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Investigation into the detection of a quiet vehicle by the blind community

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ABSTRACT

The blind community is concerned that vehicles are becoming too quiet and unsafe for pedestrians. With vehicle manufacturers successfully working to develop quieter vehicles and the emergence of a new class of quiet hybrid and electric vehicles, this concern from the blind community will continue to increase. The basis of this concern is that a blind person uses acoustic cues to determine the location and speed of vehicles to avoid dangerous situations. To begin understanding this concern a jury study at the National Federation of the Blind California conference was performed. A combustion engine vehicle was converted to an electric vehicle and speakers were attached at each corner. Blind volunteers from the conference participated in the study where the vehicle was driven past them three times under different conditions. The conditions were with no extra noise, idling engine noise and combined repeating bell / engine noise. The subject raised their hand when they heard the vehicle and the distances from the subject were noted. The results of this study indicate that the loss of normal combustion engine noises may significantly affect the ability of blind individuals to distinguish approaching vehicles and that a substitute engine noise appears to be viable option for reversing this risk.

1. INTRODUCTION

With the increasing popularity and use of vehicles with hybrid powertrains, a new challenge is facing the vehicle manufacturers and legislators in regard to vehicle exterior noise. As it is well known, vehicle exterior noise is considered a major source of environmental acoustic impact and as such is regulated across the world (see as an example the standards for the measurement of pass-by noise, such as ISO 362[1]). These regulatory requirements aim at limiting the noise emission of a vehicle in its loudest operation mode.

The current generation of hybrid vehicles poses a different concern in that they are too quiet and therefore pose a threat to pedestrians when the vehicles are traveling at low speeds. The blind community is particularly concerned about the situation because “all of the information they

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need about how traffic flows at a given intersection, comes from the sound of traffic and no other source.[2]" Preliminary studies have been performed that show a hybrid vehicle provides less auditory warning then a similar sized internal combustion engine vehicle. This helps us to understand the concern the blind community has with detecting a hybrid vehicle in the absence of a visual cue. For a blind person, this is obviously critical for all situations and needs to be addressed before hybrid vehicles become prevalent on the road.

Currently, no automotive industry standard specification exists for testing vehicle exterior noise at low speeds (10-15 mph). Testing has been performed and documented specific to hybrid noise for accelerating vehicles and for vehicles traveling at 30mph[3]. The automotive industry in North America is aware of the hybrid noise issue and has formed a Society of Automotive Engineers sub-committee to study and make a recommendation on how to address this growing concern. This sub-committee includes members of the academic community, automotive community, blind community and the Department of Transportation.

One proposed solution to this situation has been for a hybrid vehicle to produce an artificial noise so that it can be detected in a similar manner to an internal combustion engine vehicle. For this solution, the blind community would prefer the sound to be that of a current internal combustion engine vehicle. Other suggestions for the artificial noise have been to use beeps, bells, "white noise", and steady tones.

The study outlined below investigates the response of blind pedestrians to low speed approaching vehicles with different sound sources. An electric vehicle is equipped with loud speakers and tested at baseline condition, artificial engine noise emitted, and artificial engine noise + bell noise emitted. The set-up and test procedure is discussed as well as the results of the jury voting and comments.

2. DESCRIPTION OF TEST

A. Set-up

A small domestic pick-up truck was converted to an electric vehicle. An additional playback system was installed inside the vehicle that allowed the ability to play back any sound and was equipped with an amplifier and volume control to adjust the levels. Speakers were installed on the outside of the vehicle at each corner as seen in Figure 1.

Testing was performed in a parking lot, 1/8 of a mile from a busy interstate freeway. The parking lot location was in an otherwise quiet commercial area. The parking lot surface was blacktop and cleared of debris before testing.

For all testing the vehicle was driven at a steady 15mph through the evaluation area. The vehicle passed by approximately 15 feet in front of the jurors.

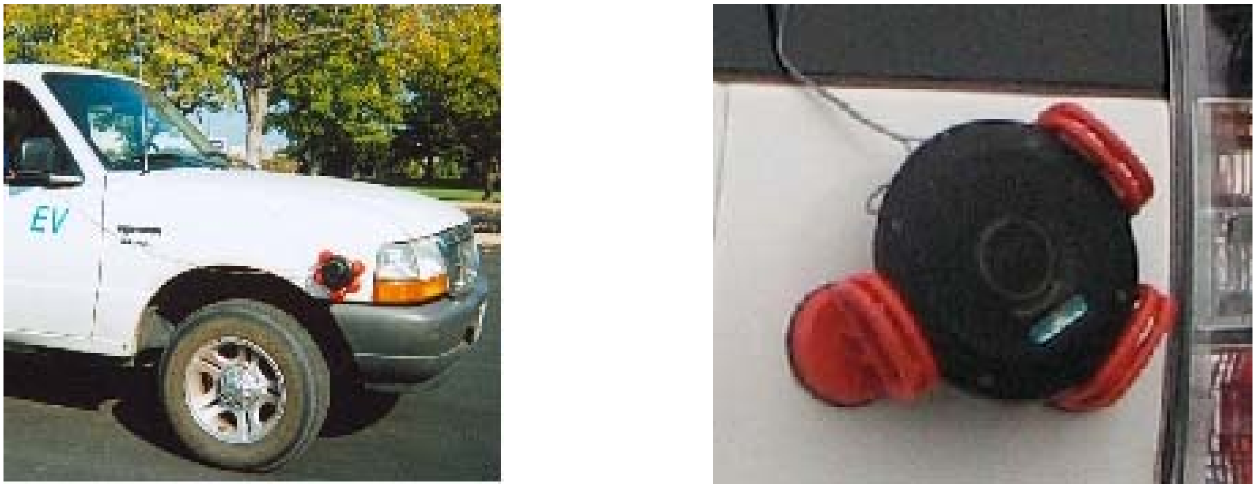

Figure 1: Depiction of the electric drive converted test vehicle (a) and external speaker system (b).

B. Jurors

The testing was performed during the National Federation of the Blind California conference and blind volunteers were used as jury subjects. 27 blind adult individuals of both sexes and varying ages came in shifts to a listening station set-up in the parking lot. The volunteers had no other physical handicaps that would require a wheel chair, walker, etc. The jurors would be considered completely mobile blind pedestrians.

The jurors were asked to raise their hands when they first heard the vehicle approaching and to keep it raised as the vehicle passed by. None of the jurors stated they had hearing limitations beyond natural hearing loss due to age. Figure 2 shows an example of the vehicle passing by the jurors.

Figure 2: Example vehicle pass-by of blind jury participants.

C. Test Conditions

The testing was performed with the jury under three conditions: Vehicle passing by with no sound emitted, vehicle passing by with engine sound emitted from speakers, vehicle passing by with engine sound and bell noise emitted from speakers.

Condition 1

The first pass was with the vehicle running on the electric motor with no extra noise emitted from the speakers. In this condition the sound from the vehicle is primarily tire noise. The sound is similar although subjectively louder then a typical electric golf cart.

Condition 2
The second pass was similar to the first pass with the difference being the engine sound generated by the four speakers. The sound being produced was idle noise from a diesel engine pick-up truck. The noise was recorded with one microphone at the driver's side front edge of the vehicle at a distance of 1 meter. The playback level was set accordingly to match the level of the recorded vehicle.

The sound signature is shown in Figure 3 below indicating typical diesel engine noise. The sound is made up of several tones related to engine rpm and they vary slightly across time due to slight changes in engine speed during idle. Subjectively it is a very typical engine sound that is easily identifiable as the noise produced by an internal combustion engine vehicle.

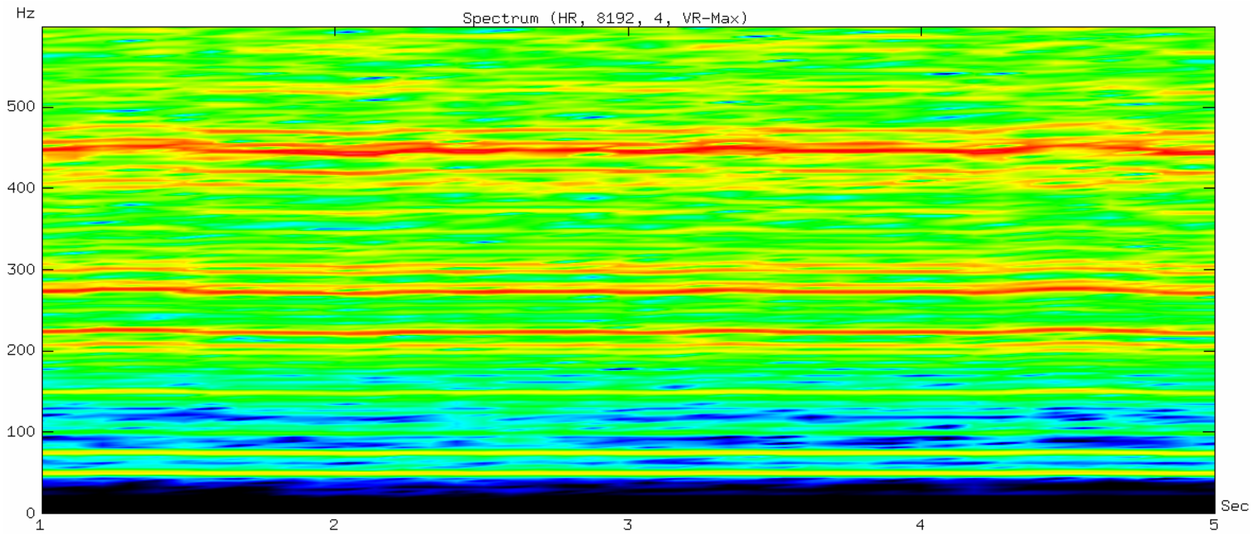

Figure 3: Vehicle sound sonogram of diesel engine idle used for play back during condition 2 test.

Condition 3
For the third pass the sound was altered by introducing a 100ms bell like tone that repeated every 2 seconds over the standard engine noise. At the 15mph test speed this resulted in a bell sound initiated approximately every 44 feet. A bell sound was selected because it is often mentioned as the standard warning sound during discussions between the blind community and the automotive community. This particular bell sound was selected because it is the sound produced as a warning signal for several other applications. The primary frequency of the bell was 510Hz with its harmonics extending in to the higher frequencies. The sonogram of the sound is shown in Figure 4 below.

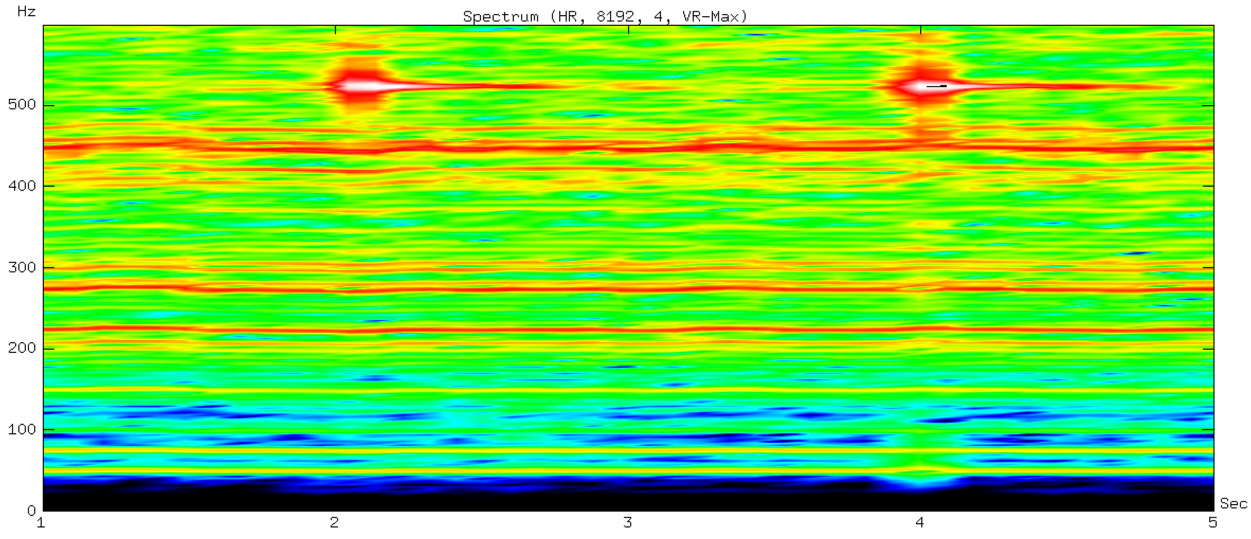

Figure 4: Vehicle sound sonogram of diesel engine idle with bell noise used for play back during condition 3 test.

The bell sound was superimposed on the idle engine noise sound. The engine noise was kept at the same level as the Condition 2 and the bell noise was added to be 10dB higher. The overall dBA sound level versus time is shown in Figure 5 below. Diesel only noise is shown in red, diesel + bell is shown in blue.

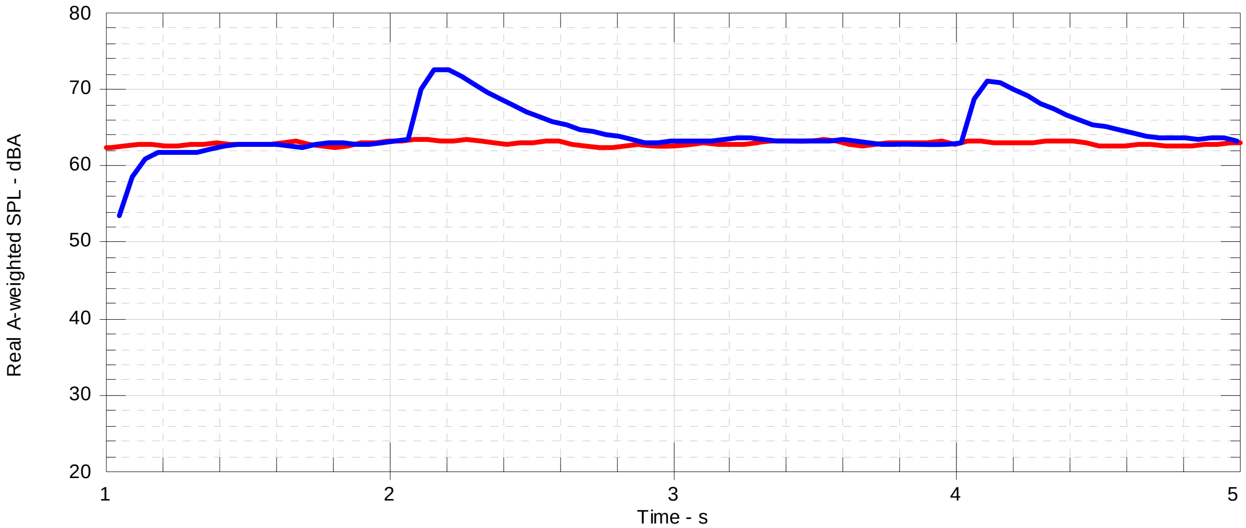

Figure 5: Overall sound level for Condition 2 (engine noise) and Condition 3 (engine plus bell noise) tests.

D. Test Procedure

The test set-up is shown below with the vehicle passing in front of the jurors at a steady 15mph. The jurors were asked to raise their hands when they could hear the vehicle moving towards them. For logistic reasons, the voting was noted in three different measurement ranges. Voting was counted when the vehicle was between 75 to 100 feet from the juror, 20 to 30 feet from the juror and 5 feet from the juror.

The vehicle always made passes in the same direction and the three conditions were tested one after another with only the break to return the vehicle to the start position. Figure 6 is an illustration of the test set-up.

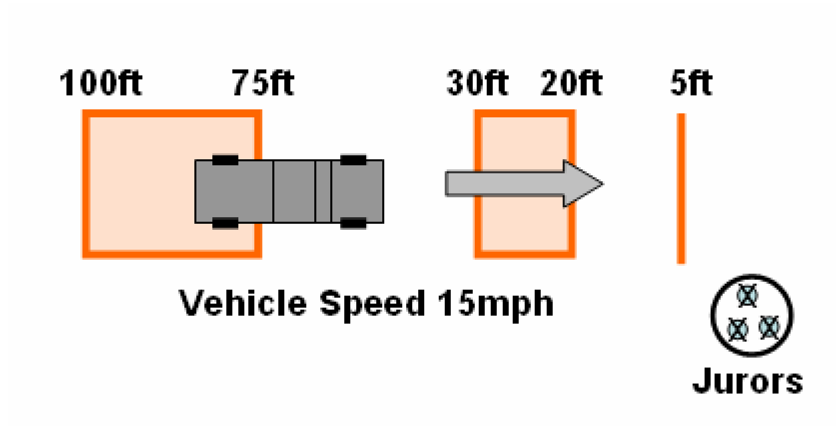

Figure 6: Schematic of test set-up showing vehicle direction, evaluation areas and juror location.

Immediately after the third pass, the jurors were asked a series of questions and their comments were recorded.

How do you feel about the quiet car issue?
What did you think about the trial?
Which was your preferred sound (condition 1 – 3)?
Do you have any comments or questions?

3. DISCUSSION OF RESULTS

A. Jury Voting

Voting was recorded for each juror by evaluating if their hand was raised as the vehicle passed through each test range. The data reported in Table 1 is the accumulated count for each range so a juror that heard the vehicle at 20-30 feet would always be counted as hearing the vehicle at 5 feet.

	75-100 feet	20-30 feet	5 feet
Condition 1 (electric motor only)	3	7	27
Condition 2 (engine idle sound added)	9	19	27
Condition 3 (engine idle with bell sound added)	11	20	27

Table 1: Jury voting results for each of the three test conditions

These results confirm the results from previous studies that a hybrid vehicle provides less auditory warning then a similar size internal combustion engine vehicle[4]. The data also show that a bell sound added to the engine noise and repeating every 2 seconds does not significantly improve the auditory warning time of the vehicle to the juror.

B. Jury Comments

All of the jurors were interested in the quiet car issue. The vast majority were concerned that the hybrid vehicle poses a danger to them as pedestrians in several environments including parking lots, stop signs and intersections.

The rest of the comments can be broken into vehicle condition:

Condition 1
"It was impossible to hear it very clearly"
"The chassis made the most noise"
"I could hear the tires on the ground but not the truck"

Condition 2
"Sounds like a car…easy to hear…a car noise is perfect –keep that"
"Much better then anything else"

Condition 3
"No, no, no! Totally confusing"
"There are enough beeps…I'm not sure I'd know what to make of it"
"I couldn't tell if the sound was coming or going"

C. Summary

The results of this jury trial with members of the blind community show a clear difference in the detection of a vehicle based upon the engine noise at low speeds.

The overall sound level of the vehicle is an important factor for detection. A bell noise improves detection range but even at relatively low speeds the 2 second time between occurrences may not provide an improvement in reaction time to a blind pedestrian, especially as a bell noise may be harder to localize and interpret.

A synthetic sound like a bell was not preferred by any of the jurors for identifying and locating the vehicle. The engine noise was the preferred sound as an auditory warning for the vehicle.

Using sound producing devices is a viable option for increasing the auditory warning time of an electric motor powered vehicle.

4. NEXT STEPS

The results of this jury trial with members of the blind community show a clear difference in the detection of a vehicle based upon the engine noise at low speeds. Further research is needed to clarify if these same detection differences may apply to the general population under conditions or in scenarios where vision is impaired or limited.

While overall sound is a key factor in the detection of a vehicle, increasing the sound level produced by a vehicle appears contrary to one of the goals of the auto industry to reduce noise pollution. A better understanding of which parts of the engine sounds are most identifiable to a pedestrian may indicate that limited emission of specific sounds could provide essential cues to pedestrians at an overall sound level equivalent or lower than today's vehicles. The jurors that participated in this study were very aware of the differences in sounds. This suggests that a more detectable sound does not necessarily have to be louder. A speaker-based system may have the advantage of directed sound where it is most needed for pedestrians, thus potentially further reducing unnecessary noise pollution. All of these considerations are important directions for future research.

ACKNOWLEDGEMENTS

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