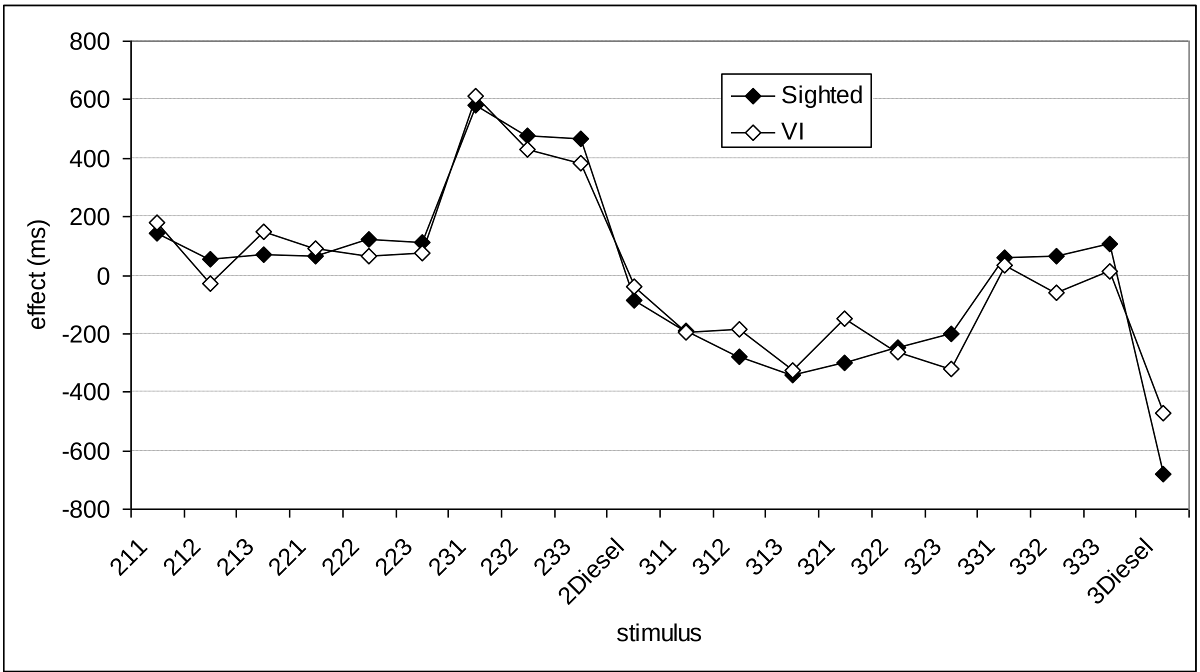

Figure 8 : stimulus effect for visually impaired and sighted subjects.

Finally, the effect of each factor was computed. When this computation is done from each set of data, it can be seen that the conclusions remain valid, whatever the partner : the main effect is due to speed, modulation frequency has nearly no effect, and the effect of pitch is surprising, as the highest pitch is associated to a slower vehicle (figure 9).

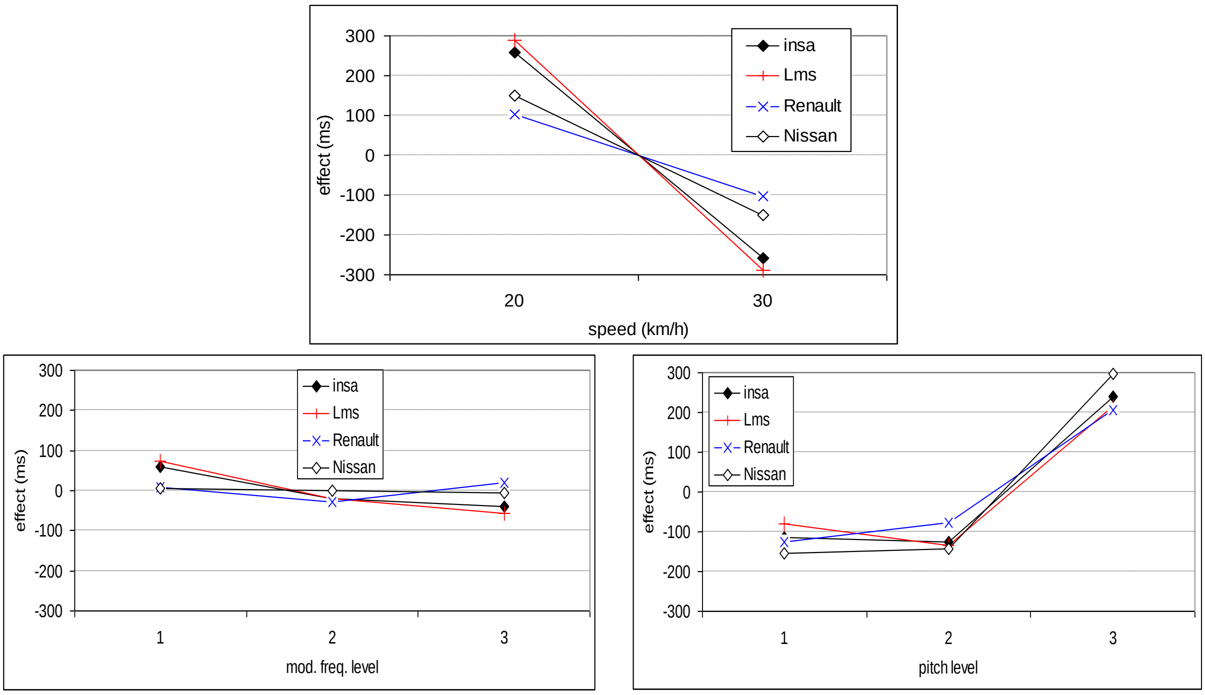

Figure 9 : factors effect. Top : speed.
Bottom left : modulation frequency. Bottom right : pitch.

When data are averaged over the four labs, factors effects are similar and the same conclusions can be drawn (figure 10).

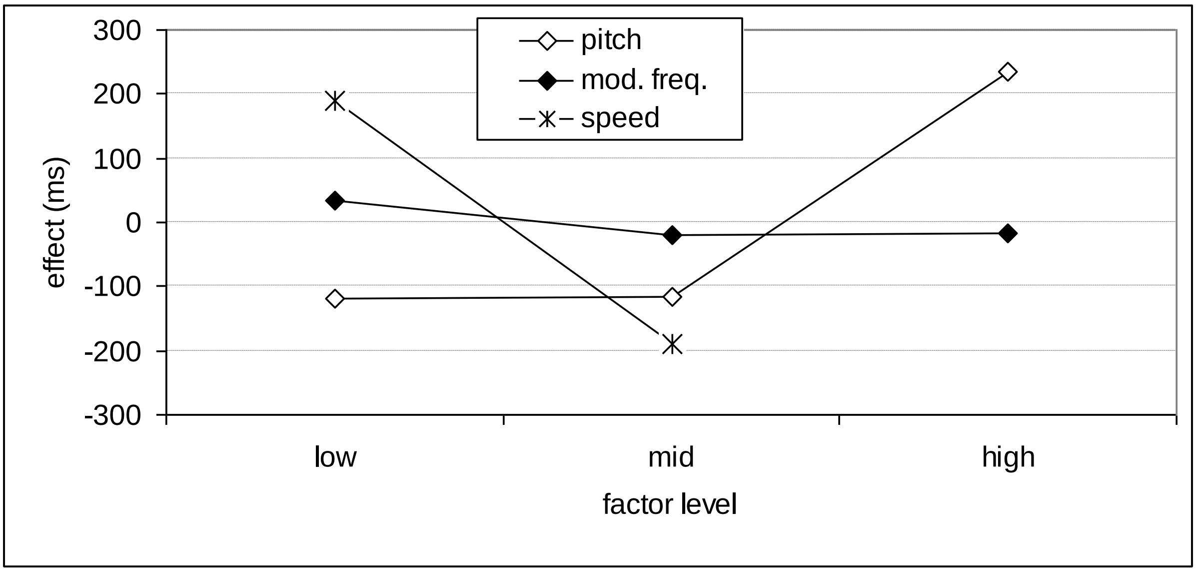

Figure 10 : factors effects (averaged data).

4 Experiment 3 : unpleasantness

In this last experiment, 20 sounds were used :

- the 11 sounds used in experiment 1 (only one arrival direction was used);
- the 9 sounds of the electric vehicle with a warning sound at the speed of 20 km/h used in experiment 2.

Two conditions were investigated : in the first one, each sound was presented without any background noise (hereafter denoted as "silence"). In the second one ("noise" condition), a low-level traffic noise (57 dBA) was added to each stimulus. Subjects instructions were the same in the two conditions (see Annex).

4.1 Subjects statistics

Data were received from INSA-Lyon, AIT, LMS and Nissan. Altogether, 145 people participated to the experiment (I think none of them was visually-impaired), see table D for details.

	"silence"		"noise"			
	male	female	male	female		total
INSA	25	14				39
Nissan			22	3		25
AIT	12	5	24	8		49
LMS			25	7		32
Total	37	19	71	18		

Table D : subjects statistics (experiment 3).

Most subjects are young (97 are below 30, see figure 12). There are some discrepancies between partners : youngest subjects are mainly from INSA or LMS, and oldest ones are from Nissan (figure 13).

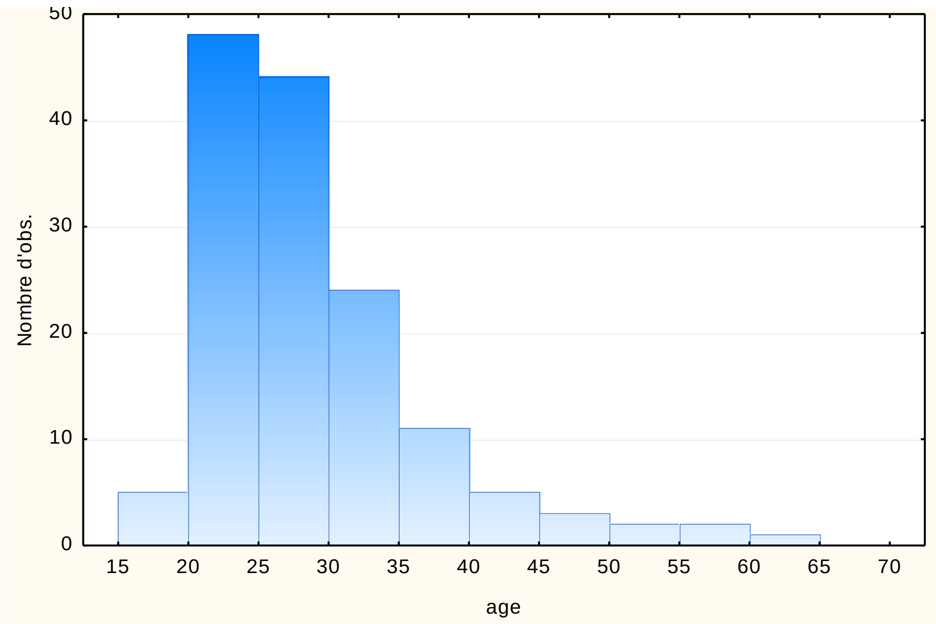

Figure 12 : histogram of subjects' ages.

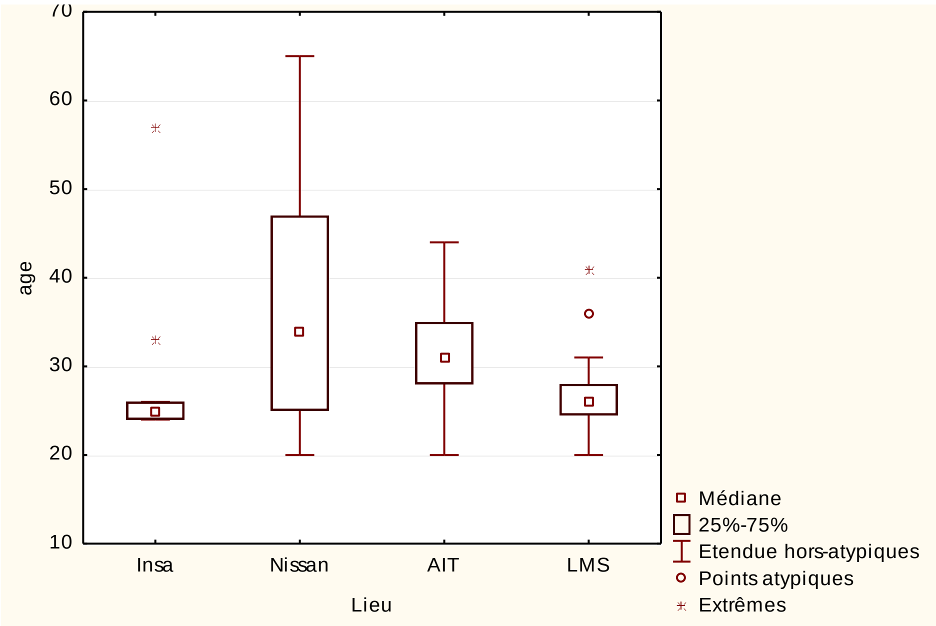

Figure 13 : mean ages of subjects from the four labs

After the experiment, subjects had to fill a questionnaire aiming at evaluating their sensitivity to noise in general. Answers given to the 12 questions were used to compute a number, which is between 0 to 36; low numbers indicate a low sensitivity. The average value is 21.35, and the range is from 3 to 35 (see figure 14). No influence of other subjects data (age, gender or lab.) on this sensitivity could be found.

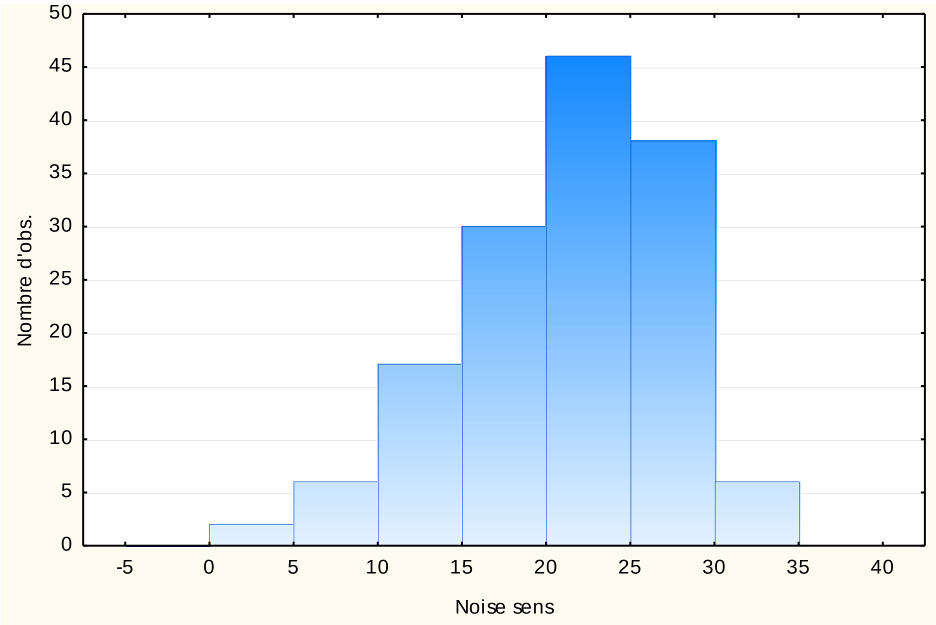

Figure 14 : histogram of subjects' noise sensitivity.

4.2 Subjects' repeatability

Each stimulus was presented twice to subjects, so that 2 values were collected. It is possible to evaluate the repeatability of the subjects by computing the number

$$C = \sqrt{\frac{1}{20}\sum_{n=1}^{20}\left(x_{n,1} - x_{n,2}\right)^2} \qquad (1.1)$$

where $x_{n,1}$ and $x_{n,2}$ are the two evaluations of sound *n* provided by the participant.

The distribution of individual C values can be seen in figure 15. Some subjects are very consistent, but for some other ones, C can be greater than 250, which indicates a full interval of the scale. No influence of lab., gender, noise condition, noise sensitivity or age could be found.

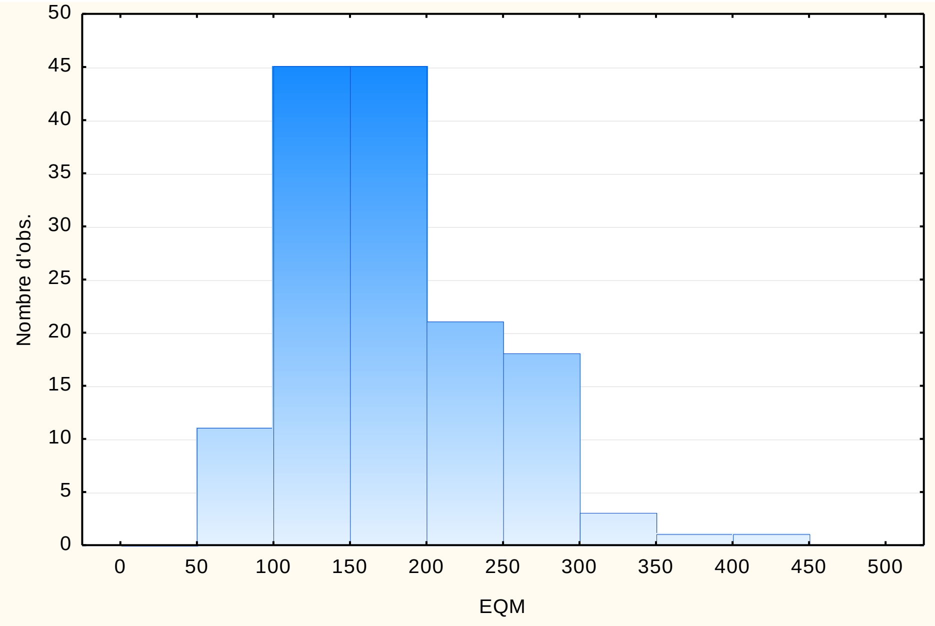

Figure 15 : distribution of individual consistency values.

It is possible to extract from the panel 56 "reliable" people, selected on the basis that their C value is lower than 150 (this is an arbitrary value, but it roughly corresponds to a third of the whole panel size). The repartition of these "reliable" people is as follows :

- lab : 15 from Insa, 10 from Nissan, 23 for AIT (congratulation to our Autrian colleagues !) and 8 from Lms.
- condition : 26 people did the experiment without noise, 30 did it with the traffic noise.
- noise sensitivity : 21 people have a low sensitivity, 14 a high one and 21 a middle one.

In the following, some analysis will be made using this sub-panel only.

4.3 Noise evaluation

Averaged evaluations (computed over the **whole** panel) are shown in figure 16. In this figure, homogeneous groups (using Scheffe correction, p=0.05) are represented by the thick lines. Roughly speaking, besides the electric vehicle and the diesel one, three groups of warning sounds can be seen :

- s1, s11 and s15 from the experiment 1, which are more unpleasant than the EV by a scale category and more than the diesel one by half a scale;
- s9 and s17 (also from experiment 1);

- All the other warning sounds, which are more unpleasant than the diesel car by more that a scale category.

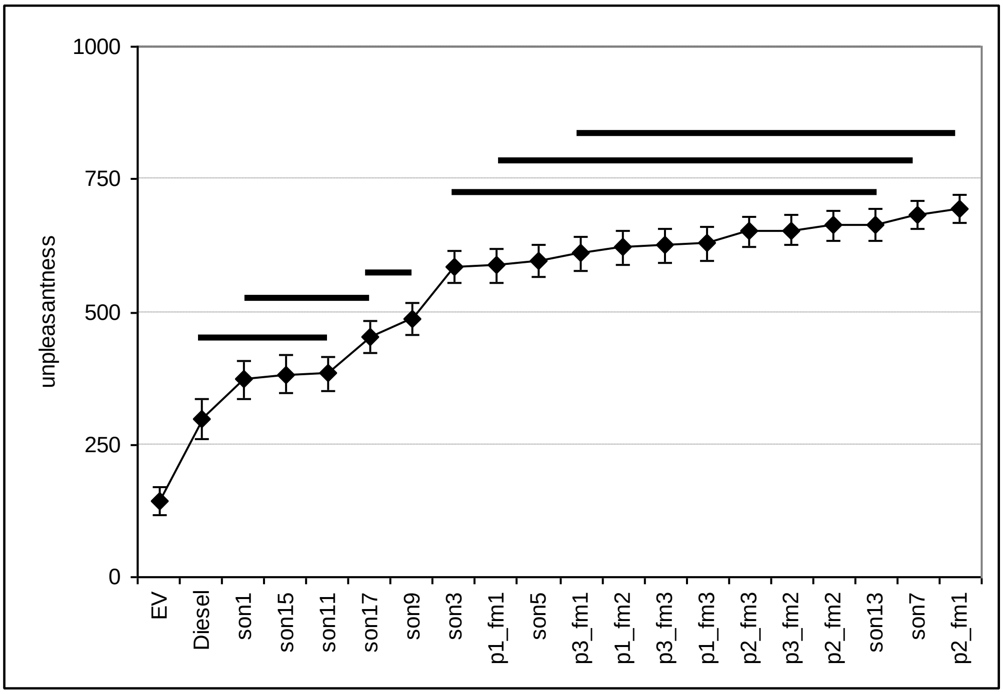

Figure 16 : averaged evaluations (in their 95% confidence interval).

A repeated measure ANOVA was conducted, with condition (silence vs. background traffic noise), accuracy, noise sensitivity as inter-individual factors and stimulus (i.e. the 20 sounds) as intra-individual factors.
Of course, stimulus is an important factor : : F(19, 2413) = 87.3, p<0.0001. But, if condition is not a significant factor, its interaction with stimulus is [F(19, 2413)= 3.73, p<0.0001]. As it can be seen in figure 17, evaluations of a stimulus can be different whether the stimulus was presented with or without background noise.

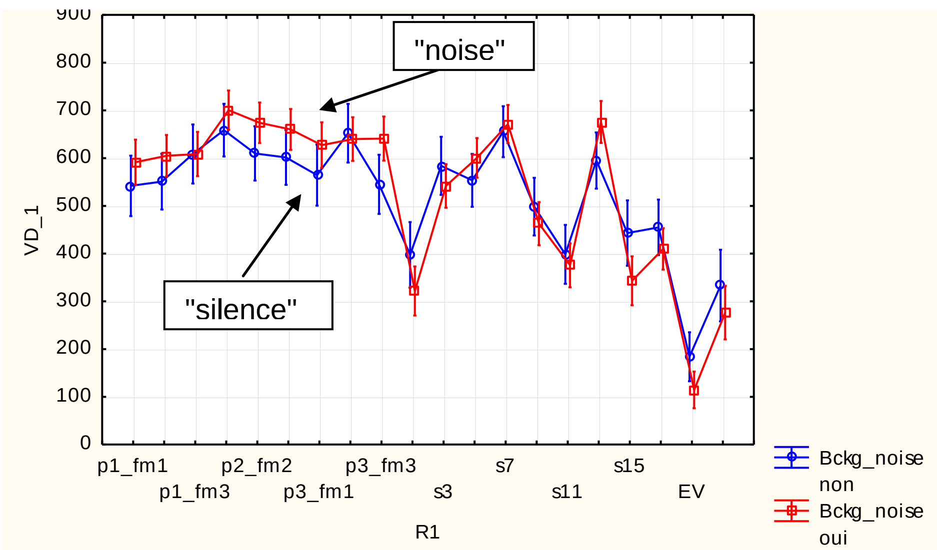

Figure 17 : averaged evaluations in the two conditions (silence, background noise)

But, if the same analysis is realised on the sub-panel of reliable subjects only, this interaction is no longer significant : people evaluated each source and were able to extract this source from the background noise.

Of course, stimulus is still a significant factor : F(19, 988)=48.5, p<0.0001. Figure 18 shows the averaged evaluations of these reliable people. Basically, the conclusions are similar to those obtained using the whole panel : sounds 1, 11 and 15 (from the first experiment) can be considered as equally unpleasant than the diesel car , while significant differences exist when using all the other warning sounds.

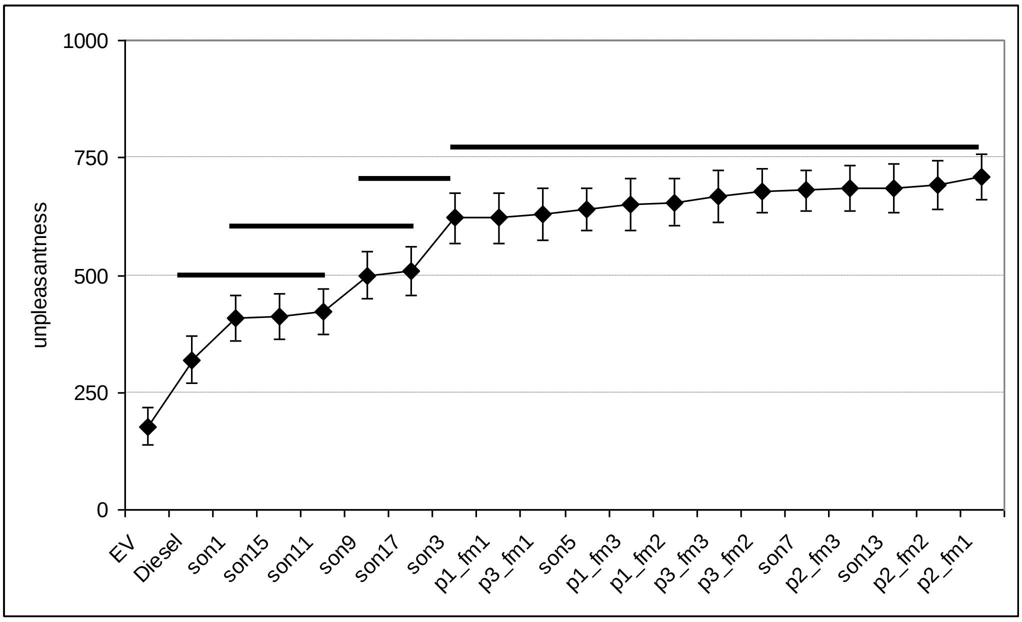

Figure 18 : averaged evaluations of the reliable subjects.

Finally, it should be noted that sound level does not accurately represent unpleasantness, as the diesel car is the loudest stimulus (it is at least 5 dBA louder than all other stimuli).

4.4 Factors effects

As in experiment 1, it is possible to compute the effect of each timbre factor on unpleasantness, by focusing on the sub-set of sounds used in this first experiment (labelled as son1, son3,…son 17 in figure 18). Most important factor is temporal fluctuation (F3 in the first experiment) : as soon as some temporal fluctuation is applied, unpleasantness increases (approximately by one scale category, see figure 19). Also, increasing the number of harmonics slightly decreases unpleasantness (second factor), which is natural as A-weighted levels of warning sounds have been equalised.

The same procedure was applied on the sub-set of sounds used in the second experiment (p1_fm1 and so on). It appeared that factors modified in experiment 2 have nearly no effect.

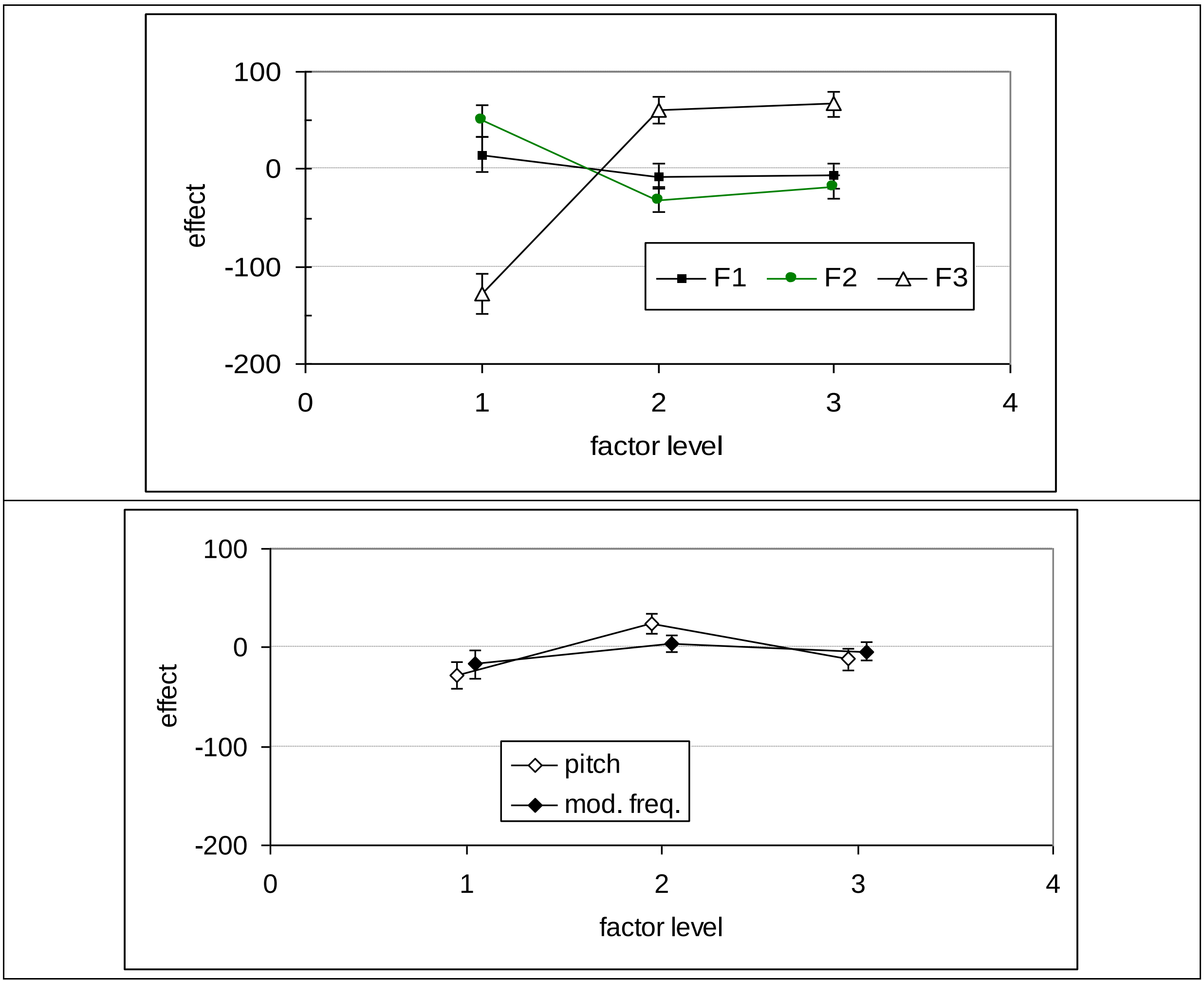

Figure 19 : factors effects. Top panel : factors used in Exp. 1.
Bottom panel : factors used in Exp. 2.

5 As a general conclusion

In figure 20, the detectability (experiment 1) and the unpleasantness (experiment 3) of 11 sounds are compared. Unfortunately, this figure shows that, for warning sounds, unpleasantness increases with the efficiency of the sound. This is in line with some previously published results about warning sounds (e.g. Tan and Lerner, 1995, Richir, 2010 or Fagerlönn, 2011).

But, if results are considered more precisely, some differences can be noted. For example, s1 and s15 are equally unpleasant, but s1 is easier to detect. On the other hand, s1 and s7 have similar performances as regard to detection, but s1 is much less unpleasant than s7. And, when looking at factors effects, the two kinds of temporal fluctuations (sinusoidal or "chaotic") have the same influence on unpleasantness (see figure 19, top panel, third factor) but the "chaotic" fluctuation is more efficient (see figure 4).

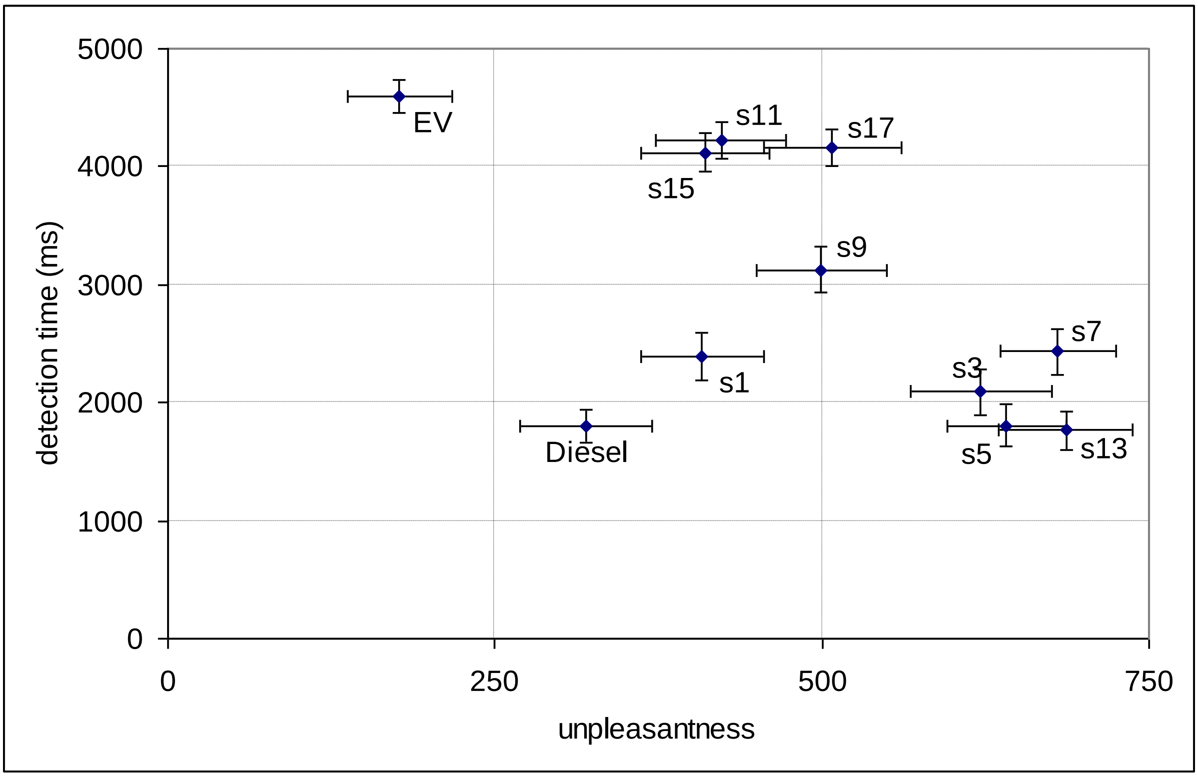

Figure 20 : comparison of results from experiments 1 and 3.

As a result of this set of experiments, s1 (3 components, no temporal and no frequency fluctuation) seems to be a good candidate as an additional sound.

Finally, it should be kept in mind that these sounds are quite new to people and the unpleasantness experiment had a very short duration. We cannot guess how people would perceive such sounds if they could hear them more often in real situation.

6 References

Fagerlönn J. "Urgent alarms in trucks : effects on annoyance and subsequent driving performance",IET Intelligent Transport Systems, disponible sur http://www.tii.se/node/268/publications

Richir B.A. "Effects of rhythm on the perception of urgency and irritation in auditory signals", rapport master Utrecht University (2010), disponible sur i*giturarchive.library.uu.nl/.../final%20thesis%20-20**bas**%20**allein**%20**richir**%200819.pdf*

Tan A.K., Lerner N.D. "Multiple attribute evaluation of auditory warning signals for in-vehicle crash avoidance warning systems", Report n° DOT HS 808 535, National Highway Traffic Safety Administration (1995).

Annex : instructions for the unpleasantness experiment

In this experiment, you will be asked to evaluate the unpleasantness of cars sounds. Imagine that you are standing in the street, facing the road and close to it. You will hear cars passing by in front of you at 20 km/h.
Some of these cars have conventional engines, some other ones are electric vehicles. As these vehicles are very silent, they can be dangerous for pedestrians, especially vulnerable ones. To prevent any collision, they are equipped with a loudspeaker emitting a warning sound and you will hear many different warning sounds.

I will now present some examples of the sounds you will hear *(please play the following sounds : son21_f.wav, p3_fm3.wav, son1_f.wav, son15_f.wav)*

In the following, you will have to evaluate the unpleasantness of each of these sounds. You will have to give your answer by moving a cursor on a scale, as you can see on the figure. You can place the cursor at any position you want (i.e. not necessary at a label position). The only requirement is that this position should express your evaluation of the sound.

You can listen to the sound by clicking on the left button "play sound". You can listen to it as many times as needed. Once you have moved the cursor to the correct position, you can switch to the next sound by clicking on the right button "next".