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EVADER: Electric Vehicle Alert for Detection and Emergency Response

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The warning effect of vehicle exterior noise for vulnerable users has recently emerged. Quieter cars could reduce pedestrians' ability to travel safely. One of the objectives of the EVADER (Electric Vehicle Alert for Detection and Emergency Response) European project is to propose technologies that will allow the best compromise between the potential risk of quiet vehicles for pedestrians and the quietness of residents. First, we identified critical safety scenarios, considering the safety risks and strategies used by pedestrians. Then, we defined the type of vulnerable people, the minimal reaction times and visual obstacles. The paper aims at characterizing different soundscapes, in order to choose psychoacoustic maskers and determine acoustic characteristics of a selection of vehicles. This work is intended to fill the gap between vehicle exterior noises perceptibility and the accident avoidance. A measurement protocol, in order to evaluate the auditory detectability of electric vehicles by pedestrians, has to be proposed, taking into account loudness equalization.

1 Introduction

Electric Vehicles (EV) tend to run quieter than many Internal Combustion Engine (ICE) vehicles at low speeds. Their relative quietness could negatively affect pedestrian and driver safety because of reduced sound cues compared to louder vehicles ([1, 2, 3, 4]). The goal of the EVADER European project is not to discuss the question if electric vehicles are so quiet that they constitute a safety hazard to pedestrians and bicyclists in traffic or if additional warning sound is the best way to improve vehicle detectability by pedestrians [5]. Actions have already been taken by the US and Japanese governments as well as UN/ECE and ISO, with the expected outcome that legal limit values for "minimum noise" of vehicles shall be established: "it should not exceed the sound level of the ICE vehicle running at a speed of 20 km/h" [6]. Here come the questions: What sound is the best candidate? How generate this sound? When to produce it? EVADER has to propose technologies that will allow the best compromise (figure 1) between the potential risk of quiet vehicles for pedestrians and the quietness of residents. In order to ensure that these technologies will be largely used at short-term, we have to take into account the acceptance of the additional noise by the residents and the cost of different systems.

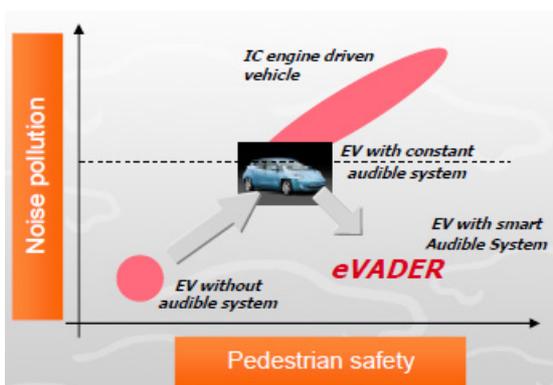


Figure 1: The goal of EVADER project is to propose the best compromise between the potential risk of quiet vehicles for pedestrians and the quietness of residents.

In this paper, we define first the scope of the study in terms of at-risk situations for pedestrians, including vulnerable people like visual-impaired people and of safety management between the vehicle or driver and the pedestrian. Then, we present environmental sound recordings, ambient noises in European cities and pass-by-noises, for vehicles approaching at low speeds. These measurements will help up to select the best candidates for alert signals and to propose an experimental setup to evaluate detectability and danger perception.

2 Definition of layout

2.1 Strategies used by pedestrians

Even if critical safety scenario could be determined from accident statistics, it seemed reasonable to observe the behaviour of pedestrians and the strategies used in the real traffic. Most research studies investigating the crossing behaviour of pedestrians have focused on behaviour at, or close to, mid-block pedestrians' crossings. Various different techniques (either video observation or self-report data obtained via surveys and interviews) have been used. When crossing the road, pedestrians could follow the safety rules or alternatively, they could accept only small gaps in traffic. It is well known that the same pedestrians could adopt different strategies in function of the environment. A pedestrian who is very familiar with its environment can show overconfidence and will not take into account the information necessary for their safety. Several factors like the age, medications or alcohol for example will change the strategy of a pedestrian. The explanatory factors of accidents caused by pedestrians [7] would be

- a too big confidence to cross,
- a bad evaluation and interpretation of the situation,
- a defect of grip of information and inattention,
- a bad estimation of their capacities.

There are more collisions while pedestrians cross streets at locations where there are no pedestrians crossing. The main reasons are situations when pedestrians suddenly appear from behind an obstacle or simply lack of attention. According to Kerber [8], persons involved in a conversation with other pedestrians are the most frequent distraction from the traffic event. Other frequent distractions represent carrying or moving things. The drunken persons and those who play sport in the street seem to be less frequent. Persons with portable music playing devices in other words, persons who do not have the same acoustic information than other pedestrians are numerous but this case was considered as a separate situation.

2.2 Minimal reaction times

Several parameters could modify the crossing behaviour of pedestrians: walking speeds can be affected considerably by the age, because he/she is encumbered by carrying a child, a heavy object or if he/she is disability. The width of the road influenced too the time taken to cross. In order to evaluate the safety risk associated with electric vehicles, the detection distance could be estimated from the vehicle speed and the pedestrian reaction time. The assumption is that only the pedestrian is responsible. According to the

NHTSA ([1], [2]), the time from first detection of an approaching vehicle to the time when the vehicle passed in front of the pedestrian refers to the time-to-vehicle arrival. The difference between the estimating crossing time and the time-to-vehicle arrival is called safety margin. This value includes the reaction time of pedestrian. It is assumed that the time it would have taken to cross a street (width of 8.4 m for a two-way urban collector), at a walking speed of 1.2 m/s is about 7 seconds. Even if we have seen that several situations affected the pedestrian's concentration, this value seems very important, compared to the 2 s of the traffic rules. One of our goals is to make noise only when it is necessary and not to produce additional annoyance. The question is to decide if this 2 s value is sufficient.

Kerber [8] measured reaction times in laboratory, with concentrated and distracted listeners. Tests conducted to typical values about 0.7 s for concentrated people whereas distracted road users had reaction times about 1.5 s. Although data can be found in the literature, real world pedestrian observations are lacking. However, Fugger et al. [9] have observed pedestrians at signal-controlled crosswalk intersections and their perception reaction to the crosswalk signal.

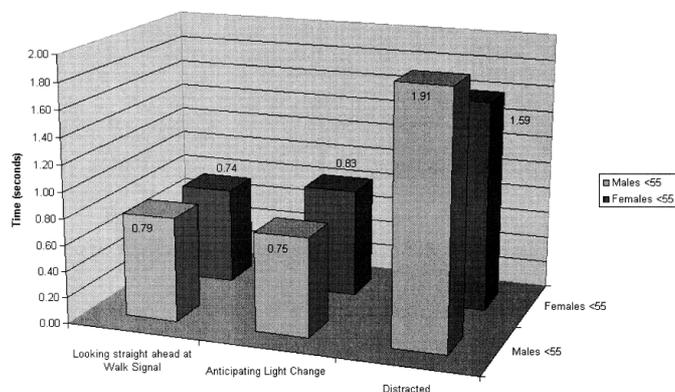


Figure 2: Perception reaction times for pedestrians under 55 years of age [9].

In their study, Fugger et al. [9] measured kinematics data on pedestrian movements using high-speed digital video. They wanted to obtain the mean acceleration and time to steady state walking velocity. 288 subjects participated to the experiment. The mean acceleration was equal at 0.14 g (more or less 0.09 g) and steady state velocity to 1.26 m/s (more or less 0.26 m/s). The figure 2 presents their results for perception reaction times. These values correspond to the reaction time of pedestrians from the illumination of the walk signal to his initial movement. No significant difference was observed between males and females. Level of anticipation was different between pedestrians: some of them looked straight ahead at walk signal; others anticipated light change and the last were distracted. For this condition, reaction times were about 1 second longer than for the anticipating condition but the maximum value was less than 2 seconds, equal to the reaction time value recommended by traffic rules.

If we considered now that the driver is the only responsible to avoid the crash, the distance corresponds to the sum of the brake reaction and the braking distance. The braking distance depends on the vehicle speed and deceleration rate. Given the typical reaction time values obtained in the laboratory, Kerber [8] supposed that the

pedestrians and the driver require the same reaction time. He calculated critical distances for the perception of different speeds, with a brake delay as a function of the driving speed of the car ($a_{\text{Brake}}=8$ m/s). He concluded that from the driver point of view, the recommended criterion is 2 s. Consequently, this value seems reasonable because it corresponds to the maximum reaction time, for a distracted pedestrian and it is equal to the mean value for a concentrated driver, assured to have good brakes.

2.3 Vulnerable people

The European project EVADER will define solutions to warn everybody as vulnerable users of a nearby moving vehicle while providing means for heightening the awareness of drivers in critical situations. The terms vulnerable groups a large number of users: pedestrians (visually impaired, hearing-impaired, children, older), bicyclists, etc. It is important to precise what means this adjective at this state of the project.

Acoustic cues are helpful to pedestrians' strategies in order to ensure their security. A significant reduction in auditory cues from vehicles may affect the ability of pedestrians who are blind and other visual-impaired pedestrians to travel safely. For visually impaired people, environmental sounds are sometimes the only source of information in order to avoid conflicts. Visually-impaired people use auditory information to orient themselves towards the crosswalks, to identify a time to cross and to travel straight across the street: traffic sound helps them ([1], [2]). Without traffic control, when it is quiet, they have to identify a gap in order to cross. The JASIC ([3], [4]) conducted interviews with visual-impaired people and they concluded that: "As the warning sound of an approaching vehicle, it is important to use a sound that is obviously coming from vehicles or a uniform sound that is widely known as such sound". The optimal warning sounds should intuitively be recognized as sounds coming from a vehicle, it should be possible to localize the vehicle and the sound should indicate vehicle manoeuvres (speed and speed changes). The sounds should not have annoying characteristics and should be equalled audible as the internal combustion engines, making it easier to identify quieter vehicles.

However, many other people could be considered as vulnerable for our study, particularly old people. Many studies have observed walking speeds well below the usual standard textbooks signalling lights offering time for walking speed of 1.2 meters per second. These factors (very slow walking speeds and difficulty of estimating speeds of vehicles) are often combined in the elderly to an overestimation of their own walking speed, thereby increasing the risk of being involved in a collision with a vehicle. We did not focus here on incidence rates for bicyclists' collisions or other vulnerable people crashes. It would be interesting to widen our research for these groups.

3 Environmental sound stimuli

3.1 Ambient noises in European cities

In order to have European representative data, four different partners carried out the noise measurements near their location, in three countries: Paris (France), Barcelona

(Spain) and Darmstadt (Germany). A common protocol was defined. All background noises were recorded using a binaural head on the pavement at 1m from the road and 1,5m height. The noise recordings at all points were carried out with a binaural system as time histories of the perceived sounds. The linear filter was chose to record ambient noises. The goal was to create a database of several background noises, representative of different urban environments (city centre, suburbs, countryside), in order to quantify the level of background noise during working days and the noise range covered.

The 1st site was chosen for its low traffic volume with a moderate noise level (around 40-50 dB(A)): low wind speeds, flat, clean asphalt pavement. The ambient level in the area should be representative of a quiet suburban area, which may be encountered by pedestrians.

The 2nd site was chosen by partners for its moderate traffic volume with a noise level more representative of a city centre (60-70 dB(A)). It will be necessary to have recordings during which no car is passing in front of the artificial head during clear sequences.

The figure 3 shows the dB(A) noise levels for four sites in Paris and near Guyancourt. The results show that the expected variability between different locations is about 20 dB. The reference locations have been chosen that correspond with zones of low traffic volume (40-50 dB(A)) and zones of moderate traffic volume (60-70 dB(A)). The noise spectra of the various measurements show the same trends with a relatively higher value at frequencies from 200 to 5000 Hz.

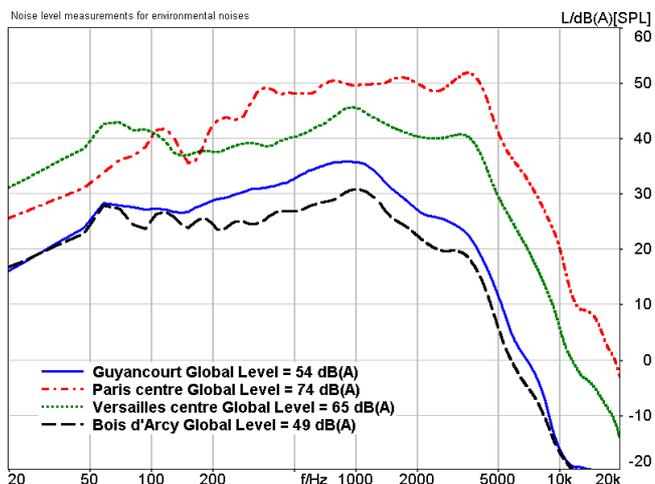


Figure 3: Noise level measurements for background noises in cities.

3.2 Vehicles approaching at low speeds

We compared noise levels for EV and ICE vehicles approaching at low stationary speeds (10 km/h, 20 km/h, and 30 km/h). Renault did the tests on ISO proving ground at Aubevoye, France. The figure 4 shows a schematic representation of the measurement protocol. A pair of microphones was at 2 m on the road and 1.2 m height. The detection of the measure beginning was done via the passage of photocells from -20 to +20m.

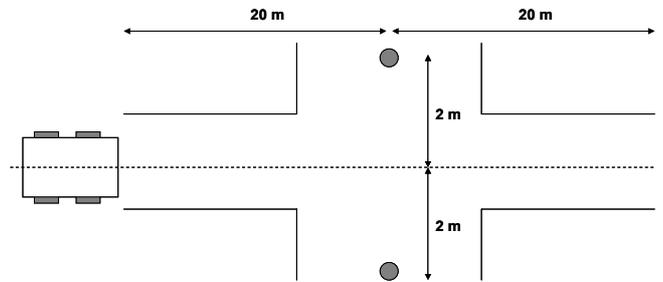


Figure 4: Microphones position relative to the vehicle, approaching at low stationary speeds (10 km/h, 20 km/h, 30 km/h) on ISO proving ground.

The mean sound level of the background noise was about 43 dB (A). The figure 5 shows the dB(A) noise levels at 10 km/h for the three vehicles (diesel, gasoline and electric) as a function of the vehicle position in meters. The difference between the electric vehicle and the ICE vehicles is the most important at 0 meter, in front of the microphone. The noise levels differences are equal to 11.3 dB(A) between the gasoline and the electric vehicles and only equal to 15.2 dB(A) if we considered the diesel vehicle.

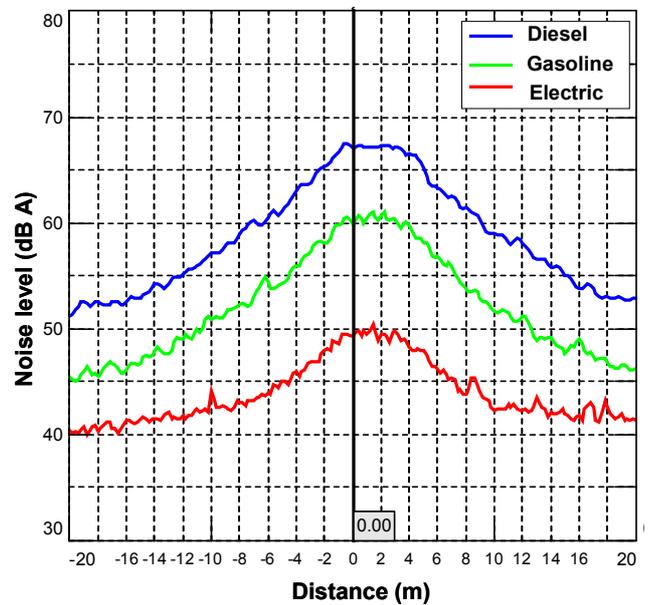


Figure 5: Comparison of measured levels for a vehicle approaching at low stationary speed (10 km/h), on ISO proving ground.

We have begun exploring the audibility of EV sounds in the presence of the masking effects of traffic noise by calculating instantaneous partial loudness [11] in order to propose future alert signals for laboratory tests. A good alert signal should fulfil several requirements in the temporal and frequency content. The Approaching Vehicle Sound for Pedestrians developed by Nissan [10] was designed with a “twin peak” sound spectrum. The first peak is at 600 Hz and modulated to accommodate people with high frequency age-related hearing loss. The second peak is at 2.5 kHz, corresponding to a frequency range well detectable by people without hearing loss.

The background noises and pass-by-noises recordings will be used in the future work package to defined jury tests under laboratory conditions. The environmental noise will be mixed with the vehicle pass-by-noise and then synchronize with the alert signal. An important point is

related to the loudness of alert signals. It is important to compare stimuli (signal added to the masker, in others words the background noise plus the vehicle exterior noise) with a similar loudness, as perceived by the pedestrian, on the pavement. Consequently, the stimuli equalization would be of good importance to not underline this parameter on the results. Several loudness models have been tested but present limitations to evaluate the loudness of unstationary sounds. A preliminary subjective experiment would be more precise but more time consuming.

4 Conclusion

The first workpackage of the EVADER project aimed to define the scope of the study in terms of at-risk situations for pedestrians, of reduction of the overall noise level in cities, of safety management between the vehicle and the pedestrian. It is recognised that sound level is important to compare ICE and EV vehicles and give us some information about vehicle detectability in city centre. However, it is not the only consideration for alert sounds: the sound timbre, time variance (modulation and unmodulation) can enhance the audibility of an individual vehicle. In the second workpackage of the project, tests in laboratory will give us scientific data to evaluate the detectability, the meaning of the sound (indicating a danger) and the annoyance for residents. We have to determine what signal characteristics have an influence to hear it and to interpret it as a vehicle approaching.

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