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A Pilot Study of Pedestrians with Visual Impairments Detecting Traffic Gaps and Surges Containing Hybrid Vehicles

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Abstract: The increasing number of hybrid and quiet internal combustion engine vehicles may impact the travel abilities of pedestrians who are blind. Pedestrians who rely on auditory cues for structuring their travel may face challenges in making crossing decisions in the presence of quiet vehicles. This article describes results of initial studies looking at the crossing decisions of pedestrians who are blind at an uncontrolled crossing (no traffic control) and

a light controlled intersection. The presence of hybrid vehicles was a factor in each situation. At the uncontrolled crossing, Toyota hybrids were most difficult to detect but crossing decisions were made more often in small gaps ended by a Honda hybrid. These effects were seen only at speed under 20 mph. At the light controlled intersection, parallel surges of traffic were most difficult to detect when made up only of a Ford Escape hybrid. Results suggest that more controlled studies of vehicle characteristics impacting crossing decisions of pedestrians who are blind are warranted.

Keywords: blind, hybrid, visually impaired, pedestrian, crossing, gap

1.1 Introduction

In 2004, National Health Interview Survey (NHIS) data revealed prevalence rates of visual impairment of 8.8% or 19.1 million ([Lethbridge-Cejku, Rose & Vickerie, 2006](#)). [The Eye Diseases Prevalence Research Group \(2004\)](#) estimates a 70% increase in [legal] blindness as well as in low vision by 2020. Given such numbers, it is fair to assume that a significant portion of this population is accessing public sidewalks and thoroughfares as pedestrians. In doing so, there is a certain probability that a pedestrian with a visual impairment will come into conflict with an automobile. This probability increases as pedestrians with visual impairments encounter increasingly complex traffic situations (e.g., roundabouts) or have limited access to important orientation information (e.g., the sound of an approaching vehicle) ([Ashmead, Guth, Wall, Long & Ponchillia, 2005](#); [Barlow, Bentzen & Bond, 2005](#)). There is a fear that increasingly quiet vehicles on the road will increase pedestrian-vehicle conflicts in the near future (e.g., [TheGreenCarWebsite.co.uk, September, 2008](#)) prompting calls for research and legislative action ([Wunder, 2008](#)).

Epidemiological research on pedestrian safety during the past decade ([Campbell, Zegeer, Huang & Cynecki, 2004](#); National Center for Statistics & Analysis, 2002) shows that approximately 5,000 pedestrians are killed annually in pedestrian-vehicle crashes in the U.S. and about 78,000 sustain nonfatal injuries. However, data regarding risk of pedestrian injuries, and especially pedestrians with visual impairments, have not been assessed ([Legood, Scuffham, & Cryer, 2002](#)). Such data are difficult to obtain and interpret, not only because vision status is rarely recorded in accident reports, but also because there is no reliable information on the extent to which persons

with visual impairments avoid pedestrian situations that they perceive as unacceptably risky.

Research has confirmed the common sense proposition that some pedestrians with visual impairments are at an elevated risk level at complex intersections. [Carroll and Bentzen \(1999\)](#) found that individuals with visual impairments reported difficulty knowing when to begin crossing, traveling straight across wide streets, determining whether there was a pushbutton to activate a pedestrian signal, and determining to which crosswalk a pedestrian signal applied to. Of the 163 respondents, 13 reported that they had been hit by a vehicle and 47 reported that their cane had been run over. [Marston and Golledge \(2000\)](#) studied street crossings by blind pedestrians at intersections with visible but not audible pedestrian signals. Almost half of the participants' crossings occurred when the DON'T WALK signal was on. Furthermore, about half of the participants made crossings that were deemed unsafe on each of their 20 attempts to cross the street. Studies with blind pedestrians at high volume or multi lane roundabouts have shown increased wait times, an inability to reliably detect crossable gaps in traffic, and an increase in risky crossing decisions, compared to sighted pedestrians ([Ashmead, Guth, Wall, Long, & Ponchillia, 2005](#); Guth, Ashmead, Long, Wall, & Ponchillia, 2005).

Pedestrians with visual impairments rely on vehicle sounds to detect approaching vehicles, perceive alignment to streets, and detect when vehicles start moving. Traffic sounds are one of the most consistent and useful forms of environmental information for pedestrians with visual impairments. Sounds from vehicles in the established traffic lanes are used to maintain alignment when walking on a sidewalk, to align for street crossings, and to maintain heading during the crossing. Auditory motion perception has not been thoroughly investigated ([Grantham, 1997](#)), so the perceptual constraints on listening for traffic patterns are not well understood. One of the seminal articles using real moving vehicles to investigate how people with visual impairments use traffic sounds for guiding their mobility was [Guth, Hill, and Rieser \(1989\)](#) but there has been little research geared toward detailing what the critical acoustic information is for the performance of certain mobility tasks.

Even though the critical acoustic information for mobility tasks in the current travel environment has not been well described, the acoustic landscape stemming from traffic is changing with the increasing number of quieter vehicles, especially hybrid and electric vehicles. These vehicles have much less engine noise than traditional automobiles, being almost silent when idling and very quiet when in motion, especially at slow speeds. This is because at slow speeds the electric engine often propels the vehicle, making less intense sounds. Sales of hybrid-electric cars in the U.S. reached 1.3% of all light vehicles sold in 2005, and this is projected to reach 4.2% by 2012 with about 35 models available ([J. D. Power and Associates, 2006](#)).

Sound intensity of traditional vehicles measured from a pedestrian position near moderately traveled urban roadways varies from about 75 dB-A to about 85 dB-A with a higher proportion of the sound at lower frequencies (<500 Hz) ([Wiener & Goldstein, 1977](#); [Wiener et al., 1997](#)). The dB-A measurement scale expresses sound intensity as it is filtered by the human auditory system. Normal conversation when people are standing near one another is at about 60 dB-A ([Durrant & Lovrinic, 1995](#)). Pilot data indicate that sound intensity from vehicles accelerating from a stop differs greatly between cars with internal combustion and hybrid engines. Average intensities were 81 dB-A for internal combustion engines and 76 dB-A for hybrid engines (Wall Emerson, unpublished data). A difference of about 6 dB corresponds to a doubling of the physical intensity of the sound, so the difference of 5 dB between the internal combustion and hybrid engines is a very substantial difference in terms of audibility.

The sounds from moving vehicles come from two sources, tires and engines ([LeLong, 1999](#)). Engine noise predominates for vehicles in 1st and 2nd gear while tire noise is predominant for vehicles in high gears ([Hendriks, 1998](#)). Blind pedestrians often need to pay attention to cars operating in lower gears at intersections. This occurs as the pedestrian decides when to begin crossing a street, as nearby cars in the parallel street accelerate from a stopped position, or when cars travel slowly in a roundabout ([LeLong & Michelet, 1999](#)). In these situations engine noise will predominate ([Nelson, 1987](#)). However, when walking on a sidewalk alongside a road, it is more likely that a pedestrian will be listening to cars traveling at higher rates of speed, in higher gears, when tire and wind noise will predominate ([Wiener,](#)

[Naghshineh, Salisbury & Rozema, 2007](#)). This is also the case at an intersection when a pedestrian is listening to cars approaching from a distance. The fact that a pedestrian who is blind needs to pay attention to both slow and fast moving vehicles in different situations means that both tire noise and engine noise are factors in deciding how useful vehicular information will be in a given situation. Of course, noise quality and intensity also vary with environmental and meteorological conditions.

The two studies described in this paper are initial attempts to document the effects that the presence of hybrid vehicles have on two situations where blind pedestrians gain useful information from the sound of traffic. In the first case, detecting oncoming vehicles to reliably determine when a crossable gap in traffic exists and, in the second case, detecting when a surge of parallel traffic occurs at a lighted intersection (the surge of parallel traffic is often used as a cue for when a blind pedestrian should begin a street crossing at a traffic controlled intersection).

1.2 Material and Methods

In the first study, participants who are blind and participants who are sighted stood at the side of a one way road with traffic approaching from the right side. All participants stood approximately 1 m from the side (see [figure 1](#)).



Figure 1. Set up of pedestrian listening position for study 1.

The road was a two lane, one way paved road leading away from the engineering complex at Western Michigan University. All vehicular traffic not part of the study was made up of vehicles leaving the engineering campus. The road was far enough away from any buildings so that there was no effect on sound localization. The point where participants stood was a mid-block crossing with no signalization or other traffic control but a place where a person might reasonably be expected to cross from a central park area with walking paths to a business complex. All participants walked back and forth across the roadway before starting the study so that they could make informed crossing decisions.

Confederates in Honda Civic, Honda Accord, Toyota Prius, and Ford Escape hybrid vehicles circled a large central walking park area to create a continuing series of single approaches of hybrid vehicles. Drivers were asked to drive by at a constant speed (some used cruise control to do so) but to vary this speed randomly over the course of their passes. Internal combustion vehicles in the study were those vehicles that happened to pass by during the course of data collection. Participants were asked to press a hand held button whenever they would initiate a street crossing. They were to continue holding the button as long as they would start to cross the street. They were asked to let up on the button when they would no longer start to cross

the street (e.g., when they heard a car approaching near enough to pose a safety concern). An experimenter pressed a similar battery powered button box to code each passing vehicle type (internal combustion, Toyota hybrid, Honda hybrid, Ford hybrid). The environmental sound level was constantly monitored with a Cel 490. A sound level meter (Casella) set 1 meter from the side of the roadway and 4 feet off the ground. The speed of any approaching vehicles was measured by a radar gun (SR3600, Sports Radar Ltd.). All data (sound level, vehicle speed, participant button presses) were streamed into a laptop computer. Sound data were recorded in unweighted dB and dB-A was calculated later.

In the second study, participants who were blind were asked to stand at the light controlled intersection of two one way streets in a downtown area. Participants were always positioned on the NW corner, facing west, so that traffic on the EW street approached from behind them on the left to stop at the light and then either pass through the intersection or turn left. Traffic on the NS street the participants were facing crossed from right to left in front of the participants.

Participants were positioned where they would stand if they were intending to cross the NS street. Participants were asked to press a button when they heard the surge of parallel traffic on the EW street that indicated a green for both that traffic and the pedestrian. There were no accessible pedestrian signals at this intersection and participants made no actual crossings during the study (see [figures 2](#) and [and33](#)).



Figure 2. Pedestrian listening location for study 2 showing idling vehicle location.



Figure 3. Pedestrian listening location for study 2 showing location of accelerating vehicles.

Confederates in Honda Civic, Toyota Prius, and Ford Escape hybrid vehicles circled the area to come up behind participants on the EW street at red lights, wait until the light turned green, then accelerate as they would normally and proceed through the intersection. Drivers were asked to try, as much as possible, to come

up to the intersection when their car would be the only one at the intersection when the light turned green. This was accomplished on 37.8% of the attempts (87/230). Trials where internal combustion traffic joined with the hybrid vehicle were analyzed separately. A continuous measure of the environmental sound level (using the same equipment as in study 1), the presses of participants' buttons, and the presses of an experimenter's button were captured in real time on a laptop computer. The experimenter pressed buttons to code the types of vehicles that approached the red light on the EW street and when the light for that street turned green. All traffic in both studies was videotaped.

1.2.1 Participants

Participants were recruited through flyers posted in the student area at Western Michigan University and from presentations regarding the proposed study at local training centers and vision loss support groups. All participants signed an informed consent document approved by the Institutional Review Board of Western Michigan University before taking part in the study. [Table 1](#) shows the demographics of participants in both study one and study two while [table 2](#) shows the demographics of the hybrid vehicles used in each study. Blind participants ranged in age from 14 to 62 with a mean of 31.5 years old. Seventeen of the 28 blind participants reported being visually impaired since birth. Acuities ranged from 20/200 to no light perception but the majority (19 out of 28) had either light perception (LP) or no light perception (NLP) in both eyes. All blind participants were questioned about their travel habits and reported that their daily independent travel included street crossings at controlled and uncontrolled crossings. All participants were compensated for their involvement. Vehicles and drivers were recruited for the study by placing a description of the proposed study in the university newspaper and through an interview with one of the experimenters on a local radio station.

Study	Date	ID	Vision	Etiology	Onset	Gender	Age	Ethnicity
Study 1	9/13/07	R1	NLP	RDP	Birth	F	27	Asian
		R2	LP	RDP	Birth	M	24	Cauc.
		R3	20/200 OD	RP	15	M	25	Middle Eastern
	9/14/07	R4	20/200 OS, NLP OS	RP	Birth	F	26	Cauc.
		R5	20/800 OS, NLP OD	Congenital defect	Birth	M	27	Cauc.
	9/21/07	R6	LP	Birth defect	Birth	M	34	Cauc.
		R7	NLP	Diabetic retinopathy	23	F	46	AF Am.
		R8	NLP	Lesh's amaurosis	Birth	M	23	Cauc.
	9/22/07	R9	LP	RDP	Birth	M	30	Cauc.
		S1	20/20	n/a	n/a	M	23	Cauc.
		S2	20/20	n/a	n/a	F	33	Cauc.
		S3	20/20	n/a	n/a	F	24	Pacific Islander
		R10	NLP	Diabetic retinopathy	34	M	33	Cauc.
		R11	NLP	RP	27	F	63	Cauc.
		R12	NLP	Diabetic retinopathy	25	F	45	Cauc.
		S4	20/20	n/a	n/a	M	40	Cauc.
		S5	20/20	n/a	n/a	F	33	Cauc.
		S6	20/20	n/a	n/a	M	58	Cauc.
	R13	NLP	Glaucoma	16	M	73	Asian	
	R14	NLP	RDP	Birth	M	23	Asian	
	R15	NLP	Retinoblastoma	Birth	F	18	Hispanic	
	S7	20/20	n/a	n/a	M	26	Cauc.	
	S8	20/20	n/a	n/a	M	50	Middle Eastern	
S9	20/20	n/a	n/a	M	32	Cauc.		
R16	NLP	Optic atrophy	Birth	M	26	Cauc.		
R17	NLP	Retinoblastoma	Birth	M	25	Cauc.		
R18	LP	RDP	Birth	F	22	Cauc.		
S10	20/20	n/a	n/a	M	42	Cauc.		
S11	20/20	n/a	n/a	F	35	Cauc.		
Study 2	8/16/08	R4-2	Shadren/Stars	RP	27	F	62	AF Am.
		R5-2	NLP	Diabetic retinopathy	25	F	46	Cauc.
		R6-2	NLP	Retinoblastoma	Birth	F	26	Cauc.
	8/23/08	R1-2	Shadren/Stars	Stargard's	12	F	42	Cauc.
		R2-2	LP	Optic atrophy	Birth	F	27	Cauc.
		R3-2	20/400 OS, NLP OD	RP	Birth	F	26	Hispanic
	9/11/08	R7-2	20/400 OS, 20/200 OD	Tauara	18 mo.	F	22	Cauc.
		R8-2	NLP OS, 20/60 OD	RDP	Birth	M	25	Cauc.
		R9-2	20/140 OS, NLP OD	Birth defect	Birth	M	28	Cauc.
		R10-2	NLP	Glaucoma	16	M	52	Asian

Table 1. Characteristics of Participants

Study	Date	Vehicles	Tires
Study 1	9/13/07	2003 Toyota Prius	P175/65 R14 84S
		2003 Toyota Prius	P175/65 R14 84S
		2005 Ford Escape	P235/70 R16 104T
	9/14/07	2003 Honda Civic	P185/70 R14 87S
		2003 Toyota Prius	P175/65 R14 84S
	9/21/07	2005 Ford Escape	P235/70 R16 104T
		2003 Honda Civic	P185/70 R14 87S
	9/22/07	2003 Toyota Prius	P175/65 R14 84S
		2008 Ford Escape	P235/70 R16 104T
		2008 Ford Escape	P235/70 R16 104T
		2003 Toyota Prius	P175/65 R14 84S
		Honda Accord	Unknown
	9/11/08	2003 Honda Civic	P185/70 R14 87S
2003 Honda Civic		P185/70 R14 87S	
2005 Ford Escape		P235/70 R16 104T	
2006 Toyota Prius		P195/55 R16 86V	
Study 2	8/16/08	2003 Toyota Prius	P175/65 R14 84S
		2006 Ford Escape	P235/70 R16 104T
		2003 Honda Civic	P185/70 R14 87S
	8/23/08	2003 Honda Civic	P185/70 R14 87S
		2008 Ford Escape	P235/70 R16 104T
	9/11/08	2008 Ford Escape	P235/70 R16 104T
		2003 Toyota Prius	P175/65 R14 84S
		2006 Toyota Prius	P195/55 R16 86V

Table 2. Characteristics of Hybrid Vehicles

Note that in study 1, a sample of sighted participants was included. This was done in order to be able to compare distances at which blind and sighted pedestrians detected the different types of vehicles. It was expected that the sighted participants would detect vehicles further away because they were allowed to use their sight but this procedure allowed a comparison of how much farther away a vehicle of each type would be before a sighted person would no longer

begin to cross the street. This allowed a relative measure of safety between sighted and blind crossing judgments to be derived.

1.3 Results

1.3.1 Study 1

In both studies, data were sampled at .1 s intervals to allow for accurate detection of pushbutton status changes. In study 1, the time when a participant let up on the pushbutton (i.e., would no longer begin to cross because they detected an oncoming vehicle) was identified by a change in the electrical potential for that button. This point in the data stream was compared to the time when the next vehicle passed in front of the participant to obtain a "safety margin". This safety margin was the amount of time that participant would have had to complete a crossing at the last point they would have started one, in front of the next vehicle. Note that the true measure of safety is this raw number minus the time it would take the participant to cross the street. For the purposes of these data, an assumed walking speed of 4 ft/s ([Federal highway Administration, 2007](#)) across the 24 foot wide roadway (two lanes) gave a general crossing time of 6 seconds. So any raw safety margin less than 6 seconds would constitute a possibly unsafe decision. One might argue that if a pedestrian was within a second of completing a crossing, they could be considered relatively safe since most approaching vehicles could avoid them. This would lead to a crossing time of 5 seconds being acceptable. However, one could also argue that it takes a second or two for a pedestrian to decide to cross and then initiate a crossing. This would add to the acceptable gap length. To balance these two arguments, we have elected to accept the actual crossing time of the roadway as the time necessary for a "crossable gap" in traffic (i.e., 6 seconds). The time from a vehicle's passage in front of a participant to the time when they next pressed their button (indicating that they would begin crossing) was a measure of lag. This measure gave a sense on how long a passing vehicle impinged on a participant's ability to confidently assess whether another vehicle was already approaching. Pedestrians who are blind must generally wait longer than pedestrians who are sighted to make a crossing decision because

of the effect of masking noise of a receding vehicle on the sound of any approaching traffic.

Three measures taken for each passing vehicle were the speed, the sound level, and the frequency spectrum. The speed was obtained by taking an average of the .1 s samples over a course of a 10 second time frame ending 5 seconds before the vehicle passed in front of the participant location. While most of the drivers of hybrid vehicles were careful to drive at a relatively constant speed, drivers of passing internal combustion vehicles tended to slow slightly when passing the participants. Taking an average speed measure slightly before the vehicle arrived at the participant location reflected the speed of the vehicles when they tended to be auditorily detected by participants. As such, it more accurately reflected the speed of the vehicles relevant for the study. The sound level of each vehicle, however, was taken as the loudest overall sound level (measured in dB-A) made by that vehicle as it passed the participant location. This was not always when the vehicle was directly in front of the participants but was always within a second before or after this point. The sound frequency spectrum for each vehicle was also taken from the time sample from which the loudest point was taken.

During the gathering of data in study 1, measurements were taken of the ambient sound level for that environment. [Table 3](#) shows the ambient samples taken for each date and the amount of time that went into each sample. Ambient measures were only taken once the most recent passing vehicle had gone and the sound level had fallen to a stable level. Samples were only taken when no obvious masking sounds were heard by the experimenters. The average ambient sound level across the study was 52.8 dB-A.

Date	Sample	Average dB-A	Sampling time (s)
9/13/07	1	53.43	9.7
	2	54.73	31.1
	3	53.38	13.8
9/14/07	1	52.09	23.0
	2	52.70	17.3
	3	53.62	16.8
9/21/07	1	53.12	5.6
	2	52.99	19.3
	3	52.08	18.5
9/22/07	1	52.11	123.9
	2	50.60	9.3

Table 3. Ambient Sound Levels in Study 1

One of the basic comparisons made from the data was to see how blind and sighted pedestrians differed in their abilities to detect vehicles. It was expected that sighted pedestrians would exhibit similar detection abilities for all vehicle types and that they would be able to detect many vehicles before the blind pedestrians who were using only sound to detect vehicles. [Table 4](#) shows the crossable (6 seconds or longer) or short (< 6 seconds) gaps taken or not taken by the blind and sighted pedestrians.

		Crossable gaps taken	Crossable gaps not taken	Short gaps taken	Short gaps not taken	Median safety margin
Blind	ICE*	307	227	14	652	4.8
	Toyota hybrid	95	55	1	71	4.4
	Honda hybrid	119	91	3	51	4.9
	Ford hybrid	102	63	1	62	6.1
	Total	622	437	19	836	
Sighted	ICE*	64	17	0	60	7.0
	Toyota hybrid	48	12	0	30	7.0
	Honda hybrid	63	14	n/a	n/a	6.5
	Ford hybrid	61	13	1	23	6.4
	Total	237	57	1	113	

* ICE = internal combustion engine.

Table 4. Gaps Accepted by Blind and Sighted Participants by Vehicle Type

These data show that, overall, the sighted pedestrians were much more precise about accepting gaps large enough to afford enough time to cross and not accepting gaps that were too short. Only 14.2% of their decisions were not optimal (e.g., not taking a long enough gap or taking a gap that was too short) compared to 23.8% for the blind pedestrians. Not accepting crossable gaps implies a loss of efficiency in crossing but accepting gaps that are too short point to potentially dangerous decisions. The sighted pedestrians had only .2%

of these potentially dangerous decisions, compared to blind pedestrians' 1%.

Given the median safety margins in [table 4](#), and using the median speeds across all instances of each vehicle type, we calculated how much closer a hybrid had to be to a blind participant than a sighted participant to be detected. For ICE vehicles, the difference of 2.2 seconds in median safety margin, combined with the median speed of 26.21 mph, indicated that ICE vehicles needed to be 84.5 feet closer to a blind participant than a sighted participant to be detected. The Toyota hybrids had to be 99.4 feet closer, the Honda hybrids 56.1 feet closer, and the Ford hybrids 11.0 feet closer. Note that the Ford Escapes were actually detectable by the blind participants farther away than the average ICE vehicle.

Above a certain speed, much of the sound of an approaching vehicle comes from tire noise, so we limited the dataset to only those vehicles that approached at less than 20 mph. [Table 5](#) shows the gaps taken and safety margins for the blind participants detecting these vehicles. At these speeds, it seems that the Toyota hybrids were more difficult to detect reliably.

Vehicle type and average speed (mph)	Gaps taken	Crossable gaps taken	Median safety margin
<i>Blind</i>			
ICE (15.99)	65/173	62/90	5.5
Toyota hybrids (14.15)	9/35	6/9	2.1
Honda hybrids (15.5)	61/94	50/75	5.1
Ford hybrids (15.55)	22/39	22/33	6.75

Table 5. Gaps Accepted for Vehicles Traveling Less Than 20 mph

Lags will not be discussed much in this paper, except to say that, as expected, blind participants demonstrated larger overall lags than sighted participants (medians of 4.5 s versus .85 s). This is simply a function of blind participants having to wait until a passing vehicle had cleared from the ambient sound field before being able to detect another vehicle.

Since it appeared that there was a difference in detectability between hybrid and ICE vehicles, especially the Toyotas, we investigated the spectral composition of the vehicle sounds to see whether systematic differences showed up. [Figure 4](#) shows the

relationship between speed and sound level for each of the four vehicle types in the study while [figure 5](#) shows the same relationship for those vehicles that approached after a crossable gap.

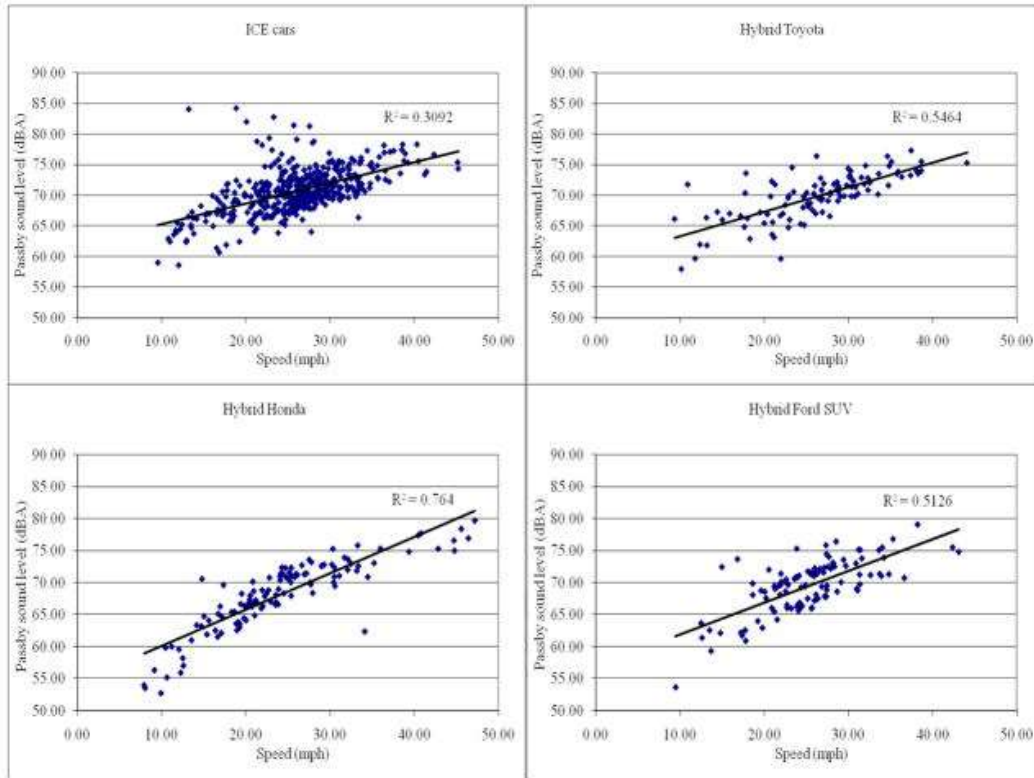


Figure 4. Relationship between speed and sound level for all vehicles.

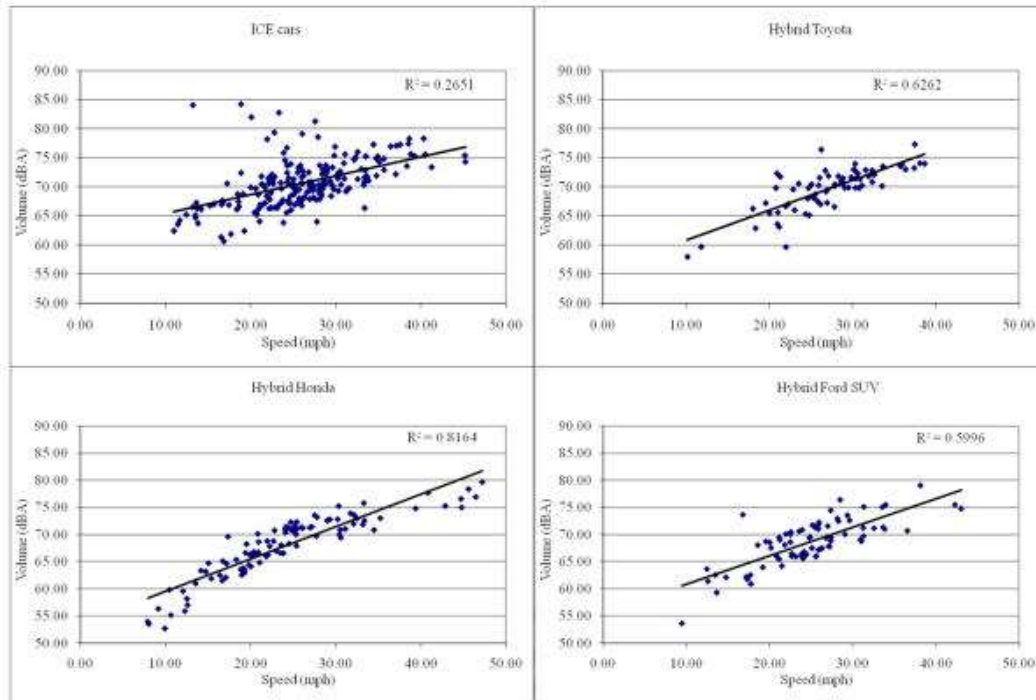


Figure 5. Relationship between speed and sound level for vehicles approaching after a crossable gap.

For all of the hybrid vehicles, there was a high correlation between speed and overall sound, this held true for vehicles that ended a crossable gap (e.g., no masking sound from the previous passing vehicle). This is expected since faster vehicles have the addition of tire noise and wind noise as they pass a pedestrian's position. The smaller connection between these two variables for the ICE vehicles was due to some slower moving but very loud vehicles (e.g., buses). Note in [figures 4 and 5](#), however, the cluster of vehicles that passed at less than 20 mph. It is these vehicles that may pose the greatest detection issue. In the figures, there appears to be several passes of Honda hybrids that have overall sound levels very close to the ambient sound level (about 53 dB-A). And yet it was the Toyota hybrids that had much smaller safety margins at these speeds. This suggested that the spectral composition of the vehicle sounds might be a component of detectability.

The sound pressure level of 1/3 octave frequency bands from 100 to 10000 Hz were compared for the four types of vehicles in study 1. The level used for each frequency band was the difference between

the intensity for a specific vehicle type traveling at less than 20 mph and the background intensity at that frequency band taken at the time just before that vehicle's sound began to affect the sound level meter reading. Every vehicle had a demonstrable period of quiet before it appeared. As such, these vehicles reflect the best possible listening condition for that environment. And, since the ambient sound level fluctuated, each vehicle was compared to the ambient sound level just before that vehicle approached. The resulting average differences reflected that component of a certain type of vehicle's sound signature that was different from the background sound shape.

As expected, the ICE vehicles demonstrated a much higher intensity at many of the frequency bands. The Ford Escape hybrids, which tended to be detected as well as the ICE vehicles, showed high intensities only at 1000 Hz or lower. Finally, the Toyota hybrids, which seemed to be problematic for blind participants to detect, showed a particularly lower intensity at only a couple of frequencies, and was often much higher than the Honda or Ford hybrids. These mixed findings suggest that it was not overall sound level that impacted detectability, nor was it certain component frequencies of spectral shape. Instead, the issue of what makes a vehicle perceptible in noise is much more complicated and may involve attentional factors, how the sound appears (suddenly or slowly), or momentary fluctuations in the vehicle sound shape and the ambient sound shape. More research is needed to determine exactly what the critical components for acoustic detection are.

1.3.2 Study 2

We conducted a second study in which the spectral shape of the sound and vehicle speed should not have been factors in detectability. In study 2, vehicles traveling parallel to the participants' facing direction (implied direction of street crossing) were stopping at a red light. Environmental sound levels were taken continuously but due to traffic on the cross street, no measure of individual vehicles or groups of vehicles comprising a parallel surge could be assigned. Sound levels were used only to characterize the overall sound of the environment and to indicate times when there was an inordinate amount of competing or masking sounds. The main measures in this study

related to whether and when participants indicated that they heard the surge of parallel traffic when the light turned green for both the traffic and the participant. A note was made of all surges that were or were not detected by a participant (and what types of vehicles comprised each surge). If a participant indicated detection of a parallel surge more than 1 second after the start of a surge, the lag time was also noted. This lag was rounded to the nearest half second to reflect the variability in measuring the start of a surge. An experimenter labeled a surge by pressing a button. This was done when the lead vehicle began to move forward from a stop. A note was also made of false positives, wherein a participant indicated a parallel surge when none had occurred.

In all, 8 subjects made detection decisions on 322 traffic surges. Surges included a range of vehicular situations. The percent of surges containing a specific type of vehicles only (e.g., hybrid Toyota, hybrid Honda, hybrid Ford Escape, etc.) under different criteria are shown in [Table 6](#). Catching a surge within 1 second of the surge initiation was a baseline conservative criterion. Catching a surge within 2 seconds was deemed a basic level for identifying a parallel surge and initiating a crossing with enough time to cross the street within the designated crossing phase. [Table 6](#) also shows the most liberal criterion wherein a participant indicated that they heard a surge at any point after that surge began but before the perpendicular phase began. Note that this liberal criterion includes trials where a participant most likely is not responding to the initial surge but to a later vehicle coming through the intersection after the light has been green for some time. Sighted pedestrians react to a visual walk signal within about 1 second ([Fugger, Randles, Stein, Whiting, & Gallagher, 2000](#)). Given that a pedestrian with a visual impairment reacting to the auditory signal of a parallel surge must also wait to make sure that the traffic is proceeding through the intersection rather than turning, the authors consider the 2 second criterion as the most appropriate for discriminating on detection of parallel surges in a reasonable time to cross.

	Surges	Surges caught, including late (%)	Surges caught in <1 s (%)	Surges caught in <2 s (%)	Surges missed (%)
Toyota hybrid	14	85.71	0	35.71	14.29
Honda hybrid	27	92.59	29.63	48.15	7.41
Ford Escape hybrid	46	54.37	4.35	11.11	45.65
ICE	92	97.83	48.91	76.09	2.17
Toyota hybrid + ICE	67	91.04	40.3	67.16	8.96
Honda hybrid + ICE	35	94.29	25.71	45.71	5.71
Ford Escape hybrid + ICE	41	92.68	26.83	41.46	7.32
All ICE combined	235	94.47	39.15	62.98	5.53
False surge	30				

Table 6. Parallel Surges Caught by Participants

The data show that even with ICE vehicles involved in a surge, only 50 to 75% of the surges are caught early enough to afford ample crossing time. If the criterion is broadened, then well over 90% of the surges involving an ICE vehicle are caught. As expected, surges involving only hybrid vehicles are caught at a much lower frequency but it was the Ford Escape hybrids that proved to be the most difficult to detect. Even accepting the most inclusive criterion, only about half of the surges involving only a Ford Escape were detected at all.

Due to availability of vehicles, some testing sessions had more of one vehicle than another. This means that some participants provided detection data on some types of surges more than others. The type of vehicle distributed most unevenly across the testing sessions was the Toyota Prius (see [Table 7](#)). However, since the most surprising result was in the detection of the Ford Escape hybrid, it is reassuring to note that these vehicles were distributed fairly evenly across sessions and participants. It should also be noted that two different Ford Escape vehicles provided data, a 2006 model and a 2008 model. The newer model was detected slightly less often than the older model (61.5% for the 2006 model versus 48.6% for the 2008 model).

	Session 1	Session 2	Session 3	Session 4	Session 5
Toyota hybrid	2	2			4
Honda hybrid	5	4	3	4	
Ford Escape hybrid	4	5	5	6	9
ICE	3	7	13	13	19
Toyota hybrid + ICE	5	5		1	25
Honda hybrid + ICE	5	7	4	8	
Ford Escape hybrid + ICE	5	3	3	5	7
False surge	21	6	2		1

Table 7. Distribution of Surges Across Sessions

1.4 Discussion

Previous research has found that while the Toyota Prius hybrid is up to 8 dB quieter than some ICE vehicles, it still produces enough sound energy to be heard reliably when accelerating from a stop or from at least 110 feet away when approaching at speeds of about 30 miles per hour ([Wiener, Naghshineh, Salisbury, & Rozema, 2007](#)). When approaching at speeds under 20 mph, the Toyota Prius hybrid was detectable only an average of 2 seconds away. Two seconds corresponds to 58.6 feet at 20 mph. At higher approach speeds, The Toyota Prius hybrids, the Honda hybrids, and the ICE vehicles were all detected by the blind participants at 4 to 5 seconds away. This detection time was less than the time it took to cross the street. One implication of these data is that, while hybrid vehicles are quieter, they are not the sole issue when blind pedestrians are making safe crossing decisions. Many ICE vehicles are not easily detectable far enough away to afford a long enough gap for crossing a street ([Wall Emerson & Sauerburger, 2008](#)). More research needs to be done on what the critical information is for reliably detecting a crossable gap in traffic and then determining how to best provide that information.

Our data indicated that the Toyota Prius hybrid was often detectable when accelerating from a stop but that the Ford Escape hybrid was much less detectable. This might be because the Toyota Prius tends to switch to internal combustion at 5 mph but the Ford Escape does not do so until approximately 30 mph (Naghshineh, unpublished data). The implication of the lack of detection of hybrids at lighted intersections means that a pedestrian with a visual impairment may have to wait through another light cycle or two to obtain a surge they could demonstrably detect. However, it does point to the larger issue of auditorily detecting hybrid vehicles when they are moving slowly. For the Ford Escape hybrids, it generally took several seconds for them to move through the intersection. For participants to not hear these vehicles at all half the time indicates that these vehicles pose a serious threat at low speeds. In situations where a hybrid vehicle is turning right on green, moving slowly in a parking lot, or backing out of a driveway, it would be very difficult to detect reliably. While pedestrian conflicts with slower vehicles may reduce the likelihood of serious pedestrian injury, or at least result in fewer

fatalities, ([Rosen & Sander, 2009](#)) the fact that pedestrians with visual impairments will have a harder time hearing slow moving hybrid and electric vehicles makes this pedestrian population more at risk than others.

1.4.1 Limitations

These studies focused on the crossing decisions of pedestrians who were blind. As such, certain characteristics of the vehicles were not controlled for. Although differential effects were seen for the Toyota Prius at the uncontrolled crossing and the Ford Escape at the light controlled intersection, these results cannot be universally applied to these makes and models of vehicles. Factors such as tire tread wear, the state of repair of the vehicle engine and exhaust systems, whether drivers were running the fan or radio in their vehicles, and the state of charge of the batteries may all have impacted noise output in potentially important ranges. We could also not verify that hybrid vehicles were in electric mode when going at certain speeds but could only infer so based on knowledge of the manufacturer specifications. As such, the results of these studies point more broadly to the fact that hybrid vehicles may, in some situations, be more difficult to detect than internal combustion vehicles, rather than one type of vehicle being particularly more difficult than another. More controlled studies of vehicle characteristics needs to be undertaken to identify vehicle factors most involved in detectability.

- Above 20 mph, hybrids and ICE vehicles were detected equally well.
- Under 20 mph, Toyota hybrids were heard less well than other hybrids or ICE vehicles.
- Starting from a stop, Ford Escape hybrids were detected only half the time.

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Footnotes

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