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Hazard detection in noise-related incidents – the role of driving experience with battery electric vehicles

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ABSTRACT

The low noise emission of battery electric vehicles (BEVs) has led to discussions about how to address potential safety issues for other road users. Legislative actions have already been undertaken to implement artificial sounds. In previous research, BEV drivers reported that due to low noise emission they paid particular attention to pedestrians and bicyclists. For the current research, we developed a hazard detection task to test whether drivers with BEV experience respond faster to incidents, which arise due to the low noise emission, than inexperienced drivers. The first study ($N = 65$) revealed that BEV experience only played a minor role in drivers' response to hazards resulting from low BEV noise. The tendency to respond, reaction times and hazard evaluations were similar among experienced and inexperienced BEV drivers; only small trends in the assumed direction were observed. Still, both groups clearly differentiated between critical and non-critical scenarios and responded accordingly. In the second study ($N = 58$), we investigated additionally if sensitization to low noise emission of BEVs had an effect on hazard perception in incidents where the noise difference is crucial. Again, participants in all groups differentiated between critical and non-critical scenarios. Even though trends in response rates and latencies occurred, experience and sensitization to low noise seemed to only play a minor role in detecting hazards due to low BEV noise. An additional global evaluation of BEV noise further suggests that even after a short test drive, the lack of noise is perceived more as a comfort feature than a safety threat.

1. Introduction

In discussions regarding the strengths and weaknesses of vehicles with an electric power train (EVs), concerns related to their low noise emission have been raised (National Federation of the Blind, 2011; Rosenblum, 2009). Hybrid electric vehicles (HEVs) and battery electric vehicles (BEVs) especially pose a potential threat to blind pedestrians, as these road users mainly rely on auditory cues when navigating in traffic (Wall Emerson et al., 2011). Research on EV safety has mainly focused on the perceptibility of these vehicles, which means that pedestrians – in particular blind pedestrians – were tested to determine their ability to detect an approaching vehicle (e.g., Garay-Vega et al., 2010; Robart and Rosenblum, 2009). In the present paper, we aim to address the issue from the driver's perspective utilizing a hazard perception (HP) approach (McKenna and Crick, 1994). During the transition phase, with only a few BEVs on the road, driver behavior is crucial in mitigating potential risks resulting from low noise emissions. Therefore, it is of vital interest to determine if and when drivers detect situations which might become dangerous due to the lack of engine noise.

In our paper we term those situations as "noise-related" situations, incidents or hazards which can occur due to the reduced external noise cues of BEV at low speeds. In particular, we wanted to investigate (1) at which point drivers with differing levels of practical BEV experience detect hazards in noise related situations in traffic, and (2) how they evaluate such incidents. In the second study, we wanted to investigate (3) if sensitization to low noise has an impact on hazard detection and evaluation, and (4) how drivers evaluate the low noise of BEVs in general. To address these issues, we conducted two experimental studies with drivers who had extensive BEV experience and others who did not.

2. Background

2.1. Accident and incident characteristics of HEVs and BEVs

A report by the National Highway Traffic Safety Administration (Hanna, 2009) revealed that HEVs had significantly higher incidence rates for accidents than vehicles with internal

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combustion engines (ICE). In turning maneuvers, the risk of a HEV colliding with a pedestrian was significantly higher; during slowing or stopping, backing up and entering or leaving a parking space, the risk of an accident involving a pedestrian and a HEV doubled. The latter maneuvers were grouped into one category as they most likely occurred at low speeds where the difference in noise emission between vehicle types is greatest. An increased likelihood was also reported for accidents with bicyclists (Hanna, 2009). Verheijen and Jabben (2010) questioned the NHTSA report, arguing that the report did not clarify whether low HEV noise was the cause of the accidents. In their analysis of Dutch accident data, Verheijen and Jabben (2010) found that HEVs did not have an increased incidence rate for accidents with pedestrians or bicyclists. The results mentioned above do not clearly indicate whether EVs in general pose a greater safety risk than ICE vehicles. Especially since the registration rates of electrically propelled vehicles are still low, these numbers need to be treated with caution. The aforementioned maneuvers were identified by studying HEV accident data. Another approach was reported by Cocron and Krems (2013) who investigated situations where the low noise emission of BEVs played a crucial role. Such noise-related incidents were identified based on interviews with BEV drivers. When questioned after driving a BEV for three months in urban traffic, 67.5% of participants (N = 40) reported incidents which were related to noise emission; no accident was reported. Based on the drivers' feedback, a catalogue of noise-related incidents was compiled. If a particular incident was reported by a driver, this incident was only assigned to one category. The categories were labeled as follows: (1) <30 km/h, (2) traffic light/turning, (3) overtaking/passing, (4) exit/parking lots, (5) straight ahead driving, and (6) other maneuvers. According to the BEV drivers, noise-related incidents occurred seldom; the drivers rated the hazardous potential of the reported incidents low to medium (Mdn = 4.0 on a 10-point scale, 1 = nonhazardous to 10 = extremely hazardous). The majority of the incidents occurred at speeds below 45 km/h and involved pedestrians or bicyclists. The categories (1) <30 km/h, (2) traffic light/turning and (4) exit/parking lots reported by Cocron and Krems (2013) partially overlap with the maneuvers described by Hanna (2009). Both studies served as the empirical basis for the creation of the noise-related scenarios which were used for the hazard detection task in our studies.

2.2. Noise emission of EVs and its meaning for different road users

To date, various studies testing the perceptibility of EVs at low speeds have been conducted. In such studies, participants were typically either blindfolded or were visually impaired. EVs and ICE vehicles of a similar type and brand approached at different speeds or conducted various maneuvers, while the sound level and participants' reactions were recorded. The participants' task was to indicate when they detected the vehicle. The greatest difference between electrically propelled and ICE vehicles in noise emission is usually found at speeds up to 10 km/h (e.g., Garay-Vega et al., 2010; Morgan et al., 2010). These differences diminish at 20 km/h (Morgan et al., 2010), and at 32 km/h (Garay-Vega et al., 2010), no difference in noise levels between vehicle types can be detected. The fact that EVs are less perceptible at lower speeds has led to a debate about artificial sound as a countermeasure to address safety risks associated with quieter vehicles (Dudenhöffer and Hause, 2012; Sandberg, 2012; Sandberg et al., 2010). Steps toward legislative action have already been initiated, e.g., in the US (Pedestrian Safety Enhancement Act, 2009). Still, when approaching the issue from a different perspective, the lack of sound significantly benefits the road environment.

Gärlig (2001) reported that low noise emission is part of the driving pleasure for BEV drivers. A study conducted in the UK revealed that drivers also appreciated the low noise emission in BEVs; however, these drivers additionally mentioned safety concerns (Carroll, 2010). Results from a German field trial with BEVs suggest that BEV drivers are aware of noise-related hazards, as they reported paying particular attention to pedestrians and bicyclists (Cocron et al., 2011a). Still, in this field study, the evaluation of low noise emission changed with experience. Although safety concerns existed before driving the vehicle for the first time, they decreased as drivers gained more experience with driving the BEV in urban traffic. The findings reported by Cocron et al. (2011a) suggest that drivers seemed to be aware of noise-related risks (risk perception) and reported anticipating such incidents (HP). In this context, Deery's (1999) model of behavioral response to potential hazards provides a useful theoretical structure. According to the model, risk taking behavior as the behavioral outcome is dependent on the individual's risk threshold and driving skill. Further, the risk threshold is defined as the individual's risk perception, whereas driving skill is determined through self-assessment of one's ability to prevent hazards from resulting in an accident. Directly associated with the potential hazard is HP, which is defined as the detection of the hazard and the quantification of its hazardous potential. Cocron and Krems (2013) investigated the degree to which BEV drivers perceived risk associated with low noise. In our research, we aim to investigate response to low noise-related hazards in more detail. Therefore, HP is the focus of the present work and is discussed in more detail in the next section.

2.3. Hazard perception

The driver's notion of increased attention to vulnerable road users (VRUs) raises the question of whether drivers adapt their driving after utilizing a BEV over an extended period of time. Drivers reported that they were aware of the hazards due to low noise and accounted for this problem in their day-to-day driving (Cocron et al., 2011a). Therefore, one could argue that anticipatory skills might be acquired over time to avoid noise-related collisions. In the literature on road safety, the awareness of potential hazards is usually referred to as hazard perception (McKenna and Crick, 1994). HP in the driving context usually refers to “the ability of individuals to anticipate potentially dangerous situations on the road ahead” (Horswill et al., 2008; p. 212). As the overlap with Endsley's (1995) concept of situation awareness (SA) is apparent, Horswill and McKenna (2004) described HP as “drivers' situation awareness for potentially dangerous incidents in the traffic environment” (p. 156). Focusing on driving, Baumann and Krems (2007) proposed a comprehension-based model on construction and maintenance of SA. Underwood et al. (2011) conceptualized the perception of the current environment and the knowledge about the origins of the present situation using the levels of Endsley's model of SA (1995), with the former corresponding to level 1 (perception of elements in current situation) and the latter to level 2 (comprehension of current situation). According to Underwood et al. (2011), anticipatory skills regarding how a situation might develop correspond to the third level of SA (projection of future status); HP tasks should ideally test skills at this level. In HP tests, drivers usually view a set of short videos showing traffic scenes and are asked to press a response button or use a computer mouse to click on a relevant road user as soon as they predict a potential traffic conflict (Wetton et al., 2011). Reaction times and number of reactions in each video are usually recorded (for an overview see Horswill and McKenna, 2004).

Although several studies suggest that experienced drivers respond faster in HP tests (Horswill et al., 2008; McKenna and Crick, 1994; Sexton, 2000; Wallis and Horswill, 2007; Wetton et al., 2010), the empirical evidence is not consistent. Other