On Adding Sound to Quiet Vehicles

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Alternative energy vehicles such as hybrids and electric tend to run quieter than many hydrocarbon fueled vehicles. Their relative quietness could negatively affect pedestrian and driver safety because of reduced sound cues compared to louder vehicles. The present study examined preferences for sounds that might provide an acceptable auditory cue to quiet vehicles. Participants heard and then rated 18 sounds (3 variations in six categories). Each sound was displayed in conjunction with a video of a moving hybrid vehicle. The sounds of an engine, white noise, and hum sound in that order were most preferred as added sound to a quiet vehicle. Implications for adding sounds to facilitate pedestrians' detection of moving vehicles and for aiding drivers' awareness of speed are discussed.

INTRODUCTION

Alternative-energy vehicles are increasingly being operated on the U.S. roadways. One type of alternative energy vehicle runs partly on electric motor/batteries and partly on gasoline. On the horizon are purely electric/battery vehicles and hybrids using other alternative fuels such as solar and hydrogen. The electric motor in many of these vehicles makes (or will make) them very quiet relative to most internal-combustion engines. Even some internal combustion engines are very quiet. Of course, hybrid, fully electric, etc. vehicles are not completely quiet while in motion, as there is usually some noise during acceleration and at higher speeds due to tires and wind (Robbins, 1995). Nevertheless, alternative energy vehicles can be much quieter in operation than most current vehicles.

However, the use of very quiet vehicles may have some drawbacks. One problem is the potential negative influence on pedestrian and bicyclist safety (e.g., Huppert, 2008). Most moving internal-combustion vehicles provide sound cues from which vehicle position, speed and direction can be determined. Also, auditory information can assist in sound characterization as well as amount of traffic (Wall, Ashmead, Bentzen, & Barlow, 2004). Without adequate sound cues, visually impaired persons would have more difficulty detecting and predicting the movement of vehicles and would be at added risk as pedestrians with quieter vehicles on the roadways.

Wall et al. (2004) states that some form of noise is needed for visually impaired pedestrians to safely cross streets by themselves, unless an auditorily augmented pedestrian crossing is added (see also Barlow, Bentzen, and Bond, 2005). Even without visual impairment, people use sounds as cues for the presence of vehicles operating in an area. Thus persons without visual impairments are at risk without available sound cues (Wogalter, Ornan, Lim, and Chipley, 2001).

Not only might pedestrians be at greater risk with quieter vehicles, but also such vehicles could negatively affect *drivers'* awareness of speed. To drivers, an increase in loudness from their vehicle's internal combustion engine is an indication of greater speed-particularly in conventional automatic transmission vehicles. Even with manual transmissions, engine sounds are often used as cues to shift gears. Reducing sound transmission to the driver may reduce awareness about the speed of the vehicle and RPM of the engine. In correspondence to this notion is research that indicates that drivers with diminished hearing underestimate vehicle speed across a wide range of movement rates (Evans, 1970).

One way to remedy the reduced sound-cue problem is to add sound to vehicles that otherwise would not provide adequate sound cues to pedestrians and drivers. To start with, it is necessary to determine whether people are concerned enough about the problem that they are willing to allow artificial sounds to be incorporated into otherwise quiet vehicles. Even if they agree with concerns about needing sound to benefit safety, it may matter what sounds are used. Marshall, Lee, and Austria, (2007) describe annoyance, urgency, and appropriateness of in-vehicle alerts as concerns of drivers.

Data collected by Björkman and Rylander (1997) indicate that the noise levels in current internal-combustion motor vehicles tend to relate to both vehicle size and speed. Based on a limited number of measurements, they found that only 1% of vehicles exceeded a loudness level of 75 dBA (the lower threshold of annoyance, Rylander et al., 1993).

The present research follows from previous work by Wogalter et al. (2001). Their first study examined attitudes about electric and hybrid vehicles including safety issues associated with their quietness. Seventy percent of participants responded that lack of noise from an electric car would be a potential danger for pedestrians. Eighty-six percent agreed with the statement that sounds emitted from a moving vehicle made them more aware of its location and direction. In addition, most participants (73%) reported that when crossing streets they have used sound as a cue to determine whether a vehicle is approaching. Approximately half (48%) responded that, as a *pedestrian*, a totally silent vehicle would concern (bother) them. However, only 30% thought that, as a *driver*, a silent vehicle would concern (bother) them. Sixty eight percent agreed that including some type of engine sound would make electric vehicles safer for pedestrians.

In addition, Wogalter et al. (2001) asked participants for suggestions / recommendations for the type of sound that could be added to an electric vehicle. Participants indicated that they preferred a traditional engine sound or 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 relatively-low frequency responses varied from music to horn sounds to beeps and whistles.

A second study reported in Wogalter et al. (2001) asked participants to rate the level of acceptability of 14 types of sounds that were listed on a questionnaire. The results supported the findings of their first study but also found that white noise was considered an acceptable sound to add to quiet vehicles. The Wogalter et al. (2001) research was entirely based on questionnaire presentation of stimuli, using names of sounds to prompt judgments. However, judgments produced from the names of sounds may be different than judgments of actual sounds. Thus, to increase external validity, the present study used actual sounds (18 in total) that were selected based on Wogalter et al.'s (2001) findings.

The main research question was whether a similar pattern of results as that found by Wogalter et al. (2001) using paper-based questionnaire research would be found using a more externally-valid stimulus set and context.

METHOD

Participants

Twenty four individuals participated from the NC State University participant pool in the Department of Psychology (14 males and 10 females). Mean age was 19.4 (SD = 1.2). Fourteen participants needed corrective lenses and 3 had astigmatism; all were wearing corrections during the session. None of the participants had any known diagnosed hearing problems.

Design

The 18 sounds that were used belonged to 6 different categories of sounds with three variations in each. The six categories were engine, horn, hum, siren, whistle, and white noise. Three were sound categories rated highest in the Wogalter et al. (2001) study: engine, hum, and horn. The two lowest rated sounds in the earlier study, siren and whistle, were also included along with white noise as a middle rated sound. How the three variations in each category were obtained is described later.

Apparatus

An Apple MacBook (OS 10.4) laptop with 1.83 GHz Intel Core 2 Duo processor and 1 GB of memory was used. Sound files were played while showing a video using Microsoft PowerPoint. The video of a moving 2007 Toyota Prius was recorded with a Sony™ Handycam® DCR-HC42 miniDV camcorder at 720 x 480 dpi resolution. All of the sounds were from an Internet sound database called The FreeSound Project (http://freesound.iua.upf.edu/). The three variations of each sound category were taken from this database. For example, the three engine sounds used were of a diesel motor, a 1982 Z28 pace car with a V8 motor, and a Volkswagen 4 cylinder motor.

The sounds were edited and manipulated with Steinberg Cubase LE™ software. Short sounds were repeated to form longer strings of sounds for inclusion in the video. A Radio Shack sound level meter model 33-2055 using "dBA" weighting was used to maintain the same average 78 dBA with a tolerance of plus or minus one dBA. On the video, the levels of sounds faded in at the start (-10 dBA) and faded down at the end (-10 dBA). "Wav" sound files were combined with the video using Apple iMovie software.

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) diagonal LCD screen with a native resolution of 1600 x 1200. The sound-level meter was positioned 1 cm from the left headphone while a white noise sample was played using Apple Quicktime software to calibrate the MacBook's volume level until the meter indicated 78 dBA.

Procedure

After signing a consent form, participants were given a one page sheet with text describing the relative quietness of hybrid and electric vehicles and the potential safety hazard to pedestrians and drivers. Also, participants were told a video would be played of a Toyota Prius with different sounds. They were told that the sounds were added to help make these vehicles more prominent to pedestrians and bicyclists. They were told that they would rate each sound based on their own belief of their acceptability as an added sound to quiet vehicles. Ratings were made on a 5-point scale with the following numerical and text anchors: 0 (not at all acceptable), 1 (somewhat acceptable), 2 (acceptable), 3 (very acceptable) and 4 (extremely acceptable). This was the same acceptability rating scale used in the Wogalter et al. (2001) study.

The participant was positioned approximately 1 meter (three feet) away from the monitor in a desk-type chair. The experimenter asked the participant to wait until each 10 second video/audio clip stopped before giving their rating. Participants donned headphones and listened to six practice trials to familiarize them with the task. This was then followed by the 18 sound trials for which data were collected. Sound orders were randomized. After all the ratings were complete, the participant then indicated in a post task questionnaire which sound they most preferred and which they least preferred for the purpose of adding auditory cues for pedestrians and drivers of (otherwise) quiet vehicles. Lastly, participants were debriefed and thanked.

RESULTS

The ratings of the three variant sounds of each sound category were combined for analysis. Table 1 displays the means (and standard deviations) ordered from high to low.

Table 1. Mean acceptability ratings (and standard deviations) of 6 sound categories ordered from high to low (N=24).

Sound Category	*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

A one way (six sound categories) repeated measures ANOVA was conducted on the data. The effect of sound category was statistically significant, F (5, 143) = 11.44, $p<.0001$. Based on Tukey's HSD post-hoc test (at p = .05), sounds comprising engine, hum, and white noise were rated significantly higher than horn, siren, or whistle sounds. However, differences within each of the two groupings above were not significant (among engine, hum, and white noise; and among horn, siren, and whistle sounds).

Table 2 shows the frequencies that were tabulated from the post task questionnaire for most preferred and least preferred sounds as a function of sound category. The engine sound was most preferred, while the horn sound was least preferred. The responses are greater than 24 since these are qualitative responses totaled from two sets of questions for most preferred and least preferred sound as drivers and pedestrians. The most and least preferred show the same basic pattern except in reverse. These preference ratings also concur with the acceptability ratings in Table 1.

Table 2. Response frequencies of most preferred and least preferred categories of sound (N=24).

Sound Category	*Frequency (f) Most Preferred*	*Frequency (f) Least Preferred*
Engine	22	2
White Noise	9	3
Hum	8	3
Whistle	3	4
Horn	5	20
Siren	1	16

Note. These are the summed frequencies of specific sounds in their respective categories.

DISCUSSION

This study examined whether there are sounds acceptable for adding to quiet vehicles to provide cues for pedestrian and cyclists. An earlier study (Wogalter et al., 2001) used a questionnaire to examine preferences. That study suggested that engine, hum and white noise were acceptable as added sounds to quiet vehicles. However, only names of sounds were given as stimuli in the earlier study. The present study used actual sounds from six categories that were presented in context of watching a video of a moving hybrid vehicle. Participants made ratings while taking the viewpoint of being a pedestrian while viewing the vehicle and hearing the sounds. Thus, the present study was a more realistic and externally valid test in comparison to previous questionnaire research.

Despite substantial differences in method, the results of the present research show high correspondence with the results of Wogalter et al. (2001). Engine, white noise and hum were rated higher than the other categories of sounds, with no significant differences among them. This result suggests that the top three sound categories have similar levels of acceptability. The sound categories given low ratings were predictable both from previous research (Wogalter et al., 2001) and because they had characteristics that tend to be annoying, such as discontinuity (Marshall et al. (2007).

The data from the least and most preferred sounds (Table 2) also confirm the findings of Wogalter et al. (2001) and the earlier-discussed ratings. Thus, despite different methodologies employed, the same basic pattern of results is found suggesting some validity to the findings. A possible reason for the convergence of findings is that engine, white noise, and hum sounds have long been associated with motor vehicles, particularly engine sounds. Thus, familiarity and expectations might have played a part in participants' generation and assessments of the sound types.

Most of the detection problems inherit in quiet vehicles happen at low speeds. There would be a point where wind and tire noise would make the vehicle noisy and thus might not need sound augmentation. A "smart" sound augmentation system that would turn itself off when the sound cues are adequate would correspond with the notion that noise pollution should be kept to a minimum. Suppressing of excess noise should be a consideration in sound augmentation systems (e.g., Noise Abatement Society, 2007).

The National Federation for the Blind has issued a resolution regarding quiet cars in which it is stated “the only solution to the quiet car emergency is a continuous sound emitted by the vehicle itself” (Pierce, 2006). Recent legislation in the U.S. Congress (Pedestrian Safety Enhancement Act of 2008) requires the Secretary of Transportation to study and then implement hybrid vehicles to emit non visual alerts for pedestrians. This and other research support the notion that adding sounds to otherwise quiet vehicles is acceptable and appropriate for safety.

Besides vehicles on the roadway, other kinds of quiet vehicles might need sound augmentation. Electric wheelchairs, golf carts, Segways®, and other quiet-electric vehicles can move and change direction rapidly and are potential hazards for pedestrians or bystanders. Additionally, older individuals with sensory and motor declines or impairments ought to be factored into determining which kinds and loudness of added sounds to use in various non-roadway vehicles.

The intent of the present research was *not* to determine an absolute “best” sound to use on otherwise quiet vehicles. Nevertheless, this research offers some headway into that determination. A main goal of the research is to call attention to a potential safety problem of alternative energy vehicles, which tend to be quieter than most hydrocarbon-fueled vehicles in use today. In addition, the research shows that certain categories of sound are considered more appropriate than others.

Adding sounds to vehicles might seem counter-intuitive, particularly since there are also societal concerns about noise pollution, especially in urban environments. However, as changes occur to the ways people transport themselves, some consideration ought to be given to the possibility that there may be hazards introduced by new technologies that were not a problem with older technologies. We believe that this is the situation here. New technology may create a hazard that conflicts with other goals such as the reduction of noise pollution. Appropriate decisions are helped by data as this research begins to provide.

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