

2019:00062 - Unrestricted

Report

Adaptive acoustic vehicle alerting sound, AVAS, for electric vehicles

Results from field testing

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REPORT NO	PROJECT NUMBER	VERSION	DATE
2019:00062	102018376	01	2019-02-20

KEYWORDS: Acoustics, Noise,
Electric vehicles, AVAS

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CLIENT(S)
BUFdir

CLIENT'S REF.
Anders Eriksen, 49578

NUMBER OF PAGES/APPENDICES:
21 + appendices

CLASSIFICATION
Unrestricted

CLASSIFICATION THIS PAGE
Unrestricted

ISBN
978-82-14-06846-7

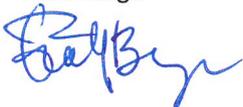
ABSTRACT

Acoustic vehicle alerting sound (AVAS) is implemented on electric and hybrid vehicles (in electric mode) as a safety tool to warn pedestrians at low vehicle speeds⁰. The main objective of this project has been to evaluate if the present regulations for AVAS could be improved, by including an adaptive functionality, with relation to the level of background noise.

A test of different sound levels of AVAS and with different levels of background noise has been conducted using a panel of 8 test persons. Of these, 3 were blind/visually impaired. In the test, the test persons were asked to press a button whenever they could hear the approaching vehicle (at 20 km/h). By so, a detection distance could be established depending on the sound level of AVAS and background noise level. The results showed that when the background noise is relatively high (around 65 dB), the level of the AVAS signal should be somewhat increased, if shall function as a safety warning signal. For the specific electric vehicle used for the test, the present sound level of AVAS, has no warning effect at 20 km/h, even with a low background noise level (40-50 dB), as tyre/road noise is dominating at this speed. However, the detection distance under these conditions is higher than a proposed safety margin of 11 m.



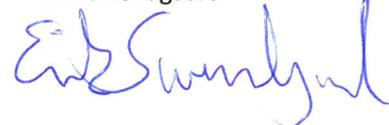
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Document history

VERSION	DATE	VERSION DESCRIPTION
01	2019-02-20	Final

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Publicity

1. Introduction

Electric vehicles and hybrid vehicles in electric mode are in most cases significantly quieter at speeds lower than 20 km/h, compared to cars with internal combustion engines (ICE)¹.

With increasing number of such "silent" vehicles in the traffic, a strong concern has been raised by blind and visually impaired persons. They have found it more un-safe to move around in traffic, where these electric/hybrid vehicles have become more frequent. Usually, visually impaired persons rely on their hearing abilities to define if it is for example, safe to cross a street with approaching vehicles.

Even if Norway has the highest density in the world of electric and hybrid vehicles (as a percentage of the total vehicle fleet, see also chapter 3), there have been no reports so far of any fatal or serious accidents between this category of vehicles and pedestrians/bicyclists. However, some near misses have been reported. In 2017, a blind person with a white stick was nearly hit by an electric car, when he was crossing the street at the zebra crossing. His stick was broken, and he claimed that he could not hear that this car was approaching him without stopping.

Under the term of "universal design", the ability to move around safely in a traffic environment is a civil right for every citizen, independent on any physical disability. It is in this context, the national organization of blind people in Norway has complained about the situation and asked for measures to make it safer for them to move around in trafficked areas.

It is within a research program for "universal design" funded by the Norwegian Directorate for Children, Youth and Family Affairs (BUFdir), SINTEF Digital has conducted this research project. This report presents the main findings from this investigation.

2. International regulations on Quiet Road Traffic Vehicles (QRTV)

Partly based on initiatives from the World Blind Union and other organizations for visually impaired people in the U.S, international regulations have been developed describing requirements of the minimum of external sound levels of vehicles running at speeds below 20-30 km/h (QRTV). By the UN, the ECE Regulation 138² was introduced from October 2016. In the US, the NHTSA rule FMVSS 141³, which also regulates the minimum sound of vehicles, has recently been adopted. The requirements in the US rule is somewhat different from the ECE regulation, especially concerning maximum vehicle speed and tonality requirements for the artificial sound. The basic principles of UN ECE Reg. 138 has been implemented by EU in the regulation 540/2014⁴. This regulation states that all new vehicles type approved after 1 July 2019, must meet these requirements. By 1 July 2021, all new quiet vehicles must meet the regulation. For electric vehicles and hybrid vehicles running in electric engine mode, it requires an additional artificial warning sound, named AVAS (Acoustic Vehicle Alerting System) to meet these regulations.

Both regulations are based on (identical) international approved sound measurement methods ISO 16254⁵ and SAE J2889-1⁶.

In the ECE regulation, the minimum sound level at 10 km/h is set to 50 dB and 56 dB at 20 km/h at 2 m distance from the centre line of the driving lane. The maximum sound level (of AVAS) shall never exceed 75 dB, independent of speed. These requirements are set so that the sound from these quiet vehicles shall not be higher than ICE vehicles, but at the same time give enough sound to warn pedestrians/bicyclists, especially when the background sound levels are low.

The regulations define AVAS, with respect to the minimum sound required in the 1/3rd octave bands from 160 to 5000 Hz. The pitch of the sound shall also increase with increasing speed, simulating the

increase in tonality of a combustion engine with increasing rpms. A different sound when the vehicle is in reverse mode is also required.

The European Blind Union (among several other) has expressed concern of the present UN ECE regulation⁷. The main objections are:

- the present allowance of a pause switch should be abandoned
- the AVAS should be active up to 30 km/h (as in the US)
- AVAS should be mandatory also when the vehicle is stationary

The removal of the pause switch has already been proposed, both by EU and in Geneva (UN ECE) and it is likely that this option will be removed before the introduction of the regulations.

3. Sales of electric and hybrid cars in Norway

Even if the quantity of the number of sold electric and hybrid cars are higher elsewhere in the world (like in China and US), the *density* of these cars compared to the fleet of ICE cars in Norway is the highest in the world. Per December 2018, more than 180 000 pure electric vehicles are running on Norwegian roads. This is nearly 7 % of the total fleet of cars. On the sales statistics for 2018, more than 1/3rd of all cars sold were pure electric vehicles. If hybrids are included, these two groups constitute about 60 % of the new cars sold. Of the 10 most sold models, none of these were with diesel engines. In 2018, the new Nissan Leaf was the most sold model, beating the VW Golf, which have had this position for many years.

Figure 1 shows the increasing sales in Norway of electric, plug-in hybrids, hybrids and hydrogen cars over the years 2010 to 2018⁸. The sales of hybrids and plug-in hybrids dropped somewhat in 2018, mostly due to an increase in vehicle taxes for this group and stop of sales of some of the PHEVs due to the introduction of the new WLPT test cycle for fuel consumption and emissions.

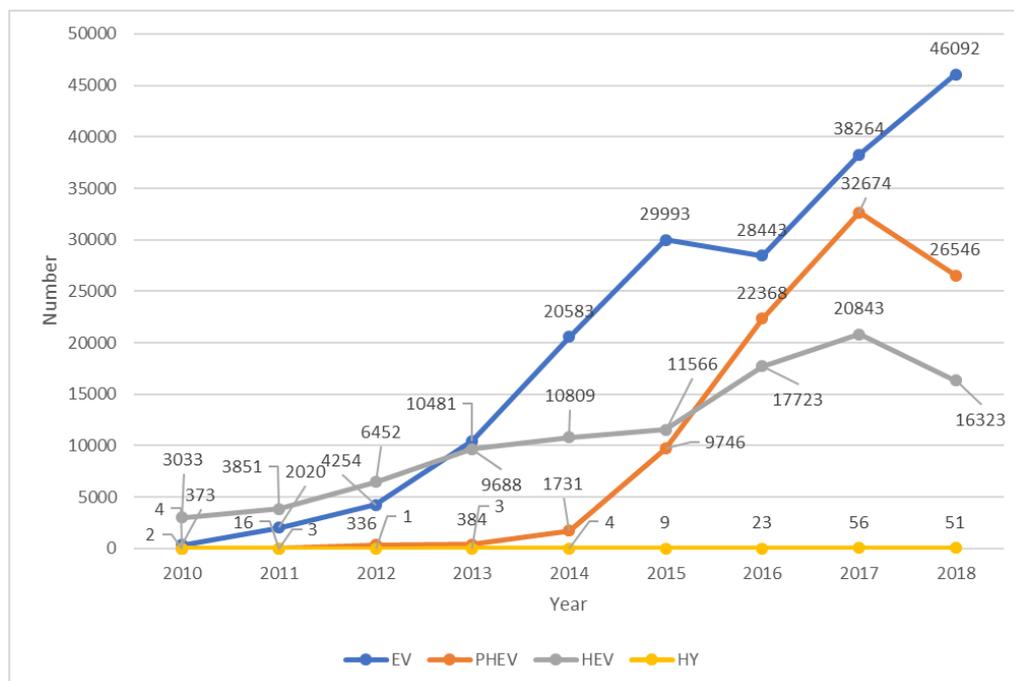


Figure 1. Sales of electric (EV), plug-in hybrid (PHEV), hybrid (HEV) and hydrogen (HY) in Norway over the period 2010-2018⁸.

The reasons for this high rate of change of the vehicle fleet from ICE vehicles are related to a wide range of economic and user incentives from the parliament.

The most important economic incentives are no VAT and much lower annual vehicle taxes for EVs.

The main user incentives are:

- Free passing at toll gates
- Free admission to ferries on the national roads
- Free parking on public parking areas and parking houses
- Free charging at public parking areas, except for high speed charging.

In most cities, there are now reserved parking lots for EVs and PHEVs, both in streets and in parking houses. Many companies/institutes now offer reserved parking lots with free charging for employees during working hours.

Due to the increasing fleet of electric vehicles, some of these incentives are now being revised and, in some cities, EVs have now to pay for parking and passing of toll gates (however, with reduced fees).

4. Survey among EV owners in Norway

In 2017, the Association of electric cars in Norway conducted a survey among their members on behalf of SINTEF⁹. The main purpose was to investigate their views on AVAS as a safety issue for pedestrians/bicyclists. A questionnaire was sent out to 6728 owners of EVs and a total of 3280 (48,8%) responded to the questions. The main findings were:

- Approximately 1/3rd of the EVs were delivered with AVAS installed. For some of the EVs, AVAS could be chosen as optional equipment to a price of around 100 €. Most of the EVs with AVAS were delivered with a "pause switch", allowing the driver to disengage AVAS during driving. However, the AVAS was always turned on, when restarting the car.
- 56 % of the respondents have had their EV less than 2 years.
- 49 % were introduced to AVAS and the "pause" function when they bought the car, and 41 % were not (the rest did not remember).
- About 19 % were motivated NOT to use the pause switch during operation, while 60 % were not given such motivation.
- 64 % do not consider AVAS as annoying from the driver's seat, while 31 % found the sound annoying.
- On the question if they ever had experienced any dangerous situation with pedestrians/bicyclists due to lack of sound (or very low sound level) from their car, the response was as follows: 83 % said **no, never** 11 % **yes, more than once**, and 6 % **yes, once**. This is quite similar response to an investigation made by the association in 2012, where the numbers were 81, 13 and 6 %. It is interesting, however, to see the results when they are grouped into two: those who have AVAS and those who do not have. For the group **with** AVAS, 18 % answer that they have experience dangerous situations **more than once**, while only 6 % of those without AVAS have experience this more than once. It is also a clear majority (87 %) of those without AVAS who **never** have experienced any dangerous situations, compared to 75 % of those who have AVAS. This may indicate that AVAS, as implemented, do not have any major influence on the safety situation for pedestrians.
- 66 % of the dangerous situations occurred in an urban street with very little traffic. About 40 % in a parking area/house and 30 % in a busy city street.
- 46 % believed that AVAS is **not** a good technology to warn vulnerable groups, while 36 % approved the technology. 18 % had no opinion.
- About 70 % were positive to an alternative technology, such as a system where AVAS was engaged only when needed, for example based on input from other driver assistant systems (camera, GPS, etc.). 20 % were negative.

- A majority (49 %) were also positive to a technology where a signal was given only to those who wanted a warning, for example through an audible signal to or a vibration of a smart phone. 41 % were negative.

In addition to the defined questions, there was also a possibility to comment on the issue of AVAS and silent vehicles. This opportunity was used by many of the respondents. Obviously, a topic of interest! The comments can be summarized as follows:

- Most of the respondents claimed that their driving style had changed driving an electric car. They are more conscious that their car is creating less sound at low speeds for pedestrians/bicyclists and adopt their driving behaviour to this fact. They claimed that (young?) people with headphones listening to music were the most important people to be aware of not hearing their car. Patience from the driver could avoid most dangerous situations.
- Many of the car owners would like to have a possibility to use a warning signal such as the bell of a bicycle to warn people. One person suggested a change in the behaviour of the car horn: A short pressure could give a low volume warning signal, while a long pressure could give the normal sound.

As a general comment to the survey, the association said that this investigation indicated that AVAS could be a false safety issue (make the car owner to believe that AVAS always could prevent accidents). The survey shows that there is no indication that cars without AVAS are more involved in accidents than cars with AVAS. For example, 92 % of Tesla owners answered that they never have been in any dangerous situations with pedestrians/bicyclists.

5. Development of AVAS and testing

Since the possibility to develop an artificial warning sound for quiet (electric) cars came up, there has been a considerable work going on internationally, mainly in Japan, USA and in some European countries (Germany, UK). It has been decided that the warning sound should "sound like a car" and not like any other artificial and natural sounds, like a bell, a siren, a melody, bird or insects. Thus, the focus has been on psycho-acoustics, and to design a sound signal that easily could be detected especially by visually impaired persons but also all groups of pedestrians/bicyclists. The work done has been both based on laboratory listening tests and field tests^{10,11,12,13,14,15,16}.

A similar type of test as described in our project, was conducted in the US by Virginia Tech Transportation Institute, Virginia Polytech Inst. and GM¹⁷. 4 cars were tested using the method described in the UNECE regulation²:

- EV without AVAS (VOLT)
- EV with AVAS (ELR)
- Hybrid car in EV mode with AVAS (Prius)
- ICE car as reference (SRX)

The cars were tested at both 10 and 20 km/h. A total of 24 persons took part in the test, both blind and normal seeing people (with sleep shades). As in our experiment, the test persons pressed a button, when they could hear the approaching vehicle.

The background sound level, simulating traffic noise, was reproduced from loudspeakers behind the test persons and adjusted to either 55 dB or 60 dB.

Table 1 show the overall maximum A-weighted sound pressure levels (SPL) and standard deviation at the two speeds.

Table 1. Maximum measured SPL at two speeds and UNECE requirements¹⁷

Vehicle	Test @ 10 km/h	UNECE @ 10 km/h	Test @ 20 km/h	UNECE @ 20 km/h
VOLT	55 ± 0.1 dBA	50 dBA	62 ± 0.1 dBA	56 dBA
ELR	56 ± 0.1 dBA	50 dBA	63 ± 0.1 dBA	56 dBA
Prius	54 ± 0.1 dBA	50 dBA	61 ± 0.1 dBA	56 dBA
SRX	60 ± 0.1 dBA	50 dBA	64 ± 0.1 dBA	56 dBA

At 20 km/h, the sound levels are dominated by the tyre/road noise and not by the AVAS signal. All vehicles exceed the minimum sound levels as required in the UN ECE regulation, by 4-5 dB.

Figures 2 and 3 show the results at these two conditions with background levels.

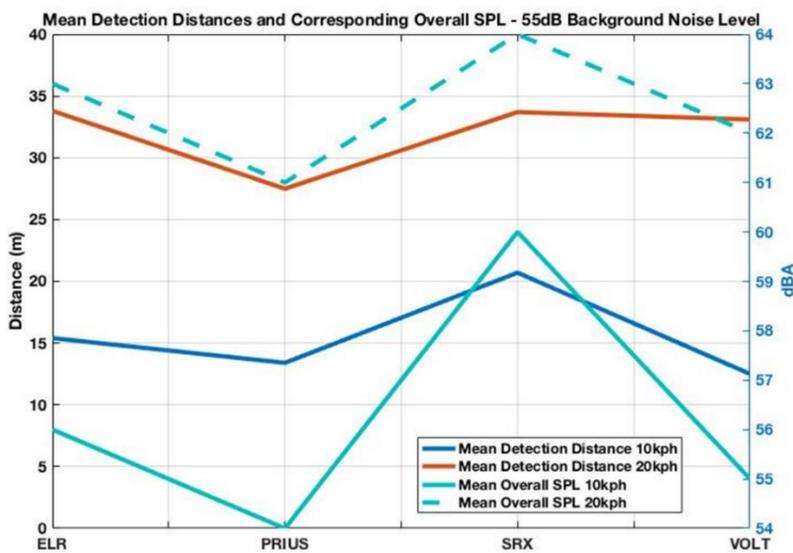


Figure 2. Mean detection distance and overall SPL, with background noise level of 55 dB¹⁷

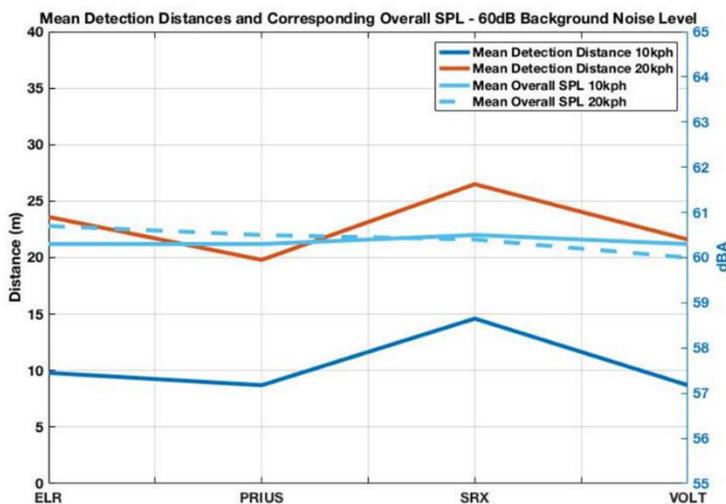


Figure 3. Mean detection distance and overall SPL, with background noise level of 60 dB¹⁷

For both cases, the minimum safe distances set by NHTSA³ of 5 m at 10 km/h and 11 m at 20 km/h are met. When the background noise level increases from 55 to 60 dB, the detection distance is reduced in the order of 30 %. There is a clear difference in detection distance of the ICE car (SRX) compared to the EV/HEV.

6. Why testing an adaptive AVAS?

The regulations do not specify any adaption of the sound pressure level of AVAS, depending on the background noise level. This means that the sound level of AVAS at a given vehicle speed is the same, independent if the car is in a quiet residential area during night time or in a busy city street during day time. Most of the present EVs with AVAS engaged have a sound level around 60 dB¹⁸ at 20 km/h. In a quiet residential street during night time, the background noise level can be 40 dB or lower. In these conditions, the audibility of the AVAS signal can be very high. Complaints have been made from people experiencing a neighbor parking his/her electric car near to their bedroom, when the window is open. Then the AVAS signal (especially the reverse signal) has been reported as annoying, since it can be 10-20 dB higher than the background noise levels.

In the opposite situation, in a busy city traffic, the background noise level can easily be in the range of 65-70 dB. In these situations, it can be very difficult to hear the AVAS signal at all. However, it may be that blind people in general then do not rely on hearing the individual vehicle to make decisions to stop or go, unless the vehicle is very close. Any increase in the sound level of AVAS to improve this situation must in any case be balanced against the general need to reduce road traffic noise. However, it may be solved if the AVAS is for example, only engaged at special locations (by GPS) as near pedestrian crossings, schools or kindergartens.

It has been calculated that the potential reduction of road traffic noise is around 3-4 dB, if all present ICE vehicles are replaced by electric vehicles¹⁰.

The main objectives of the project presented in this report have been twofold:

- 1) To investigate if the sound level of AVAS could be increased if the background noise is high
- 2) If the sound level of AVAS could be reduced at low background noise levels and still be detectable

The results could then be part of an evaluation of the principles of an adaptive AVAS, as a supplement or amendment of present regulations.

7. Layout of field test

A panel of 4 test persons were placed along the road at a defined distance from the 0 m-line, as shown in the figure 4. At the 0 m-line, a lidar and a microphone was placed. The microphone at 2 m distance from the center line of the road, measured the sound level continuously when the car approached the test area.

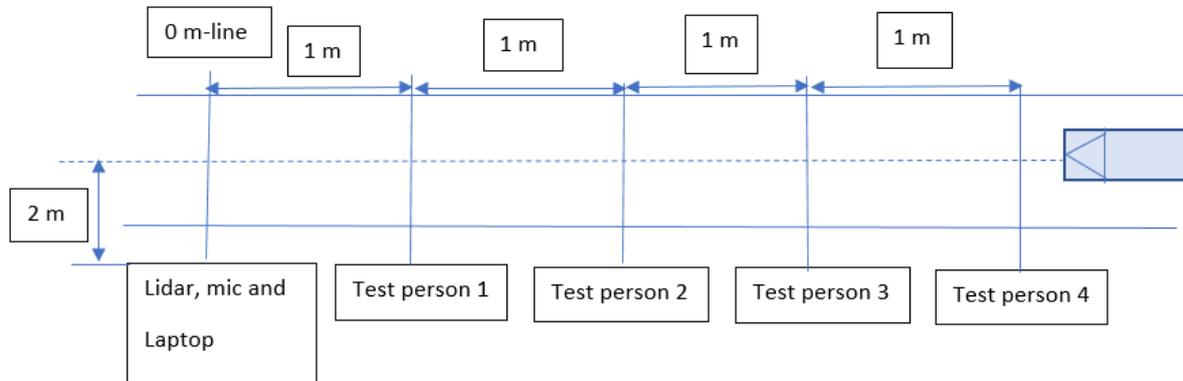


Figure 4. Layout of test area

The lidar works like a radar, except using the reflection and spread of a light signal instead of radio waves. The lidar does not require a reflection mirror, as needed for a laser-based system. The lidar gives information about location and speed of the car.

All test persons were equipped with a button to be activated whenever they could hear the car approaching. All signals from these buttons, the signal from the lidar and the microphone signal was recorded to the same data file on the laptop, using a program made with LabVIEW. This simplified the post-analysis of the measurement data.

The signal from the button, corrected for the individual position of the test person (figure 4) defines the detection distance of the car from the 0 m-line.

Figure 5 show the positions of the test persons near the road and figure 6, the lidar, microphone and the loudspeaker.



Figure 5. Test persons located on the road side



Figure 6. Microphone and loudspeaker (left behind on grass) and Lidar (right)

A loudspeaker was placed behind the test persons (see figure 6). From this loudspeaker, the background noise level was played at different levels, calibrated at the microphone position. The normalized noise spectrum is shown in figure 7. It is a recommended noise spectrum to be used in such listening tests. It is based on recordings of 1-5 minutes of background noise levels at several locations in Copenhagen¹⁰.

The benefit of using such a standard noise signal, compared to a time-variable noise signal (as found in a city), is that it is possible to make repeatable and reproduceable test conditions.

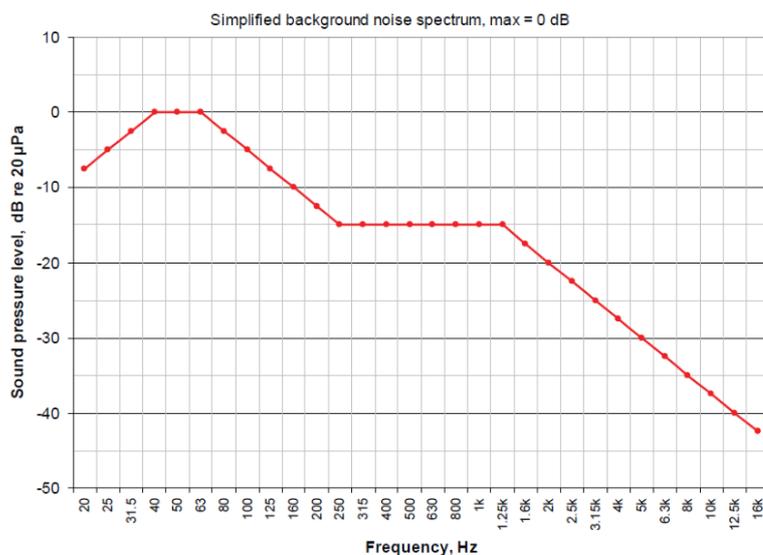


Figure 7. Normalized noise spectrum used as a background noise signal¹⁰

Table 2 gives an overview of the test persons, gender, age and their visual ability. All the normal seeing people had sleep shades during the test. Since only the hearing was used to detect the vehicle, it would have been interesting also to include a hearing test of all the participants, but this was not feasible within the time set for the test.

Table 2. Test panel

Test person no	Gender	Age	Visual condition
1	M	75	Normal
2	F	55	Blind
3	F	58	Visually impaired (ca.5 %)
4	M	62	Normal
5	M	67	Normal
6	M	54	Blind
7	M	28	Normal
8	M	28	Normal

Two cars were used for the test. As an ICE reference car: a VW Caddy, with a diesel engine and manual transmission, see figure 8. During the test, only 2nd gear was used at the speed of 20 km/h. The electric vehicle (EV) was Nissan e-NV 200, see figure 9. This is a rather large EV with 7 seats. Tyres on the EV: Goodyear EfficientGrip 185/65 R15.



Figure 8. VW Caddy with diesel engine

Figure 9. Electric car: Nissan e-NV200

The Nissan car was equipped with standard AVAS from the manufacturer, including a pause switch allowing a test of the car without AVAS engaged. It is not known if this AVAS fulfill the UN ECE or the US regulations.

In addition to the standard AVAS (emitted from a loudspeaker hidden under the wheel case on the left side of the car), a modified system for AVAS was implemented. A loudspeaker was mounted in the front of the car, with the membrane directed down, as shown in figure 10. A recorded AVAS signal (from a Renault Zoe at a speed of 20 km/h) was used as a "modified" AVAS. This modified AVAS was adjusted to different sound levels at the position of the microphone in figure 4. This means that during each test, AVAS was constant both regarding tonality and sound level.



Figure 10. Mounting of loudspeaker for modified AVAS signal

On the location of the test, the existing background noise level was measured to be in the range of 38-40 dB, when there was no audible activity in the area. However, there were occasionally some events, like an aircraft passing, some other vehicles, etc., which could influence the tests. In case such events occurred during a test, this test was removed from the analysis.

Table 3 gives an overview of all combinations of car, sound level of AVAS and background noise levels used during the tests. All tests at 20 km/h. Note that it was not possible to measure the level of the original AVAS signal at this speed, as the tyre/road contact was the dominating noise source (see also table 4).

Table 3. Test conditions: car, sound level of AVAS and background noise level

Test no	Car	AVAS	Sound level, AVAS dB(A)	Background noise level dB(A)
1	ICE	-	-	38-40 ²⁾
2	EV	Paused	-	38-40
3	EV	Original AVAS	- ¹⁾	38-40
4	EV	Mod. AVAS	50	38-40
5	EV	Mod. AVAS	50	50
6	EV	Mod. AVAS	55	50
7	EV	Mod. AVAS	60	60
8	EV	Mod. AVAS	60	65

1) Not measured due to tyre/road noise level

2) Natural background noise level at the location

A total of 8 test persons were used (table 2), with 4 in each test. Each test condition was repeated 5 times, to reduce the statistical uncertainty. This created a total of 80 data files for further analysis. However, some of these files were removed due to unwanted noise events during the test.

8. Results

8.1 Analysis of maximum noise levels and detection distance

The sound level of the car was measured during the pass-by for each test. The maximum A-weighted sound level and the standard deviation is given in table 4, as the average of 5 runs.

In test 2, the original AVAS has been paused, while it is engaged in test 3. As table 4 show, there is no significant difference in the maximum sound levels, indicating that the tyre/road noise contribution is the dominating noise source at 20 km/h.

In test 4 to 6, the maximum noise level is unchanged, even if the background noise signal from the loudspeaker has a level of 50-55 dB and the modified AVAS level is 50 or 55 dB. For all these test conditions, the maximum noise level at the position of the microphone is defined by the tyre/road noise on this electric vehicle and tyres and on this specific road surface.

When the AVAS signal is increased to 60 dB and the background noise level is either 60 dB (test 7) or 65 dB (test 8), this gives, as could be expected, an increase on the overall maximum level of 2 - 5 dB.

*Table 4. Maximum A-weighted sound level, L_{Amax} , dB(A) with standard deviation.
Speed: 20 km/h*

Test no	Car	L_{Amax} , dB(A)
1	ICE	$70,2 \pm 0,5$
2	EV	$63,4 \pm 0,8$
3	EV	$63,4 \pm 0,6$
4	EV	$63,1 \pm 0,5$
5	EV	$63,5 \pm 0,7$
6	EV	$63,4 \pm 0,5$
7	EV	$65,4 \pm 0,4$
8	EV	$68,1 \pm 0,7$

The requirements in the regulations² for minimum sound level at 10 km/h are 50 dB and 56 dB at 20 km/h. This is met for all test conditions, as shown in the above table. The ICE car has a maximum sound level approximately 7 dB **higher** than the EV (tests 1 and 2), when the EV has no AVAS engaged.

Using the buttons, the detection time/distance to the 0 m-line was recorded for each of the test persons. This detection time/distance can then be an indicator on the margin of the time needed for a person to decide if it safe to cross a street or not. The distance could also be a measure for the time needed for a car to break and completely stop, in order to avoid a collision with a person.

In the US rule³, this safety distance is set to 5 m, when a car is driving at 10 km/h and 11 m when the car is driving at 20 km/h. 11 m is equivalent to a safety margin of approximately 2 seconds when the car is driving at 20 km/h (~5,6 m/s).

In our analysis, we have set the safety margin to 11 m. If any of the test persons activated their button less than 2 seconds before the car crossed the 0 m-line, it would mean a possible dangerous situation.

An example of the resulting analysis is shown in figure 11. In this case (test no. 5), the AVAS signal is set to 50 dB and background noise level to 50 dB. 0 second is at the 0 m-line in figure 4. The location of the points of detection for the 4 test persons is only related to the x-axis (time) and not to the level of sound (y-axis).

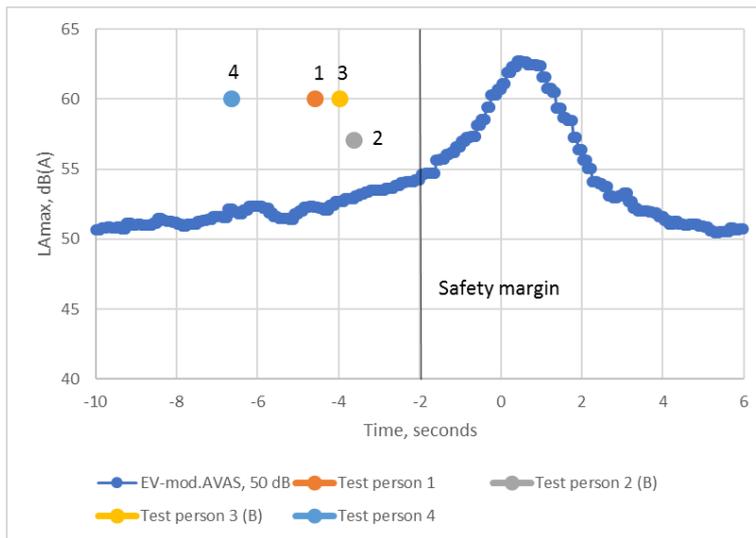


Figure 11. Example of analysis and results of one run (Test 5). Persons 2 and 3 are visually impaired

In this specific example, all test persons could hear the car before reaching the 2 seconds (11 m) safety margin.

In figure 12, the combined results for all 8 test persons and 8 test conditions are presented. For each of the 8 test conditions, the average value (5 repetitions) of the detection distance is shown, together with the 95 % confidence interval. This interval indicates that it is 95 % probability that the average detection distance lies within this interval. It is an indication of the overall spread in detection distance. The safety margin of 11 m is also shown. During tests 1 to 4, the natural background noise level at the site was used, while an artificial background noise level from the loudspeaker was used during tests 5 to 8.

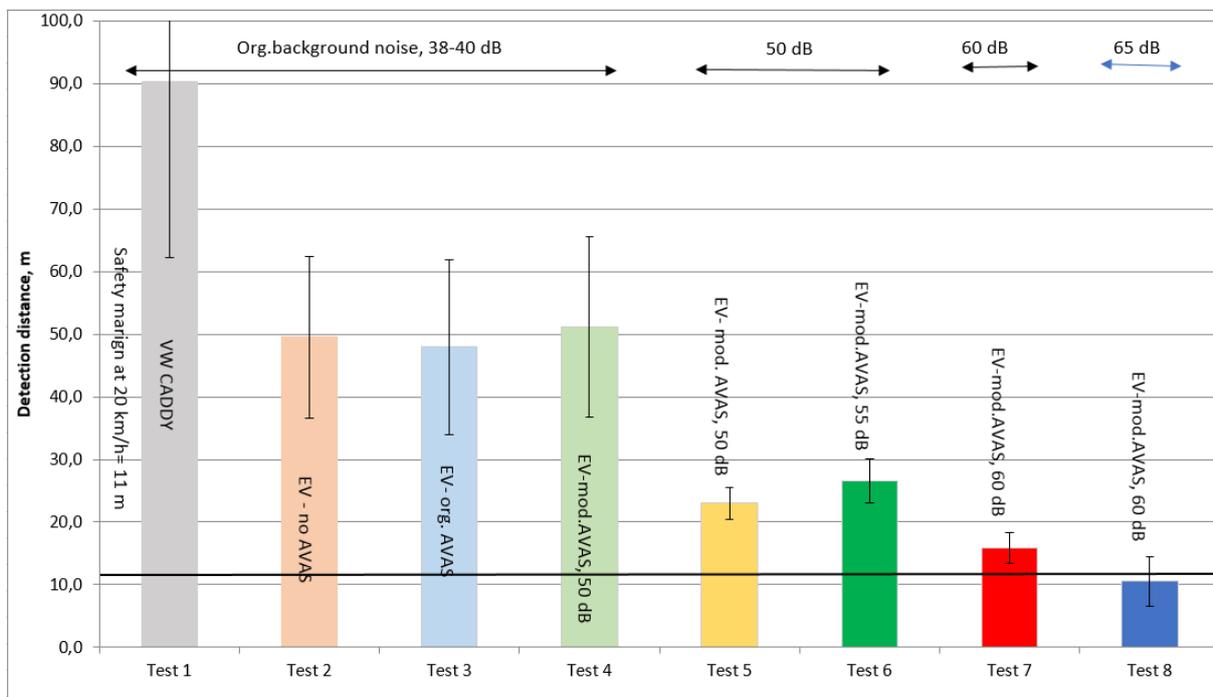


Figure 12. Average detection distance and 95 % confidence interval

In table 5, the numbered values for detection distance in figure 12 are listed, together with the standard deviation.

Table 5. Detection distance and standard deviation. Speed = 20 km/h

Test no	Car	Detection distance m	Standard deviation, m
1	ICE	90,3	40,6
2	EV	49,5	18,7
3	EV	47,9	20,2
4	EV	51,2	20,8
5	EV	23,0	3,6
6	EV	26,6	5,1
7	EV	16,0	3,5
8	EV	10,6	5,8

As shown in both figure 12 and table 5, there is a large variation in the detection distance of the ICE car (VW Caddy). However, all test persons did hear this car clearly in a larger distance than the EV, independent on the sound level of the AVAS. Reviewing seeing these results, we would have liked to repeat the test with the ICE car, also when the background noise was high, like during test 8. However, this was not feasible within the time and budget for the project.

Even if the maximum recorded sound level in tests 4 and 5 are almost identical (63,1 and 63,4 dB(A) in table 4), the detection distance is considerably reduced in test 5, approximately with 55 %. The artificial background noise level is in test 5 about 10-12 dB higher than the natural background noise level at the location and this clearly masks the sound of the vehicle when it is at a longer distance from the test panel. When AVAS is increased to 55 dB (test 6), the detection distance is somewhat increased, however, it is within the statistical variation.

Figure 12 shows that for all test conditions from 1 to 6, the detection distance is well above the safety margin of 11 m. When the background noise level is of the same order as the AVAS signal (60 dB in test 7), the detection distance is much closer to the 11 m margin, but still slightly above.

When the background noise level is approximately 5 dB **higher** than the AVAS signal (test 8), we have a situation where several of the test persons could not hear the car within the safety margin. These tests indicated that in a very common urban situation, with a traffic noise level in the order of 65 dB (or higher), AVAS as used in this test, seems useless as a safety device. For example, the average traffic noise level in the city center of Copenhagen (basis for the spectrum in figure 7) was found to be 64 dB¹⁰.

In such a situation, the sound level of AVAS should be increased, if the intention is to warn pedestrians. Alternative warning techniques should be considered, like direct communication between the car and the blind person. Another possibility is to completely rely on sensors on the vehicle to avoid dangerous situations, even if many blind people are against such alternative solutions.

In the test panel, 3 were blind/visually impaired persons and 5 with normal seeing abilities. It is known that blind people to a much higher degree than normal seeing people rely on their hearing to orientate in a traffic environment. They should then be much more trained to observe and to make decisions on what there are hearing, than the normal seeing people. In a listening test like conducted in this project, one could then expect that the visually impaired group in general would detect the car earlier than the other group, especially when the background noise level is high. In figure 13, the average detection distances from the tests are compared between these two groups.

The figure shows that we could not find any significant difference between the groups. However, one should bear in mind that there were only 3 persons in the visually impaired group. Also, the persons in this group was in the same age category (55-60 years). Another important factor is that when the normal seeing test persons were blindfolded, they had to concentrate using their ears to listen for the approaching car. This may mask any such differences between the two groups. In a "normal" situation, where the eyes are also used, the sound of the vehicle may be neglected in many situations.

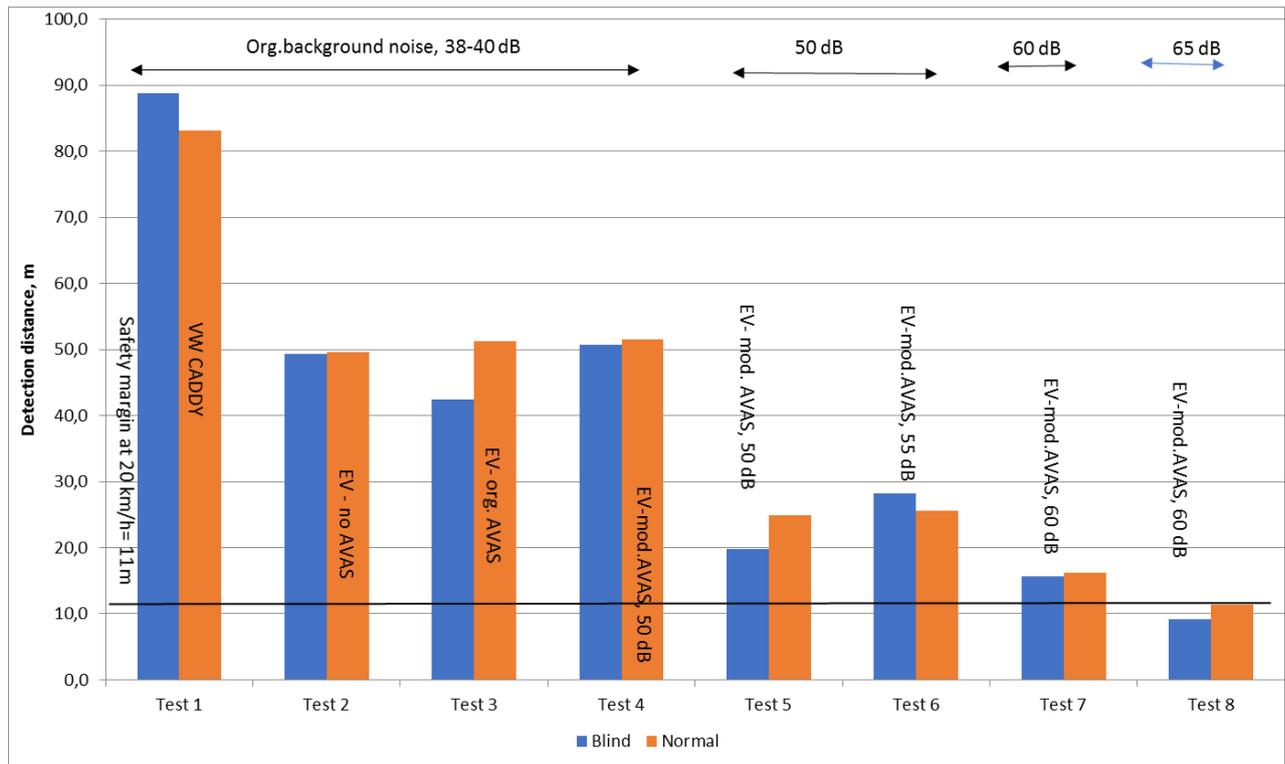


Figure 13. Comparison of detection distance between the group of blind/visually impaired and group of normal seeing

8.2 Increased safety margin

A similar project, as described in this report has been conducted by Western Michigan University, US¹⁹. In this project, a so-called "crossing margin" has been used in their analysis. This margin is defined as the margin which allows a person to cross a street, without any danger of being hit by an approaching vehicle. In their tests, this margin was set to be 6,9 seconds, based on the following assumptions:

- A person shall cross a two-way street being 7,3 m (24ft) wide and this person walks with a speed of 1,07 m/s (3,5 ft/s).

If an approaching car has a speed of 20 km/h (~5,6 m/s), the car must be 38 m before the pedestrian crossing area, in order to a safe crossing for the pedestrians. In this analysis, any possible reaction from the driver and breaking of the car is not included, only the time needed for crossing.

We have used this criterion and in figure 14, this increased crossing margin of 38 m is shown together with the detection distances.

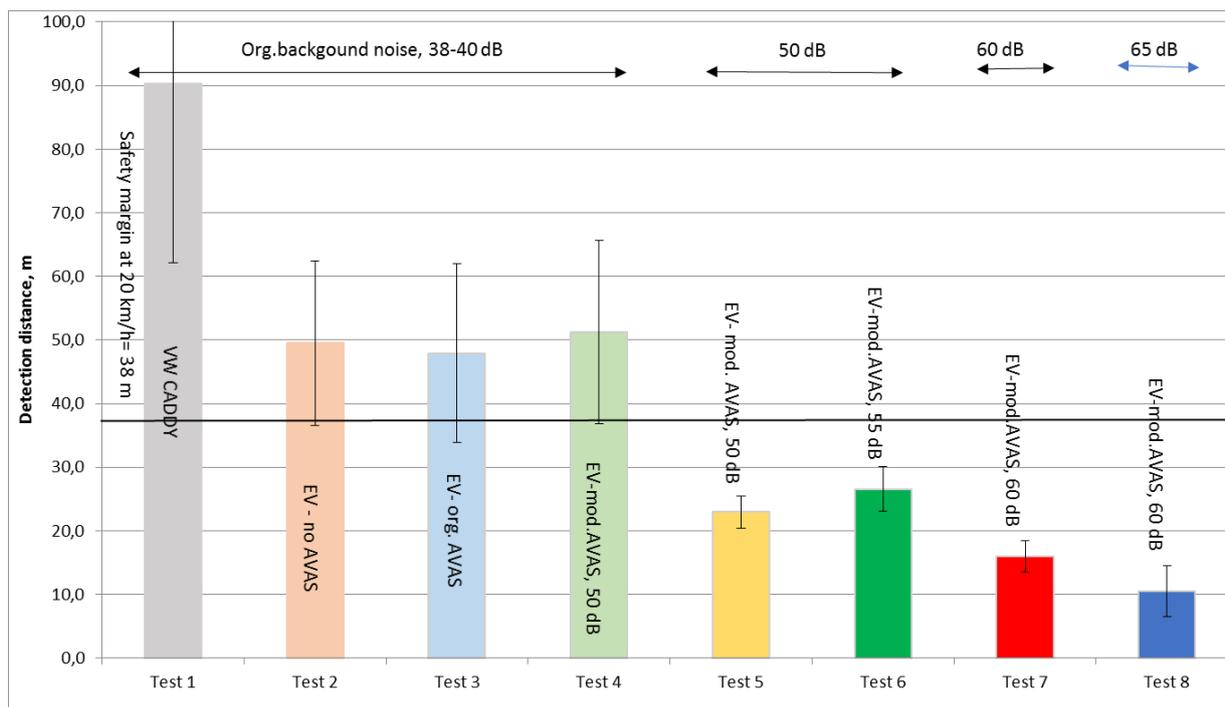


Figure 14. Detection distance with a safety margin of 38 m

Based on this criterion, we can see that when the background noise is 50 dB or higher (tests 5 to 8), it is not feasible for a blind/visually impaired person to cross the street safely if the driver is **not** aware of this person and do not break/stop the car.

The analysis is based on a fixed walking speed of the pedestrian. In reality, this speed would of course vary, due the age/physical condition etc. of the person. If the assumed walking speed of 1.07 m/s (approximately 3,9 km/h) is varying with $\pm 25\%$ (in the range of 3 to 5 km/h), it would vary the crossing margin from about 30 to 50 m. A crossing margin of 30 m will not change the situation shown in figure 13, as tests 2 to 4 still give a safe crossing. However, if the person walks with a speed around 3 km/h, which is not unrealistic, the crossing margin will be around 50 m. Then, conditions for tests 2 to 4 could be unsafe, even with a low background noise level.

Within the scope of this project, it was not possible to investigate the effect on the detection distance if the sound level of AVAS was increased, with a crossing margin of 38 to 50 m, especially when the background noise level is low.

In any case, an increased sound level of AVAS to say, 65-70 dB could be problematic and counterproductive for the need to reduce road traffic noise in general.

9. Conclusions and recommendations

The project conducted and presented in this report has some clear limitations concerning conclusions:

- The tests were conducted with only one electric car (in addition to the ICE reference car). For this car, the dominating noise source at 20 km/h was the tyre/road noise contribution. The original AVAS designed by the manufacturer had no influence on the detection of the car at the chosen test location. However, the average detection distance was well before the recommended distance of 11 m, when the speed of the approaching car was 20 km/h. It was planned to include a small set of other EVs (4-5), but this was unfortunately not possible, due to adverse weather conditions during the time of the measurements (only 3 days without rainfall in the period) and access to visually impaired persons for tests.

- When all the analysis of the results was available, it was clear that it had been valuable to include some tests also at 10 km/h, as the tyre/road noise would have been significantly lower at this speed. Then, the variation of the sound level of the AVAS signal would probably have had a greater influence on the detection distance, at different background noise levels, than at 20 km/h.
- One of the objectives of the projects was to see if it was possible to **reduce** the sound level of AVAS when the background noise level was low (as in a residential street during night time). However, due to the dominating tyre/road noise at 20 km/h (as for test 4 in table 3) it was not possible to investigate this. Additional tests at 10 km/h would have a way to do such an analysis.
- If the background noise level is in the range of 60 to 65 dB, commonly found in a busy city street, the AVAS signal seems unfit as a safety warning signal to pedestrians/bicyclists, unless the sound level is increased. However, this must be balanced against the needs to reduce road traffic noise in general.
- There were no significant differences in the detection distance between the two groups; blind/visually impaired and normal seeing persons.

It is not only the maximum sound level of AVAS which influence the potential detection by pedestrians. As part of the development of different AVAS sound design, the frequency content has been very important. In general, traffic noise has a peak around 800 - 1200 Hz, when tyre/road noise is dominating. In the regulations for AVAS and minimum noise levels, it is recommended that the frequency content is not masked by the tyre/road noise. The regulations have specific recommendations for minimum sound levels in the frequency spectra from 160 to 5000 Hz. Furthermore, it is required in the UN ECE regulation, that the pitch of the signal shall change with vehicle speed, simulation the change in tonality when the engine speed of an ICE vehicle is increasing. Within the scope of this project, it was not resources to do a frequency analysis and the effect of different types of AVAS signals. For example, the Renault Zoe is delivered with an option for the driver to choose within 3 different AVAS signals. Only one of these AVAS signals were recorded and chosen for our test program. If the project could be continued, such an analysis of differences in frequency and tonality would be of interest. Additional tests with different EVs, especially equipped with low noise tyres (like BMW i3) should also be included.

The objective of this project has been to investigate if an adaptive AVAS could be an improvement. Due to the influence of the tyre/road noise for the test car (and road surface) it was only partly successful. It was not possible to see if a reduced AVAS sound level (from the level set by the manufacturer) would be feasible, when the background noise level is low.

An adaptive AVAS can be implemented in a way, for example with an external microphone mounted on the EV at a location where the noise from the car itself is minimized or corrected for. This signal from the external microphone could then control the sound level of the AVAS signal, for example in steps of 5 dB (to avoid unnecessary rapid fluctuation of the AVAS signal).

A more advanced system could be to add a GPS signal only activating the AVAS at special locations, such as pedestrian crossing, kindergartens, schools, etc., too avoid unnecessary noise disturbances.

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Appendix: Publicity

During the first day of the test, the main radio/TV channel in Norway (NRK) was present and made a report from the trials. This report was shown during the main news program ("Dagsrevyen") on the evening of Thursday 11th of October 2018. The story was also presented on their web-site. The clip from the news can be found on this site (in Norwegian): <https://www.nrk.no/trondelag/forskning-pa-lyd-fra-elbiler-kan-hjelpe-blinde-og-svaksynte-1.14244805>

The joint SINTEF/NTNU web-based magazine GEMINI also presented the field tests: <https://gemini.no/kortnytt/elbiler-er-trafikkfarlige-for-blinde/>

A summary in English was presented by Gemini, and then several international publications made a story on the project.

Some of these are shown below (based on screen dumps):



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Adaptive tech helps keep electric cars' warning sounds from disturbing the peace



Ben Coxworth | 14 hours ago



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Electric cars are a hazard for blind people

"An electric car must emit an artificially produced sound of varying frequency but fairly constant intensity when travelling at 20 km/h or less," says **Truls Berge**, an acoustics research scientist at SINTEF. He has been carrying out research for many years on sound and noise in connection ...

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"A number of car manufacturers, including Nissan, General Motors and Renault, have shown interest in the results of this project," says lead scientist **Truls Berge**. "Norway has the highest density of electric vehicles in the world, so it's natural that electric car manufacturers look to ...

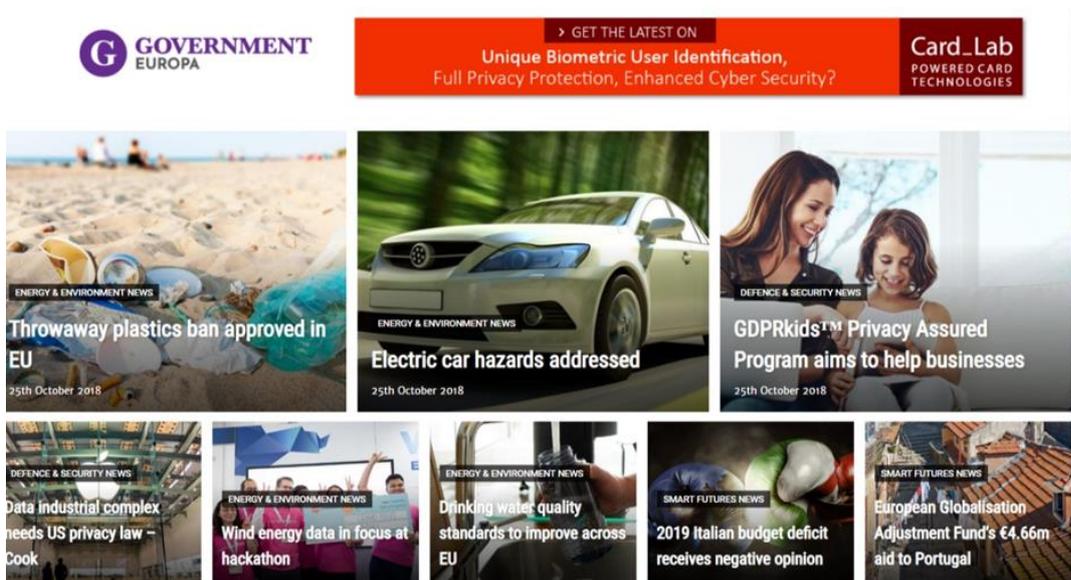
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In the Government Europa Quarterly 28, published in January 2019, there is an article about the SINTEF project: <https://www.governmenteuropa.eu/government-europa-quarterly-28/91844/>

In addition, the results from the project will be presented at InterNoise2019, Madrid 16-19 June 2019.