EUROPEAN COMMISSION
DG RTD

SEVENTH FRAMEWORK PROGRAMME
THEME 7
TRANSPORT - SST
SST.2011.RTD-1 GA No. 285095

eVADER

Electric Vehicle Alert for Detection and Emergency Response

Deliverable No.	D2.3	
Deliverable Title	Perceptual Test 2: Sound Meaning	
Dissemination level	Public/Confidential/Restricted	
Written By	Ryan L. Robart (INSA Lyon)	Feb. 20th, 2013
Checked by	Etienne Parizet (INSA Lyon)	Feb. 20th, 2013
Approved by	Juan Garcia (IDIADA)	Feb, 20th, 2013
Issue date	Feb, 20th, 2013	

Executive summary

The results of the experiments conducted in work package 2.2 showed that quiet warning sounds can be added to electric vehicles (EV) to make them as detectable as a diesel powered car. However, to achieve such results, it seems that an appropriate combination of the sound features coined *frequency detuning*, *tonal content*, and *amplitude modulation* must be attained for optimal detection. One warning sound in particular (*313*) worked particularly well for detection and was as good or arguably better than a diesel engine. The research conducted in work package 2.3 was focused on examining the utility of shifts in *313*'s parameters as it pertains to listeners' perceived safety with regard to the speed and location of an electric vehicle with added warning sounds (EV+S).

The work presented here will focus on the experiment completed at INSA, Lyon. This experiment is currently being conducted at the following labs:

1) Renault (Paris, France)
2) Nissan (Sunderland, United Kingdom)
3) LMS (Leuven, Belgium)
4) TUD (Darmstadt, Germany)

These results will be compiled and annexed to this document upon future completion. The general results of the work completed at INSA indicate that perception of danger increases with modulation rates but decrease with higher pitched sounds.

Contents

1 Introduction

The goal of this study was to try to ascertain if listener perception of danger of a highly detectable warning sound, such as *313*, shifts with the pitch and/or modulation speed of the warning sound. A 2(speed) X 3(pitch) X 3(modulation rate) repeated measures design was used to measure 27 listeners' perception of danger (response times) of the recordings of approaching cars (stimuli). The unmodified recordings (*Diesel)* served as control stimuli. Since this paradigm is somewhat novel, it was difficult to make specific predictions. However, if response times would shift with speed, such that danger was indicated earlier when the vehicles approached at 30 km/h, it would speak to the validity of our design. Also, it could be predicted that if pitch or modulation rate independently effect response times, we would see differences between the levels of the independent variables. Finally, if our dependent variable (response time) is valid, we could expect to see correspondence between responses to *Diesel* and at least 1 *EV+S*.

2 Stimuli and Soundscape Design

This section reviews the technical aspects of stimulus design.

2.1 Waiting to Cross Scenario

As outlined in WP 1, several listening scenarios were recorded at the Idiada and Renault test tracks. Due to time constraints, it was decided that only the following scenario be tested in the experiments conducted in WP 2.3(figure 1).

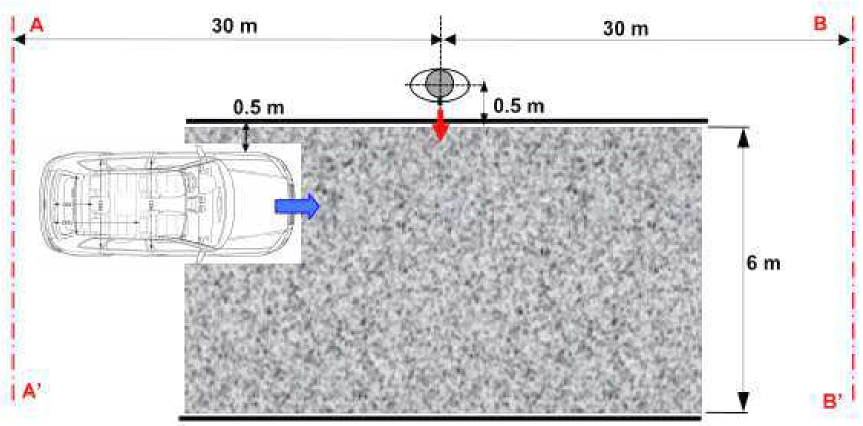

Figure 1: Graphical depiction of scenario 7 (see D1.6), or the 'waiting to cross' scenario. The recordings for the 20 kmh were used to make stimuli.

2.2 Shifting Pitch and Modulation Speed

All EV+S sounds were based on the *313* structure. Pitch and modulation speed were chosen for manipulation, along with vehicle speed (20 or 30 km/h) in this experiment. Warning sounds were designed according to Table A.

Stimulus code	Pitch f_0	Amplitude modulation
#11	225 Hz	25 % slower
#12	225 Hz	original value
#13	225 Hz	25 % faster
#21	300 Hz	25 % slower
#22	300 Hz	original value
#23	300 Hz	25 % faster
#31	375 Hz	25 % slower
#32	375 Hz	original value
#33	375 Hz	25 % faster

Table A : labels of all EV+S sounds. The "#" in the stimulus code should be considered as both 20 and 30 km/h.

All shifts were proportional the same (25%). In that, all 6 of *313'* s modulation envelopes (see appendix 2.2) were shifted 25% slower or faster in sounds that contained shifts in modulation rate.

There were 18 total EV+S stimuli (as both speeds were considered), and 2 diesel stimuli (at the same speeds).

2.3 Stimuli Synthesis and Recording Processes

As in the previous experiment, various labs were involved in the recording and synthesis process as can be seen in the figure below

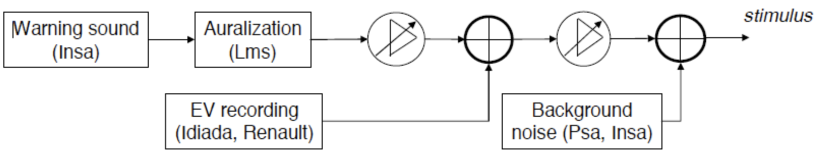

Figure 2: Path diagram showing the different lab contributions to sound synthesis and recording (see D1.6).

All recordings were made with a dummy head (Head Acoustics HMS III). As described in D1.6 the peak level (dBA) of the internal combustion vehicle (diesel) was approximately 73 dB(A) at 20 km/h and 77 dB(A) at 30 km/h, while the peak levels for the electric vehicle were measured at approximately 67dB(A) and 70 db(A) at these two speeds.

The 18 warning sounds for wp 2.3 were made using a custom synthesizer (Max/MSP). As in the previous experiment, all sounds were designed at INSA and spatially synthesized by LMS. As both 20 and 30 km/h speeds were being tested, sounds were either 10.8 or 7.2 sec in duration. The spatial synthesis involved modeling the 'waiting to cross scenario' (figure 1) which involved parameters associated with sound reflections on a textured semi-reflective surface such as concrete on a street, as heard by a pedestrian facing the road (using head related transfer functions). All warning sounds were normalized so that the average and peak levels were within 2 dbA of each other. Recordings were passed through an inverse filter designed in Matlab to correct for the frequency response of the headphones used in the experiment (Stax Lambda Pro). Once the sounds were modeled by LMS, they were layered onto the recordings of the *EV* by INSA.

All 20 stimuli were channel swapped, so that both possible directions (left->right and right->left) of pass-by could be heard. As a result, 40 stimuli were designed. The levels (dB(A)) of all stimuli were recorded and measured by tracking the stimuli through the Stax headphones (placed on the dummy-head), which was ported via XLR into a computer. This was done to ensure that original levels of the vehicle recordings were not significantly changed.

2.4 Soundscape (Background Sound) Design

As in the previous experiment a recording of *grands boulevards* in Paris, France was selected for the background because of its consistent, high-density traffic flow. This recording was thought of as a somewhat stationary (unchanging) background, as there few pauses in traffic flow, and relatively few loud and abrupt sounds. A 2 minute sample was selected that would be looped continuously during the experiment. In the interest of reducing potential confounds associated with binaural cues, only one channel of the selected sample was used. This channel was then divided into 2 channels, panned approximately 45 (right channel) and -45 (left channel). The background sound was then low-pass filtered and reduced from 69 dB(A) (detection experiment) to approximately 64 dB(A) to emulate a busy roadway approximately 100-200 meters in front of the listener and to ensure that approaching cars would be easily detected. Additional rain-sound was not used in this experiment, as detection was not our primary concern.

3 Design & Procedures

A 2(speed) X 3(pitch) X 3(modulation rate) repeated measures design was used to measure listeners' response times to the recordings of approaching cars (stimuli). The unmodified recordings (*Diesel)* served as control stimuli.

There were 10 stimuli for each speed (table A), each presented 4 times (2 per direction) over the course of each experiment. The experiment was divided into 2 blocks and each stimulus was heard twice per block. Trials were randomized separately for each participant. The inter-stimulus interval was set at 5 seconds. The total duration of a given experiment was approximately 12 minutes. There was not a limit for number of responses, and responses had no impact on the stimulus presentation.

Participants were familiarized with some stimuli in a short demonstration during the instructions. The instructions were quite extensive and are included in appendix 2.3. Essentially, participants were instructed to press the space bar when they felt they would not have time to cross a narrow street. Some participants noted that the task did not reflect their normal pedestrian behavior. In that, some participants stated that they would never think of crossing a street if they could hear an approaching car, regardless of the speed. However, most participants had no problem learning the task after the instructions (see appendix 2.3). After a participant completed a short training session (10 trials), they could begin the experiment. After the completion of the 1st block (40 trials), participants were given a short break. At the completion of the 2^{nd} block, participants were debriefed and thanked for their participation.

Twenty-eight visually impaired participants were compensated for their participation (INSA). Most participants reported normal hearing, although one participant had corrected hearing in both ears. One participant was rejected based on reports of confusion regarding the instructions.

The experiment was conducted in a dimly lit sound-attenuating chamber. A PC computer was used to present stimuli and record responses. Participants responded to stimuli using a standard keyboard. A Gina sound card was used for audio output. Stax headphones (Lambda Pro: electrostatic) and amplifier system was used to deliver the sound stimuli. The experiment was programmed using Delphi software for PC computers running Windows 7 operating system.

4 Results

The average response times for both speeds were not strikingly different for all sounds (figures #-#). As you can see in the figures below, the greatest difference in terms of distance was only 2 m at 20 kmh, but almost 5 m at 30 kmh.

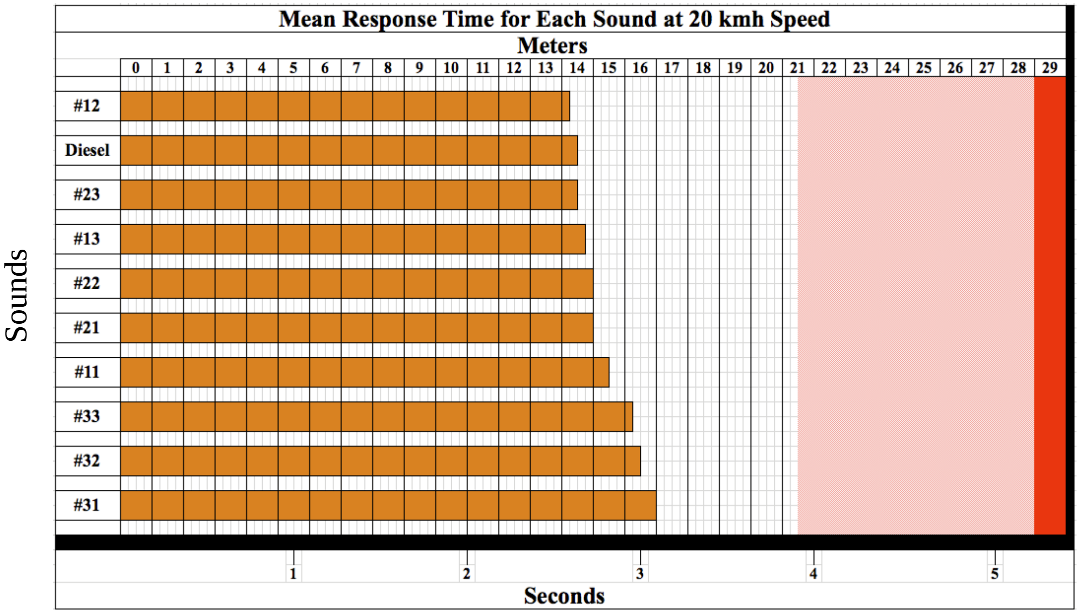

Figure 3: Response times were converted to meters to indicate the average distance from directly in front of the listeners (bright red stripe) the average listener responded to each sound for vehicles approaching at 20 kmh.

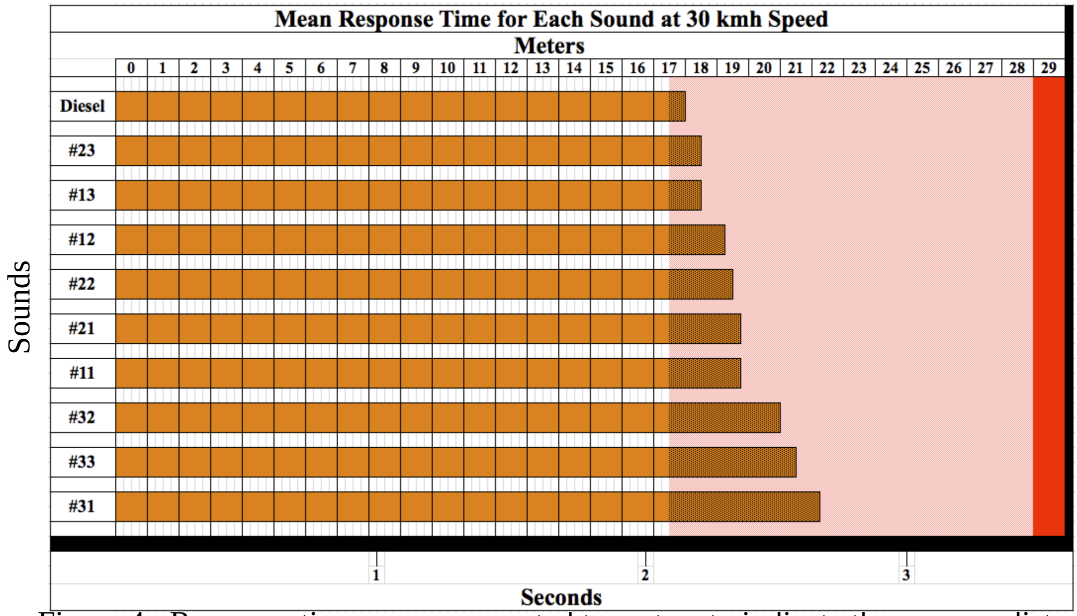

Figure 4: Response times were converted to meters to indicate the average distance from directly in front of the listeners (bright red stripe) the average listener responded to each sound for vehicles approaching at 30 kmh.

A 2 (speed) X 3 (pitch) X 3 (Modulation frequency) repeated measures ANOVA (N = 27) analyses indicates that there were main effects for all 3 independent variables (table B), while no interaction occurs.

Multivariate Tests				
Independent Variables	F	Between df	Within df	p-value
speed	55.093	1.000	26.000	0.000
pitch	21.782	2.000	25.000	0.000
modulation rate	8.233	2.000	25.000	0.002
Interactions	F	Between df	Within df	p-value
speed * pitch	0.542	2.000	25.000	0.588
speed * modfreq	0.872	2.000	25.000	0.431
pitch * modfreq	1.176	4.000	23.000	0.347
speed * pitch * modfreq	1.578	4.000	23.000	0.214

Table B: Repeated Measures ANOVA table displaying results for main effects and interactions. The highlighted p-values indicate significant effects.

Breaking down the main effects, we can see that responses were faster when the cars were approaching at 30 kmh $F_{(1,26)} = 55.093$ ($p < .05$).

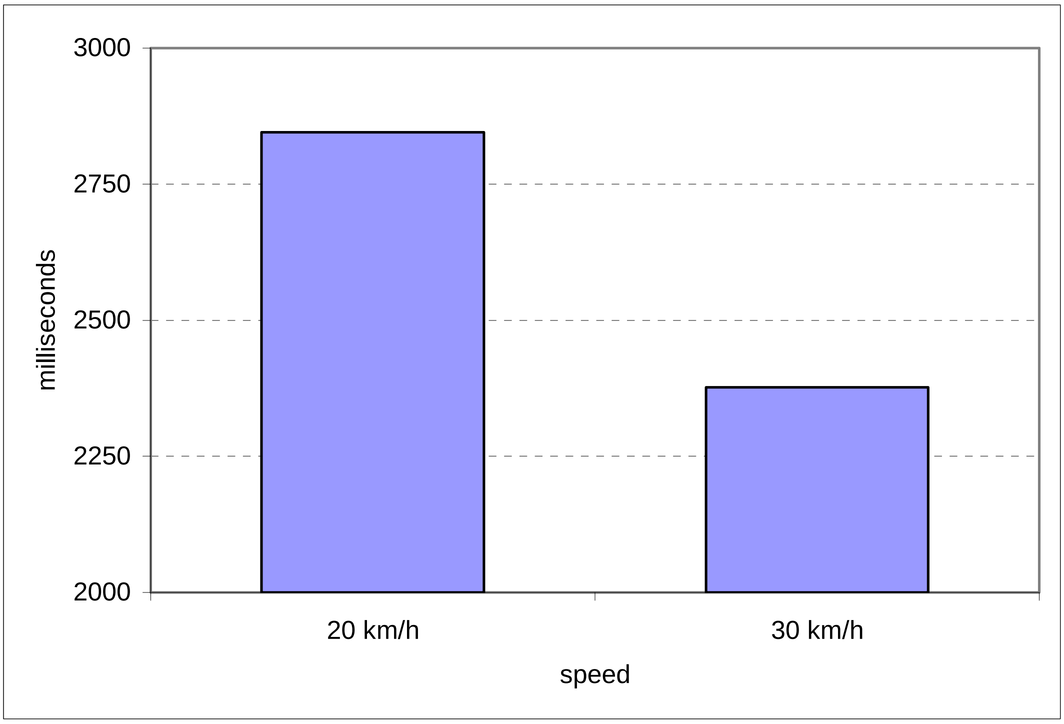

Figure 5: averaged response times for all vehicles travelling at the 20 km/h and 30 km/h speeds.

The main effect of pitch $F_{(2,25)} = 21.782$($p < .05$), was due to participants responding significantly later to the highest pitched sound (figure 6).

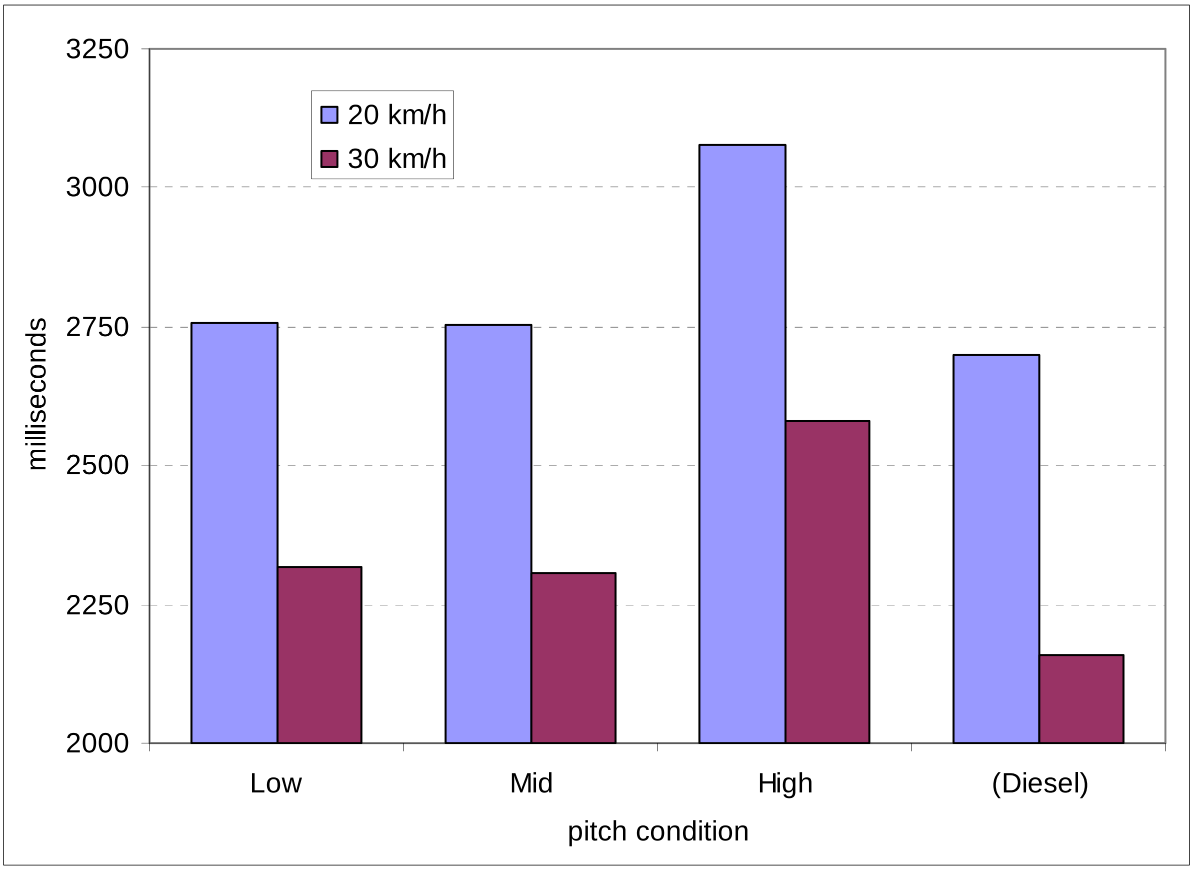

Figure 6 : response times for all warning sounds, averaged according the pitch value at each speed. The averaged values for the Diesel car are also represented as a reference.

This result is contradictory to our expectations : a higher pitch does not indicate a greater danger.

The main effect for modulation frequency $F_{(2,25)} = 8.233$ ($p < .05$) was primarily driven by participants responding later to the slowest modulation frequency. However, there was a negative linear trend ($p < .05$) for participants to respond sooner when as the modulation frequency increased.

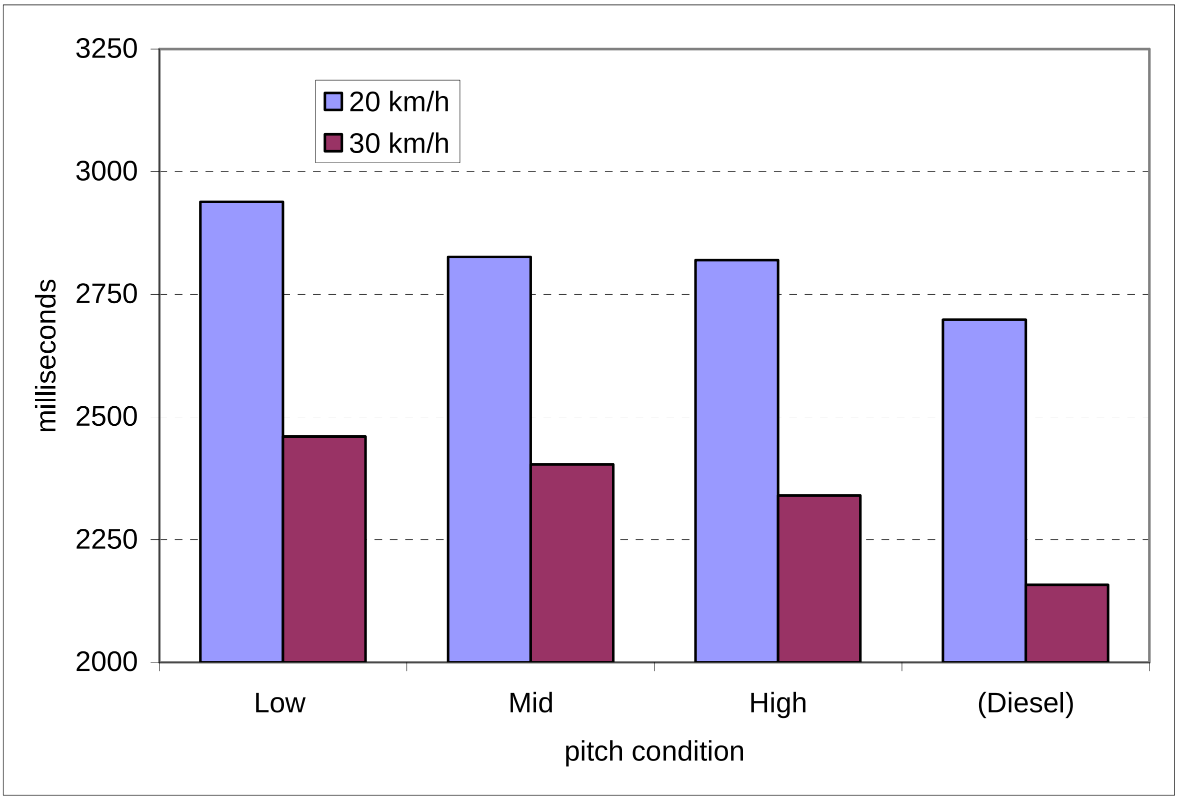

Figure 7: response times for all warning sounds at both speeds, averaged according the modulation frequency value. The averaged values for the Diesel car are also represented as a reference.

This result is in accordance with our expectations : the higher modulation frequency, the greater the danger, as felt by test participants. But this effect is low (at both speeds, the difference between the low and high values is 100 ms, which represents 0.55 m at 20 km/h and .85 m at 30 km/h).

5 Conclusions, Recommendations and Discussion

Preliminary conclusions are that these sounds do not confuse the listeners regarding the speed of the car (20 km/h vs. 30 km/h). Also, it seems that response time becomes faster with increasing modulation rates. Such that, they respond sooner when the sound is 'rippling' at a faster rate. Finally, the highest pitched sounds significantly slowed response times. This suggests that higher pitched sounds are likely not as informative as lower frequencies as to a vehicles speed when the sounds are quiet. This result needs to be explored more to determine why this is the case. An analysis of the warning sound loudness profiles suggests that responses were not based on loudness. Overall, it seems that higher frequencies should be avoided, and that modulation speed is most likely the most informative regarding vehicle speed. Still, it seems that that even though the results were significant, when the response time data were transformed into distances (see figures 3-4), the distances were arguably small (2-5 meters). Generally, this could be seen as an indication that the shifts in pitch and modulation rates may not be used by listeners to determine a vehicle's speed. Instead, it seems that listeners might rely on the rate of increase in loudness of these sounds to determine speed. If this is true, then it may mean that the process of adding sound to a vehicle need not include manipulating parameters of the warning sounds with a vehicles dynamics. However, it can be expected that a change of pitch or modulation frequency can easily indicate that the speed of the car is varied, which is a useful information for a pedestrian.
Though, it is highly recommended that more tests be conducted with vehicles accelarating/decelarating to approach the question of the utility of warning sounds for pedestrian perception of vehicle dynamics.

Another important issue for future research might be the examination of the role of training in such a task. That is, in this experiment we tested if there was a natural way that we could enhance listener perception of the danger of an approaching car by using sound. It would be interesting to try to impliment some training or familiarization beyond that of the limited short training sessions we used in our experiments. One can imagine that it may be possible for a standard modulation rate to be estabilished for any speed 0-30 kmh. In order to achieve this standardization, it would be necessary to examine listener rates of learning and retention of such sounds.

Annex 2.3: Instructions

Procedural Instructions:

Summary:

Background: **You may have noticed in your everyday life that cars are increasingly becoming less noisy. You may have had an experience while walking where you were surprised by a very quiet car. Recent research suggests that quiet cars such as electric and hybrid vehicles may be dangerous to pedestrians, especially in a noisy environment.**

Goal: **We are interested in learning about the important aspects of the sound that pedestrians may use to avoid being struck by such cars. In our experiment, we have added synthetic sounds to some recordings of some cars while adding no sound to others. Some of these recorded cars are moving faster than others. These recordings will be presented within the context of a realistic noisy urban environment. The noise consists of heavy traffic on a distant freeway.**

Task: **You will hear many different cars approaching and eventually passing by on a street directly in front of you. Your task will be to indicate when you feel it would be dangerously too late for you to step into the street by pressing the space bar.**

Detailed environmental description: **We ask that you imagine that you are walking in a part of a city that is near the city center. You are thinking about crossing a street that is only 5 meters wide, but because the street is close to the city's center, it is somewhat busy. Imagine you are facing perpendicular to this street waiting for a safe time cross. The speed limit for the street you wish to cross is 30 km/h. From time to time you will hear the various recorded cars approaching and crossing directly in front of you from either the left or the right. There is not a traffic light, so the cars will not slow down, or stop. The speed of these cars may vary from 15-30 km/h. So, in sum:**

1. **you imagine that you are near the center of a city, which is simulated sonically over headphones**
2. **in the scenario, you are listening for approaching cars to ascertain if it safe to cross a somewhat busy street**
3. **you can expect to hear a single car approach you from either the left or the right at any given time, but there will never be more than one car approaching you at a time;**
4. **the speed limit of the street you wish to cross is 30 km/h.**
5. **the approaching cars are moving at between 15-30 kmh, which could cause injury if you were to be struck.**
6. **there is no stop light and there is only one street in front of you, it is not an intersection.**
7. **you are not really in danger!**

Any questions so far?

Some of the approaching cars you will hear will sound like normal cars you might hear while walking in your neighborhood, or perhaps on a busy street in your city. Most of the cars you will respond to will not sound like a normal car. Most will sound like an electric car that has sound emitting from a loudspeaker mounted on it.

Any questions about this?

At this point I would like to play you samples of these approaching cars. Please keep in mind that these are only a few of the sounds you will hear during the experiment.

Open the folder 'demo sounds' and click on the first file in the list. Watch the playbar and when the sample terminates, ask them:

While listening, is it clear that it becomes more dangerous as the car approaches you?

Once they have successfully heard all examples, remind the participant that the sounds they just heard will be heard in a noisy background. If they have no questions, then move on to the training.

Any questions?

<u>Training instructions</u>

During the training and the actual experiment, your task will be to indicate when you feel the approaching car is dangerously close and it would be too late to begin to cross the street. Remember, the street is 5 meters wide. You will indicate that you feel it is too late to cross by pressing the spacebar. You can press the space bar multiple times during each trial if you like, we will measure only the final time you press it. Also, you can tap the space bar only once during each trial. It is also possible to press the spacebar down and hold it until you feel like it would be dangerously too late to step into the street. You can try any method you like during the training. Please remember that there are only two errors you can make here:

1. **by waiting until the car actually passes in front of you before pressing the space bar.**
2. **By not pressing the space bar at all**

We are interested in learning about your estimation of when the approaching cars become dangerously too close. Please just try to do your best.

If the participant indicates that they are having a problem understanding why they would cross at all when a car is approaching you can try this alternative explanation:

It is understandable that you might not even consider crossing the street if you can hear a car approaching. Another way you can do the task is to press the space bar when you think the approaching car is around 5 meters from crossing in front of you.

Are you ready to begin the training session?

Do you have any questions?

Open the ‘practice’ folder and click on the experiment program when they are ready. Monitor their progress on the screen to ensure they understand what they are doing.

Once it has concluded…

Great! It looks like you are ready for the actual experiment!

Do you have any questions before we begin?

Remember that after the end of the first block, you will be given a short break in case you need a drink etc.

So, if you feel ready, lets get started!

<u>Block 1 instructions</u>

Open ‘block 1’ folder and click the program file when they are ready.
Monitor their progress.

When the first block concludes…

How are you doing?

You now have a few minutes to take a break if you like. Feel free to get a drink, use the rest room etc.

Any questions before completing the final part of the experiment?

<u>Block 2 instructions:</u>

Open ‘block 2’ folder and click the program file when they are ready.
Monitor their progress.

When the second block concludes…

Great job! You have successfully finished the experiment. Now that you are finished, I would like to tell you more about our project.

<u>Debriefing:</u>

You may have noticed that some cars were more difficult to hear than others. These were likely electric vehicles. With the decrease in noise produced by hybrid and electric vehicles, urban environments are increasingly getting quieter as well. In fact, it certainly is an overall benefit to have quiet vehicles in terms of the reduction of noise pollution. However, it is also the case that pedestrians and even animals are at risk as a result. This is especially true if the drivers are not paying close attention to

the road. With the ever increasing technology of mobile phones and computer interfaces within vehicles, drivers are markedly more distracted than they have ever been. The goal of this project is to try to find the important aspects of synthetic sounds that may be added to quiet cars that are at least as effective as the sound of a normal car (ICE). Furthermore, we hope that there is a way to use a much quieter sound while remaining just as effective as a normal car. These sounds can be emitted through an intelligent sound distribution system for optimal performance. Thanks to yours and other participants help, we may be able to help keep our environment quiet and safe.

Do you have any questions?

If you have any questions regarding your performance or your experiment in general, I would be happy to provide details once we have analyzed your data. Please feel free to contact me via email. Thank you again for helping us, your participation is appreciated.

Have a nice day!