Acoustic Vehicle Alerting Systems (AVAS) for Electric Trucks: Initial Thoughts for the Requirements

Berkay Kullukcu[1], Robert Rosenkranz[1,2], M. Ercan Altinsoy[1,2]
[1] Institute of Acoustics and Speech Communication, TU Dresden Chair of Acoustics and Haptics
Helmholtzstr. 18, 01069 Dresden, Germany
[2] Centre for Tactile Internet with Human-in-the-Loop (CeTI), TU Dresden
01069 Dresden, Germany
Email: berkay.kullukcu@tu-dresden.de

Introduction

Compared to internal combustion engine (ICE) vehicles, electric vehicles (EVs)−especially electric trucks, or E−trucks−pose a distinct acoustic difficulty on city roadways. Since EVs run silently at low speeds in contrast to ICE vehicles, cyclists and pedestrians who might not hear them coming could become concerned about their safety. Many countries have used Acoustic Vehicle Alerting Systems (AVAS) to solve this problem. AVAS alert pedestrians to the presence of EVs nearby by producing sounds.

However, further challenges are involved in creating an efficient AVAS for E-trucks. Trucks, in contrast to passenger automobiles, frequently have unique sound features related to their larger size and strong motors. It might not be the best idea to just transfer AVAS sounds intended for smaller EVs onto E-trucks because this could lead to aural dissonance or fail to convey information to pedestrians about the necessary sense of safety and alertness.

The first step toward creating design recommendations for efficient AVAS in E-trucks is taken by this article. We report on the preliminary results of a psychoacoustic study including a jury test that contrasted how trucks and vehicles but also electric and ICE differ in terms of sound feature and how existing AVAS noises on E-cars are perceived by examining the ratings given on a semantic differential scale.

Design Approach

As the quantity of E-trucks on urban road increases, they generate distinct acoustic challenges in comparison to their internal combustion engine counterparts. A design approach was created to measure the differences in perception between the sounds of the present AVAS and the intended truck-like features to iterate sound designs for an improved AVAS system for E-Trucks.

A wide range of vehicle sounds, such as ICE trucks, ICE cars, E-cars with and without AVAS, and E-trucks with and without AVAS, were collected. Semantic differentials from the literature indicate several types of sound quality metrics, such as "fast", "powerful" and "annoying". Sound pressure levels of the sounds were shifted based on their maximum peaks over time to 75 dB(A) for equalization. In addition to the spectral content from every sound sample, objective psychoacoustic properties were obtained. From these metrics only tonality and roughness explained differences in the perceptual features.

The design approach also included determining requirements for maximizing the components of "truck-likeness" and "electric-likeness," finding relationships between subjective evaluations and objective metrics, and developing target AVAS sounds that combine desirable truck/electric-like attributes while reducing the annoyance to the minimum possible value.

By integrating subjective and empirical data, our multi-methodological approach lays the groundwork for the development of E-Truck AVAS sounds that successfully address safety issues while maintaining community and pedestrian acceptance.

User Studies

User studies were conducted to assess ratings for car and truck sounds based on the scale given in Figure 1. The scale was mapped between 0 and 100 for proper data analysis. The study drew inspiration from [1] and [2] to capture participants' perceptions across three dimensions: complex features (effortless/strained, fast/slow), signal-related characteristics (howling, purring, whistling), and overall quality (annoying).

18 individuals (6 females, 12 males), ranging in age from 22 to 60 years (mean age: 29.2 years), participated in the study. They evaluated 24 diverse vehicle sounds, including internal combustion engine vehicles, electric cars with/without AVAS, and electric trucks with/without AVAS, based on the spectra shown in Figure 2. Each participant rated each sound on 24 semantic differential keywords (Table 1) across 8 blocks, resulting in 576 data points per individual. The results of this study are given in Figure 3 which reveals:

- An ICE car sound found more truck-like, thick, booming, fast, aggressive, and powerful compared to an ICE truck sound.
- An E-truck sound was perceived as whistling, hissing, high, and thin. It was also less truck-like, harsh, fast, aggressive, powerful, effortless, and hard even compared to the E-car.
- An E-car with AVAS sounds more whistling, rickety,

and howling. The same vehicle sound has a lower perceived thickness, power, and speed. This suit with the initial design goal of differentiating E-cars from traditional vehicles.

- An E-truck with AVAS was perceived as more effortless than an E-car with AVAS, while having lower scores on all other semantic differentials. This strengthens the initial design goal of making electric cars and trucks sound distinct from each other.

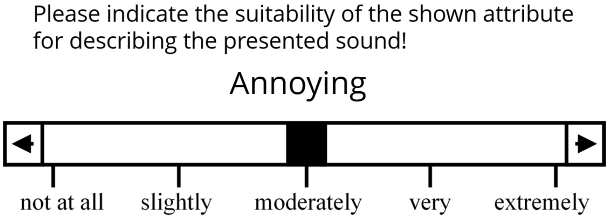

Figure 1: Rohrmann Scale was used in the jury tests.

Table 1: Principle component values for semantic differentials used in the jury test.

	Component		
	1 - Truck-Like	2 - Electric-Like	3 - Impulsive
Hard	0.970	0.064	0.136
Booming	0.954	-0.055	-0.126
Powerful	0.925	0.190	-0.219
Humming	0.924	-0.212	0.074
Roaring	0.910	-0.259	0.003
Aggressive	0.905	0.338	-0.015
Thick	0.889	-0.316	-0.015
Harsh	0.885	0.235	0.207
Loud	0.860	0.375	0.006
Rattling	0.840	0.034	0.459
Buzzing	0.818	0.048	-0.411
Purring	0.815	-0.231	0.018
Fast	0.791	0.321	-0.403
Clattering	0.760	-0.007	0.506
Truck	0.632	-0.348	0.343
Annoying	0.437	0.755	0.371
Howling	0.414	0.130	0.075
Turbine-Like	0.371	0.527	-0.574
Hissing	-0.279	0.888	-0.098
Whistling	-0.413	0.845	0.125
High	-0.491	0.814	-0.010
Effortless	-0.585	-0.633	-0.108
Rickety	-0.616	0.278	0.672

Psychoacoustic Property Analysis

Psychoacoustic parameters used in vehicle sound analysis provide insights into the correlation between sound and perceived "truck-likeness" and "electric-likeness."

The spectral characteristics are shown in Figure 4. The ICE truck has a dominant peak at 572 Hz, illustrating its lower-frequency focus, but the E-car with AVAS has a peak at 1.2 kHz, indicating a substantial high-frequency component.The ICE vehicle, with a peak frequency of 947 Hz, falls in the center. This implies that AVAS sound frequency content manipulation might affect how truck-like a sound is perceived, with lower frequencies possibly contributing to a more truck-like quality. Low -frequency sound component domination in overall ICE truck sounds can also be observed from [3],[4],[5] and [6].

The tonality metric of the vehicles is shown in Figure 5. The ICE truck has its biggest peak at 162 Hz, but the E-car with AVAS has notable tonality peaks at 549, 738, and 1650 Hz. A moderate peak is displayed by the ICE vehicle at 242 Hz. These results suggest that tone peaks may be used by AVAS designers to affect how certain traits are perceived; higher frequencies may be associated with an electric-like and alert character, whereas lower peaks may be associated with truck-likeness.

The examination reveals how perceived attributes and sound properties interact. Higher frequencies and clear tone peaks over 500 Hz may elicit an electric-like experience, whereas lower frequencies and prominence in the

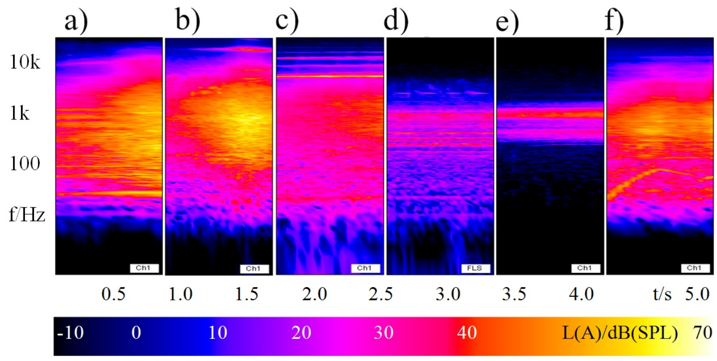

Figure 2: FFT vs. Time plots for the sound stimuli: a)ICE Truck b)E-Car without AVAS c)E-Truck without AVAS d)E-Truck with AVAS e)E-Car with AVAS f)ICE Car.

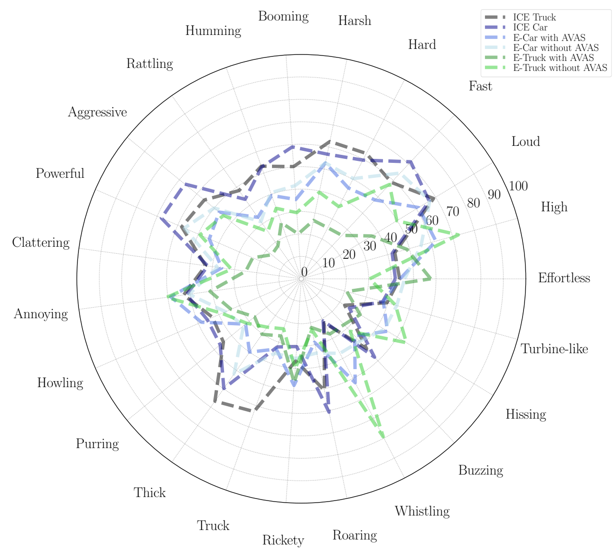

Figure 3: Results from the jury test.

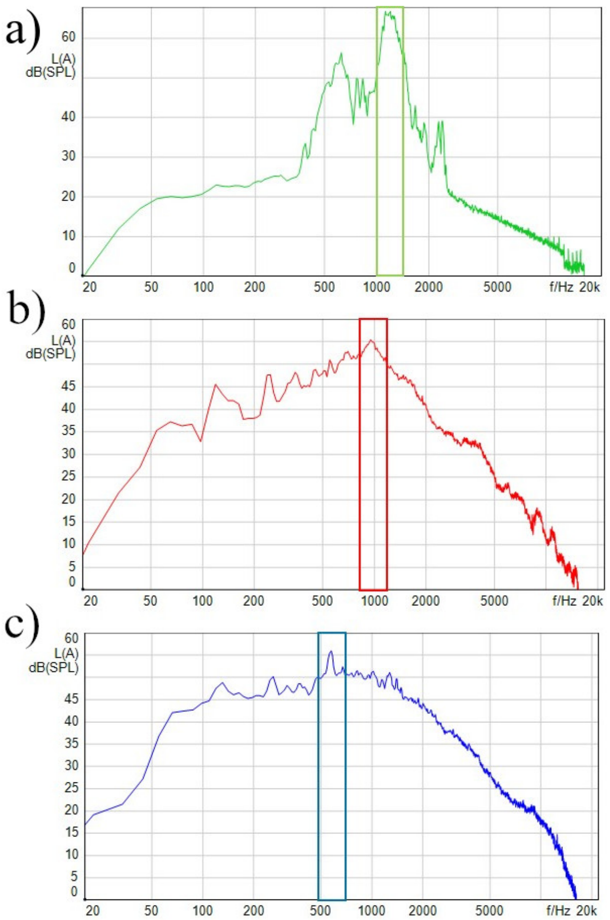

Figure 4: Average spectra of various types of vehicle sounds from pass-by measurements: a)E-Car with AVAS b)ICE Car c)ICE Truck (x-axis: Frequency Bands/ y-axis: Sound Pressure Level).

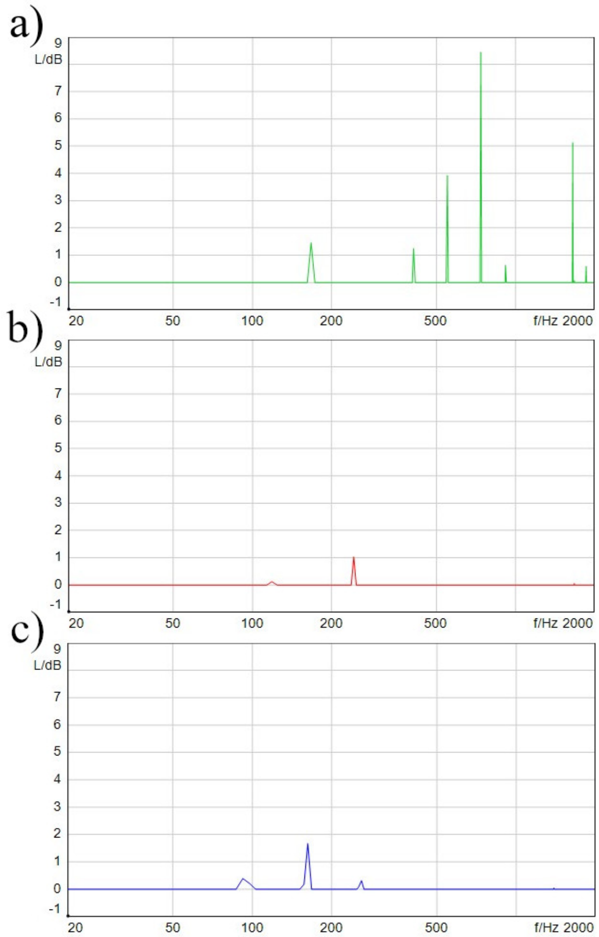

Figure 5: Average tonality plots of various types of vehicle sounds from pass-by measurements: a)E-Car with AVAS b)ICE Car c)ICE Truck (x-axis: Frequency Bands/ y-axis: Tonality values calculated according to DIN45681).

100-250 Hz region appear to contribute to a truck-like sensation. This highlights the necessity for AVAS designers to strike a balance between these attributes. Finding the ideal ratio of spectral content to tonality peaks that accomplishes the appropriate amount of "truck-likeness" while reducing discomfort is necessary to properly communicate the intended message without producing an excessively annoying or alarming sound.

Beyond spectral content and tone, roughness influences perceived truck- and electric-likeness. Figure 6 shows the roughness values for the studied vehicles. As seen, the E-car with AVAS has the lowest roughness at 0.199 asper, which likely contributes to its smoother and more electric-like experience. Conversely, the ICE truck has a maximum roughness of 0.317 asper, which corresponds to its rougher and more powerful engine sound. The ICE automobile falls in the middle, with a roughness value of 0.245 asper. This investigation implies that AVAS designers can control roughness to alter perceived attributes, with smoother sounds perhaps increasing electric-likeness and rougher sounds possibly contributing to a more truck-like perception.

Conclusion

E-trucks provide unique acoustic difficulties on city streets compared with their ICE counterparts. Their quiet operation at low speeds creates safety issues for pedestrians and cyclists, who may not hear them coming. Acoustic Vehicle Alerting Systems solve this issue by generating noises that notify pedestrians of nearby EVs. However, building efficient AVASs for E-trucks has additional hurdles because of their unique sound characteristics caused by their larger size and strong electric motors. Simply moving AVAS noises from smaller EVs to E-trucks may not be ideal, perhaps eliciting a wrong expectation of vehicle size or failing to convey an adequate of risk awareness and attentiveness to pedestrians.

This study sought to take the initial steps toward providing design suggestions for successful E-Truck AVAS. We conducted a psychoacoustic research, which included a jury test, to look at how sound quality changes between E-trucks and ICE trucks, as well as how existing AVAS sounds on E-cars are perceived.

Our findings show that changing various sound features, such as spectral content, tonality, and roughness, can affect perceived "truck-likeness" and "electric-likeness."

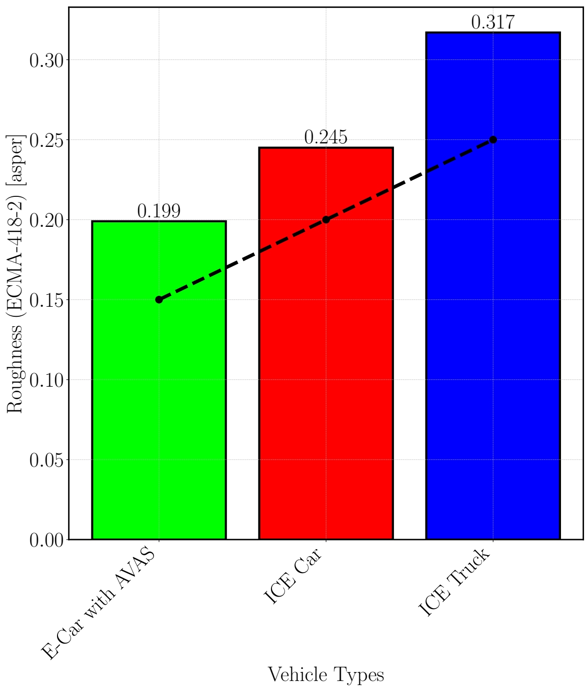

Figure 6: Roughness values of various types of vehicle sounds.

Lower frequencies and prominence in the 100-250 Hz range lead to a truck-like sensation, whereas higher frequencies and distinct tonality peaks beyond 500 Hz produce an electric-like sensation. Smoother noises (lower roughness) improve the electric-likeness, whereas rougher sounds add to a more truck-like perception.

These findings show the importance of careful balance during AVAS design. To achieve the necessary amount of "truck-likeness" while limiting annoyance, the best combination of spectral content, tonality peaks, and roughness must be determined. This study establishes the groundwork for striking this precise balance.

Additional studies are needed to investigate how psychoacoustic properties such as loudness and timbre influence sound perception. Individual and cultural preferences should be considered because various populations may prefer different AVAS sounds. Based on these findings, AVAS designs should be tested to ensure their effectiveness and acceptability in real-world scenarios. By expanding on this study, the design of E-Truck AVAS sounds may be adjusted to efficiently address safety issues while remaining acceptable to pedestrians and the community, creating a safer and more harmonious soundscape on our roadways.

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