

# Electric Vehicle Detectability: a Methods-Based Approach to Assess Artificial Noise Impact on the Ability of Pedestrians to Safely Detect Approaching Electric Vehicles

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## ABSTRACT

Hybrid and electric vehicles (HVs and EVs) have demonstrated low noise levels relative to their Internal Combustion Engine (ICE) counterparts, particularly at low speeds. As the number of HVs/EVs on the road increases, so does the need for data quantifying auditory detectability by pedestrians; in particular, those who are vision impaired. Manufacturers have started implementing additive noise solutions designed to increase vehicle detectability while in electric mode and/or when traveling below a certain speed. A detailed description of the real-time acoustic measurement system, the corresponding vehicular data, development of an immersive noise field, and experimental methods pertaining to a recent evaluation of candidate vehicles is provided herein. Listener testing was completed by 24 legally blind test subjects for four vehicle types: an EV and HV with different additive noise approaches, an EV with no additive noise, and a traditional ICE vehicle. The primary results examined the distances at which subjects detected each oncoming vehicle and the corresponding acoustical measurements upon detection. Vehicle approach scenarios included two levels of steady-state speed: 10 kph and 20kph. Participants were seated on a closed-test track, and asked to identify auditory detection of each oncoming vehicle within the presence of continuous, spatially distributed, spectrally shaped noise at 55dBA and 60dBA. The spectrum of the noise matched that of typical average urban background noise. The acoustic data was collected using measurement grade microphones positioned directly above each participant's head. Findings suggest that although mean detection distances trend higher for vehicles with an additive noise component, they aren't significantly different from the traditional EV at speeds of 10kph. Moreover, all EV/HVs were detected at significantly shorter distances relative to the ICE vehicle when traveling at 10kph. At 20kph these differences become nearly indistinguishable.

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## INTRODUCTION

As the adoption of hybrid and electric vehicles (HVs and EVs) increases, concerns have emerged regarding their relative quietness with respect to pedestrian detectability. Although all pedestrians face a possible increase in risk due to the lower operating noise associated with HVs and EVs, the visually impaired community faces an even greater potential for risk due to their reliance on hearing as an assessment for when it is safe to cross.

In order to address these concerns, vehicle manufacturers have begun implementing additive noise solutions designed to enhance vehicle detectability while in electric mode and/or when traveling below a certain speed.

## Standards and Regulations

The United Nations Economic Commission of Europe (UNECE) has developed a method for assessing these various additive vehicle noise solutions [1]. EVs and HVs tend to be quieter than Internal Combustion Engine (ICE) vehicles, particularly when operating at low speeds when road and wind noise is lessened. As such, these vehicle types pose a greater potential risk to pedestrians, particularly those who are visually impaired, when operating at low speeds. In order to assist in the detection of EVs and HVs the 2010 Pedestrian Safety Enhancement Act (PSEA) required that the National Highway Traffic Safety Administration (NHTSA) issue a performance standard to ensure that these quiet vehicles emit a sound that meets certain minimum requirements such that they are "recognizable" as a "motor

vehicle” in operation [2]. A notice of proposed rulemaking (NPRM) was subsequently issued, announcing a proposal to establish Federal Motor Vehicle Safety Standard (FMVSS) No.141, which would require “hybrid and electric passenger cars, light trucks and vans (LTVs), medium and heavy duty, trucks, and buses, low speed vehicles (LSVs), and motorcycles to produce sounds meeting the requirements of this standard” [3]. The aforementioned NPRM highlights the three phases of research conducted by NHTSA from 2009 to the present. Phase 1 activities included the identification and investigation of scenarios in which visually impaired or blind pedestrians may be at risk; documentation of EV, HV, and ICE acoustic measurements, as well as ambient noise levels within pedestrian roadway crossing environments where sound may be the only indicator of a vehicle’s presence; examination of auditory detectability of EVs, HVs, and ICEs in scenarios of concern; and examination of potential countermeasures. Phase 2 built on the results of Phase 1 by developing potential specifications for additive vehicle noise using the psychoacoustic modeling and human subjects testing from Phase 1. Phase 2 research found that synthetic sounds for EVs and HVs that resembled ICE sounds produced similar detection distances, and the results suggested, “Synthetic sounds that contained only the fundamental combustion noise are relatively ineffective.” Of note, this research found that visual impairment, or lack thereof, did not have a significant impact on the ability of participants to detect vehicle approach sounds. Phase 3 used data from Phases 1 and 2 to develop “an objective, repeatable test procedure and objective specifications” for EV and HV minimum sound requirements in order for additive sounds to be “detectable and recognizable as a motor vehicle.” The recommendations from this proposal to increase recognition include thresholds for amplitude modulation and total tonal power, multiple harmonics equal to ICE frequency, high amplitude first or second harmonics coupled with as low as possible frequency in the lowest harmonic, and increase of amplitude as a function of speed. As of this writing, a new proposed regulation, Federal Motor Vehicle Safety Standard No. 141 by NHTSA [7] has been announced that provides guidelines or minimum EV noise emission. NHTSA characterizes these “simple” noises as two or four tones between 315 and 5000 hertz, separated in one-third-octave intervals. Additionally, the volume must go up by three decibels for every 6-mph increase in speed. Electric cars must make the sounds between 47 and 67 decibels.

### Related Work

Some related studies considered the presence of ambient noise and sought to perform experiments within a controlled environment under specified ambient noise conditions. Pliskow, Naghshineh, Emerson, Kim, and Myers (2011) conducted a study on a closed test-track facility, which included controlled, low ambient sound. Vehicles were driven across a pedestrian crossing path at a target velocity of 15 kph (note the dataset included velocity errors up to  $> 5$  kph and acceleration  $< 1.5$  kph/sec). The study found that the peak sound pressure level (SPL) at the location of the participants was directly related to the velocity of the vehicles driving by. In addition, the SPL at the

participants’ location was in direct relation to the distance between the approaching vehicles and the participants’ location. Finally, the authors found that at the time of detection, “approaching vehicles had the most acoustic energy above ambient levels in the 1,000 and 2,000 Hz 1/1-Octave bands” [4]. In Kim, Emerson, Naghshineh, and Myers (2014), ambient noise level patterns were evaluated in addition to examining the timing and performance of visually impaired pedestrians’ critical street-crossing decisions [6]. A variety of residential, major or minor, and signalized intersections were selected for this study. Mean overall sound levels, with noticeable fluctuations, were measured and used for analysis. The authors determined that ambient noise plays a significant role in the detection of quiet vehicles, indicating that fewer risky decisions were made to cross the street when the ambient noise level was lower. However, the authors note that the determination of participants’ greater or lesser risky behavior was based on the assumption that the one sighted experimenter made reasonably accurate decisions in all trials. At residential and major-minor unsignalized street intersections, participants made the majority of their crossing decisions during “all quiet” periods, or periods when the ambient sound level was below the 25<sup>th</sup> percentile and gaps in traffic occurred. Furthermore, “the percentage of risky crossing decisions was significantly lower when the decisions were made at ambient sound levels below the 25<sup>th</sup> percentile.” The authors note that visually-impaired pedestrians often attempted to compare ambient sound just prior to the “surge” of near parallel traffic to determine whether an intersection was safe to cross; therefore, the authors state that “the ambient sound level at a signalized intersection may not be the most appropriate measure of background sound level for determining how loud a target vehicle should be at these intersections.” To fully understand the impact of ambient sound levels in a variety of roadway environments, the authors suggest that a comprehensive set of orientation and mobility tasks should be tested “at a larger number of intersections with different environmental characteristics.” Pliskow et al. (2011) conducted their study in a controlled, low ambient noise environment and suggested that further testing be conducted under higher ambient noise levels. Emerson et al. (2011) conducted testing under real-world conditions, in an uncontrolled higher ambient noise level environment. Kim et al. (2014) also conducted testing in various environments under real-world conditions, resulting in fluctuating ambient noise levels. The last two studies discussed provided insight into typical higher ambient sound level environments; however, both had to take into account fluctuations in sound levels. In addition, these studies may not have reflected the traffic and surrounding noise that may be found in deep urban environments; rather, the figures provided indicate that they may have taken place in a more suburban setting, with relatively low traffic density and little noise from surrounding activities. As such, further testing in a controlled environment in which higher ambient noise level conditions would remain steady across the study, and in particular, across each test scenario, is still warranted. IN regard to additive noise solutions to aid detection, a study by Emerson et al. (2012) tested five artificial sounds emanating from the vehicle’s front bumper against an ICE vehicle and a set of Chevrolet Volts operating in “quiet mode,” in a real world, uncontrolled intersection environment. Results from this study indicate that it is not the

characteristics of artificially added sound but the interaction of the artificially added sounds with the ambient background noise that impact blind pedestrians' performance of orientation and mobility tasks. The study determined that ambient sound energy between 500-1,000 Hz hinders detection of vehicle noise [5].

The project discussed in this paper was conducted with the goal of evaluating the UNECE's proposed method, as well as to assess listener responses to four vehicles: 1) Two different EV's with additive noise solutions, 2) one EV with no additive noise solution, and 3) a traditional internal combustion engine. These listener tests were conducted in a controlled environment in the presence of artificially generated, background noise at 55dBA and 60dBA with a spectrum that was shaped to match average urban background noise [2]. Twenty-four legally blind subjects were instructed to push a button when they detected the approach of oncoming vehicles. The final study design accommodated three within-subject factors including vehicle-type (4 levels), approach speed (3 levels), and background noise level (2 levels). This 4×3×2 design provided 24 unique configurations, each repeated across three separate trials, for a total presentation of 72 scenarios per data collection session. The paper is organized as follows. First, the overall experimental method is discussed, which includes properties of the test site chosen, acoustic data acquisition hardware and software, and acoustical measurements of vehicle drive byes as per the UNECE. An analysis of the average detection distances and corresponding average overall sound pressure levels, and corresponding 1/3 octave band results follows.

## EXPERIMENTAL METHOD

### Test Site Selection

As the primary focus of this evaluation was based on vehicle detection within a noise-controlled environment, selection of an appropriate site location to support both the benchmark vehicle noise testing, as well as the subsequent "listener" evaluations, was critical. Under ideal circumstances, this location would provide the following:

- A safe (controlled) environment conducive to testing with 'pedestrians' seated on or near the roadway
- Low ambient noise levels
- A level roadway
- A road surface representative of typical roadways
- A site length appropriate for dynamic maneuvers

The research team identified and conducted benchmark vehicle noise testing at multiple sites before selecting the section of roadway near the lower turnaround of the Virginia Smart Road, a closed test bed adjacent to the Virginia Tech Transportation Institute (VTTI) in Blacksburg, VA (see shaded area in [Figure 1](#)). This location came closest to meeting the ideal requirements identified above.



Figure 1. Virginia Smart Road test site.

As Smart Road access is controlled, testing could be conducted with the guarantee that no other vehicles would enter the defined testing area. The noise levels at the selected site were the lowest of any measured site, and were not directly impacted by any surrounding primary roadways. The roadway was relatively level (an approximate 1% grade) with sufficient distance to support the maneuvers performed during the listener testing. Finally, the condition of the roadway surface was representative of a typical asphalt-paved roadway throughout Virginia ([Figure 2](#)), but was not representative of new pavement.



Figure 2. Smart Road Asphalt Surface at Test Site

### Data Acquisition and Analysis System

#### Acoustical Measurements

Three types of acoustical measurements were recorded during the course of this project: acoustic pressure, overall A-weighted SPL and 1/3 octave band SPLs (also A-weighted). The major components of the noise measurement data acquisition system (DAS) were as follows:

- Four G.R.A.S. 46AQ ½" TEDS Microphones
- One National Instruments cDAQ USB Data Acquisition Rack
- One National Instruments NI 9234 analog to digital converter module