# The silence of electric vehicles – blessing or curse?


**Peter Cocron***
Cognitive & Engineering Psychology
Chemnitz University of Technology
Wilhelm-Raabe-Str. 43, D-09120 Chemnitz
Phone: (49) 371-531-37785
Fax: (49) 371-531-837785
E-Mail: peter.cocron@psychologie.tu-chemnitz.de

**Franziska Bühler**
Cognitive & Engineering Psychology
Chemnitz University of Technology
Wilhelm-Raabe-Str. 43, D-09120 Chemnitz
Phone: (49) 371-531-38235
Fax: (49) 371-531-838235
E-Mail: franziska.buehler@psychologie.tu-chemnitz.de

**Thomas Franke**
Cognitive & Engineering Psychology
Chemnitz University of Technology
Wilhelm-Raabe-Str. 43, D-09120 Chemnitz
Phone: (49) 371-531-37589
Fax: (49) 371-531-837589
E-Mail: thomas.franke@psychologie.tu-chemnitz.de

**Isabel Neumann**
Cognitive & Engineering Psychology
Chemnitz University of Technology
Wilhelm-Raabe-Str. 43, D-09120 Chemnitz
Phone: (49) 371-531-37767
Fax: (49) 371-531-837767
E-Mail: isabel.neumann@psychologie.tu-chemnitz.de

**Josef F. Krems**
Cognitive & Engineering Psychology
Chemnitz University of Technology
Wilhelm-Raabe-Str. 43, D-09120 Chemnitz
Phone: (49) 371-531-36420
Fax: (49) 371-531-836420
E-Mail: josef.krems@psychologie.tu-chemnitz.de



August 1st, 2010
Word Count: 6000 + 1 table + 4 figures (250 each) = 7250 total



*corresponding author

**Citation:**
**Cocron P, Bühler F, Franke T, Neumann I and Krems J F (2011, January).** *The silence of electric vehicles – blessing or curse?* Paper accepted to appear in proceedings of the 90th Annual Meeting of the Transportation Research Board, Washington, D.C.

# The silence of electric vehicles – blessing or curse?


## ABSTRACT

In the discussion about the impact of electric vehicles (EVs) concerns about their low noise level are often expressed. Studies on acoustics of these types of vehicles mostly focus on the perception of pedestrians, hearing-impaired or blind people. Especially for the transition period with only limited numbers of electric vehicles on the road, most of the assumed responsibility for the safety of all road users lays upon the drivers of such vehicles. In the present study we will report results on EV test-drivers and their experiences relating to the lack of noise of EVs. In a naturalistic driving study setup, 40 participants drove an EV for the period of six months within the Berlin metropolitan area and were repeatedly questioned about their experiences. Data from the interviews and the questionnaires indicate that the drivers appreciate the low noise emission, but at the same time are very much aware of the potential dangers related to it. The few incidents which are reported mostly involve pedestrians as well as cyclists and mainly occur at low speeds, e.g. at traffic lights. These incidents usually have no critical consequences as drivers are aware of the vehicle´s soundlessness and adapt their driving accordingly.


**Key Words:** Electric Vehicle, low noise, driver experience, traffic safety

## INTRODUCTION

Faced with growing $CO_2$-emissions and a scarceness of fossil fuels, efforts are increasing to establish a more sustainable transportation system. In this context much effort is being made to further develop and promote alternative power trains. Especially Hybrid Electric Vehicles (HEV), Fuel Cell Vehicles (FCV) and Electric Vehicles (EV) have been repeatedly referred to as the most promising solutions to address the challenges mentioned above. Whereas FCVs convert hydrogen to electric energy and EVs solely rely on stored electricity, HEVs do this only for short period of time when starting the vehicle and during low speed. If these vehicles are introduced to the market on a large scale, the consequences for the traffic environment are obvious. $CO_2$-emissions and related smog - a particular problem of urban areas - would decrease and at the same time increase the quality of life in the cities. When these vehicles drive fully electric, they emit substantially less noise than vehicles with internal combustion engines (ICE). At higher speeds acoustic cues exist due to the wind and the noise of the tires. Thereby the average noise level within cities would decrease considerably, while not only drivers and pedestrians could benefit from the lower noise level but also local residents. High levels of noise in cities have been found to be related to e.g. self reported sleep disturbances and headaches (*1*). Nevertheless the low noise emission might also have serious consequences for road safety, which need to be investigated. In the present paper we will report findings a German field study on EVs and evaluate the low noise according to the driver´s perspective.

### Low Acoustic Cues: Implications For Traffic

In the last decade the interest in EVs and HEVs has risen again, especially focusing on the low acoustic output of those vehicles. Most of the literature deals with safety-relevant issues of the low noise emission. Some of the findings should be briefly summarized in the next section:

Wogalter et al. (*2*) conducted a survey asking participants about their attitudes concerning EVs, while especially focusing on the quietness of those vehicles. While the majority of the participants reported to consider purchasing an EV, concerns about the lack of noise of the vehicle are widely expressed. 70 % of the participants believed that EVs were a potential danger for pedestrians. When asked how they acted as pedestrians in traffic, 73 % indicated that when crossing a street, they used the sound of a vehicle as a stimulus to assess whether there is a vehicle approaching. Asked if a quiet vehicle would bother them as pedestrians almost 50 % agreed, when asked if this also applies to being a driver, only 30 % agreed. As a solution for the issue, 68 % of the participants said that EVs would be safer for pedestrians, if there was some type of engine sound built in. These findings clearly indicate that there is a considerable concern about the safety of pedestrians due to the small acoustic output of EVs. However none of participants had personal experience driving an EV for a substantial period of time and the comparison of EVs with e.g. a quiet ICE vehicle is missing.

A study which was conducted by the NHTSA (*3*) compared the incidence rates of crashes involving HEVs and ICEs. The study revealed higher crash incidence rates for HEVs involving pedestrians, e.g. when the vehicle is slowing or stopping, backing up, or entering as well as leaving a parking space. HEVs were two times more likely to be involved in this kind of accident than ICE vehicles. The critical maneuvers were grouped into one category as these mainly occurred at very low speeds. Especially while operating HEVs at low speeds the difference to the sound levels emitted by ICE vehicles is maximal and therefore poses the biggest hazard to pedestrians. Apart from that higher incidence rates for pedestrian crashes are reported for HEVs in situations when the vehicles were making a turn. For bicycle crashes the picture is similar. HEVs were significantly more involved in crashes with bicyclists at very low speeds. Especially at intersections HEV are reported to have a significantly higher incidents rate to be involved in a bicycle crash when compared to conventional vehicles. Although the sample size in the study was limited, the results show unambiguously where accidents related to the low noise emission of HEV are likely to occur.

Findings from experiments on the auditory detectability of HEVs compared to ICEs suggest that subjects are able to determine the direction of a slowly approaching ICE much sooner than of a HEV. If background sounds are added, the perception of HEVs is disproportionately hindered. These experiments were also conducted with blind subjects and revealed the same pattern of results (*4*).

Similar findings were reported also by another NHTSA study (*5*), which focused on the impact of HEVs and EVs on the safety of blind pedestrians. For that purpose safety critical scenarios for visually impaired pedestrians were identified, such as vehicles turning right into a pedestrian´s path, vehicles approaching at a constant speed, vehicles backing out, vehicles accelerating from a stop, and stationary vehicles that might abruptly move. Similar to the study by Robart and Rosenblum (*4*) the tested HEVs were detected later than the ICE vehicles by subjects in a laboratory. The authors argue that the time span in which the subjects detected the vehicle would normally be sufficient for the pedestrian or the driver to avoid collision. According to the authors the findings can serve as a baseline for acoustics and detectability of quiet vehicles, although the results cannot be generalized to a more complex environment, in which numerous vehicles need to be noticed.

**Engine Sounds As Potential Countermeasures**

Countermeasures, such as different kinds of sounds, have been proposed especially due to the concerns expressed by the National Federation of the Blind (*6*). Goodes et al. (*7*) for example conducted a study with blindfolded participants. Results indicate the loss of normal ICE sounds may have a substantial impact on the blind person´s ability to distinguish approaching vehicles. Engine noises as an option to increase the auditory cues of the vehicle have been preferred to synthetic sounds such as bells. Another study, conducted with subjects without defective hearing, points in the same direction: engine sound, white noise and hum sound are mostly preferred (*8*).

**Focus On The Driver**

Summarizing, the studies mentioned above clearly emphasize that there are considerable safety concerns when it comes to the low noise emissions of HEVs and EVs. Nevertheless there are no data reported how *drivers* actually handle the issue and what actions they take to maintain safety in traffic. Technological solutions, such as enhancing sound bear clearly a lot of potential for safety, but especially for the transition period, when only a small number of HEVs and EVs are on the road and standards have not been defined, drivers bear the most responsibility for the traffic safety of all road users affected.

In our field study we wanted to examine how drivers deal with the low noise on a daily basis and whether they report to adapt their driving behavior. Another goal of the present study is to point out road users who are at risk, furthermore to identify the relevant characteristics of hazardous situations and finally to show how many times severe incidents occur according to the drivers.

## METHODS

The present field study is part of a number of field studies around the world, e.g., in the UK and US, which evaluate whether EVs are suitable for everyday use. The German study consists of two settings, a so called `private setting´ and a ´fleet setting´. The study as a whole is split into two periods of six months, whereas for each study period 40 different private users are selected, who drive the EV on a daily basis. Methods and results of the present paper refer to the first study period within the ´private setting´. During this study period, users are interviewed three times: before they receive the vehicle (T0), after three months of driving the EV (T1) and when returning the vehicle after six months (T2). The repeated measures design allows the detection of expectancies and concerns and how these are affected by actual experience with the vehicle. Four key issues have been identified for the psychological evaluation of EVs (*9, 10*). These are `range`, `human-machine interaction`, `implications for traffic` and `acceptance`. To address these issues, a number of research methods has been adjusted and developed. These methods included in depth interviews, think aloud, questionnaires, travel and charging diaries and experimental tasks such as a conjoint analysis and a trip game. These methods are described in detail elsewhere (*11*, *12*). The data are supplemented by data from onboard data loggers, which continuously recorded parameters like speed, charging cycles, mileage and trip length.

**Applied Methods For Acoustics**

In the present paper the focus is on ´implications for traffic´, namely the role of the low noise emission of EVs. Therefore only relevant methods for this issue are described. To achieve a better understanding of the advantages and challenges of the low noise emission of EVs, in depth interviews with the drivers are conducted three times. Especially for the assessment of benefits and drawbacks of Plug-in Hybrid Electric Vehicles (PHEVs) a similar methodological approach has proved valuable in the past (*13*). Additionally, questionnaires are administered assessing the expectancies and experiences of the subjects. Usually six point Likert-Scales ranging from 1 to 6 are applied. For approval rates in percent, the scale is additionally dichotomized (disagree = 1-3, agree = 4-6). Especially the in-depth interviews provide valuable insight to the user concerns and experiences with the low noise of EVs.

## Participants

The participants of the field study were recruited via an internet application form. More than 700 people applied to be part of the study. To be selected for further consideration applicants had to live in the Berlin metropolitan area, own a garage for the charging station and had to be willing to participate in the accompanying research. Other conditions such as the willingness to pay the monthly leasing rate and a suitable connection for the power supply had to be full filled as well. 161 applicants met those criteria and were the basis for the selection of the scientific sample (N = 40). Two main criteria were applied when selecting the sample: The first factor involved the prospective use of the EV, meaning that half of the participants would be *frequent drivers* (more than 250 km / ~155 mi per week), the other half would be *infrequent drivers* (less than 250 km / ~155 mi per week) according to their applications. The second factor was the type of household, which originates from the *Hybrid-Household-Hypothesis* (*14*). Applying that hypothesis as a factor means that those households which integrate the EV in the current household vehicle holdings are called *hybrid households*, those which use the EV as their only vehicle are referred to as *EV-households*. As only a few participants expected to have the EV as their only car in the household, the sample consists only of nine EV-households and 31 hybrid households. In the analysis this prospective factor is not accounted for as it did not prove of value. Other factors such as gender, age and level of education were considered as well. The selected sample comprises of 33 male and seven female participants, which are on average 48.1 years (*SD* = 8.9) old. 75 % of the participants graduated from university, 12.5 % completed an apprenticeship, 7.5 % finished vocational school and 2.5 % hold a high school graduation as their highest degree. 75 % of the users report to have no previous experience with EVs. There was a drop out (N = 2) during the course of the study.

In general the sample consists of a very ecologically aware and technology minded group of drivers, which might not be representative for the general population, but for the environmentally conscious early adopters, who are mostly likely to drive those vehicles at an early stage.

## Test Vehicle

The EV used in the present field study is a standard MINI Cooper, which was converted to an EV by removing ICE components and assembling EV specific components such as a lithium ion battery pack. The vehicle is a two-seater featured with 150 kW power and 220 Nm torque and reaches a top speed of 152 km/h (~95 mph). To fully charge the battery it takes minimum four hours (32 Ampere), whereas the vehicle can be charged at home (*wall box*), at public charging stations throughout the city and with an adapter at normal sockets (12 Ampere). Whenever the driver lifts the foot from the accelerator, the regenerative braking system transfers kinetic energy from the momentum back to the battery. Thereby the driver can actively prolong the range through driving behavior. Under ideal conditions the vehicle reaches 250 km (~155 mi) on a single charge.

**Interviews & Questionnaires**

*Vehicle Handover (T0)*

The first data collection consisted of three parts. At first the participants were asked about their expectancies in general. Relating to the low noise level, they were queried whether they expect problems concerning the lack of engine noise. Apart from that they answered questions about their expectancies concerning their ability to assess the speed of the vehicle correctly with the absence of normal engine sound. After the initial interview users drove the vehicle for the first time while accomplishing a think aloud task (*15*). After the test drive participants reported their first experiences and answered questions about the test drive in general and expected difficulties related to the low noise.

*After Three Months (T1)*

After three months of driving an EV participants evaluated the low noise emission of the EV in the interview and in the questionnaire. For example they rated whether they experienced problems due to the lack of noise of the vehicle and whether the acoustic feedback of the vehicle matched their perception of speed. Apart from that they indicated how often they were not noticed by different road users due to the lack of noise. As sound designs have been discussed intensely in the media, the drivers were also asked whether they would prefer a special sound design in their EV.

*After Six Months (T2)*

The aim of the final interview after six months was to evaluate the low noise emission in general and to point out safety critical situations and how often these occurred during six months of EV usage. For that purpose drivers described these situations in detail and rated different maneuvers which appear to be most crucial concerning traffic safety. Concluding the drivers mentioned possible solutions to address this issue.

## RESULTS

As only the first study period is completed, results from the first six months will be reported in this paper. User quotations are translated from German in italic letters and are labeled with a subject number *[SN]*. In the interviews multiple answers were possible; therefore the numbers of mentions are put in brackets e.g. [N=22]. The questionnaire items, their means (*M*), standard deviations (*SD*) and the dichotomized values for the evaluation of the low noise of the EV are displayed in table 1.

**TABLE 1 Questionnaire Items for the Evaluation of the Low Noise**

| | **Item** | ***M*** | ***SD*** | **Approval Rates (dichotomized)** |
|---|---|---|---|---|
| **T0** | The lack of noise will cause problems. | 2.82 | 1.59 | 45 % agree |
| | Even without engine noise I will be able to judge my speed correctly. | 4.28 | 1.28 | 78 % agree |
| **T1** | I like the low background noise of the MINI E. | 5.85 | .37 | 100 % agree |
| | The acoustic feedback of the vehicle coincides with my perception of speed. | 4.31 | 1.52 | 69 % agree |
| | The lack of noise has caused problems. | 1.77 | 1.22 | 5 % agree |
| | I would prefer a special sound design in my MINI E. | 1.85 | 1.40 | 13% agree |
| **T2** | To me the lack of noise of the MINI E is endangering traffic. | 2.11 | 1.29 | 13 % agree |

**T0** = before receiving EV, **T1** = after three months, **T2** = after six months of driving

### At Vehicle Handover (T0)

When the drivers were interviewed before the vehicle handover, they named the biggest advantages and disadvantages of EVs. Apart from the low $CO_2$-emissions [N=22], the potential for external storage of renewable energies [N=15] and remarks about environmentally friendly transportation [N=12], users referred to the low noise emission [N=12] as one of the main advantages of EVs. Nevertheless barriers are mentioned such as the limited range [N=19], the costs [N=10] and the currently unavailable charging infrastructure [N=6]. Only twice the lack of noise is regarded as a general disadvantage of EVs. Nevertheless considerable concerns exist about safety. One driver expressed his concerns about bicyclists as follows:

> « *You have to be attentive, you have to be very attentive that you don´t harm other road users…if you´re overtaking a bicyclist; simply by being quietly overtaken by a car he might get frightened and fall. The possibility exists and you cannot do anything about it. You cannot blow the horn every time you see a bicyclist. [SN 24]* »

When asked before the test drive to rate whether they expect the lack of engine noise to cause problems, 45 % of the drivers agree. During the test drive, while thinking aloud, 80 % of the drivers mentioned the low noise of the vehicle. They referred to it as a « comfortable » and « astonishing » feature, although drivers have to adapt to it.

> *« Unbelievable how silent the car is. I like it….the sound is astonishing, I am driving along and… hear nothing at all. That is extremely astonishing» [SN 35].*

At the same time potential problems are mentioned by the participants, some have experienced the consequences of the lack of noise already during the test drive:

> *«She hasn´t looked left a single time … that lady with the bike. Did she notice me? No idea...when she started moving, I had the impression that she did not notice me» [SN 02].*

> *« Here, I have to pay attention that he is not suddenly jumping on the street, because he does not hear me. I think that I have to look out for the bicyclist. He does not hear me, so attention… not that he is suddenly turning left and we´ll have an accident» [SN 40].*

Before the test drive, participants rated in the questionnaire, if they expect to judge their speed correctly even without engine noise. 78 % of the drivers agreed. When testing the vehicle for the first time and thinking aloud, 25 % of the drivers mentioned that the small acoustic cues of the vehicle also affected their own perception of speed. Some of the drivers reported that they look more often to the speed indicator to estimate their current speed during the test drive.

Summing up the results from the first interviews and questionnaires it becomes clear that the test drivers generally appreciate the low noise emission of the vehicle. For them one major advantage of EVs is that urban regions may become a lot quieter if EVs are adopted by a larger number of drivers. Nevertheless considerable concerns exist among the sample. Especially pedestrians and cyclists are regarded as road users at risk. Another noteworthy, but less outstanding factor is the perception of speed among the drivers. Some of the users expect it to be more difficult to judge the current speed.

**After Three Months (T1)**

Like in the first point of data collection, the interview after three months of EV usage contained also quantitative and qualitative elements. Asked via questionnaire whether they liked the low background noise of the MINI E, 100 % of the drivers agreed. Concerning the acoustic feedback from the vehicle 69 % agreed that the feedback of the vehicle coincides with their sensation of speed. The positive attitude towards the low sound emission can also be found in the interviews, when drivers are asked, how they would assess the acoustics of the MINI E.

> *«I find it very enjoyable…At the beginning I thought bicyclists and pedestrians would not hear me, but it only happened once to me that one [person] was really surprised, when I was approaching»[SN 10].*

> *«I was surprised that at 50 km/h [~31 mph] the tire noise comes to the fore quite intensely. If you´re driving along at 50 km/h [~31 mph], the noise is almost comparable to driving at constant speed in a well insulated ICE» [SN 12].*

> *«It is very comfortable, I must say. When the weather was nice, I switched off the radio and opened the windows, just to enjoy the quiet noise… » [SN 24].*

Although the drivers evaluate the low noise emission overall positively, they report incidents being missed by other road users. These situations are relatively seldom and are reported to be mostly not safety-relevant.

> *«It is quiet. You cannot hear it. In the beginning I thought that I had to pay more attention to pedestrians, because they just don´t hear you in situations, they would usually hear a conventional vehicle. Such situations are extremely rare…I might have experienced that two or three times…» [SN 36].*

> *«A bicyclist in Berlin almost fell from his bike, when I passed him. He had headphones in his ears and probably wouldn´t have noticed if a normal car had been next to him. It is only a problem, because there are so few vehicles which are quiet... if it was more common, people would get used to it» [SN 16].*

In the questionnaire, drivers rated the frequency of events when they were missed by other road users. On a six point scale ranging from "never" to "nearly all the time", drivers estimated the frequency of having been missed by *other drivers*, by *pedestrians* and by *cyclists*. The frequency distribution is displayed in figure 1 and shows that incidents rarely occur and that it is mainly pedestrians and cyclists who miss EVs.

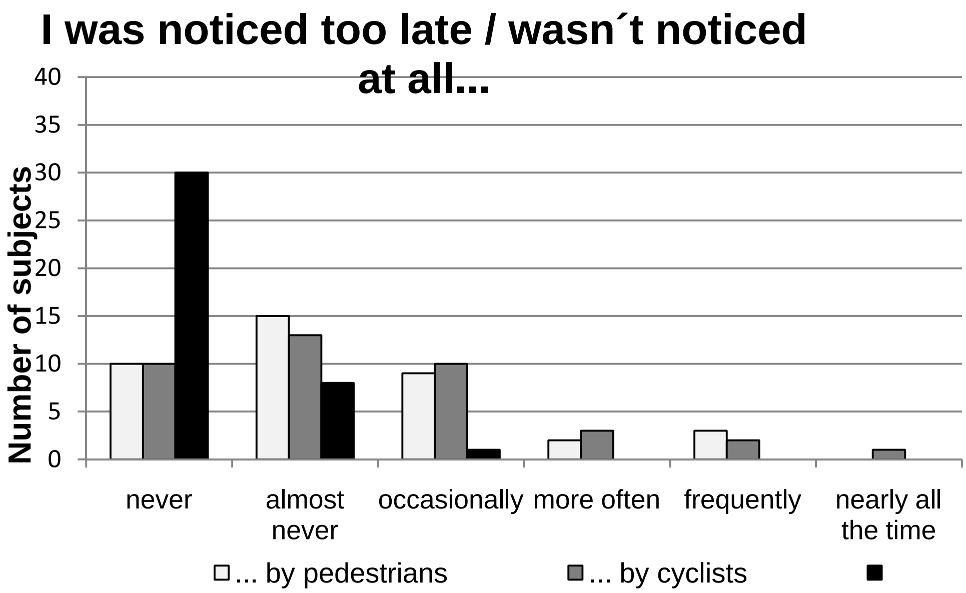


**FIGURE 1 Frequency Of Being Noticed Too Late / Not Noticed At All**

Looking at the data from the interviews after three months, drivers report to adapt their driving behavior with EVs. Regarding speed users mainly differentiate between speed above and below 50 km/h (~31 mph), whereas the latter is decisive. Particularly in low speed environments such as in quiet streets, parking lots and residential areas drivers report to drive more cautiously while continuously thinking ahead for pedestrians and bicyclists. Cautious driving involves increased attention when entering those environments and passing road users at risk very carefully. Dangerous incidents are very rarely reported, some drivers evaluate the issue as follows:

> *«…I didn´t have any negative acoustic experiences. However, I paid special attention to forego bicyclists. That you should do anyhow with an EV – because of the acoustic – I do that even more deliberately than I would do it with a conventional ICE. [In an ICE] I would expect to be heard at least when I am behind the person. With an EV I assume that, that he doesn´t hear me. And I adjust. That way it is no problem anymore. On the contrary, I have a good feeling driving it, because I have the idea although I am driving my car, I am not polluting the environment » [SN 02].*

> *«The acoustic issue is positive for me….but the problem is that you have to think ahead for the traffic, that is bicyclists and pedestrians….road users, who orient themselves acoustically, that is pedestrians and bicyclists, there you got a problem. You must think ahead, if you´re driving such a vehicle» [SN 07].*

> *«If a bicyclist doesn´t hear you at all and you appear suddenly as a shadow next to him, he will get frightened. I am always very cautious. I haven´t experienced it at all that passersby walk on the street with noticing me. But of course, I drive more slowly in small streets » [SN 19].*

> *«At least in small streets, where there are no other noises, where there are only bicyclists and pedestrians. Then you have to pay attention as they won´t notice you from behind. But not elsewhere, actually. However in small streets you should be more careful» [SN 35].*

After three months drivers are again asked in the questionnaire whether the lack of engine noise caused problems. The concerns expressed in the initial questionnaire, substantially decrease during the first three months. The difference is significant ($t$ (38) = 3.896; $p < .01$, $d$ = 0.74). The frequency distribution and the compared means are diagramed below in figure 2.

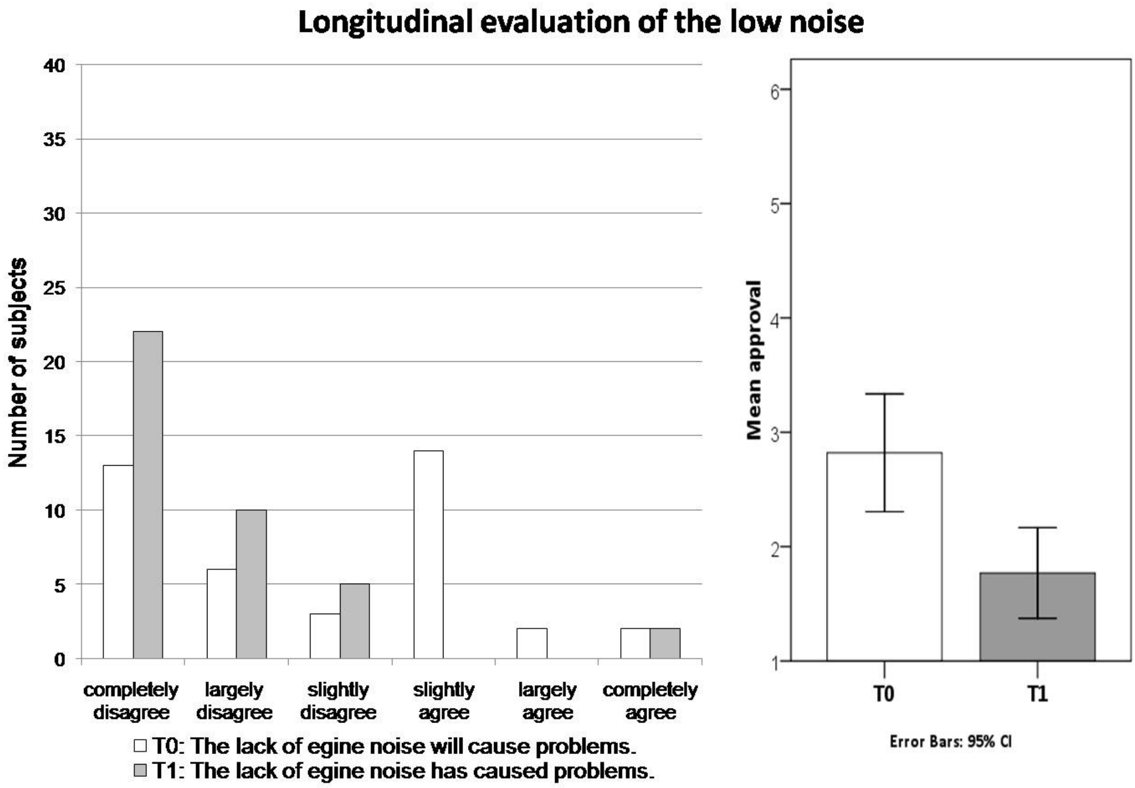


**FIGURE 2 Longitudinal Evaluation Of The Low Noise Of EVs**

*The role of active sound design*

Additionally, drivers were questioned whether they would prefer a sound to be integrated in the EV to prevent critical incidents. In the interviews many drivers indicate that they would not prefer to have a special sound to be integrated in the vehicle. This corresponds clearly with the data of the questionnaires. Only 13 % of the drivers preferred to have a special sound design in their vehicle.

**After Six Months (T2)**

In the final interview drivers rated the frequency of situations, in which they were not noticed by other road users. The scale was again a six point Likert scale which ranges from 1 (“never”) to 6 (“nearly all the time”). Although the mean frequencies are all relatively low, “parking lots” are significantly rated higher than “bringing up to speed” ($t$ (37) = 2.321; $p$ < .05), “parking maneuvers” ($t$ (37) = 3.224; $p$ < .01) and “turning” ($t$ (37) = 3.340; $p$ < .01).

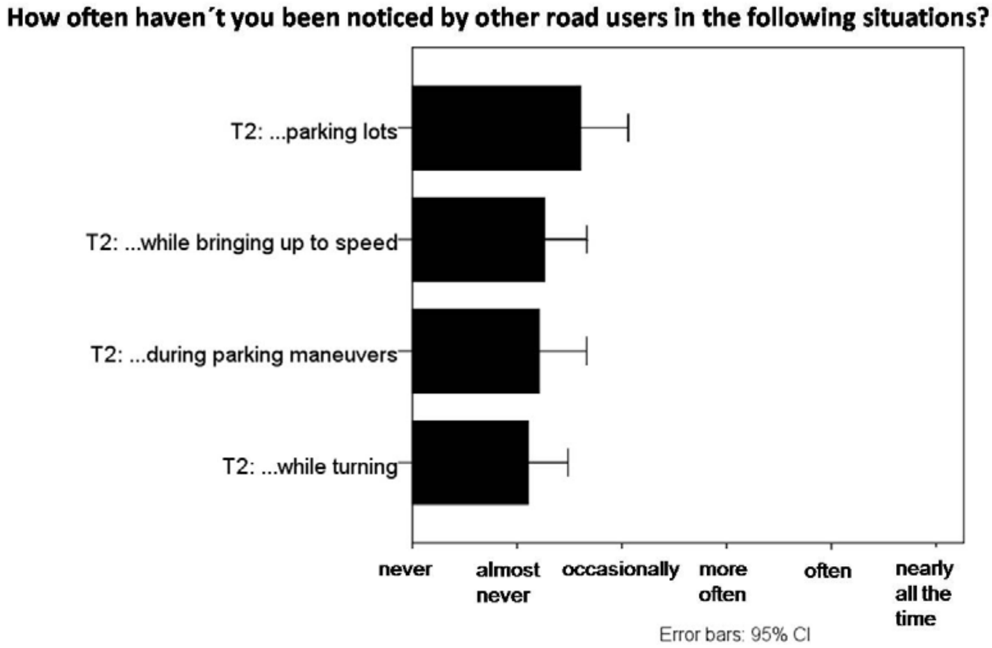


**FIGURE 3 Mean Frequencies Of Not Being Noticed In Specific Maneuvers**

These finding relate to the findings from the interview after three months as well as to the remarks made by the drivers during the final interview. As a final evaluation of the low noise of the EV only 13 % of the drivers rated the lack of noise of the MINI E as endangering traffic. Apart from that the number of critical incidents related to the low noise emission of the vehicle had to be indicated. No accidents related to the low noise were reported. Both skewed right distributions are displayed below in figure 4.

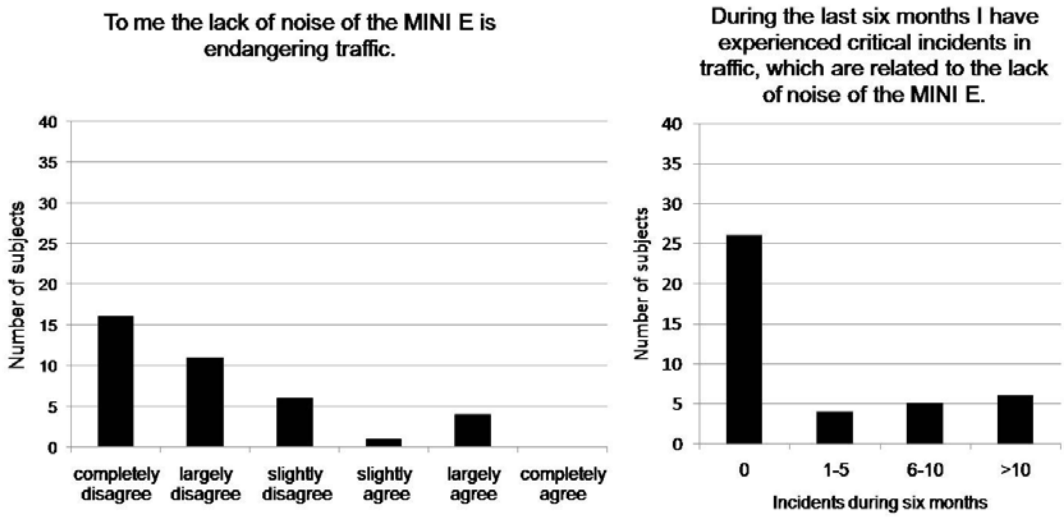


**FIGURE 4 Final Evaluation And Number Of Reported Critical Incidents**

As one might assume, these measures correlate significantly ($r$ = .475; $p$ < .01). The more critical incidents are reported due to the lack of noise, the more the lack of noise is regarded as endangering traffic. Furthermore one could assume that these measures are depending on the VMT (vehicle miles travelled) meaning the exposure with the EV, but in the present study this is neither the case for the final evaluation ($r$ = -.034, $p$ = .839) nor for the number of critical incidents reported ($r$ = - .237; $p$ = .153).

### Suggested Solutions

As in the interviews after three months but to a lesser extent, there are some drivers who do not want any additional sound at all [N=12] as they do not regard it as a problem. Generally speaking a behavior based approach is favored, which means to promote increased attention among *all* road users. Nevertheless ideas for technical solutions are suggested by a considerable number of participants [N=23]. Technical solutions such as external sound should be depending on the speed of the vehicle. That means that from 0 to 30 km/h (~19mph) there could be a temporary sound included which could warn pedestrians and bicyclists. Nevertheless drivers regard the low noise emissions as one of the biggest advantages of EVs, which should not be diminished by simply integrating a permanent artificial sound. Rather drivers advert to the responsibility of all road users to take care of the others. That way, according to the test drivers, a lot can be achieved by adjusting the individual behavior.

## DISCUSSION

### Expectancies And Experiences

According to the test drivers the low noise emission of the EV is one of the biggest potentials of EVs. If EVs were to be introduced on the market on a larger scale, the noise level of cities would substantially decrease and contribute to more quality of live in urban areas. Nevertheless there is a high awareness among the EV test drivers for the low acoustic output of their EV. Concerns for pedestrians and bicyclists are very often expressed in interviews and questionnaires. This is eminently the case when drivers have no experience with the vehicle. After considerable time of driving the vehicle, concerns drop significantly. Drivers report that they expected substantial problems due to the lack of noise, but have experienced only few incidents. These results clearly emphasize that daily experience with EVs generates a less worried, possibly more balanced evaluation of the low acoustic cues of EVs. In future studies drivers of conventional vehicles should be included to allow for direct comparisons.

Relating to the perception of their own speed, the drivers are quite confident that they can assess their speed correctly even without conventional sound cues of ICEs. Nevertheless these are subjective ratings and past research has shown that hearing the vehicle´s sound is decisive in the task of speed estimation (*16*).

### Critical Events And Preventive Strategies

Only few critical incidents due to the quietness of the EVs are reported. Drivers report that this is mostly the case in low speed environments, as usually between 30 km/h (~19 mph) and 50 km/h (~31 mph) the tire noise is comparable to ICEs. Incidents mostly take place on parking lots and sometimes while accelerating or in quiet side streets. Typically EVs are being overheard by pedestrians and bicyclists, who tend to orient themselves acoustically. The locations of the incidents and the involved road users are conform to the findings of an initial accident analysis of HEV crashes conducted by the NHTSA (*3*). For future studies on the low noise emissions of EVs it might be reasonable to include a control group, as some the reported incidents could have happened also to drivers with quiet conventional ICE vehicles.

One possible explanation for the low incidence rate is that accidents in traffic are very unlikely in general (*17*). Near misses or even accidents are even more unlikely, if they involve certain types of road users such as pedestrians and cyclists. An additional reason might be and that is also mentioned by the drivers that they pay particular attention to pedestrians and bicyclists.

In the interviews after three and six months drivers state that they quickly learned to identify those situations which might be crucial. Reported strategies involve increased attention in parking lots, quiet streets and during parking maneuvers. Other drivers were seeking eye contact with pedestrians or started talking to them. By continuously "thinking ahead" drivers are trying to actively anticipate potential hazards so they can prevent dangerous encounters with road users at risk.

### Suggested Solutions

Although the drivers did not favor an active sound design in their EV after three months, suggestions were made after six months. Possible solutions might involve a behavioral *and* technical component, meaning that *all* users should be encouraged to take more care in traffic. Apart from that technological solutions such as temporary sounds for certain speeds are suggested, which could especially warn hearing impaired pedestrians. Additionally special driver trainings for HEVs / EVs seem to be a promising solution, especially for transition period when no permanent driver assistance systems are implemented in quiet vehicles. As Advanced Driver Assistance Systems (ADAS) sometimes have an adverse effect on traffic safety (*18*) due to behavioral adaptation, it is essential not only to focus on technical solutions, but also on the drivers. In the future driver awareness trainings could be integrated even in the conventional driving lessons for young drivers.

## CONCLUSION

The findings reported in the present paper show that EV test drivers are very aware of the hazards related to the low acoustic cues of EVs and that they adjust their driving accordingly. Especially for the transition period with only few EVs and HEVs on the streets, which also might not be equipped with special sounds, much responsibility for the safety of all road users lays upon the drivers. Therefore it is essential to also include the driver perspective and behavior in the discussion about soundless vehicles.

## ACKNOWLEDGEMENT

The present study is funded by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety. We have to thank our consortium partners Vattenfall Europe AG (Dr. Eckhardt, F. Schuth) and BMW Group (Dr. A. Keinath, Dr. M. Schwalm) who gave us the chance to conduct our research.

## REFERENCES

1. G. Belojevic , B. Jakovljevic, and O. Aleksic. Subjective reactions to traffic noise with regard to some personality traits. *Environment International*, Vol. 23, No. 2, 1997, pp. 221-226.
2. Wogalter, M. S., R. N. Ornan, R. W. Lim, and M. R. Chipley. On the risk of quiet vehicles to pedestrians and drivers. *Proceedings of the Human Factors and Ergonomics Society*. Vol. 45, 2001, pp.1685-1688.
3. National Highway Traffic Safety Administration. *Incidence of Pedestrian and Bicyclist Crashes by Hybrid Electric Passenger Vehicles.* Technical Report DOT HS 811 204, 2009.
4. R. L. Robart, and L. D. Rosenblum, L. D. Are hybrid cars too quiet? *Journal of the Acoustical Society of America*, *125*(4), 2009, 2744.
5. National Highway Traffic Safety Administration. *Quieter Cars and the Safety of Blind Pedestrians*. Technical Report DOT HS 811 304, 2010.
6. Maurer, M. *The Danger Posed by Silent Vehicles*. National Federation of the Blind, Feb. 20, 2008. http://quietcars.nfb.org/. Accessed July 27, 2010.
7. Goodes, P., Y. B. Bai, and E. Meyer. *Investigation into the Detection of a Quiet Vehicle by the Blind Community and the Application of an External Noise Emitting System*. SAE International Paper Number: 2009-01-2189. DOI: 10.4271/2009-01-2189, 2009.
8. Nyeste, P., and M. S. Wogalter. On Adding Sound to Quiet Vehicles. *Proceedings of the Human Factors and Ergonomics Society*, Vol. 52, 2008, pp. 1747-1750.
9. Krems, J. F., T. Franke, I. Neumann, and P. Cocron. (2010). Research methods to assess the acceptance of EVs - experiences from an EV user study. In T. Gessner (Ed.), *Smart Systems Integration: 4th European Conference & Exhibition on Integration Issues of Miniaturized Systems - MEMS, MOEMS, ICs and Electronic Components*. Como, Italy. CD ROM: VDE.
10. Cocron, P., F. Bühler, I. Neumann, T. Franke, and J. F. Krems. Methods to assess the acceptance of electric vehicles, 2010. (Submitted August 2010).
11. Neumann, I., P. Cocron, T. Franke, and J. F. Krems (2010). Electric vehicles as a solution for green driving in the future? A field study examining the user acceptance of electric vehicles. In J.F. Krems, T. Petzoldt and M. Henning (Eds.). Proceedings of the European Conference on Human Centred Design for Intelligent Transport Systems, Berlin, Germany, Lyon: Humanist Publications, pp. 445-453., 2010.
12. Franke, T., I. Neumann, F. Bühler, P. Cocron, and J. F. Krems. Experiencing Range in an Electric Vehicle – Understanding Psychological Barriers. Chemnitz University of Technology, Germany, Submitted June, 2010.
13. Heffner, R. R., K.S. Kurani, and T. S. Turrentine. Driving Plug-In Hybrid Electric Vehicles: Reports from U.S. Drivers of HEVs Converted to PHEVs. Presented at the 88th Annual Meeting of the Transportation Research Board, Washington D. C., 2009.
14. Turrentine, T., and K. Kurani. The Household Market for Electric Vehicles: Testing the Hybrid Household Hypothesis - A Reflively Designed Survey of New-car-buying, Multivehicle California Households. Institute of Transportation Studies, UC Davis, 1995. http://www.escholarship.org/uc/item/5xp5h6xc?display=all#page-1. Accessed July 27, 2010.
15. Ericsson, K. A. and H. A. Simon. Protocol Analysis: Verbal Reports as Data. MIT Press, 1993.
16. Evans, L. Speed estimation from a moving automobile. Ergonomics, Vol. 13, 1970. pp. 219-230.
17. National Highway Traffic Safety Administration. The 100-Car Naturalistic Driving Study, Phase II – Results of the 100-Car Field Experiment. Technical Report DOT HS 810 593, 2006.
18. Rudin-Brown, C. M. and H. A. Parker, Behavioural adaptation to adaptive cruise control
19. (ACC): implications for preventive strategies. Transportation Research Part F, Vol.7, 2004.pp. 59-76.