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On the hazard of quiet vehicles to pedestrians and drivers

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ABSTRACT

The need to produce more efficient and less polluting vehicles has encouraged mass production of alternative energy vehicles, such as hybrid and electric cars. Many of these vehicles are capable of very quiet operation. While reducing noise pollution is desirable, quieter vehicles could negatively affect pedestrian safety because of reduced sound cues compared to louder internal combustion engines. Three studies were performed to investigate people's concern about this issue. In Study 1, a questionnaire completed by 378 people showed substantial positive interest in quiet hybrid and electric cars. However, they also indicated concern about the reduced auditory cues of quiet vehicles. In Study 2, 316 participants rated 14 sounds that could be potentially added to quiet alternative-energy vehicles. The data showed that participants did not want annoying sounds, but preferred adding "engine" and "hum" sounds relative to other types of sounds. In Study 3, 24 persons heard and rated 18 actual sounds within 6 categories that were added to a video of a hybrid vehicle driving by. The sounds most preferred were "engine" followed by "white noise" and "hum". Implications for adding sounds to facilitate pedestrians' detection of moving vehicles and for aiding drivers' awareness of speed are discussed.

1. Introduction

The trend across the world is to reduce the use of hydrocarbon fuels because of predicted future energy shortages and to reduce air pollution in large metropolitan areas. For example, in 1990, the U.S. Environmental Protection Agency's (U.S. EPA) Clean Air Act was amended to encourage automotive manufacturers to build more alternative energy vehicles, such as hybrid (part-gas, part-electric), hydrogen, and fully electric cars. The main purpose of the act was to improve air quality in urban areas such as southern California, where smog has been a major problem. The use of reduced emission vehicles has been shown to be beneficial in reducing the amount of air pollution in certain areas of the U.S. (Meotti, 1995). The State of California has enacted low emission laws that are being met, in part, by alternative energy vehicles. Additionally because of political conflicts in oil producing countries and predictions of future fuel shortages, alternative energy vehicles may also provide societal benefits by reducing fossil fuel use.

Alternative-energy vehicles tend to operate more quietly than vehicles fully powered by internal combustion engines. Hybrid vehicles run partly on an electric motor to conserve gas, but its use also makes them very quiet. Although they are not completely quiet, as there is usually some noise during acceleration and at higher speeds because of tires and wind (Robbins, 1995), they can be much quieter in operation than most current vehicles that are completely powered by hydrocarbon based fuel. Certainly, high-density neighborhoods in urban areas could benefit from reduced noise pollution.

However, the use of quiet vehicles may have drawbacks. One potential problem is the potential effect on pedestrian and cyclist safety. The threat to safety is due to reduced engine noise typical of vehicles on roadways. This issue has been substantiated by news reports of accidents (e.g., Huppert, 2008), a 2006 Resolution of the National Federation of the Blind (Pierce, 2006), and an Act of the U.S. Congress to study the effects of quiet vehicles on pedestrians (Pedestrian Safety Act of 2008).

Sound characterization and localization (Wall et al., 2004) are important in order to gauge where vehicles are coming from and the amount of traffic. Certainly, blind persons would have more trouble detecting and predicting the movement of quiet vehicles. However, non-blind persons, too, may sometimes rely on auditory cues to signal the presence of vehicles. The lack of those cues could result in failing to detect a moving vehicle in their path. Thus, it is vital that some form of noise is heard by both blind and non-blind pedestrians (Wall et al., 2004; Barlow et al., 2005). More pedestrian accidents can be anticipated as directional cues are decreased.

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The reduction of sound emitted by alternative-energy vehicles could affect drivers' awareness of speed. Louder sound from a vehicle's internal combustion engine is usually indicative of faster speed. Research by Evans (1970) indicates that drivers with diminished hearing have a diminished sensation of speed – tending to underestimate it. Anman and Blommer (1999) showed that driving performance is reduced when motor loudness is not matched to vehicle acceleration. Also, Nelson and Nilsson (1990) showed that in complex driving tasks (e.g., shifting gears), performance deteriorates when auditory cues were eliminated. Thus, with the reduction of sound cues in today's quiet vehicles, drivers could be less aware of the speed of their vehicle.

One way to remedy the reduced sound-cue problem is to add sound to quiet vehicles. The added sound to quiet vehicles could benefit both drivers and pedestrians. However, this method is not without some potential issues. One is whether people believe that the issue of quiet vehicles ought to be dealt with. Even if people agree that quiet vehicles present safety concerns, do they believe it should dealt with by incorporating an artificial sound? Still another issue is what kinds of sounds that consumers believe are appropriate for the application.

Simply increasing the sound level is a potential method. Data collected by Björkman and Rylander (1997) indicate that typically noise levels in current internal combustion type motor vehicles positively correlates with speed. Their data suggested that few vehicles (approximately 1%) exceed a loudness level of 75 dBA, which according to earlier research is the lower threshold of annoyance (Rylander et al., 1993). Besides loudness, another critical variable is the form of the added sound itself. One aspect of this is spectral content. If a limited band of frequencies are used, the sound could be masked by other sounds. Also some waveforms might be more annoying than others and thus could be considered less acceptable as an added sound to quiet vehicles. According to Marshall et al. (2007) some in-vehicle alerts (e.g., ones that repeat after small intervals) are perceived as highly urgent and thus are useful as alerts but they are also highly annoying. Therefore, some kinds of sounds could be judged as more appropriate as an added sound to quiet vehicles than others. Studying this issue is important as vehicle sound can give critical information to pedestrians and drivers.

Three studies are described. Study 1 examined people's attitudes toward electric and hybrid cars. Among the issues examined were respondents' interest levels in alternative-energy vehicles, their opinions regarding reduced auditory cues for pedestrians and drivers, and their suggestions for types of auditory cues. In Study 2 another group of participants rated the level of acceptability of 14 sounds if added to otherwise quiet vehicles. Participants were asked to indicate the level of acceptability of 14 types of sounds that were listed on a questionnaire. To increase external validity, Study 3 evaluated 18 actual sounds from 6 categories combined with a video of a hybrid vehicle.

2. Study 1

This study examined people's: (a) interest in alternative-energy vehicles, (b) beliefs about the safety of pedestrians and drivers in relation to quiet vehicles, and (c) suggestions for added sounds.

2.1. Method

2.1.1. Participants

Data comes from 378 individuals living in various locations of the State of North Carolina, USA, but most were collected in Raleigh, NC. Participants were 230 males and 148 females. Ages ranged from 14 to 91 years old with a mean of 26 (SD = 11).

2.1.2. Materials and procedure

The questionnaire contained items that asked participants for their opinions about current technology. Included were items associated with alternative-energy vehicles and issues associated with sound cues. They were:

(1) Electric vehicles are quieter than traditional gasoline engine-powered vehicles. Would this lack of noise pose any threat to pedestrians?
(2) Would you consider purchasing an electric vehicle?
(3) Would you consider purchasing a vehicle powered by a hybrid (part electric/part gasoline) motor?
(4) When crossing the street, have you used the sound of a vehicle as a cue that the vehicle is approaching?
(5) Does the sound emitted from a moving vehicle make you more aware of the vehicle's location and direction?
(6) As a pedestrian, if a moving vehicle were totally silent would that bother you?
(7) As a driver, if a moving vehicle were totally silent would that bother you?
(8) Do you think that including an artificial sound like that of an engine or something else would make hybrid/electric vehicles safer to pedestrians?
(9) What type of sound do you recommend be implemented? (e.g., whistle, hum, engine noise, chimes, etc.).

The first eight items requested yes or no answers. The ninth item was open-ended and asked participants for suggestions/recommendations for the type of sound that could be added to a quiet electric vehicle.

2.2. Results

Table 1 shows the percentage agreement for the yes-no items. Most respondents (72%) expressed interest in purchasing a vehicle powered by electricity. A somewhat larger percentage (83%) responded that they would consider purchasing a hybrid (part electric/part gasoline) vehicle. Most (70%) believed that the lack of noise of an electric car would be a potential danger for pedestrians. A sizeable number (86%) agreed that sounds emitted from a moving vehicle made them more aware of its location and direction. In addition, most participants (73%) said that when crossing a street they have used vehicle sound as a cue that a vehicle is approaching. Approximately half (48%) responded that, as a pedestrian, a totally silent vehicle would bother them. However, only 30% thought that, as a driver, a silent vehicle would bother them. Finally, 68% agreed

Table 1
Percentage agreement for questionnaire items ($N = 378$).

Question item	Percentage (%)
(a) Would you consider purchasing an electric vehicle?	72
(b) Would you consider purchasing a hybrid (motor part electric/gasoline) vehicle?	83
(c) Would lack of noise by electric vehicles pose a threat to pedestrians?	70
(d) Does sound make you more aware of vehicle location and direction?	86
(e) When crossing street, have you used sound as a cue that a vehicle is approaching?	73
(f) As a pedestrian, if a moving vehicle were totally silent, would that bother you?	48
(g) As a driver, if a moving vehicle were totally silent, would that bother you?	30
(h) Do you think that including an artificial sound would make vehicles safer to pedestrians?	68

that including some type of engine sound would make electric vehicles safer for pedestrians.

The last item asked participants to give suggestions or recommendations for the type of sound that could be added to a hybrid/electric vehicle. The frequencies of suggested sounds are shown in Table 2. Approximately 28% (106 of 378) did not give any suggestion (left the item blank) but among the nearly 72% (272 of 278) respondents that did, participants indicated that they preferred a traditional engine sound and a hum sound most often (40% each). The next most frequent response (11%) was a preference for no sound being added at all. The remaining low frequency responses varied from music to horn sounds to beeps and whistles.

2.3. Discussion

The results of Study 1 indicate that while a large percentage of people would consider purchasing a hybrid or electric vehicle, only about half indicated concern about the safety of such vehicles to pedestrians who may not have sound cues when crossing a street.

If a pedestrian misjudges the presence and direction of a moving vehicle or a driver misjudges their speed, there is an added risk of serious injury. Therefore, some auditory feedback may be important for pedestrians and drivers.

While the results showed some concern about quiet vehicles for pedestrians, there was somewhat less concern about drivers operating vehicles such vehicles. This might be partly due to people not being aware that sound is a cue for vehicular speed, and that without sound, speed may be judged inaccurately as shown in previous research (Evans, 1970; Anman and Blommer, 1999; Nelson and Nilsson, 1990). Also other persons in the passenger compartment do not need sound cues and they probably prefer to be isolated from exterior noise.

A sound added to an otherwise quiet vehicle would probably be a useful cue to aid to pedestrians and drivers in making them aware of vehicle movement and speed. Not every kind of sound is considered acceptable, however. In this study, participants' most common recommendation for added sound were engine and hum sounds. These suggestions are not unexpected because existing motor vehicles make these sounds. Also apparent in the findings was a relatively high preference for no additional sound to be added. One possible explanation for this finding is that these participants were concerned about annoyance of added sounds. The sound-type findings are somewhat limited by the use an open-ended question in which participants were to generate a suggestion. A more sensitive measure of preference would be to have participants evaluate different kinds of potential sounds rather than to generate a suggestion of a preferred sound. This was the method employed in Study 2.

Table 2
Response frequencies of suggestions for added sound to quiet vehicles, ordered from high to low ($N = 272$)[a].

Sound	Frequency (f)
Engine	109
Hum	109
No response	106[b]
None	31
Music	14
Whistle	8
Beeps	5
Horn	5
Clicking	2
Exhaust	2

Note:
[a] Indicates number of persons responding to this question. Frequencies total to 285 because some respondents gave more than one suggestion.
[b] These individuals left blank the space provided.

3. Study 2

This study examined the issue further regarding people's preferences for various sounds that might be added to otherwise quiet vehicles. Participants rated a list of different kinds of sounds.

3.1. Method

3.1.1. Participants

A questionnaire was distributed to 319 individuals in the Raleigh, North Carolina, USA area. Of those, 316 completed the questionnaire. This sample was comprised of 209 males and 107 females with ages ranging from 18 to 73 years ($M = 22.5$, SD $= 3.5$).

3.1.2. Materials and procedure

Participants read a short vignette regarding the increased use of alternative-energy vehicles, which discussed their quiet operation on the roadway. The vignette noted that pedestrians might be more at risk by such vehicles without the addition of sound to alert their awareness. Participants were then asked to rate the acceptability of 14 randomly-ordered sound types on a 5-point Likert-type scale ranging from 0 to 4 with the points having the following word anchors: 0 (not at all acceptable), 1 (somewhat acceptable), 2 (acceptable), 3 (very acceptable) and 4 (extremely acceptable). The sound types were generated from the Study 1's participants' suggestions, which were supplemented by the authors' including the item "not annoying".

3.2. Results

The mean acceptability ratings (and standard deviations) for each of the 14 sounds are shown in order from highest to lowest in Table 3. A repeated-measures analysis of variance (ANOVA) was conducted on the data, $F(13, 4095) = 94.18$, $p < .0001$. Comparisons were performed using Tukey's HSD post-hoc test (at $p < .05$).

The highest mean rating occurred with the item "not annoying" and it was significantly higher than all of the other items. The highest rated sounds were engine and hum, which did not differ statistically. These and several other sounds were rated between the "acceptable" and "somewhat acceptable" anchors on the scale.

The item "no noise" was significantly lower than engine and hum sounds. As shown in Table 3 there were several sounds that were given low ratings in the unacceptable range of the scale. These sounds were significantly lower than the higher rated sounds.

Table 3
Mean acceptability ratings (and standard deviations) of 14 sound types ordered from high to low ($N = 316$).

Sound	Mean (SD)
"Not annoying"	2.80 (1.32)
Engine	1.80 (1.29)
Hum	1.74 (1.34)
Horn	1.45 (1.47)
No noise	1.35 (1.42)
Exhaust	1.17 (1.21)
Driver selects	1.07 (1.32)
White noise	1.04 (1.27)
Music (Any)	1.00 (1.27)
Music (Classical)	.80 (1.14)
Beep	.74 (1.07)
Click	.71 (.96)
Whistle	.63 (.98)
Siren	.39 (.92)

3.3. Discussion

Participants judged the addition of a "not annoying" sound as the most acceptable on the list. This is not a specific sound; it is a category within which the actual sounds must fit. Using just any added sound was not acceptable. The next highest-rated items were specific sounds, namely engine and hum. Note that these two sounds were also the most frequent of the recommended sounds by Study 1's participants. The item "no noise" was significantly lower than engine and hum sounds, which was also a pattern shown in Study 1. This latter finding confirms that people believe there is a need to include additional sound to otherwise quiet vehicles.

Familiarity of engine noise and hum sounds may have contributed to their acceptability. These two sounds have long been associated with vehicles and motors. Horn was the third highest rated specific sound. It might have received relatively high ratings as an effective auditory warning (albeit in short durations) and it is a familiar sound associated with vehicles. It was somewhat surprising to find exhaust and white noise in the middle of the pack since these sounds seem amenable to this application. Sounds like clicks, whistles, or beeps lack a strong and well-established association with motor vehicles, and they were probably considered too annoying for this particular application.

4. Study 3

In the previous two studies, items were generated or rated by participants. They never actually heard sounds. People's conceptions of the listed sounds may differ. Preferences might also differ when actually hearing exemplar sounds. Study 3 was an attempt at greater external validity by using actual sound from six categories and placed in the context of viewing a hybrid vehicle driving by.

4.1. Method

4.1.1. Participants

Twenty-four undergraduate students (14 males and 10 females) taking an introductory psychology course at North Carolina State University participated. Their ages ranged from 17 to 23 years ($M = 19.38$, $SD = 1.24$).

4.1.2. Design

The 18 sounds used belonged to six different groups of sounds that had three variations each. These are listed in Table 4.

4.1.3. Apparatus

An Apple MacBook laptop was used with a 1.83 GHz Intel Core 2 Duo processor and 1 GB of memory that played the sound files and showed a video using Microsoft™ Powerpoint® with Mac OSX 10.4 operating system. The video of a 2007 Toyota Prius was recorded with a Sony Handycam DCR-HC42 miniDV camcorder at 720 × 480 pixels. All of the sounds were taken from an Internet sound database called The FreeSound Project (http://freesound.iua.upf.edu/) by finding various examples of engine, hum, white noise, siren, horn, and whistle sounds. For example, the engine sounds were composed of a diesel motor, a 1982 Z28 pace car V8 motor, and a VW 4 cylinder motor.

The sounds were edited and normalized in Steinberg Cubase LE™ and then edited down to 10 s or repeated to 10 s if the sounds were short (i.e. horn samples). A Radioshack Digital-Display Sound-Level meter model 33-2055 was used with A weighting and slow response to make sure each sound was outputting the same 78 dB(A) with a tolerance of plus or minus one dB(A). A master sound level automation in Cubase LE was created to start the level of sound at −10 dB(A), linearly increase to zero in the middle, and then linearly decrease down to −10 dB(A) at the end for all sounds. This was done to approximate the sound level differences as a car goes by at low speeds. The sounds were outputted to wav format in stereo to be combined with the Prius video using iMovie on a G4 Mac with Mac OSX 10.3.

A Sennheiser PC150 headphone was used by the participants to listen to the sounds while viewing a Dell 2001FP 51.05 cm (20.1 inch) LCD screen with a native resolution of 1600 × 1200 pixels. The Radioshack Sound-Level meter was positioned 1 cm from the left headphone with A- weighting and slow response while a white noise sample was played using Apple Quicktime adjusting the MacBook's volume until the meter read 78 dB(A).

4.1.4. Procedure

Participants were seated at a desk in front of a monitor. They completed a short questionnaire requesting demographic information. Following this, participants were asked to read a paragraph

Table 4
The *freesound project* list of sounds used in Study 3.

By laurent (http://freesound.iua.upf.edu/usersViewSingle.php?id=8556)
moteur_diesel.wav (http://freesound.iua.upf.edu/samplesViewSingle.php?id=21110)
By han1 (http://freesound.iua.upf.edu/usersViewSingle.php?id=45540)
claxon.wav (http://freesound.iua.upf.edu/samplesViewSingle.php?id=19026)
By weebrian (http://freesound.iua.upf.edu/usersViewSingle.php?id=44318)
1982 Z28-Start Cold-Idle-Off001.wav (http://freesound.iua.upf.edu/samplesViewSingle.php?id=16692)
By dobroide (http://freesound.iua.upf.edu/usersViewSingle.php?id=8043)
20050821.engine.VWGolf.mp3 (http://freesound.iua.upf.edu/samplesViewSingle.php?id=18592)
20060308.police.siren.wav (http://freesound.iua.upf.edu/samplesViewSingle.php?id=16772)
By Krisboruff (http://freesound.iua.upf.edu/usersViewSingle.php?id=61521)
Laundry_Roomtone.wav (http://freesound.iua.upf.edu/samplesViewSingle.php?id=17770)
By Incarnadine (http://freesound.iua.upf.edu/usersViewSingle.php?id=36298)
bottle_sound-24oz_plastic_soda_bottle.wav (http://freesound.iua.upf.edu/samplesViewSingle.php?id=16112)
By Percy Duke (http://freesound.iua.upf.edu/usersViewSingle.php?id=132851)
White Noise.mp3 (http://freesound.iua.upf.edu/samplesViewSingle.php?id=28024)
By Dr. Fab (http://freesound.iua.upf.edu/usersViewSingle.php?id=176346)
WhiteNoise01.wav (http://freesound.iua.upf.edu/samplesViewSingle.php?id=26229)
By nathanshadow (http://freesound.iua.upf.edu/usersViewSingle.php?id=731)
Thruster_Level_III.aif (http://freesound.iua.upf.edu/samplesViewSingle.php?id=22456)
By noid (http://freesound.iua.upf.edu/usersViewSingle.php?id=64288)
cello_himself.aif (http://freesound.iua.upf.edu/samplesViewSingle.php?id=17596)
By PoisedToGlitch (http://freesound.iua.upf.edu/usersViewSingle.php?id=9626)
Viral_Vocoded Flick.wav (http://freesound.iua.upf.edu/samplesViewSingle.php?id=7262)
By DrNI (http://freesound.iua.upf.edu/usersViewSingle.php?id=154509)
roland-juno106-lfo-to-dco-sirene.wav (http://freesound.iua.upf.edu/samplesViewSingle.php?id=27788)
By DJ Chronos (http://freesound.iua.upf.edu/usersViewSingle.php?id=103319)
created siren.mp3 (http://freesound.iua.upf.edu/samplesViewSingle.php?id=26375)
By fogma (http://freesound.iua.upf.edu/usersViewSingle.php?id=93683)
My Car Horn - Beep.wav (http://freesound.iua.upf.edu/samplesViewSingle.php?id=26186)
By Kibben (http://freesound.iua.upf.edu/usersViewSingle.php?id=138558)
edited horn beep.wav (http://freesound.iua.upf.edu/samplesViewSingle.php?id=23276)
By euroblues (http://freesound.iua.upf.edu/usersViewSingle.php?id=97596)
Trainwhistle SBB Re 420 euroblues.wav (http://freesound.iua.upf.edu/samplesViewSingle.php?id=20065)
By pitx (http://freesound.iua.upf.edu/usersViewSingle.php?id=40665)
PitidoGlobo_Bb.wav (http://freesound.iua.upf.edu/samplesViewSingle.php?id=16980)

that noted the quietness of hybrid and electric vehicles. They were told that they would be rating a series of sounds that might be used to help make these vehicles more conspicuous to pedestrian and bicyclists on the extent that the sounds would be acceptable in this application.

Each sound was presented for 10 s. Concurrently with each sound presentation was a video of the same duration showing a hybrid vehicle, a Toyota Prius, moving along a roadway with the camera panning from left to right (approaching the observer and then receding). The sound was modulated to increase in volume as the vehicle approached the observer from the left and decreased in volume as the vehicle receded to the right of the observer. After each sound, they were told to give a rating using a 5-point Likert-type rating scale ranging from 0 to 4 with the points associated with the parenthesized word anchors: 0 (not at all acceptable), 1 (somewhat acceptable), 2 (acceptable), 3 (very acceptable), and 4 (extremely acceptable). A short pause was given after each trial to allow time for participants to record their ratings. Participants were given six practice trials to familiarize them with the task before the 18 sound trials started. Half of the participants received one of two random trial orders. After completing their ratings, participants were asked which sound they liked best if they were a pedestrian hearing the sound from the hybrid vehicle, and a similar question was asked with respect to which they liked best if they were a driver of the hybrid car.

4.2. Results

Ratings of the three individual sounds from each category were averaged for each participant. Table 5 displays the means (and standard deviations) of the six sound categories ordered from high to low. A one way repeated measures ANOVA on these data was significant, $F(5, 143) = 11.44$, $p < .0001$. Based on Tukey's HSD post-hoc test (at $p < .05$), there appeared to be two groupings of sounds, with one being rated more acceptable than the other. Significantly higher ratings were found for engine, hum, and white noise than for horn, siren, or whistle sounds. However, differences within each of the two groupings were not significant.

Participants were also asked which sound was most preferred when taking the perspective of a pedestrian or a driver. Because both the pedestrian and the driver questions produced nearly identical responses these selection frequencies were combined. Table 6 shows the frequencies for sounds selected as the most and least preferred. The pattern of these selections correspond with the ratings, with engine noise selected most frequently followed by white noise and hum. The pattern for the least preferred sounds and the acceptability ratings was also similar.

4.3. Discussion

The present study was designed to have greater external validity compared to Studies 1 and 2 since actual sounds were presented. Also the sounds were heard concurrently with a video of a moving hybrid vehicle with the sound modulated in volume as it moved toward and away from the observer. Additionally each of the six sound categories was comprised of three different actual sounds from that category. These procedures were used to give more realism than the tasks and procedures employed in Studies 1 and 2.

Engine noise, white noise, and hum were the three highest rated sound categories. White noise was given the second highest ratings in this study. The high ratings (and high preference selections) of these three sound categories are probably at least partly due to its similarity to sounds currently associated with vehicles – having frequency characteristics that the sounds of vehicles with internal combustion engines plus wind and tire noise. The findings show that whistle, horn, and siren are not considered acceptable sounds for this particular application of adding them to quiet (electric/hybrid) vehicles.

Table 5
Mean acceptability ratings (and standard deviations) of 6 sound types ($N = 24$).

Sound categories	Mean (SD)
Engine	2.00 (0.95)
White noise	1.58 (1.12)
Hum	1.50 (1.11)
Whistle	0.97 (1.11)
Horn	0.64 (1.21)
Siren	0.60 (0.78)

Table 6
Response frequencies of most preferred and least preferred sounds summed across items for pedestrian and driver.

Sound category	Frequency (*f*)	
	Most preferred[a]	Least preferred[a]
Engine	22	2
White noise	9	3
Hum	8	3
Whistle	3	4
Horn	5	20
Siren	1	16

Note:
[a] Frequencies of specific sounds that were presented to participants have been summed into their respective categories.

5. General discussion

Instigated by new technologies, more stringent air quality standards, and a desire for reduced use of fossil fuels, alternative-energy vehicles such as hybrids and fully electric vehicles are starting to take their niche in the marketplace and may become commonplace on future roadways. However, the expected rise of alternative-energy vehicles raises a safety concern given their tendency for quiet operation. The safety concern or "side effect" is that such vehicles are relatively quiet and thus increasing the difficult of pedestrians to localize the presence, location, direction of travel and speed of such vehicles.

There was substantial interest in alternative-energy vehicles as indicated in the data of Study 1. However, there were also safety concerns associated with these vehicles. Many of the respondents agreed with the notion that pedestrian safety could be adversely affected by the reduced sound output. Loss of sound cues for drivers (for higher speeds) was less of a concern.

Given the safety concern of quiet vehicles for pedestrians, the question becomes what sounds should be added? Different types sounds for adding to quiet vehicles were evaluated. In Study 1, participants suggested potential sounds in an open-ended questionnaire. In Study 2 participated rated a list sounds on their acceptability as an added sound. Both studies indicated that engine noise and hum were the two top recommended sounds. Study 3, in which actual sounds were given, confirmed this finding, and also showed high ratings for white noise.

There were methodological differences between all three studies. In Study 1 participants freely generated names of sounds that might be acceptable to add to quiet vehicles and frequency counts were taken. In Study 2, participants rated a set of named sounds given a list. In Study 3 they rated actual sounds. Despite the methodological differences, the studies yield roughly similar results. Engine noise and hum were two of the three highest rated sound categories in Studies 2 and 3. White noise was rated in the middle of the pack in Study 2 but was given the second highest ratings in Study 3. Possibly this latter result was due to participants being able to actually hear the sounds, whereas they only saw the names of the sounds in Study 2. Some of Study 2′s participants may not have known what "white noise" is or sounded like and so gave it lower ratings. But when participants were able to hear the representations in Study 3, they deemed it as an acceptable added outboard sound. White noise, engine noise and hum similarity to sounds currently associated with motors and vehicles.

Also both Studies 2 and 3 indicate that certain sounds are considered unacceptable as added sounds to quiet vehicles for the purpose of providing cues to pedestrians and drivers. Whistle, horn, and siren are not considered acceptable sounds for the particular application of being added to quiet (electric/hybrid) cars. Although siren and horn are associated with vehicles, they are usually used in quite different applications: typically used in short durations, presented at high amplitudes and in emergency situations (Marshall et al., 2007). Thus while people believe that pedestrians' safety could be adversely affected by losing auditory cues in quiet vehicles, they do not want just any sound to be added. As indicated in Study 2, they did not want the added sound to annoy.

The sounds that were most preferred (i.e., engine, white noise, and hum sounds) have long been associated with motor vehicles. They also have frequency characteristics that resemble wind and tire noise. This suggests that familiarity and expectations may play a role in participants' preferences. It may also be that the preferences also reflect that these sounds have characteristics (broad frequency band) that are most amenable to this kind of application.

Although there was a general preference for an engine sound, it does not mean that the added sound be that of an internal combustion engine. The present study demonstrates that there are alternative sounds. Interestingly, engineering majors in Study 3 rated highly (and selected as best) the three sounds comprising the hum category, possibly because of their experience with electric motors, which often have a characteristic hum- and whiny-type sound when running. A version of white noise such as pink noise or other filtered noise could be considered. Moreover, an artificial type sound combining parameters of the preferred sound categories might be better than sounds from a single category. Related to this is the fact that exhaust systems of many current internal combustion vehicles are purposely tuned to emit an acoustic environment that befits its particular vehicle classification (e.g., economy, luxury, sports cars) (Amman and Blommer, 1999). Sports cars have a "throaty" exhaust with more intense and complex acoustics compared to a quieter, muffled luxury sedan. Thus sounds added to vehicles might also be tuned to fit its vehicle category, and might also allow some limited sound tuning according to user preference. Potentially, then, manufacturers might provide a set of appropriate available sounds for which consumers could choose and tune further. To the extent that the sounds can be modifiable by consumers, the available sounds should not be annoying and confusing. The physical parameters for the range of permissible sounds might have to be limited to some extent by a government agency, with rules hopefully based on empirical research.

Based on prior experiences, people expect sounds to emanate from moving vehicles. People expect reduced sound by slower vehicles and by vehicles further away. Frequencies shift when moving toward or away from the listener. Thus, sound cues added to quiet vehicles also should have these cues. In other words, the sound added to quiet vehicles should have a sound-speed correlation (Amman and Blommer, 1999).

There are other factors important to consider. One is sound localization, or the ability to identify an object's position in space by its sound. Broadband noise (noise containing sound energy across many frequencies) is generally the easiest to localize. Fortunately, most engine noise is broadband. The vehicle should be sufficiently loud so that it could be heard over other noise in the environment–at some level of decibels above the ambient/environmental noise level. This would minimize noise pollution. A microphone outside of the vehicle, isolated from the engine, could record the ambient noise and send those data to a control unit, which could modify the sound level. The extent of loudness above the background would have to be determined in research, but clearly the generated sound should not be so annoying as to cause people to complain and attempt to disable the sound generation equipment. The sound should also not be so low as not to be heard and noticed when needed. At faster speeds, there may be a point where wind and tire noise would make the vehicle sufficiently loud by itself wherein no sound augmentation is needed.

Active noise suppression technology could be used to limit or filter unwanted sound inside the vehicle. The system should not filter out all sounds, however. Certain auditory cues should be let through to alert drivers, including speed cues. For example, a noise suppression device might filter out the frequency components associated with wind noise but not important sounds like ambulance sirens or car horns that may be crucial to driver performance (Heatwole and Bernhard, 1995).

Additional investigation is needed to identify specific sounds in the engine, hum and white noise categories that would provide the most benefit in this application. This would involve testing various parameters of sounds to determine the characteristics that maximize user benefits. Iterative design prototyping and other usability and human factors methodologies have been employed successfully in other content domains (Ruspa et al., 1995). The present research provides a useful starting point for the development of sounds appropriate for this application. Additional research could examine whether the findings generalize to real world safety.

Sound augmentation could benefit not only hybrid/electric vehicles on roadways, but also other kinds of quiet vehicles. These include electric wheelchairs, golf carts, Segways®, and other quiet-electric vehicles. These vehicles can move quickly and unexpectedly and are a potential risk to pedestrians. Future research needs include determining sound characteristics for populations most at risk such as older adults, blind and visually challenged persons, and issues associated with the environments in which the vehicles may be used (e.g., city traffic vs. rural). Testing should be done with older drivers and pedestrians to insure that sound levels are appropriate and detectable in varied anticipated conditions of use. For example, a low-level sound for golf carts might be a successful cue at a quiet county club, but may not be detectable for a golf course near the ocean or a busy highway.

This research calls attention to the potential problems of quiet vehicles for pedestrian safety and makes some preliminary recommendations about the types of sound that might be used. Adding sounds to a vehicle may seem somewhat counter-intuitive due to vehicles being one of the main sources of noise pollution. Noise is usually to be avoided and quiet usually is preferred. Decision making on this safety-related topic will surely be better informed with additional research. Decisions on sound levels and sound selection should probably lean towards the direction of safety for the pedestrians as opposed to the desire for complete quiet.

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