# A SILENT FUTURE RESEARCH

## Road traffic safety of silent electric vehicles


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# Abstract

The hypothesis of this research paper is that EVs (electric vehicles) have a higher accident risk than their ICV (internal combustion vehicle) counterparts and that this is due to the quietness of electric vehicles and the inexperience with EVs of vulnerable road users. The researchers made use of literature research, interviews & experiences in the field and a self-developed online questionnaire to shed light on the issue. They found no substantial evidence of more accidents occurring with electric vehicles and vulnerable road users. Although there is a difference in sound produced by EVs in comparison with ICVs (EVs are more silent) and detection times of vulnerable road users are longer with EVs than ICVs, they do not result in more accidents. This paper defines potential high-risk traffic situations such as 'pedestrian crossings', 'intersections' & 'low speed zones' and concludes that in order to be audible an EV must produce a minimal of 2dB(A) above the background noise. The researchers come up with possible road safety improvements like 'adding a warning signal to EVs' and 'inducing a behavioral change of EV drivers' so that they become more aware of their surroundings and better anticipate to fellow road users. The questionnaire the researchers developed can be used in future follow-up research with a larger target group for measuring road safety issues of near silent EVs. Additionally the researchers believe that the introduction of silent EVs will eventually result in safer traffic situations for all road users with less noise pollution resulting in what they would like to call a safer more silent future.

# 1 Introduction

***The hum of the cars is the voice of the city.***
*L.V.J. Hoogeveen*

The noise around us seems to be increasing day by day [Bluhm G, Nordling E, Berglind N, 2004]. The majority of this noise pollution consists of traffic sounds. The ongoing technological advances in the transportation industry will soon silence these sounds. We are talking about the introduction of electric vehicles (EVs) on our roads today. These vehicles come in many different forms, 'hybrid vehicles (HEV), 'electric scooters' (E-scooters), 'electric buses' (E-buses) and of course the full electric or battery electric vehicle (BEV). For convenience we will group these electrical means of transportation under the name 'electric vehicles' (EVs). EVs are growing in popularity (see paragraph 1.1), in large part this is due to the advantages of this type of vehicle over the normal 'internal combustion engine vehicles' (ICVs), that is, they have zero emissions, have a low cost per kilometer driven and have low maintenance costs. Below 20km/h (12 mph) they become significantly quieter than ICVs, almost silent, due to the revolutionary design of the electric propulsion system with only one moving part as opposed to the ICV with thousands of moving parts with additional combustion sounds. Our concern is that, being this quiet, the EV poses a possible danger to vulnerable road users, such as, small children, the elderly, the blind, cyclists, runners, and pedestrians. These traffic participants often rely on sound as an early warning signal for detection of approaching vehicles, in practice most individuals are less likely to look for a vehicle that they do not hear. Next to vulnerable road users, visually impaired pedestrians have potentially the highest risk of being hit by an EV, because they particularly on sound to determine whether it is safe to cross a street.

Our hypothesis is that EVs have a higher accident risk than their ICV counterparts and that this is due to the quietness of the electric vehicle and the inexperience with EVs of vulnerable road users. By conducting literature research, obtaining field experiences and questioning EV drivers with a self developed online questionnaire, this research will try to prove our hypothesis. In our research we focus on four different aspects for investigation of our main hypothesis:
- the sound produced by an EV in operation is less then that of an ICV, this results in lower detection rates of vulnerable road users.
- Additionally, the signal to noise ratio, ambient noise is an important factor for detecting EVs but also ICVs. The higher the ambient noise the more difficult to detect an EV or ICV thus resulting in potential dangerous situations.
- Recent research about the use of electronic devices while riding a bike [Goldenbeld et al., 2010] generated interest in the traffic hazards of distractions. While distracted, sound is important for warning people of upcoming dangers. When listening to a mp3-player, this warning sound will become less audible. This in combination with an almost silent EV creates a possible hazard.

- Last but not least, it is interesting to investigate if there are certain traffic situations that cause higher accident risks between vulnerable road users and EVs. To sum up these research aspects, we have: ‘vehicle produced sound’, ‘ambient sound’, ‘distractions’ and ‘traffic situations’, and we will address them one at the time. Finally we will come to a conclusion from insights gained from international research, interviews with involved parties and data from a questionnaire we developed.

## 1.1 Popularity

To address the importance of researching the possible safety hazards of EVs in modern day traffic situations, we point out that the EVs are currently gaining in share of the global vehicle market and will continue to do so over the years to come. The worldwide sales of EVs show a steady and rising increase year after year and according to predictions will only continue to increase over the years to come [GreenTech, 2010]. The United States and Japan are the leaders in the EV market today. The Netherlands is the fourth largest hybrid market worldwide [HybridCars, 2009]. In Japan 17% of newly sold cars in July 2009 was an EV and one can see that the number of EVs in Japan has been increasing rapidly after April 2009, due to government campaigns (subsidy and tax reliefs), and car-company advertisements [JASIC, 2009]. Other big upcoming markets like China show that the annual electric scooter sales in figure 1a [Yang, Chi-Jen., 2010] have a big increase. This large increase is mostly due to government policies that restrict non-electric motorcycles in city-centers.

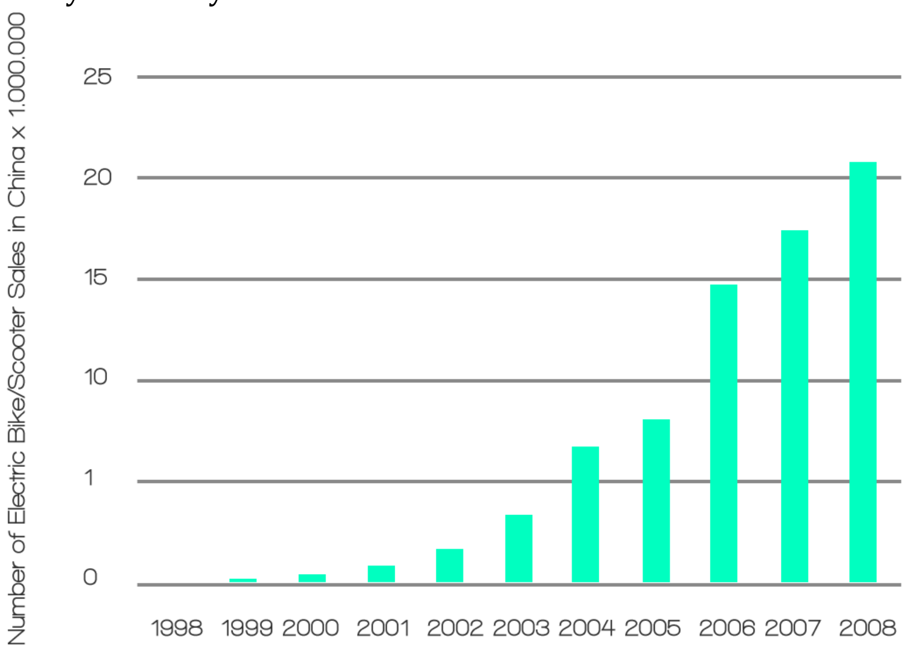



**Figure 1a.** Growth in Electric scooter sales in China, adopted from [Yang, Chi-Jen. , 2010]

How can you translate these numbers to the Dutch situation? Mainly by acknowledging that there is a global trend towards electric transportation. The Dutch government is very active when it comes to promoting electric transportation initiatives. To name a view: ‘The New Motion’, ‘Electric

Transportation Netherlands (EVN)' and 'Dutch Organization for Electric Transportation (DOET)'. This translates into overall increased sales for EVs in the Netherlands. Evidence of this is seen in the sales of electrical scooters in the Netherlands that have increased substantially (figure 1b) in 2009 in comparison with 2008 [EVN, 2010].

| | Aantal 2008 | % 2008 | Aantal 2009 | % 2009 |
|---|---|---|---|---|
| **Benzine** | 382069 | 98,96% | 430305 | 98,42% |
| **Diesel** | 41 | 0,01% | 43 | 0,01% |
| **Elektrisch** | 4266 | 1,10% | 6781 | 1,55% |
| **Onbekend** | 83 | 0,02% | 83 | 0,02% |

**Figure 1b.** Growth in Electric scooter sales in The Netherlands, adopted from [EVN, 2010].

As opposed to no increase in sales of fossil fuels scooters. Concluding that the e-scooters are gaining popularity over their fossil fuel variants. In The Netherlands there is also a big growth of electric bicycle sales. But these electric bicycles are not included in this research. We argue that because of the already silent nature of 'normal' bicycles the electric bicycle is not that different, sound wise. As we are researching the road traffic safety of 'silent' electric vehicles compared to their 'noisy' counterparts, we are not interested in already silent bicycles. Although electric bicycles are faster and heavier that normal bicycles and this could affect road traffic safety, these effects lie beyond the scope of our research. But, what are the numbers for Dutch car sales? Statistics from SWOV (table 1) show us that in 2004 only 518 vehicles had an electric propulsion system. In 2010 this number increased to 39.585, accordingly 0.52% of the total car fleet. Gasoline powered cars seem to be decreasing in percentage of total car fleet, with 81.4% in 2004 to 79.6% in 2010.

**Table 1.** Dutch car fleet by type of fuel 2004 till 2010

| Fuel type | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|---|---|---|---|---|---|---|---|
| Gasoline | 5,624,642 | 5,683,229 | 5,740,891 | 5,810,798 | 5,905,281 | 6,011,945 | 6,070,432 |
| annual growth | | 1.04% | 1.01% | 1.22% | 1.63% | 1.8% | 0.97% |
| from total | 81.4% | 81.2% | 80.9% | 80.4% | 79.9% | 79.7% | 79.6% |
| Diesel | 1,022,087 | 1,068,593 | 1,117,019 | 1,184,300 | 1,251,082 | 1,277,128 | 1,289,544 |
| annual growth | | 4.55% | 4.53% | 6.02% | 5.64% | 2.08% | 0.97% |
| from total | 14.8% | 15.3% | 15.7% | 16.4% | 16.9% | 16.9% | 16.9% |
| Gas | 261,642 | 238,483 | 229,770 | 227,398 | 224,244 | 229,870 | 222,679 |
| annual growth | | -8.85% | -3.65% | -1.03% | -1.39% | 2.51% | 3.13% |
| from total | 3.79% | 3.41% | 3.24% | 3.15% | 3.03% | 3.05% | 2.92% |
| Electric | 518 | 1,669 | 4,612 | 7,680 | 11,295 | 23,387 | 39,585 |
| annual growth | | 222% | 176% | 66% | 47% | 107% | 69% |
| from total | 0.00749% | 0.0239% | 0.065% | 0.11% | 0.15% | 0.31% | 0.52% |
| Unknown | 1 | 0 | 1 | 2 | 1 | 1 | 113 |
| Total | 6,908,890 | 6,991,974 | 7,092,293 | 7,230,178 | 7,391,903 | 7,542,331 | 7,622,353 |
| annual growth | | 1.2% | 1.43% | 1.94% | 2.23% | 2.03% | 1.07% |

Electric vehicles cannot longer be overlooked in our every-day traffic. They are becoming an increasingly important factor in present-day road safety. The Netherlands does not stay behind the global trend of adaptation to electric vehicles. That is why it is important to investigate the road safety consequences of this new type of road user in the Dutch situation. In the next section we argue that this trend will continue over the years to come and that this is not a temporary fling but more a complete change of global mentality towards change.

If we project the current trend into the future, the prediction is that the fleet percentage of electric vehicles will continue to increase [Shell, 2010; E.N.G. Verheijen et al., 2010; C,MM,C,, 2009; Nu.nl, 2010]. If you take the growth statistics in mind you can see that the market share of electric vehicles is increasing year after year, mostly due to government policies that subsidize the electronic vehicle market and new innovations like that of 'Better Place' in addition to collaborations between renowned car companies and brand new electric vehicle initiatives (Tesla motors & Toyota). The growing popularity of EVs means that if there are any safety issues right now, these could be enlarged in the future. Electric vehicles are here to stay, so we better start paying attention to them.In the next section we try to derive possible safety issues from the currently available literature.

### 1.2 Safety risk

We can speculate all we want about how dangerous electric vehicles are in modern day traffic situations, but nothing other than actual accidents with these vehicles give us a clear indication of the severity of the problem. To get a clear idea of the problem we ask ourselves the following questions: 'Are there more accidents with electric vehicles?', 'Could this be due to the quietness (sound production) of EVs?', 'Are there any specific traffic situations that have a higher accident occurrence?', 'What are the effects of ambient sound levels?' and, 'Does a distraction like an mp3-player or mobile phone add anything to the equation?'. In this chapter we will approach the hypothesis with the four different perspectives, 'sound production', 'ambient sound', 'distractions' and 'traffic situation', to get a clear view on possible safety hazards for EVs. Because of the silent features of the electric vehicle we predict that more accidents will occur because of vulnerable road users that do not hear them approaching in time. This will mostly occur at low speeds because of the big difference in sound production between ICVs and EVs at these speeds. According to the American organization NHTSA there is such evidence. The National Highway and Traffic Security Agency or NHTSA is an US organization that is dedicated to achieving the highest standards of excellence in motor vehicle and highway safety. In 2009 the NHTSA conducted research into possible risk factors introduced by the appearance of electric and hybrid vehicles in traffic. They concluded that during low-speed maneuvers, electric vehicles are 50% more likely to collide with pedestrians and cyclists than ICVs [Hanna R., 2009]. This finding is particularly interesting for the Dutch situation, because of the large amount of cyclists on the road today. The bicycle is the most popular means of transportation in the crowded Dutch cities like 'Amsterdam', 'Rotterdam' and 'Den Haag'. Of course the outcome for pedestrians is also applicable to the Dutch situation, but the cyclists situation in The Netherlands is pretty unique. Electric scooters that travel on bicycle paths, have a high likelihood to cause dangerous traffic situations with bicyclists. They concluded that in the case of crashes with pedestrians and with bicyclists, EVs have a significantly higher overall accident rate than ICVs. For special vehicle maneuvers (performed at very low speeds) there was a significant difference between pedestrian crashes with EVs and ICVs. For special maneuvers, situations where the vehicle is 'backing out', 'slowing or stopping', 'accelerating from stop' or 'entering leaving parking space/driveway', EVs had a significant higher accident rate then their ICV counterparts. There were also significantly more crashes with EVs in zones with a speed limit less than 56 km/h (35mph). In zones with higher speed limits there was no significant difference in accident rate between the types of vehicles, so speed is an important factor [Hanna R., 2009]. One could argue that at low speeds an EV is less audible than it's ICV counterpart, resulting in more traffic accidents. Then again, another factor could be at work, for instance 'location of vehicle use'. Overall there are higher accident rates in urban areas versus suburban rural areas and EVs are used more often in urban areas because of their fuel efficiency in these conditions (a lot of pulling up and braking). This could be one of the reasons why there are more accidents at low speeds with EVs. In Japanese research [JASIC, 2009] they have not yet found evidence indicating a higher accident rate for electric vehicles. They claim that in the database of accidents statistics, they didn't find any accidents caused by EVs being too quiet. Nevertheless, they are investigating the possibility for increasing pedestrian safety by adding sounds to EVs, just as a precaution. The Dutch Institute for Road Safety Research (SWOV) proclaims that it is not possible to determine the danger of electric vehicles with the help of statistical research because of the low percentage of EVs on the road today. In 2008 the percentage of EVs that were involved in an accident was 0.2%, 230 out of 140.000 reported accidents [Schoon, C., 2009]. When accidents occur at low speeds, there is a high chance that the injuries are minor. In the instance of a minor injury it is mostly not necessary to ask for police assistance. So we question if it is possible at this time to acquire enough reports to gather solid evidence. Although the Dutch police EV accidents reports were very limited we could obtain a small amount of data represented in table 2. Accidents that occurred with e-buses, and e-scooters are not represented in this table because of low availability. In total there were 2 accidents with pedestrians interacting with e-scooters and 3 accidents with bicyclists. These all took place in speed zones below 50 km/h. The e-buses had 1 bicycle accident and 2 pedestrian accidents also within speeds zones of 50 km/h. The police report does not mention if these accidents were due to the silent nature of the electric vehicle.

**Table 2.** Traffic accidents in The Netherlands from 2007 till 2009

| First vehicle | Second vehicle | Speed limit zone in km/h | | | | |
|---|---|---|---|---|---|---|
| | | <15 | 15<30 | 30<50 | >50 | Total |
| Electric car | Pedestrians | 1 | 0 | 9 | 1 | 11 |
| | Bicyclists | 0 | 10 | 32 | 4 | 46 |
| | Sum | 1 | 10 | 41 | 5 | 57 |
| | % of total | 2% | 18% | 72% | 9% | |
| Non-electric car | Pedestrians | 35 | 683 | 2.421 | 267 | 3.406 |
| | Bicyclists | 73 | 3.631 | 17.411 | 1.887 | 23.002 |
| | Total | 108 | 4.314 | 19.832 | 2.154 | 26.408 |
| | % of total | 0% | 16% | 75% | 8% | |

When analyzing the accidents numbers we cannot draw any other conclusion that there is almost no difference in accident rates between EVs and internal combustion ICVs. The Dutch data do not indicate any significant proof that could back-up the NHTSA finding that EVs have a higher accident rate at low speeds. This could be due to the small availability of EVs; maybe if we have more EVs on the road, a tendency towards accidents at low speeds can be seen. But for now, this is not the case. Overall you can note that most of the accidents with bicycles and pedestrians happen in speed zones of 50 km/h. This is almost equally true for EVs and ICVs (72% versus 75%). In lower speed zones (15 and 30 km/h) a total of 20 percent of EV accidents occur versus 16% ICV accidents. This looks like a tendency to more accidents with EVs but due to low 'n' values this percentage is represented by only 11 cases. If we conduct a Chi-test on this data we come to the conclusion that the difference in accident rate between EVs and ICVs is not significant in speed zones with a max of 30 km/h, $\chi^2(1) = 2.02$, $p = .16$. For speeds below 50 km/h a similar result is obtained, a non-significant difference with $\chi^2(2) = 2.64$, $p = .27$. In conclusion, there seems to be more 'concern' about the quiet EVs then that there is 'proof' of an existing problem. By proof we refer to actually accidents happening. Only the NHTSA found evidence of significant more EV accidents happening at low speeds but unfortunately the researchers did not compensate for differences in 'total miles driven' and/or 'location of use', this causes the validity of this research to be very low. Japanese as well as Dutch statistics don't indicate any form of evidence that EVs have substantial more accidents while traveling at low speeds. The fact that there is no solid evidence of more accidents happening right now does not mean that there isn't a safety thread in the future. That is why we ask ourselves additional questions to investigate if there really aren't any additional safety risks with EVs as opposed to ICVs. 'Is an electric vehicle significantly harder to detect than a 'normal' internal combustion version?' that is the question that we ask ourselves in the following chapter. Although there is in general, no substantial proof of more accidents occurring, maybe a higher potential accident risk can persuade us to take immediate actions to make EVs safer. We try to map this potential accident risk with the help of our four safety factors; 'vehicle produced sound', 'ambient sound', 'distractions' and 'traffic situations'.

### 1.2.1 Vehicle produced sound

To investigate if the low sound production of hybrid vehicles is an important factor in detection, Rosenblum and Robart(2009) conducted research to measure the exact moment at which sighted and blind people hear a EV approaching [Rosenblum et al., 2009]. The results from this research where that in all the vehicles tested in an added noise condition (+ 8dB(A)), subjects had a longer reaction time then in the condition without the added noise. Thus indicating that there is indeed a significant difference in detection time between EVs and ICVs. But research of the NHTSA in 2010 gives us another perspective on EV detection times [Garay-Vega et al., 2010]. The results showed that overall sound levels of the EVs tested in this new test are again lower than their ICV counterparts and resulted in longer reaction times although the time to arrival would usually still be sufficient for the pedestrian or the driver to take evasive action. The researchers additionally noted that in a more naturalistic situation the time to vehicle arrival could be shorter because of the complexity of multiple vehicles and variables. The fact still remains that the long reaction times that were found in Rosenblum's experiment were not found in the NHTSA research of 2010. The biggest difference was noted at 8 or 10 km/h (5 or 6 mph), a small difference at 16 km/h (10 mph) and zero to none difference at speeds above 32 km/h (20 mph). A vehicle that was backing out also showed a big difference in reaction times and audibility, but was not significant to cause a dangerous situation. On the opposite, there was a better detection of EVs than ICVs when the vehicle was slowing down from 32 to 16 km/h (20 to 10 mph. This because an EV produces more sound than an ICV while decelerating due to regenerative breaking, a system designed to convert braking energy into usable battery power, this system produces a 5 kHz tone witch is very easy detectable. This finding was not yet discovered in earlier research and gives a totally different perspective to the situation, because the EV while slowing down actually makes more noise than an ICV. The National Federation of the Blind, out of concern that EVs are becoming too quiet and unsafe for visually impaired, conducted research [Goodes et al., 2009]. The study showed that without engine noise the ability to detect a vehicle decreases significantly and is reversed when an artificial engine noise is added. According to the researchers there was a clear different in detection of a car running solely on an electric motor. They speak out there concerns about this low detectability for visually impaired but do not conclude that it poses a significant danger. They do suggest adding artificial engine noises to make an EV safer for visually impaired. Just as the American research teams, Japanese researchers have concluded that EVs are difficult to perceive at low speeds, < 15km/h, because they are too quiet. In Japan there is an ongoing discussion between the MLIT (Ministry of Land, Infrastructure, Transport and Tourism), JAMA (Japan Automobile Manufacturers Association), JAIA (Japan Automobile Import Association) and the JFB (Japan Federation of the Blind), about solutions for the problem of the quiet car. In a JASIC study in 2009 they evaluated the detectability of near silent hybrid vehicles in electric mode [JASIC, 2009]. They found that the difference in noise levels of HEVs and ICVs are the biggest when the vehicles are running stationary (figure 2 [JASIC, 2009]), +/- 20dB(A). Noise level difference of speeds of 20 km/h (12 mph) or higher are neglectable.

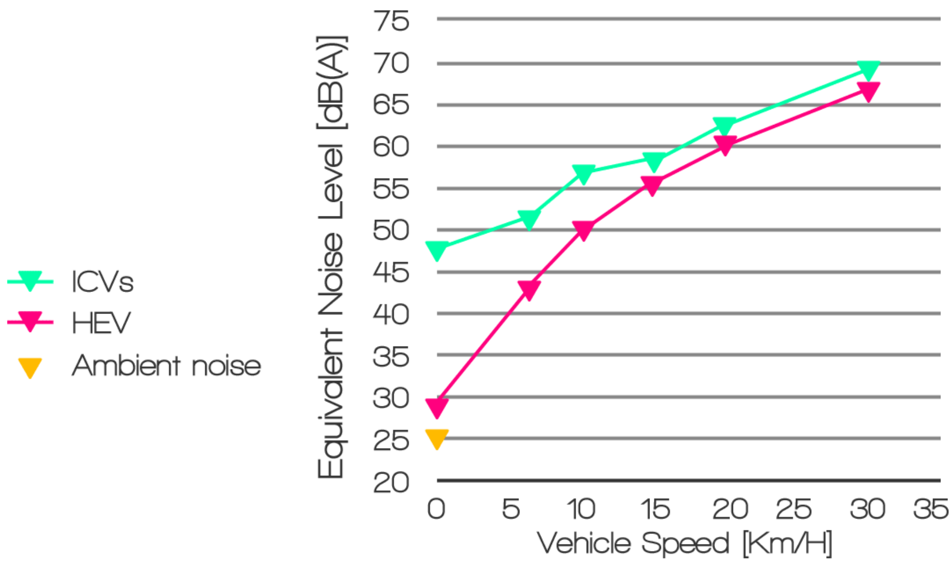
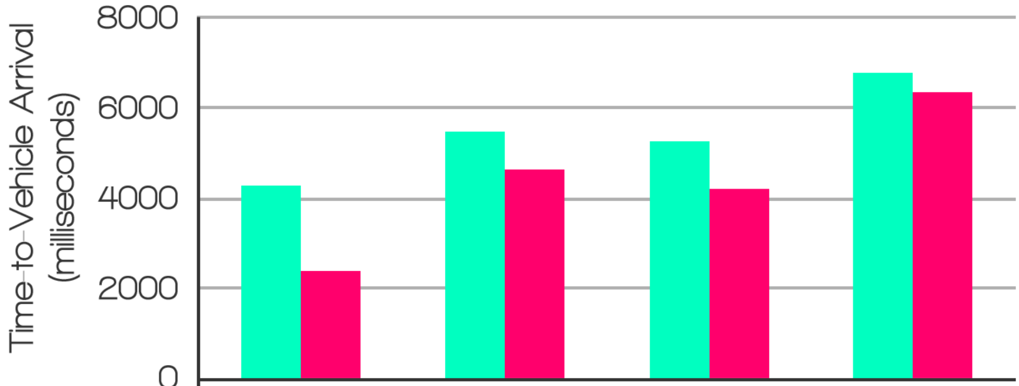



**Figure 2.** Comparison of Equivalent Sound Level between HEV and ICV

The Japanese research concludes that a pedestrian perceives an EV, traveling at low speed, later then an ICV in the same condition. Although there is some evidence of longer detection times for EVs, it is not know if this results in a dangerous traffic situation.
In the next paragraph we will investigate how ambient sound influences EV road safety.

### 1.2.2 Ambient sound

Ambient sound is a big factor in the audibility of electric vehicles. Detection of upcoming vehicles not only depends on the sound production of the vehicle but also on the surrounding sounds that masks its audible approach. When you look at the results mentioned earlier from the experiment conducted by Rosenblum [Rosenblum et al., 2009] you could clearly see the effect. The louder the background noise, the harder to detect a quiet electric vehicle or even an ICV. This could lead to higher accident risks in places with a high ambient noise, for example in cities. The data obtained in a follow-up experiment of Goodes [Goodes et al., 2009] show that a vehicle is consistently detectable when the sound level of the vehicle reaches 2 dB (A) above background noise. This means that you can either increase vehicle driving sounds or try to decrease overall ambient noises to obtain an optimized detectability. In the study of the NHTSA (2010) researchers found a similar result. In most cases, subjects detected vehicles later in situations with a high ambient background noise then in a low ambient noise background (figure 3 [Garay-Vega et al., 2010]). But the time to detect EVs (Prius Hybrid & Highlander Hybrid) was longer then for ICVs, especially in a high ambient situation.




| | Prius Hybrid | Matrix ICV | Highlander Hybrid | Highlander ICV |
|---|---|---|---|---|
| Low Ambient | 4303 | 5496 | 5301 | 6754 |
| High Ambient | 2378 | 4600 | 4124 | 6260 |

**Figure 3.** Mean Time-to-Vehicle-arrival: Vehicle Approaching at Low Speed [Garay-Vega et al., 2010]

Japanese research mentioned earlier [JASIC, 2009] investigated if ambient sound level is effecting the detection of HEVs and ICVs. And what the detection ratio is between these two types of transportation. The vehicle sound detection results are shown in figure 4.

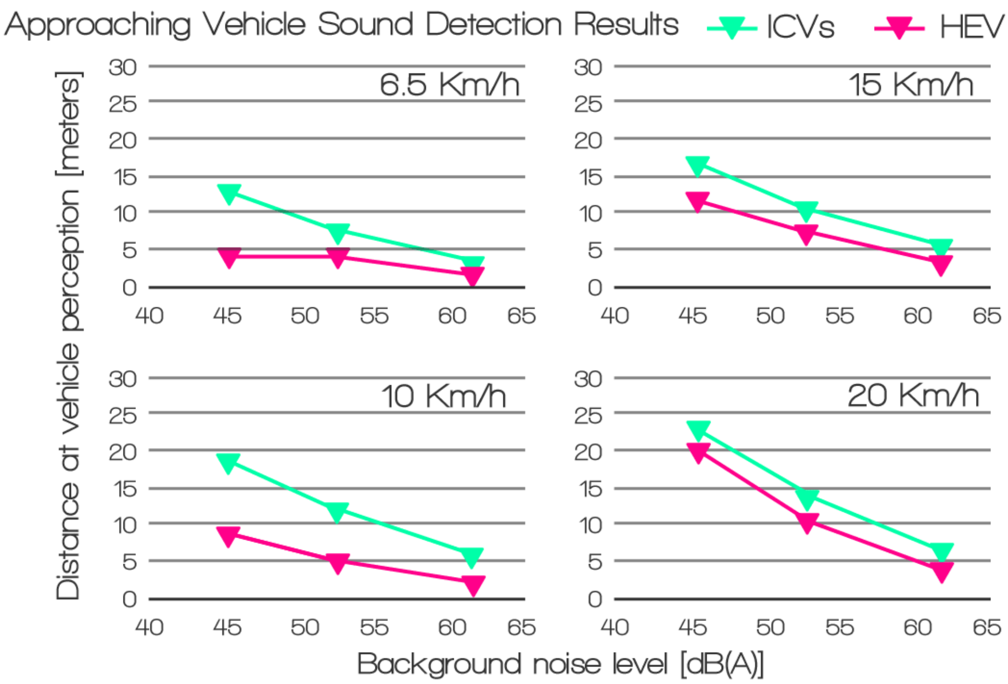



**Figure 4.** Evaluation of detection by subjects in 3 different background noise levels [JASIC, 2009].

At speeds exceeding 20 km/h (12 mph) the detection distances between HEVs and ICVs are almost the same across all background noise levels. With speeds of 15 km/h (9 mph) there is still a difference in detection between HEVs and ICVs on low and middle background noise levels, but this difference disappears when a loud background noise level is present. For speeds below 15 km/h a bigger difference in detection times is measured, but is still very dependent on the background noise level presented. We can conclude that ambient noise is most certainly a key player in electric vehicle detection.

### 1.2.3 Distractions

Vehicle approaching sounds are especially important in situations were other road users are preoccupied of distracted. The detection of approaching sound sources is evolutionary build into our survival systems. As uncovered by neurological research by Seifritz [Seifritz, E. et al., 2002], people have a build-in collision detection system that activates certain brain areas allowing us to quickly stop and look around to note the upcoming danger. When we hear a sound approaching, a specific part of our brain, that is associated with attention and motor action (flight response), is activated. Additionally, listeners typically overestimate increasing sound intensity as compared to equivalent decreasing intensity or stationary sound, thus overestimating the time of contact with the approaching sound source. Giving an advantage in time, used to avoid danger.
A study by Gurth et al. [Gurth, D. et al., 2005] emphasized the importance of sound detection in their study of blind and sighted people at roundabouts. In their study the researchers show the importance of detecting vehicle sounds for safely negotiating roundabouts. As mentioned before, we have an auditory warning system that can detect approaching objects running as background progress, so that we can multitask and pay attention to other stimuli, for example checking our mobile device for mail. But when there is none or very little approaching sound coming from a vehicle, this mobile device distraction may become hazardous. The opposite could also be the case, that we cannot hear that warning sound because of auditory distractions. A Dutch study by the SWOV [Goldenbeld et al., 2010] showed that 15 percent of bicyclists listen to music during almost every trip and 3.3 percent of the cyclists make a phone call while cycling. In these distractive cases, not only do they divert their cognitive attention to something else than driving, but they also reduce the audible detectability of other road users. They artificially raise the ambient sound intensity, thus making it harder to detect approaching vehicles, resulting in 'auditory distraction'. Overall, the use of mobile devices (portable devices that can be used to make telephone calls or to listen to music) during every bicycle trip increases the crash rate with a factor of 1.3 in comparison to cyclists who never do this. This research shows that only 12 percent of the cyclists could still hear every background sound while listening to music. The other 78 percent of the cyclists had a slightly to largely reduced ability in detecting background sounds. This research indicates that not detecting vehicle approach sounds does increase the crash rate for vulnerable road users such as cyclists. As mentioned earlier, vehicles are detected if their sound level is 2 dB (A) above background noise [Goodes et al., 2009]. Reducing ambient sounds levels or making vehicles more audible could help detection. The SWOV research by Goldenbeld also showed that a high loud sound is detected in approximately 92 percent of auditory distractive cases tested. Adding a warning sound to EVs would be favorable if you want detection by distracted road users.

Trying to reduce use of phones or mp3 players by vulnerable road users requires a more intensive approach and is less feasible.

### 1.2.4 Traffic situations

Interaction between electric vehicles and vulnerable road users takes place in certain traffic situations. Some of these situations are more accident-prone. By examining previous research, we intent to subtract the characteristics for these traffic situations. A couple of the scenarios have already come to our attention. In the NHTSA research [Garay-Vega et al., 2010] mentioned before, they proclaim that due to the great difference in sound level of a EV versus an ICV while traveling at low speeds, the accident risk is accordingly higher. The first element of a potential dangerous traffic situation is that it is a low speed zone. NHTSA research from 2009 [Hanna R., 2009] confirms this belief. They conclude that there are significantly more accidents with EVs in low speed zones. When looking more specific at the traffic situations that have a heightened accident risk, we conclude that for pedestrians a 'vehicle making a turn' posed the highest risk. In a bicycle situation, 'being overtaken' poses the highest risk. In the Japanese research [JASIC, 2009] possible problem area's where defined as parking lots, roads in residential areas and intersections with poor visibility. These locations where obtained through interviews with visually impaired people. Again, these are areas were vehicle drive at low speeds, when EV sound is almost absent, and places where sound is key in detecting, such as intersections with poor visibility. Another Japanese research shows their impression of potential dangerous traffic scenarios. Examples can be seen in figure 5, 6 and 7 [MLIT, 2010].

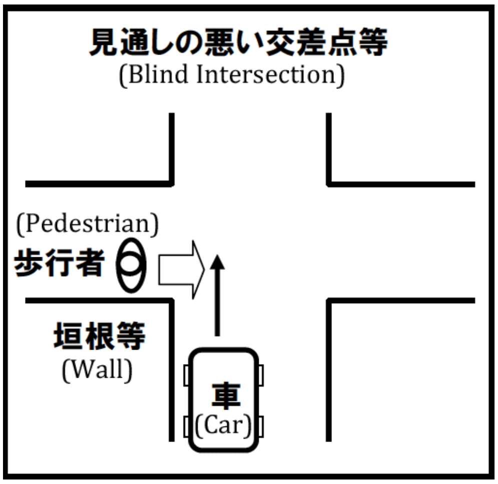



**Figure 5.** Blind intersections

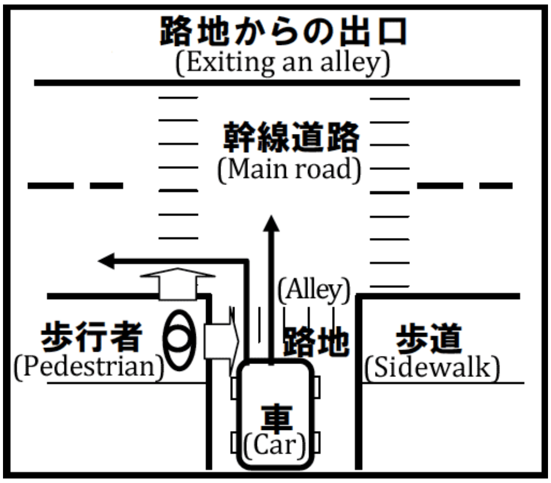



**Figure 6.** Exiting an alley

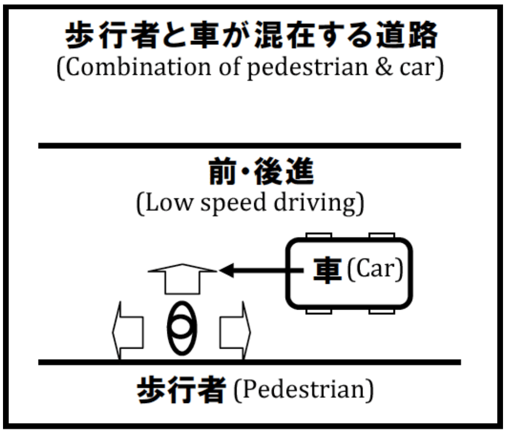


**Figure 7.** Pedestrian crossing or on the road

As mentioned before, as a pedestrian is crossing or traveling on the same road as a car, the crash risk increases. In conclusion, possible dangerous traffic scenarios for EVs interacting with vulnerable road users have the following characteristics: 'are within low speed zones', 'intersections with poor visibility', 'overtaking maneuvers from the rear (blind spot)' and 'crossings for pedestrians'. When searching for a possible solution to the lowered detectability of EVs, the solution has to apply to all these different traffic scenarios.

### 1.3 Discussion

The EV market is growing steadily and will continue to grow over the years to come. Making the topic of discussion, 'safety of quiet electric vehicles', increasingly relevant. The Netherlands is one of the leading countries in Europe when it comes to electric vehicle initiatives and promotion. That is why we have to know what the effect is on present and future road safety in the Dutch situation. There is evidence of a higher accident rate of electric vehicles at low speeds by one American research [Hanna R., 2009] but this evidence is questionable because the researchers didn't take 'driven kilometers' or 'location of use' into account and the study contained a small amount of EVs. We can however say that overall detection times to approaching electric vehicles are longer than that of normal ICVs. But a correlation between accidents and detection time cannot be made. Unless the results, the U.S. and Japan are making proposals to add artificial driving sounds to electric vehicles, this in an attempt to decrease possible danger risks for vulnerable road users. Although it is wise to do so, one must consider the added noise pollution and adverse health affects that are caused by noise annoyance [Knol, A. & Staatsen, B., 2005; Bluhm G, et al., 2004]. Research tells us that background or ambient noise is a key player in the detection of EVs by vulnerable road users. One way to increase EV detection would be to reduce ambient noises, something that would automatically occur when more 'near silent' EVs where used instead of ICVs. In the case of auditory distracted vulnerable road users, the most effective way of alerting them for approaching EVs is to use a warning sound coming from this vehicle itself. When searching for a possible solution for increasing traffic safety with EVs, we have to keep in mind that it must apply to traffic situations with the following character tics; 'low-speed zone', 'intersections with low visibility', 'blind spot overtaking' and 'pedestrian crossings'. In the next chapter we will make use of interviews and first hand experiences to derive a questionnaire tool for further investigation of the Dutch status of 'EV/vulnerable road user' safety issues.

# 2 Method

### 2.1 Interviews & experiences

For developing a valid questionnaire that can be used to research our main hypotheses, we made use of present day experiences of people who often come into contact with electric vehicles. These experiences were obtained by visiting and having conversations with EV shops (Juizz, Eco-movement), the Dutch Organization for Electric transportation (DOET), the Royal Dutch Guide Dog Foundation (KNGF), E-traction Europe (producer of the electric bus) and visiting events like 'BrightNight #4', 'National Electric Driving Day' and the 'DOET press launch'. At these events and organizations we tried to obtain as much information and gain additional insights for constructing our research questionnaire. A full report of these activities has been added to this paper as appendix 3.

### 2.2 Findings

After talking to a lot of people in our field research we came to the conclusion that there is no clear indication of actual more accidents happening with EVs in contrast to ICVs. When incidents did occur, highly distracted cyclists and/or pedestrians and not a noisy environment caused them. These people were either calling or listening to music and thus didn't notice an approaching EV. According to the people we spoke this could easily be resolved by sounding a warning sound (bell or horn), thus making them aware of your presence and restoring the safety of the traffic situation. An important factor for detection was the amount of ambient noise present. With low ambient noise an EV is easily detectable but with high ambient noise a warning sound had to used in order to notify vulnerable road users of your presence. According to a spokesman of the KNGF the most dangerous situation between an EV and a visually impaired person occurs while crossing and walking across a parking lot. His suggested solution to this problem would to also use a warning sound as indicator of EV presence. An often-heard suggestion is that a simple behavior change of EV drivers is needed in order to restore road traffic safety for vulnerable road users interacting with EVs. By using the knowledge we obtained by these interviews, experiences and our literature review, we can now develop a representative questionnaire (appendix 1) in order to study EV driver experiences in a larger scale. Variables that will be addressed in the questionnaire are as following; 'sound production', 'ambient noise', 'potential dangerous traffic situations' and 'distractions'. Special attention has to be given to factors as; 'behavioral change while using EVs', 'differences in speeds traveled by vulnerable road users and EVs' and 'possible suggestions for safety improvements'.

# 3 Research

## 3.1 Questionnaire

Because of our need for more information about the dangerous traffic situations that can occur in The Netherlands when an electric vehicle is interacting with vulnerable road users, we devised an online questionnaire for drivers of electric vehicles. With the use of this questionnaire we investigate if there is an actual posing thread for vulnerable road users when interacting with near silent EVs, and thus giving an answer to our previously mentioned research question. The subjects that were raised in our interviews & experiences and in our literature research inspire the questions we are now asking. Examples of these subjects are 'sound produced by EV', 'ambient sound', 'behavioral change', 'type of traffic situation', 'travel speed', 'distractions', 'use of warning signals' and 'startle reaction'. This questionnaire can be used as a tool for future follow-up research about the safety of EVs in everyday traffic situations. The questionnaire consists of 31 questions with both closed and open answers; a version of the complete questionnaire is added as appendix 1. With the use of this questionnaire we tried to gain information about: 1) accidents that EV drivers had, 2) the kind of vehicles they drive, 3) if the other road users notice them in time, were they mainly user their vehicle and what their personal ideas are concerning the quietness of EVs. After we constructed our questionnaire at the SWOV we send it to 'TNO Soesterberg' for further optimization. After being revised by TNO we placed the list of questions on the website 'www.studentenenquete.nl' and distributed the link with the help of twitter, electric vehicle forums, EV shops and EV organizations. We set up a Twitter account for the purpose of distributing the questionnaire but also to keep updated about new events and findings concerning electric mobility. Twitter proved to be a great way to keep in contact with the major players in the Dutch electric transportation market.

## 3.2 Results

A total of 55 electric drivers filled in the online questionnaire. 46 of these proved usable for further analyses, 9 were excluded because of faulty completion or not being in our target group (non EV drivers). 54 Men and only 1 woman filled the questionnaires. We are not certain why almost all the respondents are males. One reason could be because they are heavier Internet and forum users; another could be that they are the early adapters of new upcoming technologies such as electric transportation. 31 of the respondents were Toyota Prius Full Hybrid drivers, 8 battery electric vehicles (5 Think City's, 2 Tesla Roadsters and 1 Citroen Berlingo), 5 electric scooters and one electric motor (Vectrix VX-1). The ages of the respondents varied from 19 till 68 with a mean age 44,17. To measure the occurrence of dangerous traffic situations with EVs interacting with vulnerable road users we made use of indicators such as recalled accidents and detected startle responses to conduct our investigation. Unfortunately, from the view of the researchers, there were no recorded accidents with vulnerable road users in the subject group. There were however recorded startle responses. A startle response is measured by observing the reaction of how other road-users react to the presence of an EV. When the road users display a shocked reaction while noticing the EV, this is an indication of that they didn't see it coming. The questionnaire will categorize these events as 'startle response'. It indicates the presence of a possible dangerous traffic situation that could result in an accident. Due to the small sample size, we used simple instead of advanced statistic analytics for interpreting the results.

### 3.2.1 Vehicle produced sound

Following data has been obtained from questions 4, 15 & 19 of the online questionnaire. Of the total of 46 subjects that were questioned, 21 (46%) registered a startle response with encountered vulnerable road users (figure 8) In these startle cases, the largest part (90 %) of the subjects traveled at speeds below and equal to 25 km/h. Half (52%) of the startle responses where below and equal to 15 km/h. This could indicate that the low sound production of EVs at low speeds contributes to late detection by other road participants thus causing a startle response and possibly a dangerous traffic situation.

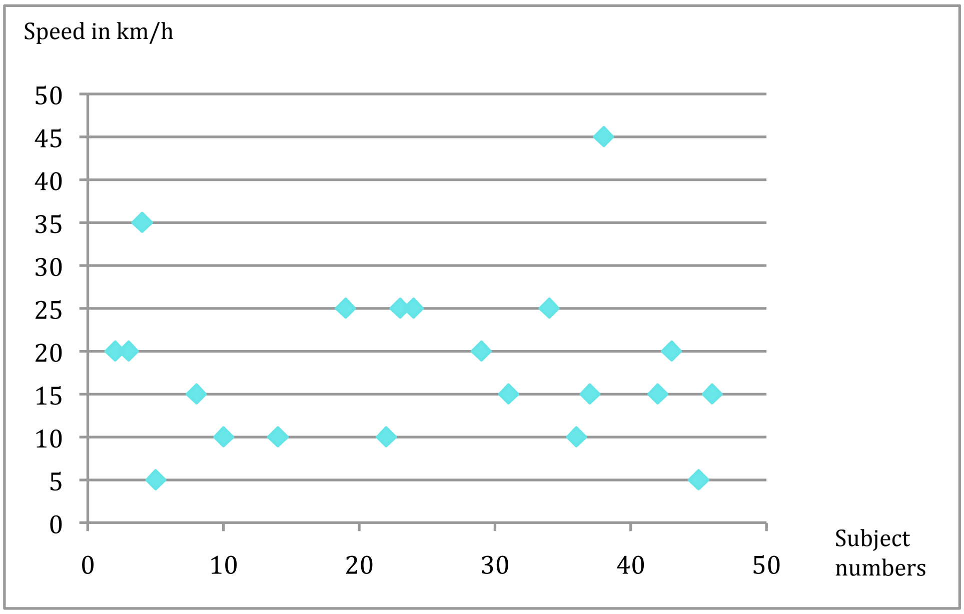


**Figure 8.** Startle response versus speed (N = 21)

Startle responses numbers didn't really differ between the types of electric vehicles. In all of the cases, half of the vehicles of a certain type recorded a startle response. Then again, all have a considerably low sound production (table 3).

**Table 3.** Startle response for type of vehicle (N = 21)

| | HEV | BEV | E-scooter |
|---|---|---|---|
| N startles | 14 | 4 | 3 |
| From total | 45% | 50% | 50% |

### 3.2.2 Ambient sound

Following data has been obtained from questions 3 & 20 of the online questionnaire. When startles were detected by the subjects, they most often happened in surroundings with medium ambient sound levels (table 4). Most of the startle responses (table 5), 81 percent, were caused by an EV driver that most often drove his vehicle in urban surroundings. These are areas with high ambient sound levels and thus nurse a lower detection response, indicated by causing a startle response.

**Table 4.** Share of ambient sound levels during startles (N = 21)

| | Silent | Middle | Loud |
|---|---|---|---|
| N startles | 2 | 17 | 2 |
| From total | 9,5% | 81% | 9,5% |

**Table 5.** Startle response versus place of most use (N = 21)

| | Urban (high ambient) | Rural (low ambient) |
|---|---|---|
| N startles | 17 | 4 |
| From total | 81% | 19% |

### 3.2.3 Distractions

Following data has been obtained from question 21 of the online questionnaire.
When we look at the distractions of vulnerable road users (table 6) that took place before they were startled, we can only conclude that there is no effect for distractions.

**Table 6.** Startle response versus distraction at the opposite party (N = 21)

| | Yes | No | Unknown |
|---|---|---|---|
| N startles | 4 | 9 | 8 |
| From total | 19% | 43% | 38% |

### 3.2.4 Traffic Situations

Following data has been obtained from questions 17, 18 & 18b of the online questionnaire.
When we look at the traffic situations (table 7) that nurtured the most startle responses we found that this happened particularly on crossings (43%) followed by overtaking (29%).

**Table 7.** Startle response versus maneuver type (N = 21)

| | Crossing | Overtake | Low speed maneuver | Drive away from stop |
|---|---|---|---|---|
| N startles | 9 | 6 | 4 | 2 |
| From total | 43% | 29% | 19% | 10% |

Startle responses were for the largest part (67%) measured on main roads (table 8). They were also detected on parking lots but in a smaller percentage (19%) and generally in zones of low speeds.

**Table 8.** Startle response versus location (N = 21)

| | Main road | Bicycle path | Parking / Low speed |
|---|---|---|---|
| N startles | 14 | 3 | 4 |
| From total | 67% | 14% | 19% |

### 3.2.5 Subject responses

Following data has been obtained from questions 5, 22 & 25 of the online questionnaire. After conducting the main research we asked some additional questions that we were interested in, about driving behavior and possible recommendations. All this data is represented in table 9. We concluded that 43 out of the 62 subjects (69%) changed their driving behavior when driving an EV instead of an ICV. Although the majority did practice some sort of change in road traffic behavior, there was not one type of behavior that prevailed. The EV drivers were overall more consciously careful in traffic, and aware of possible more difficult detection by vulnerable road users. They also expressed that they gave more warning signals to other road users when a dangerous traffic situation might be occurring. Although this looks promising, a large part (31 %)

was not changing anything of their behavior. It could be that they simple were already very conscious drivers or that they simply didn't see any extra danger risks when driving an EV.

**Table 9.** Behavioral changes of EV drivers (N = 62)

| | Nothing | More cautious acceleration | Look longer before driving away | More cautious approach intersection | More cautious towards bicyclists and pedestrians, because they don't hear you | Give more warning signals when overtaking |
|---|---|---|---|---|---|---|
| N subjects | 19 | 10 | 10 | 9 | 8 | 6 |
| From total | 31% | 16% | 16% | 15% | 13% | 10% |

In one of the final questions of our questionnaire we asked 'What can we do to make EVs more safe?', the responses are represented in the table 10.
The majority of EV drives (36%) answered that EVs are already safe and that nothing has to change at all. If something really would have to change it is the behavior of other road users (17%). They have to adapt to the presence of silent vehicles in traffic, look instead of listen. If a sound has to be added to the silent EVs they were more positive about a 'warning sound' (19%) then about a 'driving sound' (13%). Most subjects expressed that they would rather have a pleasant warning sound, specific for an EV, that give other road users a friendly notification of their presence, without startling the road users.

**Table 10.** Ideas from subjects for optimizing road safety EVs (N = 47)

| | Nothing, EVs are safe | Adding driving sound | Adding warning sound | Adaptation other road users | Behavioral change EV driver | Other |
|---|---|---|---|---|---|---|
| N subjects | 17 | 6 | 9 | 8 | 4 | 3 |
| From total | 36% | 13% | 19% | 17% | 9% | 6% |

### 3.3 Discussion

After conducting our research with the use of the online questionnaire we found results that correspond with the literature and the interviews and field experiences we obtained (chapter 2 & appendix 3). In the questionnaire we used 'startle response' as an indicator for 'too-late detection', an indicator for the occurrence of dangerous traffic situations. The results of our questionnaire indicate that potential dangerous traffic situations, when EVs are interacting with vulnerable road users, have a higher occurrence at low speeds (25 km/h and lower). This is when an EV emits the least amount of driving sounds. This finding corresponds with the results derived from the reviewed literature [Hanna R., 2009] and insights obtained in chapter 2. In the literature research we found that slow moving EVs are later detected then their ICV counterparts, due to the big difference in driving sound levels. We also experienced this low detectability during our electric scooter test-drive (appendix 3). In the included interviews this finding was confirmed by EV drivers and was considered as a known fact that you have to take into account while navigating through traffic. In our questionnaire we asked the participants to recollect the amount of ambient sound present when a startle response was detected. The result was that there is an effect for ambient sound. Higher ambient noise contributes to later detection of EVs by vulnerable road users and possibly leads to accidents. Again, this is compliant with the results from our literature research and own experiences. We noted that while driving on an electric scooter in a suburban part of Amsterdam (low ambient noise) we were detected by other road users as opposed to when we were driving in an urban part of Amsterdam (high ambient noise) where we weren't detected at all. In the literature we found a clear correlation between detection reaction time and ambient sound level additionally we found that in order to detect a vehicle it should produce a sound that is 2 dB(A) higher than the background sound level. There was no effect found for distractions of vulnerable road users when detecting an EV. According to the questionnaire, being more distracted does not lead to more startles. However, in 38 % (table 6) of the cases it is unknown if vulnerable road users were distracted when they got startled. So, it could be that the road users were distracted, only not noticeable. This makes it hard to measure distractions and making solid statements about it. We must make a note that measuring distractions of the road users could not be done very accurately, because it was obtained from the subjects themselves, this made it very subjective and far less accurate then if the vulnerable road users reported them their selves. From our questionnaire we deducted that traffic situations with the highest potential accident risks are pedestrian crossings, overtaking maneuvers from the rear and slow speed maneuvers off EVs on parking lots. These findings concur with the findings we obtained from our interviews & experiences (paragraph 2.2) and international research (paragraph 1.2.4).

# 4 Conclusion & Recommendations

We found evidence of a globally growing EV market. Small safety problems that we possibly have with EVs today could be enlarged in the future. But as the number of EVs increase, it could also be true that more and more people get used to this kind of silent vehicle and pay more attention to them. When the first cars were introduced (around 1900), pedestrians would cross the streets without looking, not expecting the approach of a fast vehicle. Through times pedestrians adjusted and eventually paid more attention when crossing the street. Paying attention to approaching vehicles, even when you do not hear them, could be the key. Our hypothesis is that EVs have a higher accident risk than their ICV counterparts and that this is due to the quietness of the electric vehicle and the inexperience with EVs of vulnerable road users. After gained results from three different sources (literature, interviews & experiences and our online research questionnaire) we come to the conclusion that we cannot confirm our hypothesis. In our research we explored the boundaries of the EV safety issue. We obtained high-risk traffic situations such as ‘pedestrian crossings’, ‘intersections’ & ‘low speed zones’. We found that ambient sound and sound produced by the vehicle itself are indeed a important factors in detecting EVs in traffic (min 2 dB(A) above background noise) and we explored the risk factors of upcoming use of mobile devices by vulnerable road users. But we could not find enough solid evidence of more traffic accidents occurring with EVs. We did explore the whole spectrum concerning silent EV traffic safety and came up with possible improvements such as ‘adding a warning signal to EVs’ and ‘inducing a behavioral change of EV drivers’ so that they become more aware of their surroundings and better anticipate to fellow road users. The questionnaire we devised can be used in future follow-up research for measuring road safety issues of near silent EVs. But an additional questionnaire with a larger target group is required to fully light the spectrum of investigation. To get a clear overview of the situation it is advised to also obtain the EV experiences of the vulnerable road users themselves. Our study does not show that the quietness of the EV actual results in more traffic accidents with vulnerable road users.

A positive effect that silence EVs bring, is that of the lowering of noise pollution, making detectability of silent vehicles higher and at the same time reducing noise annoyance. If an EV wants to give extra attention to his presence it would be suffice to simply use a warning sound. It would be desirable to use an unobtrusive and at the same time distinct warning sound. EVs have not got a specific warning sound like other vehicles, for instance the horn of an ICV, or the bell of a bicycle. This warning sound can be used if the EV driver is not sure if a vulnerable road user is aware of its presence. Another option is to make EV drivers more aware of their silent presence in road traffic. Adding an extra segment to driving lessons dedicated to electric vehicles could do this. For example an ‘EV drivers license’. In this EV driving lesson extra attention will be given to, for example ‘anticipating to vulnerable road users’ and ‘notice potential dangerous situations in time’. As mentioned before, we could make use of the silent features of the EV to lower overall ambient noise and therefore heighten the detectability of EVs and other silent road users, in traffic. We think that the reduction of ambient noise would eventually result in a safer traffic situation with less noise pollution for everyone.
Giving us the building blocks for …

## A Silent and Safer Future

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