

Investigation into the Detection of a Quiet Vehicle by the Blind Community and the Application of an External Noise Emitting System

Paul Goodes

Sound Answers, Inc.

Yun Bryan Bai and Everett Meyer

Enhance Vehicle Acoustics, Inc.

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ABSTRACT

The blind community is concerned that vehicles are becoming too quiet and unsafe for pedestrians¹. 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 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.

An investigation was then performed to begin to address two of the basic implementation issues with an external noise emitting system for electric vehicles. The first investigation is of the speed range where a system would be most applicable and the second is of the

placement and orientation of the speakers on the vehicle. This is done by evaluating an internal combustion engine vehicle as a benchmark for what is currently acceptable.

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 362-1:2007)². These regulatory requirements aim at testing for the maximum noise emission of a vehicle under specific operating conditions.

The current generation of hybrid vehicles poses a potentially 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 need about how traffic flows at a given intersection, comes from the sound of traffic and no other source¹." Preliminary studies have been performed that show a hybrid vehicle provides less auditory warning than a similar sized internal combustion engine vehicle³. 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

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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 which indicated there is no detection issue at those operating conditions⁴. The automotive industry in North America is aware of the low speed 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 first part of this study was performed under funding of the National Federation of the Blind (NFB) who has a stated policy position on the concerns for the quietness of hybrid vehicles¹. The first jury study was performed at an NFB conference to get the reaction of a group of blind jurors to vehicle noise in a relatively controlled and realistic environment. The test procedure and results of this jury study were presented in more detail at another conference⁵ but are included again here to add background and context to the issue.

The second part of this paper was done independently to address another consideration for the quiet vehicle issue, which is how to measure and standardize a test procedure to quantify the noise produced by a vehicle for detectability. The investigation documented in the second part of this paper was performed to better understand some of the key variables in performing this type of test using internal combustion (IC) engine vehicles as benchmarks.

ROAD TEST TO ASSESS DETECTION WITH ARTIFICIAL SOUNDS⁵

SET-UP - A small domestic pick-up truck was converted to an electric vehicle. An additional playback system was installed that allowed play back of 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.



Figure 1 – Test vehicle with external speaker system

Testing was performed in a cleared blacktop parking lot with 49dBA of background noise. For all testing the vehicle was driven at a steady 15mph through the evaluation area and passed approximately 15 feet in front of the jurors.

JURORS - The testing was performed during the NFB 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 and none of the jurors stated they had hearing limitations beyond natural hearing loss due to age.

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 than 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 2 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. This noise was selected because subjectively it is a very typical engine sound that is easily identifiable as the noise produced by an internal combustion engine vehicle.

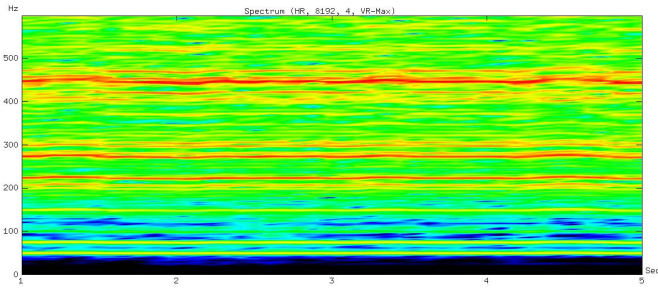


Figure 2 – Vehicle sonogram for Condition 2 test

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. The primary frequency of the bell was 510Hz with its harmonics extending in to the higher frequencies. The engine noise was kept at the same level as Condition 2 and the bell noise was added to be 10dB higher. The sonogram of the sound is shown in Figure 3 below.

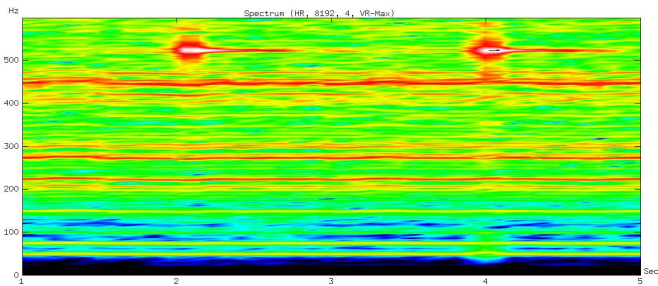


Figure 3 – Vehicle sonogram for Condition 3 test

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 first heard the vehicle approaching and to keep it raised as the vehicle passed by. For logistic reasons, the voting was noted in three different measurement ranges. Voting was counted when the vehicle was between 75 to 100 feet, 20 to 30 feet 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 4 shows an illustration of the set-up.

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 Figure 5 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.

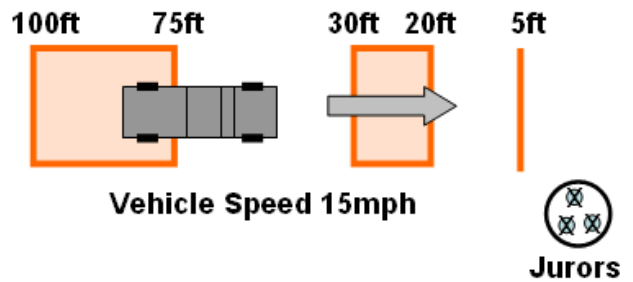


Figure 4 – Test lay-out for jury study

	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

Figure 5 – Jury voting results for 3 test conditions

These results confirm the results from previous studies that a hybrid vehicle provides less auditory warning than a similar size internal combustion engine vehicle³. 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.

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.

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

VEHICLE TEST FOR PASS-BY NOISE – STANDARD ANALYSIS

A vehicle test was performed on one vehicle to assess the differences of engine speed using a modified pass-by test. The current pass-by noise standards were used as a basis for the test procedure. Microphone position was adjusted to be 1m from the vehicle and the pass-by speed was 10 mph. The road condition was a level and cleaned paved surface with no large reflective objects within a 50m radius. Background noise level was measured as 48.9 +/- 1.5 dBA.

Two pass-by protocols were used. In the first protocol, termed “Idle Engine”, the vehicle was brought to the designated speed and 10 feet prior to the microphone, the driver began to coast. In the second protocol, termed “Active Engine”, the vehicle was brought to the designated speed and 20 feet prior to the microphone the driver engaged the gas pedal to maintain the speed. In general, the engine load was ~1,500 rpm, with the exception of the 15 mph drive-by, where the vehicle shifted to a higher gear causing a lower rpm.

The data from this test was processed for peak dBA level during the pass-by event and is shown for each condition in Figure 6.

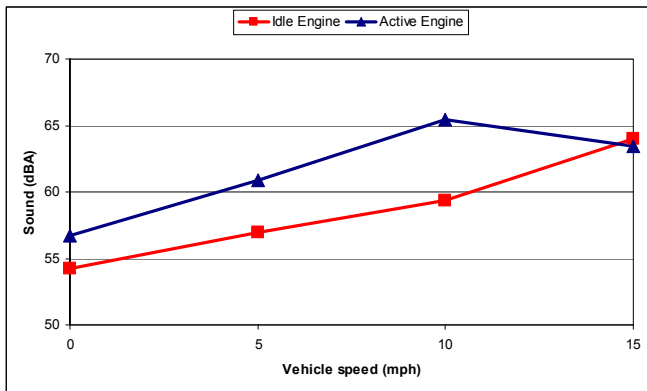


Figure 6 – Peak sound level for varying engine speed

The data from this test show the sensitivity of the measurement to engine speed. As expected, the IC engine is a major factor in the sound level produced by a vehicle at speeds slower than 15 mph. Due to the difficulty in maintaining constant engine rpm at slow speeds, any test standard should include this as a factor in performing the test.

VEHICLE TEST FOR PASS-BY NOISE - INVESTIGATION

The purpose of this section was to investigate some of the concerns stated in a previous study which involved determining the pedestrian reaction time to various hybrid and IC engine vehicles⁶. From that study a conclusion can be drawn that measurement of peak dBA during the pass-by event did not correlate to reaction time of pedestrians.

SET-UP - Based on this concern, a vehicle pass-by test was run to better understand some of the open issues involved in this test procedure. For this test, 4 IC engine vehicles were evaluated during a 10mph pass-by with stationary microphone. The test set-up also included six detection transducers at 18' increments on each side of the observer location that identified when the front tire of each vehicle passed by. The purpose of these transducers was to provide an accurate conversion to distance and location of the vehicle noise produced during the pass-by event.

The sound data for the 4 vehicles is shown in Figure 7 as dBA versus distance relative to the microphone position. The average background noise level during this test was 48 dBA +/- 1 dB as measured before and after each test run. The peak sound level for each vehicle can be seen in Figure 7 to occur several feet after the front of the vehicle passes by the microphone. For detection of these vehicles by a blind pedestrian this peak is too late as the auditory warning needs to provide enough time to elicit the proper reaction and decision making.

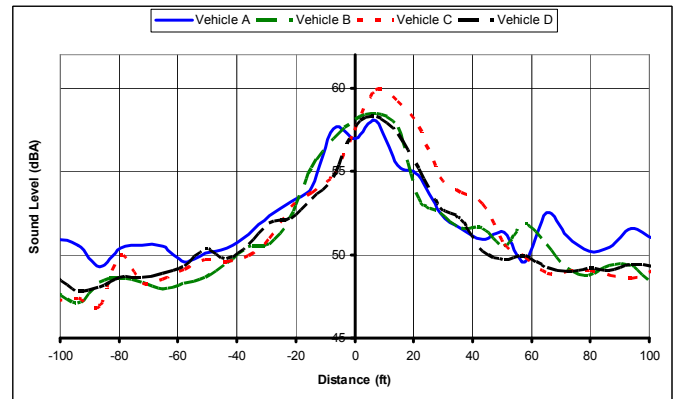


Figure 7 – Pass-by sound level versus distance

JURY STUDY - A jury study was performed by playing these sounds back to blindfolded listeners over headphones. The juror was asked to stop the recording when they could detect the vehicle approaching and the time was recorded. The four vehicle sounds were played to the juror 3 times in random order and the average detection time for each vehicle was calculated. The jury pool had intended to be 16 jurors but the results from the first 9 jurors were so repeatable that the study was truncated. The final jury pool consisted of 3 children between 10 and 12 years old, and 6 adults between 35 and 55 years old.

The data was analyzed for each vehicle and averaged across the jurors. No distinction was made for reaction time between the children and adults. Figure 8 shows the graphical results of the average detection point for each vehicle. The data is the same as Figure 7 but focused on the segment previous to the vehicle reaching the observer.

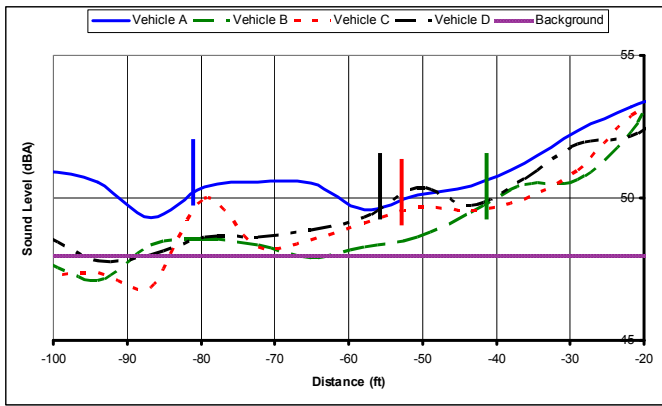


Figure 8 – Sound level at detection point

From this data the order of detection would be Vehicle A, D, C and B. Vehicle B, with average detection at 41', provides approximately half the warning as Vehicle A (81').

A summary of the data from the test is shown in Figure 9. The first data column shows peak sound level as measured during the entire pass-by event. The second data column shows the average detection time from the jury study. The third column shows the detection distance from the observer point calculated based on the detection time. The final column shows the sound level in dBA at the associated detection point for each vehicle.

	Max Sound Level (dBA)	Detection Time (secs)	Detection Distance (ft)	Sound Level at Detection (dBA)
Vehicle A	58.0	5.5	81	50.2
Vehicle B	58.4	2.8	41	49.8
Vehicle C	59.8	3.6	53	49.5
Vehicle D	58.2	3.8	56	49.6

Figure 9 – Data summary from pass-by test

This data shows that although the peak sound levels are relatively close in dB level for these 4 vehicles, the detection distance varies greatly. The data also shows that the dB levels at detection are nearly identical for each vehicle. This is shown graphically in Figure 10. The data indicates that a vehicle is consistently detectable using this test procedure when it reaches approximately 2 dB above background noise.

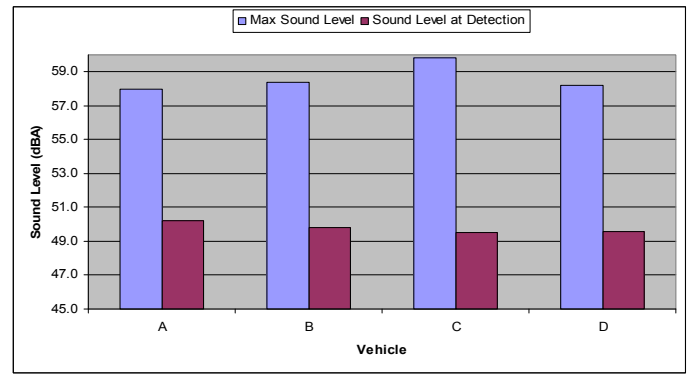


Figure 10 – Comparison of peak level and detection level for each vehicle

This base test procedure is valid for acquiring the appropriate data to differentiate a vehicle for detection if the acquisition distance range is extended beyond the detection point (in this case 81'). The analysis procedure of evaluating the data for peak sound level during pass by is not a good prediction for the detection time or the sound level at detection.

FREQUENCY ANALYSIS – The previous data indicates that the vehicle is detectable when the sound is measured as approximately 2 dB above background noise level. An understanding of the frequency content of this data is examined to determine the key frequency bands that cause this distinction. The sound data was then analyzed for frequency content. The data from Vehicle B for the 1/3 octave band results from 20 – 3150Hz are shown in Figure 11.

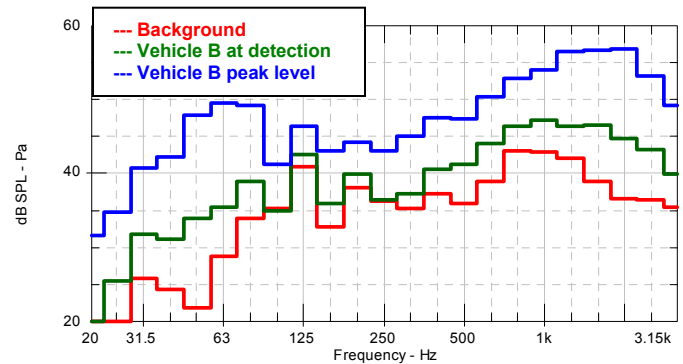


Figure 11 – Vehicle B 1/3 octave spectra for background, detection point and peak level

The sound spectrum for the detection point is seen to be higher than background noise from the 31.5 to 80 Hz and 400 to 3150 Hz bands. The separation is between 3 and 12 dB in these ranges and is enough of a difference for detection of the vehicle to occur. The peak level sound has similar frequency characteristics in the same ranges with higher amplitudes.

DIRECTIONALITY OF ARTIFICIAL SOUND SOURCE

A simplified illustration of the sound emitted by an IC engine is shown in Figure 12. For a vehicle traveling at low speeds, noise is emitted from several apparent sources; the IC engine and accessories, the exhaust and the tires. Depending on the vehicle and the powertrain configuration these apparent sources could change in ranking. A concern with hybrid and other vehicles that operate without an IC engine is the loss of IC engine related noise as a sound source. The testing at the beginning of this study indicated that an IC engine was the preferred sound signature to provide auditory cues to the blind community and that an artificial sound source was an appropriate way to produce this noise.

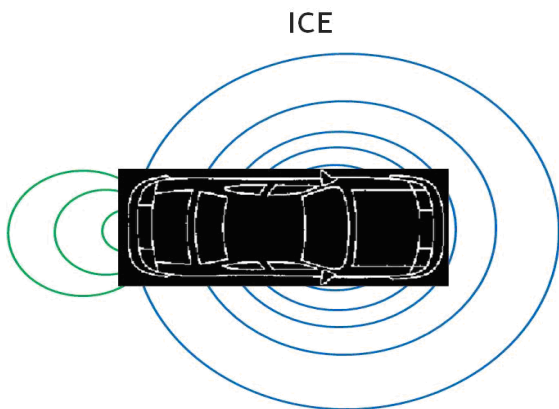


Figure 12 – Sound field illustration from IC engine vehicle

Having a vehicle produce artificial exterior noise is contrary to what has been the focus of automotive engineers and environmental noise concern activists. A possible compromise exists if an artificial noise source is able to direct the sound to a particular area. For example, in Figure 13 is an illustration of what an artificial sound field may look like for a vehicle operating at slow speeds as described in this study. A directed and active sound source could allow for a quieter vehicle to be more detectable.

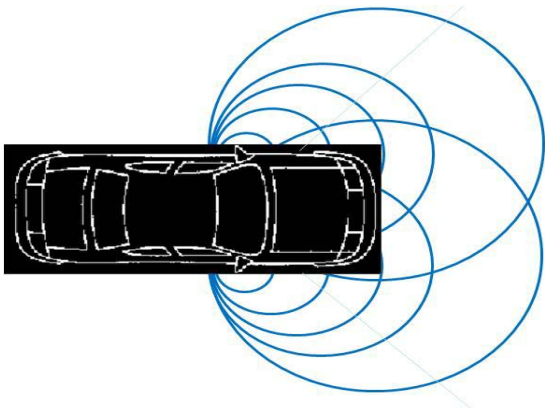


Figure 13 – Targeted sound field from speaker system

A solution could be engineered to respond to different feedback variables in the vehicle. Vehicle speed for example could be used as a variable to adjust the volume of the sound source. A vehicle traveling at 5 mph does not require as much detection time as a vehicle traveling at 10 mph so the sound field would not have to be as loud or project as far.

CONCLUSIONS

The results of the first 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.

Using sound producing devices is a viable option for increasing the auditory warning time of an electric motor powered vehicle. The engine noise was the preferred sound as an auditory warning for the vehicle.

The pass-by evaluation of an IC engine vehicle at slow speeds using a modified pass-by approach shows that engine speed is a major contributor to the overall sound level.

The pass-by noise peak sound level occurs at a location several feet after the observer and does not correlate to the sound level at detection or the detection time.

Jury analysis for detection of an approaching vehicle using headphone playback to blindfolded jurors provides consistent and repeatable results.

For this study, the IC engine vehicles were consistently detectable when their sound was 2dB above background noise to the observer.

The frequency content of the sound at the detection point and the peak level have similar frequency content and specific frequency ranges where they are above background noise.

An external noise emitting system should take into account vehicle operating variables to direct the sound towards the observer to minimize the required noise level.

ACKNOWLEDGEMENTS

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