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Driver perceptions of the safety implications of quiet electric vehicles

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ABSTRACT

Previous research on the safety implications of quiet electric vehicles (EVs) has mostly focused on pedestrians' acoustic perception of EVs, and suggests that EVs are more difficult for pedestrians to hear and, therefore, compromise traffic safety. The two German field studies presented here examine the experiences of 70 drivers with low noise emissions of EVs and the drivers' long-term evaluation of the issue. Participants were surveyed via interviews and questionnaires before driving an EV for the first time, after 3 months of driving, and in the first study, again after 6 months. Based on participants' reports, a catalogue of safety-relevant incidents was composed in Study 1. The catalogue revealed that low noise-related critical incidents only rarely occur, and mostly take place in low-speed environments. The degree of hazard related to these incidents was rated as low to medium. In Study 1, driver concern for vulnerable road users as a result of low noise diminished with increasing driving experience, while perceived comfort due to this feature increased. These results were replicated in Study 2. In the second study, it was additionally examined, if drivers adjust their perceived risk of harming other road users over time. Results show that the affective assessment of risk also decreased with increased driving experience. Based on individual experience, drivers adjust their evaluation of noise-related hazards, suggesting that dangers associated with low noise emissions might be less significant than previously expected.

1. Introduction

The increasing electrification of the power train in cars has led to intense debate about the advantages and disadvantages of hybrid electric vehicles (HEVs) and electric vehicles (EVs). One issue, which has more recently attracted public attention, is the low noise emitted by vehicles with a full or partial electric power train. HEVs drive on electricity at low speeds and during acceleration, while EVs are exclusively propelled by electricity. Concerns have been raised, especially regarding the safety of visually impaired pedestrians (National Federation of the Blind, 2011), who depend heavily on environmental sounds to navigate in traffic (Wall Emerson et al., 2011). The objective of the present article is to investigate (1) what kind of noise related incidents occur in everyday traffic and how these could be characterized, and (2) how actual drivers perceive the safety implications of quiet EVs. In particular, we examine (3) if EV drivers express concern for other road users and if (4) this evaluation is altered by individual driving experience. Finally, we aim to advance understanding of (5) how drivers evaluate artificial sounds as countermeasures. These issues were addressed in two field studies with a total of 70 drivers who drove an EV for an extended period of time.

1.1. Safety concerns and accident characteristics

Recently, the National Highway Traffic Safety Administration (NHTSA) published a report on accident characteristics of HEVs (Hanna, 2009). In the report, incidence rates of accidents involving HEVs were compared to accidents involving conventional vehicles with an internal combustion engine (ICE). In general, for crashes involving pedestrians, HEVs had a significantly higher incidence rate than ICE vehicles. Based on accident statistics of 12 US states, HEVs were twice as likely to be involved in pedestrian crashes during maneuvers, such as slowing or stopping, backing up, entering or leaving a parking space, than ICE vehicles. In the report, these maneuvers were grouped into one category as they all occurred at low speeds, where the difference in sound volume between vehicle types is maximal. Incidence rates of pedestrian crashes were also higher for HEVs when the vehicles were turning. The analysis of bicycle-related crashes showed a similar pattern; incidence rates for HEVs were higher than for ICEs in low-speed situations. Due to low registration rates, the numbers of HEVs reported in the NHTSA analysis were very small. The NTHSA report has recently been questioned as it failed to clarify if, and to what extent, low noise was responsible for the high number of pedestrian crashes (Verheijen

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and Jabben, 2010). Nevertheless, we argue that based on data from the US, it is possible to identify those maneuvers and situations which will most likely pose the greatest danger for pedestrians and bicyclists, if HEVs and EVs should become more widespread.

For the UK, similar results were reported (Morgan et al., 2010). EVs and HEVs in the UK were two times more likely to be involved in accidents that resulted in pedestrian casualties than ICE vehicles. Again, the absolute numbers of EVs and HEVs involved in pedestrian accidents was very low. The authors concluded that accidents were more likely to occur in areas with speed limits of less than approximately 64 km/h (40 mph) and that risk was also increased while engaging in slow maneuvers.

In contrast to findings from the US and the UK, a Dutch study found no statistical evidence for a higher incidence rate for accidents between HEVs and pedestrians or bicyclists. The number of examined accidents was also very low, even though the market share of HEVs in The Netherlands is the highest in Europe (Verheijen and Jabben, 2010). Due to low registration rates of EVs and HEVs, detailed and valid data on accidents involving these vehicles are still rare. The reported accident statistics from the US, UK and The Netherlands provide an inconsistent picture, indicating either an increased, or no increased risk for HEV/EV accidents involving, for example, pedestrians. Additionally, based on simple accident data it is almost impossible to determine if low vehicular noise emissions or other factors, such as inattention, caused the accident.

1.2. Noise emissions and auditory detection of HEVs and EVs

In addition to studies reporting accident statistics, HEVs and EVs have also been studied to determine the extent to which noise emissions and pedestrian detectability impact traffic safety. Morgan et al. (2010) recorded vehicle noise in different maneuvers and compared the noise characteristics of EVs and HEVs with conventional ICE vehicles. The analysis showed that during a pass-by at a steady speed of 7–8 km/h (4–5 mph), the maximum recorded noise levels tended to be, on average, lower for HEVs and EVs (52–56 dB(A)) than ICEs (51–58 dB(A)), although the authors argued that modern ICE vehicles may also be as quiet as their electric equivalents. In the initial phase of acceleration, at 0.5 m/s^{-2}, EVs and HEVs (62–64 dB(A)) were marginally quieter than ICE vehicles (63–64 dB(A)) and at higher speeds (e.g. 20 km/h), noise levels were comparable (EVs/HEVs: 63–66 dB(A) vs. ICEs: 62–66 dB(A)) as road and tire noises became more dominant. Similar findings have been reported by Garay-Vega et al. (2010), who also compared noise levels of HEVs and their ICE counterparts. The maximum noise difference (2–8 dB(A)) between vehicle types was observed when vehicles were approaching at approximately 9.5 km/h (6 mph). Smaller differences occurred at approximately 16 km/h (10 mph) and no significant differences were observed at approximately 32 km/h (20 mph) and above. Robart and Rosenblum (2009) compared the auditory detection of conventional ICE vehicles with HEVs and showed that subjects could determine the direction of slowly (5 mph) approaching ICE vehicles much sooner than HEVs. If background noises were added, HEVs were not perceived until very close to subjects. When both sets of stimuli were tested on blind pedestrians, similar results occurred.

Tests with blind pedestrians were also conducted by Garay-Vega et al. (2010); these tests were of auditory detection of HEVs and ICE vehicles with different ambient noise levels, and allowed comparison of both vehicle types and their maneuvers. The time-to-vehicle-arrival, i.e. the time from first detection to the moment the vehicle passed the subject, was found to be shorter for HEVs than for ICE vehicles in the backing out (8 km/h, 5 mph) and vehicle approaching (9.5 km/h, 6 mph) maneuvers. In other words, HEVs were closer to pedestrians by the time they were first noticed. Only when slowing was the HEV detected earlier, a finding that is most likely due to the noise emitted by its regenerative braking system during deceleration. The authors argue that the resulting detection times would normally be sufficient for pedestrians or drivers to avoid a collision. Nevertheless, it should be noted that in the experiment the pedestrians could devote their full attention to the task, which might not be possible under normal traffic conditions with multiple vehicles present. How and when blind pedestrians decide to cross a street was studied by Wall Emerson et al. (2011), where passing vehicles were either conventional ICE vehicles or HEVs. HEV speeds below 20 mph (32 km/h) also turned out to be most difficult to detect for blind pedestrians. The Toyota Prius, one of the HEVs tested, was only detected when the vehicle was an average of 2 s away, which equals 56.6 feet (17 m) at 20 mph (32 km/h). When the test vehicles were approaching at higher speeds, Toyota Prius, Honda hybrids and the ICE vehicles were similarly detected at 4–5 s away, although even this time period was not sufficient to safely cross the street.

A study on search behavior at intersections revealed that sighted pedestrians tend not to search visually for oncoming vehicles; instead, they tend to rely on auditory cues (Van Houten et al., 1997). Compared to situations in which vehicles approached from the side or head-on, the least search behavior occurred when vehicles approached from behind the pedestrian. Only approximately 30% of the pedestrians searched for vehicles approaching from behind, which suggests that with more EVs/HEVs available, these situations will also become increasingly relevant for sighted pedestrians.

In sum, findings on HEV noise emissions suggest that particularly when traveling at speeds of up to 20 mph (32 km/h), noise emissions differ between vehicle types, which makes it especially difficult for blind pedestrians to detect HEVs. To date, studies on noise emissions of HEVs and EVs have focused exclusively on perceptibility, in particular of HEVs. Here, we also examine driver experiences with EVs.

1.3. Driver experience and the evaluation of low noise

Thus far, research on how drivers evaluate low noise is still sparse and is mainly limited to general statements. In a study examining user acceptance of EVs from Sweden, participants reported that low noise contributed to driving pleasure (Gärling, 2001). Results from a study on EV fleet usage (Carrol, 2010) show that drivers generally appreciate low noise and the environmental feel-good factor; however, considerable variation in user evaluations was observed. Additionally, some participants reported that lack of noise was beneficial for the environment, and others mentioned safety concerns. Initial results from another UK trial revealed drivers' concerns about pedestrian and bicyclist safety prior to driving an EV for the first time (Everett et al., 2010). Similar findings were also reported in a German field study on EVs (Cocron et al., 2011a); although drivers generally appreciated the EVs' low noise, concern for the safety of other road users was expressed prior to driving the vehicles for the first time. As practice with an EV increased, these concerns decreased. To further investigate these effects, the theoretical framework of risk perception was used as a reference.

1.4. Risk perception

Risk perception, or the subjective experience of risk in hazardous situations, is usually referred to in discussions about the augmented accident risks of young novice drivers, who tend to perceive lower levels of risk compared to other groups (Deery, 1999). According to Brown and Groeger (1988), risk perception is determined by two factors: (1) information about the potential hazard within a traffic context (i.e. hazard perception) and (2) information regarding the ability of both the driver and the vehicle to