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Warning and Message Perception Under Ambient Noise Conditions: On-Road Experiment Report Under Crash Warning Interface Metrics 3 Program

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16. Abstract

This report describes the methods and findings of research on the effects of various vehicle interior ambient noise conditions on driver perception of warnings and messages. This task is part of a larger National Highway Traffic Safety Administration project titled Crash Warning Interface Metrics, Phase 3. In the present study, the objective was to measure various aspects of driver perception of warnings and alerts under a range of ambient noise driving conditions on actual roads. The experiment was a three-factor design, with vehicle type (compact, sedan, SUV) as a between-groups factor and interior noise condition (1) windows up, music off; 2) windows down, music off; and 3) windows up, music on) and acoustic signal (15 different tonal and voice messages, many of which were based upon current in-vehicle alerts) as within-groups factors. Ambient noise conditions had a substantial effect on all dependent measures in this experiment. Background noise from music, and especially from open windows, interfered with the perception of auditory signals presented at 65 dBA. Interference was not very pronounced for the set of 75 dBA signals, although only four signals were included at this level. The set of sounds and voice messages equated for approximately equal loudness under relatively quiet listening conditions differed substantially in noticeability and urgency even under the baseline condition and even more under the music and open windows conditions. Under noisier conditions, 65 dBA signals typically lost much of their perceived urgency, which may compromise their effectiveness as crash warnings, assuming they are even detected. Some sounds suffered low detection rates under noise, particularly the windows down ambient condition. Follow-on research described in a separate report provides a laboratory replication of these findings, an investigation of additional ambient noise conditions, and investigations of the effects of signal loudness, annoyance, and consumer acceptability.

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1 Introduction

This report describes the methods and findings of research on the effects of various vehicle interior ambient noise conditions on driver perception of warnings and messages. This task is part of a larger National Highway Traffic Safety Administration project titled *Crash Warning Interface Metrics (CWIM), Phase 3*. The CWIM project deals broadly with the effectiveness of the driver interface for in-vehicle crash warnings. The *CWIM Phase 3 Final Report* (Lerner et al., 2014) includes a summary of this ambient noise effects research effort, as well as chapters addressing the other research efforts conducted within Phase 3 of the CWIM program, which are broadly encompassed under the following research areas:

- *Research toward collision warning and lane departure warning protocol development*: Explored methodological aspects of warning DVI evaluation, including basic method (test track, simulator), incentive structure, distraction task, alert timing, training and pre-exposure to systems, and simulator motion fidelity.
- *Research on variability among warning signals*: Included three main topic areas. It continued an earlier line of research investigating the potential for negative transfer of learning when switching between vehicles with different forward collision warning (FCW) DVIs. It also included a series of experiments on categorical perception of warnings and alerts, which cumulatively defined signal parameter criteria that effectively delineate alarms from less urgent messages. Finally, this research area investigated acoustic signal detectability and perception under varied ambient noise conditions during real driving.
- *Temporal aspects of interference from other in-vehicle messages*: Included two driving simulator experiments that investigated the effects of a non-urgent alert occurring before an urgent crash warning on driver behavior. The temporal gap between alert and warning was systematically varied, as were the modalities of the early alert and the warning. The first experiment involved undistracted drivers; the second involved drivers who were distracted at the time of a critical event.

In order to be reasonably effective, in-vehicle crash warnings must be reliably and rapidly detected by the driver and properly interpreted. They must convey the proper degree of urgency so that driver response is quick and appropriate. They should be distinguishable from less urgent alerts and messages, so that distraction, annoyance, and false alarm mistrust effects are minimized. Considerable research has addressed these issues, both within the CWIM project and broadly in the literature. However, the vast majority of this work has been conducted under relatively benign in-vehicle ambient noise conditions. Whether on-road or driving simulator methods are used, the conditions have typically been moderate speeds on good quality road surfaces with major potential sources of interior noise excluded. Warnings, however, need to remain effective under the likely range of noise conditions that may be anticipated in vehicles. Very little information exists on perception of meaning and urgency in noise even if the sound is detected.

Determining the appropriate sound intensity at which to present acoustic signals is not straightforward and not all signals of the same intensity will be perceived as well under various noise conditions. Recommendations for acoustic warning signal characteristics from a variety of sources have been summarized in Campbell et al. (in preparation). Sound level recommendations from various sources cited by Campbell et al. include 20-30 dB above masked threshold; 10-15 dB above masked threshold; at least 15 dB above ambient noise level for cautionary signals and at least 20 dB above ambient noise level for alerting signals; and more. Various of the aforementioned sources also indicated maximum sound levels that should not be exceeded (e.g., 90 dBA). Under many actual driving cases with noisy backgrounds, meeting a minimum criterion above masked threshold or ambient noise level would result in exceeding the recommended maximum threshold. Furthermore, as Campbell et al. note, it may be desirable to have some classes of warnings or alerts presented at a lower intensity than others, which further limits flexibility. Of course, ambient noise levels in vehicles can vary substantially under different driving conditions, so unless the intensity of a signal is variable and intelligently adapted in real time to the current ambient noise condition, some "baseline" ambient noise level and spectrum must be assumed. Campbell et al.'s own guidance based on their review is that auditory signals should be in the range of 10-30 dB above masked threshold (with a recommended minimum of at least 15 dB) or at least 15 dB above ambient noise. The signal should not exceed 90 dB.

Despite such existing recommendations, actual practice among OEMs often results in sound levels that are lower than recommended, at least under some driving conditions. For example, Lin and Green (2013) measured sound levels for a variety of driver assist functions in ten models of 2013 cars. These included the functions of blind spot warning, lane departure warning, and park assist. Most warning sounds were in the 65-70 dBA range, although Volvo models had somewhat higher levels. Actual industry practice may be driven by various factors, including consumer acceptance if signals are perceived as overly loud and annoying.

In the present study, the objective was to measure various aspects of driver perception of warnings and alerts under a range of ambient noise driving conditions on actual roads. The characteristics and sound level of in-cab ambient noise may vary due to the vehicle's physical characteristics, the road surface, surrounding traffic, travel speed, and interior noise sources. As an initial study of this topic, only a limited set of ambient noise conditions could be included. Likewise, there are a great many types of auditory displays that might be evaluated, including various sounds as well as voice messages. Only a limited set of auditory displays could be included. The goal, then, was to provide an initial assessment of the nature and magnitude of the effects of ambient noise conditions on key aspects of driver perception of warnings. The intent was to encompass a range of noise conditions and auditory signal types. Follow-on research described in a separate report (Singer, Lerner, & Kellman, 2014) provides a laboratory replication of these findings, an investigation of additional ambient noise conditions, and investigations of the effects of signal loudness, annoyance, and consumer acceptability.

It should be noted that in addition to this study of driver perception of warnings under ambient noise conditions, the project also included a parallel effort to produce a library of recordings of ambient vehicle noise under a range of driving conditions. The audio library and accompanying documentation are provided as a separate deliverable.

2 Method

2.1 Study design

The experiment was a three-factor design, with one between-groups factor (vehicle type) and two within-groups factors (interior noise condition, acoustic signal). Three different vehicles were used in the experiment in order to provide a representative range of vehicle types: (1) a small car, (2) a larger sedan, and (3) an SUV. Each participant drove only one of these vehicles. During the drive, data were collected under three different interior noise conditions: (1) windows up, music off; (2) windows down, music off; and (3) windows up, music on. The order in which each noise condition block was presented to participants was counterbalanced within each vehicle condition.

A set of 15 different acoustic signals was presented under each noise condition. These included three unique voice messages and eight unique non-voice sounds. All eleven of the unique sounds and voices were presented at a sound pressure level (SPL) of approximately 65 dBA as measured near the driver's right ear. One of the voice messages and three of the non-voice sounds were also presented at 75 dBA, with the resultant total of 15 signals. The lower 65 dBA level is representative of a number of acoustic alerts as measured in actual current practice (e.g., Lin and Green, 2013). The higher 75 dBA level is more consistent with human factors guidance (e.g., Campbell et al., in preparation), assuming a moderate level of ambient vehicle cab noise.

Five different dependent measures were recorded to evaluate driver response. These included: (1) a measure of reaction time for the participant to detect the occurrence of a signal; (2) a rating of signal noticeability; (3) a rating of signal urgency; (4) a rating of speech intelligibility (for voice messages only); and (5) perceived meaning of the signal (chosen from a set of four alternatives).

Further details on the vehicles, driving conditions, auditory signals, and dependent measures are in sections that follow.

2.2 Participants

Participants included 34 drivers aged 22 to 49, with 13 males and 21 females. No participants reported having hearing decrements or using hearing assistive devices. All drove regularly, held valid U.S. driver's licenses and passed a screener of their motor vehicle records. Anyone with a history of serious moving violations or suspensions was excluded from the study. No participants dropped out or were removed from the study.

Participants were recruited through the Volunteers section of Craigslist and through a news item posted on Westat's intranet homepage. Westat employees were not eligible, but could refer friends or family. Participants received $75 for completing the session. Prospective participants completed a screener questionnaire. The screener questions concerned age, gender, license status, and familiarity with various types of vehicles. It also included a set of questions related to hearing impairment. A recruitment ad and the telephone screener are shown in Appendix A and Appendix B, respectively.

2.3 Instrumentation and displays

2.3.1 Vehicles

Three different classes of passenger vehicles were used in order to provide a range of vehicle types. These types were small car, sedan, and SUV. The specific vehicles used were selected from among the most popular (highest sales) models in that class and with good rental availability. The specific vehicles were:

- Small car: 2013 Hyundai Accent GLS
- Sedan: 2013 Toyota Camry LE
- SUV: 2013 GMC Terrain SLT

2.3.2 Roadway

Data collection took place on a limited access toll highway (Maryland Route 200) running East to West in Montgomery County, with a 60 mph speed limit. Participants traversed this route between Shady Grove Road and Briggs Chaney Road in both directions until data collection was complete. This span of roadway was about 13 miles in length (one way). This is a relatively new highway with smooth and uniform asphalt over most of its length. It is also generally free-flowing, without congestion. These attributes permitted good control over ambient road noise and speed conditions. The roadway has three travel lanes in each direction. Participants were instructed to travel in the right lane except when needing to pass slower vehicles.

2.3.3 Noise conditions

All drives were conducted during clear weather on dry roads, with a target speed of 60 mph. The fan on the climate control system was on but set to a low setting. During the Baseline condition, all windows were closed and music was off. During the Windows Down condition, the front windows on both sides of the vehicle were fully opened. During the Music On condition, the song "Café Amore" by Spyro Gyra played in a continuous loop. The song could be categorized as instrumental smooth jazz. It was selected because it had been used in previous research (Brodsky, 2002) and has a medium tempo and relatively constant loudness through the duration of the track. The song has a dynamic range of 14 dB, where dynamic range is defined as the difference between a song's maximum sound pressure level (SPL) and its average SPL.

The volume of the music was adjusted by the participant to the volume they would typically use for their own music while driving alone in their own car. However, the experimenter required participants to set the volume at a level equating to at least 60 dB(A), as measured in an otherwise silent vehicle. The minimum SPL was established to ensure that the music could potentially affect participants' detection and ratings of messages. A maximum SPL of 85 dB(A) was also established, but no participants attempted to exceed this level. Music SPL was measured in the vehicle by recording the SPL of a volume-matched pink noise track at the same level as the music set by participants. The bass, treble, balance, and fade settings for each test vehicle's sound system were preset to neutral "0" values.

Ambient noise level was measured continuously during data collection, with the microphone mounted approximately 12 inches to the right of the participant's right ear. This was done to define a typical ambient noise level and range under each condition, as well as being able to identify outlier ambient noise levels during any particular trial. The typical ambient sound levels during the measurement sessions, in each condition for each vehicle, are shown in Table 1. A range is shown for the Music condition, since this varied considerably based on participant preference.

Table 1. Typical ambient sound levels (dBA) in each condition

Vehicle	Noise Condition	Typical dBA
Small car	Baseline	65.56
	Windows down	76.11
	Music	70.93 (67-75)
Mid-size sedan	Baseline	63.89
	Windows down	73.39
	Music	73.00 (66-81)
SUV	Baseline	64.44
	Windows down	74.56
	Music	70.39 (66-77)

2.3.4 Auditory signals and stimulus presentation

Fifteen auditory signals were compared in the experiment. In addition, several other signals were used for training or as novel signals to help prevent the participant from recognizing that the same set of sounds was being used under each ambient noise condition. There were 11 unique alerts presented at approximately 65 dBA. Four of these sounds were also presented at approximately 75 dBA. All sounds were initially volume-adjusted to these levels, but were then adjusted for perceptual equivalence of loudness, as determined by a panel of six individually tested raters.

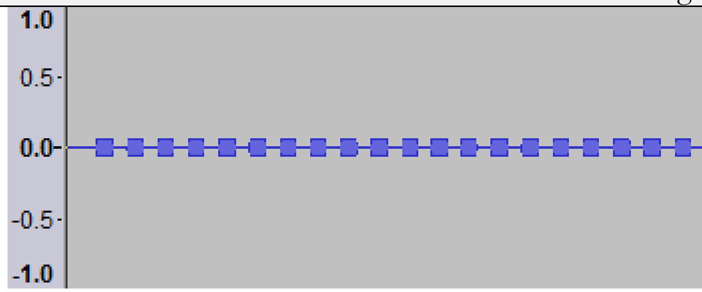
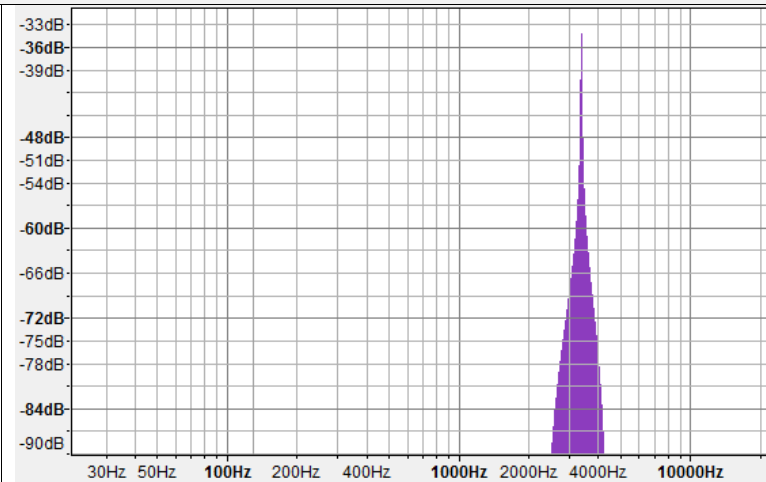
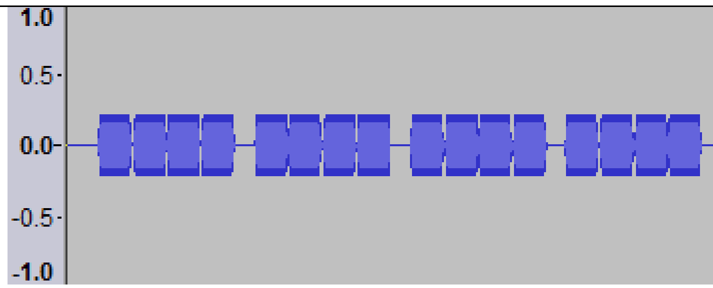
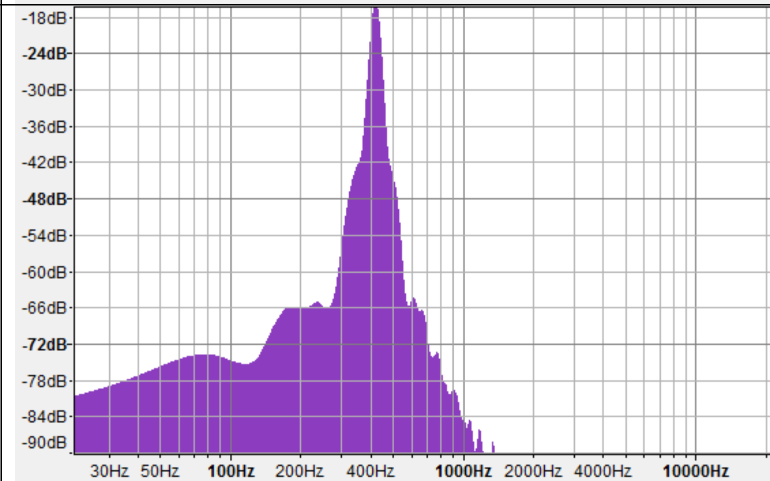
The alerts used in this experiment were adapted from examples of current in-vehicle warnings and alerts of various types, other sounds found in various sources, and synthetic speech messages created using an online text-to-speech generator.[1] The experiment was not intended as a test of any particular acoustic signal but rather to examine the effects of ambient noise across a diverse range of signals. As a set, these signals intentionally spanned a range of temporal and acoustic characteristics. Each signal was of a nominal length of 2 seconds. It is important to note that the signals that were sourced from current in-vehicle systems were presented using a different speaker in a different vehicle interior, and are not necessarily presented at the same SPL as the original alerts. Therefore, the results of this experiment do not necessarily reflect upon the messages as used in their native vehicle environments. The alerts used in this experiment are briefly described below. Note that alerts 1-8 are sounds presented at 65 dBA, alerts 9-11 are voice messages at the 65 dBA level, and alerts 12-15 are the subset of alerts presented at the 75 dBA level. Table 2 lists the 11 unique sounds and provides an amplitude waveform and a frequency spectrograph for each one.

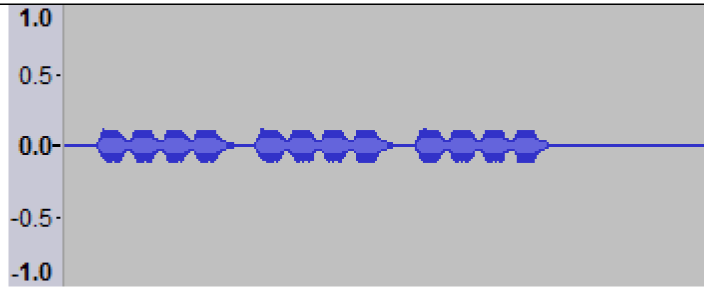
1. FCW 1: One burst of 20 fast beeps with a relatively high frequency profile.
2. FCW 2: Four bursts of four fast beeps with a relatively low frequency profile.
3. Blind spot warning: Three bursts of four fast beeps, each with a smoothed onset and decay and a sustained low intensity sound between beeps.
4. Pedestrian warning: A constant beep with a duration of 2 seconds.
5. Seat belt alert 1: A single chime that decays to silence in the span of about two seconds, with intensity varying in a wavelike pattern.
6. Seat belt alert 2: Two chimes, each of which decays to silence in the span of about one second
7. Park assist 1: One burst of eight beeps.
8. Park assist 2: Two bursts of three beeps.
9. Female voice – not urgent: Female voice says “Attention.”
10. Female voice – urgent: Female voice says “Warning, warning.”

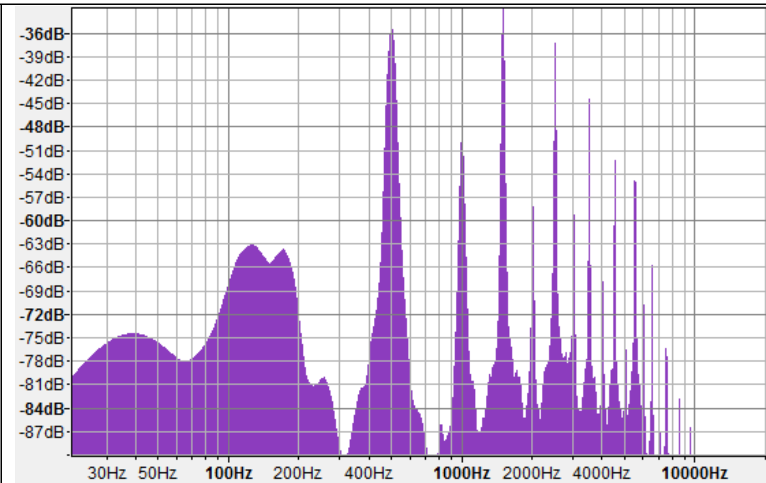
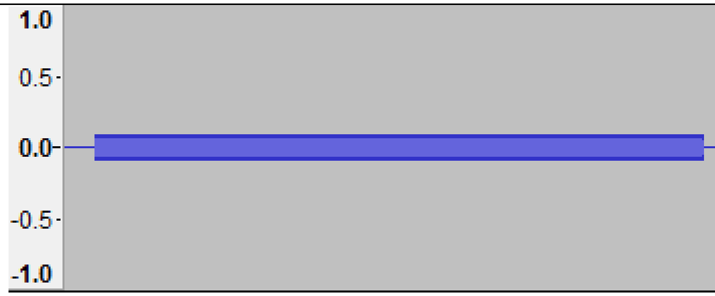
[1] http://www.oddcast.com/home/demos/tts/tts_example.php

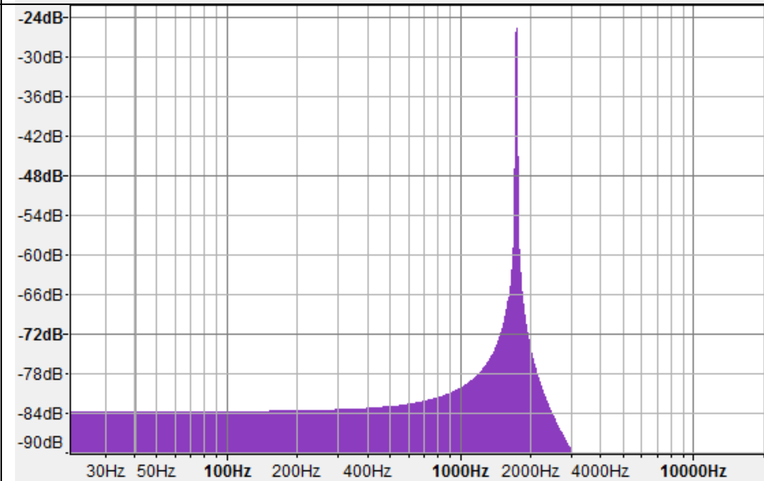
11. Male voice – urgent: Male voice says “Warning, warning.”
12. FCW 1 (high): Same as FCW 1, but presented at 75 dB
13. Blind spot warning (high): Same as Blind spot warning, but presented at 75 dB
14. Park assist 1(high): Same as Park assist 1, but presented at 75 dB
15. Female voice – urgent (high): Same as Female voice – urgent, but presented at 75 dB

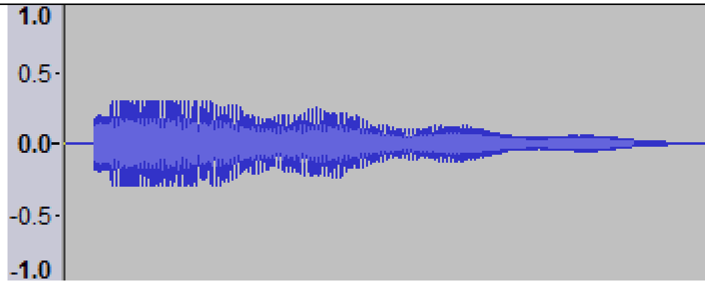
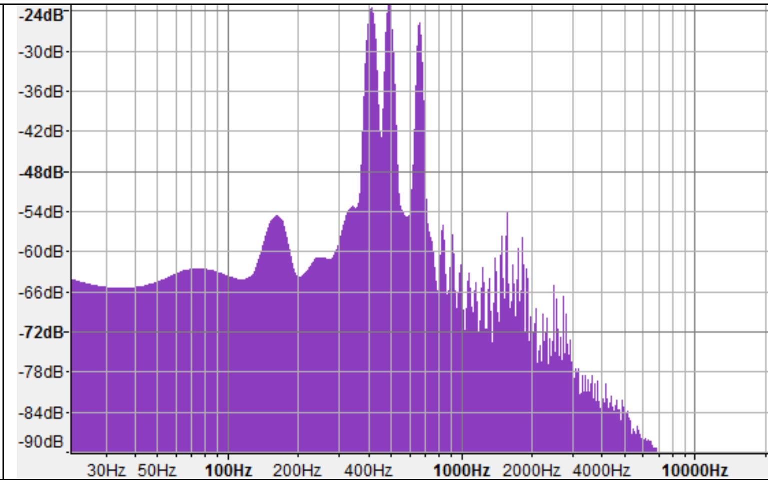
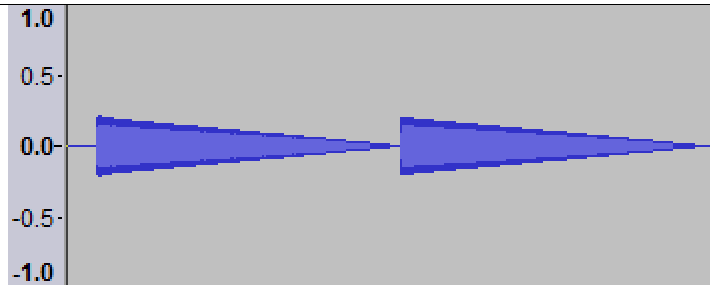
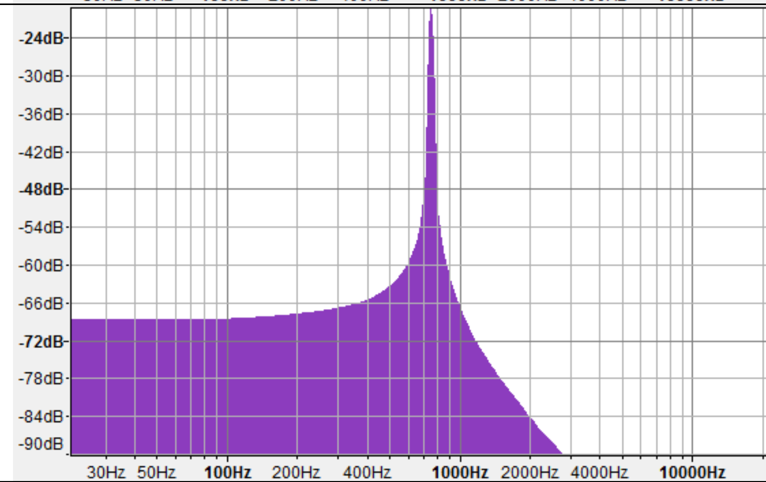
Table 2. Descriptions of auditory tones and voice signals

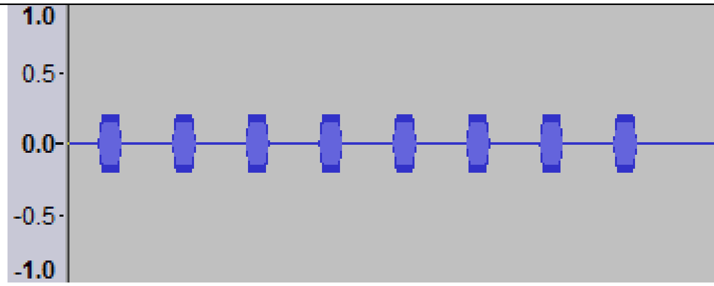
No.	Name	Amplitude waveform (2 s duration)	Frequency and intensity spectrograph (logarithmic)
Tone Signals			
1	FCW 1	 One burst of 20 fast beeps with a relatively high frequency profile.	
2	FCW 2	 Four bursts of four fast beeps with a relatively low frequency profile.	

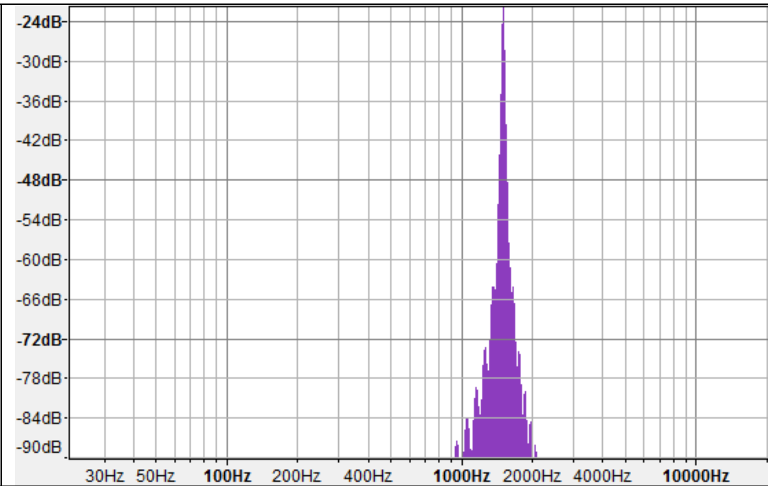
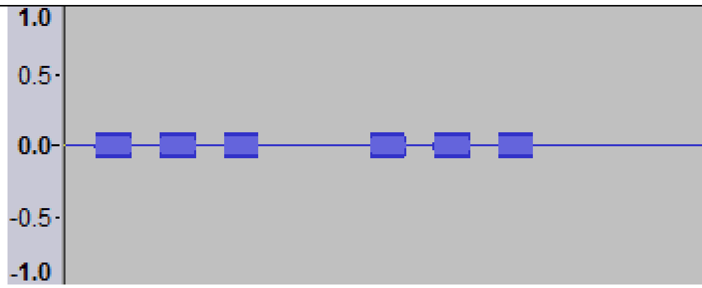
<table>
<tr>
<td>3</td>
<td>Blind spot warning</td>
<td>

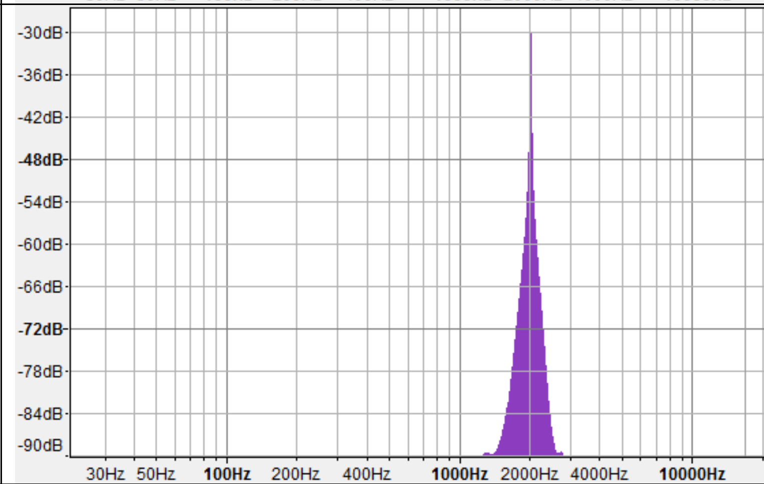
Three bursts of four fast beeps, each with a smoothed onset and decay and a sustained low intensity sound between beeps.</td>
<td>
</td>
</tr>
<tr>
<td>4</td>
<td>Pedestrian warning</td>
<td>

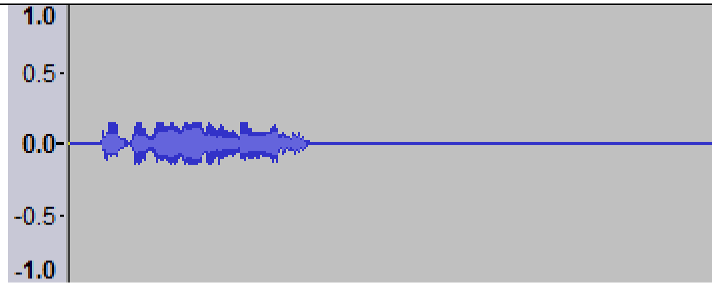
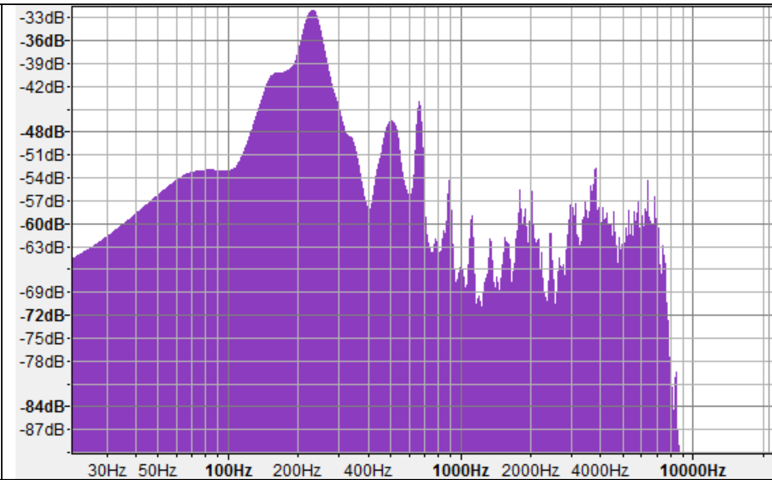
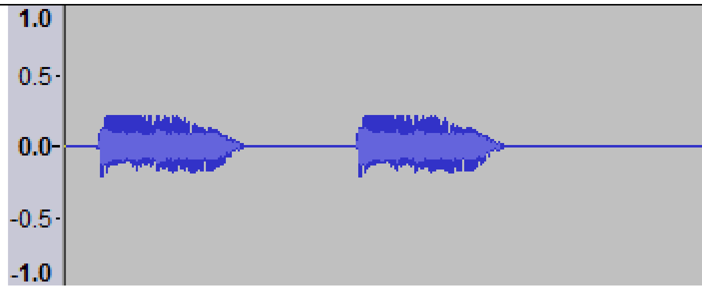
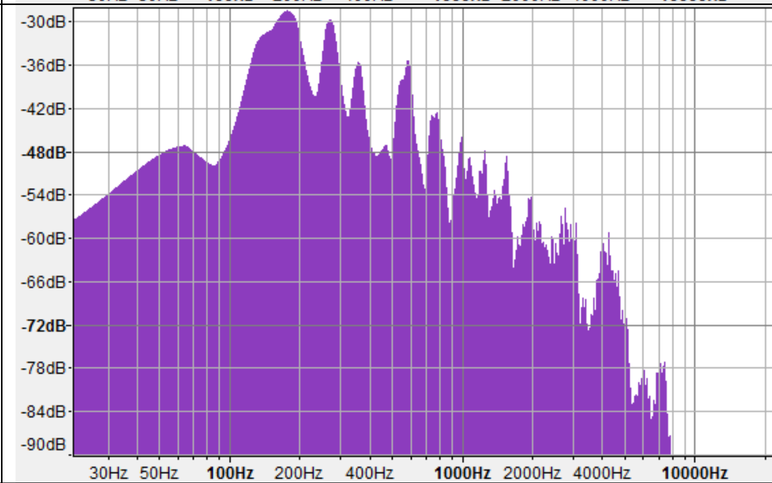
A constant beep with a duration of 2 seconds.</td>
<td>
</td>
</tr>
</table>

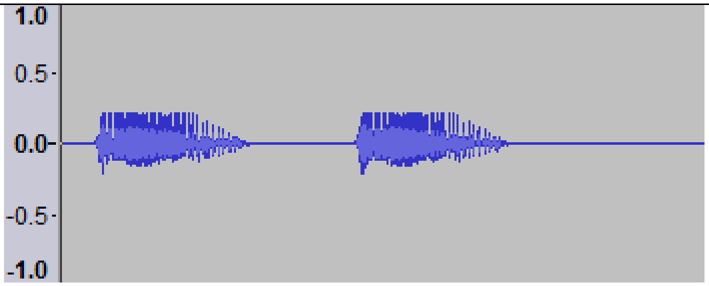
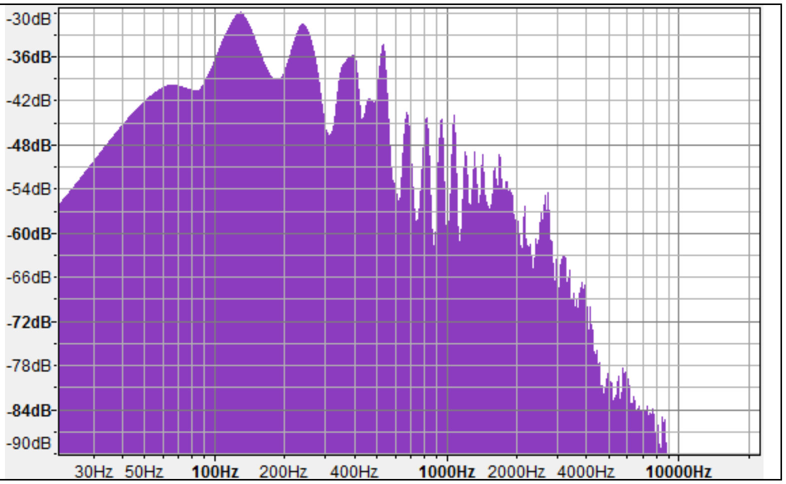
5	Seat belt alert 1	 A single chime that decays to silence in the span of about two seconds, with intensity varying in a wavelike pattern.	
6	Seat belt alert 2	 Two chimes, each of which decays to silence in the span of about one second.	

<table>
<tr><td>7</td><td>Park assist 1</td><td>

One burst of eight beeps.</td><td>
</td></tr>
<tr><td>8</td><td>Park assist 2</td><td>

Two burst of three beeps.</td><td>
</td></tr>
<tr><td colspan="4">Voice signals</td></tr>
</table>

9	Female voice – not urgent	 Female voice says “Attention.”	
10	Female voice – urgent	 Female voice says “Warning, warning.”	

11	Male voice – urgent	 Male voice says "Warning, warning."	

During the experimental drives, the auditory signals were presented by an X-Mini II XAM4 capsule speaker mounted on top of the dashboard immediately behind the steering wheel (see Figure 1). A pink noise calibration signal was used to adjust the volume so that for each vehicle the nominal baseline signal intensity was 65 dBA at the driver's position.

Figure 1. Capsule speaker used for stimulus presentation

Within each noise condition block, the experimental control software generated a random presentation order for the 15 auditory signals. The software provided a random time gap that ranged from 10 to 50 seconds and averaged 30 seconds from the completion of the previous sound's ratings to the presentation of the next sound. Once the random time had passed, the software indicated to the experimenter that the next signal could be activated. The actual triggering of the trial was done by the experimenter, who first determined that there were no usual acoustic circumstances (e.g., a large truck passing or a patch of noisier roadway surface). When triggered, a trial began with a 5-second pre-signal period to document the ambient noise level. The signal was then automatically triggered at the end of the 5 seconds. When the participant detected the signal they pressed a microswitch button, worn on their finger or thumb, to provide a reaction time. The microswitch was attached to a Velcro strap that allowed the participant to locate the switch in a comfortable but easy-to-reach position, in a manner that was unlikely to result in unintentional switch activations. The precise location on the index finger or thumb was determined by the participant.

The data collection system recorded the reaction time and then cued the experimenter to verbally present a series of rating and choice questions. The questions were:

- "How noticeable was that that sound?" (1=not very; 7=extremely)
- "How urgent was that sound?" (1=not very; 7=extremely)
- "How intelligible was that sound"? (this question only asked for voice messages) (1=not very; 7=extremely)
- "Which of the following most closely matches the meaning conveyed to you by this sound?"
    - Urgent crash warning
    - Safety information
    - Information not related to safety
    - Incoming personal communication

The participant provided verbal responses which were manually entered by the experimenter. Thus for each trial, the following data were collected: ambient noise level in the period immediately preceding the auditory signal; detection reaction time; ratings/choices for noticeability, urgency, intelligibility (voice messages only), and perceived meaning. The definitions of key terms are shown in Table 3.

Table 3. Definition of rating factors and choice options

Term	Definition
Noticeability	The sound is easily noticeable among other sounds and noises in the vehicle
Urgency	The sound conveys a sense of importance, motivating you to make an immediate response
Intelligibility	The spoken words can be easily understood
Perceived Meaning	Choose the one that most closely matches the meaning conveyed to you by this sound
Urgent crash warning	… means that there is a situation in which you must react immediately to avoid a crash. For example, imagine you are about to hit a pedestrian or about to run off the road.
Safety information	… means that there is a safety issue that you need to pay attention to, but you are not in immediate danger of a crash. For example, imagine that you are approaching a work zone where two lanes are closed or there are reports of icy roads ahead.
Information not related to safety	… means exactly what it says – you are receiving information, but the information is not safety-related. This could include various types of information, such as traffic congestion several miles ahead, prices at nearby gas stations, or a navigation system telling you to make the next turn.
Incoming personal communication	… means that you are receiving an incoming call, text message, email, or other direct communication.

2.4 Procedure

Upon arrival, the participant's driver's license was checked to confirm identity and status and the participant read and signed an informed consent form. They were then seated in the test vehicle and the seat position and mirrors were adjusted. The experimenter was positioned in the rear right seat.

The complete set of instructions to the participants is attached in Appendix C. The general purpose and procedure were first explained to the participant as an overview. Safety priorities were made clear and participants were asked to silence their cell phones so not to add any extra unintended sounds that might disrupt the study. This was followed by a period of vehicle familiarization, during which the participant drove the vehicle around the parking lot. Following this, the participant practiced opening and closing the electrically-operated vehicle front windows and adjusting the music on a CD in the vehicle stereo system. The microswitch was then attached to the participant's finger or thumb and adjusted so that they could quickly and easily activate the switch without removing a hand from the steering wheel or altering their typical hand positions while driving. The experimenter confirmed that the switch mounting position was unlikely to result in unintended switch activations.

Next, the participant was introduced to the responses they were to make when they heard an auditory signal. An example sound (distinct from any in the set of test signals) was presented with the vehicle stationary. The experimenter had the participant operate the microswitch to provide the detection reaction time. The experimenter then walked the participant through the set of ratings and choice questions. The participant was provided with a definition of each of the factors to be rated and for each choice option for the meaning of the signal. The ratings for the three attributes of noticeability, urgency, and intelligibility were all made on a scale of 1 (not very) to 7 (extremely).

Following this example, the participant was presented with a second practice trial. This time the signal was a voice message, distinct from other voice messages in the set of test signals. The participant clicked the microswitch after detecting the message and then made ratings about each attribute. During this trial, the experimenter introduced the intelligibility question, which was not asked for the previous practice question. Following this training, the experimenter directed the participant onto the test roadway (Maryland Highway 200) and the data collection portion of the session began. The participant was instructed to try to maintain a target speed of 60 mph and to travel in the right lane except when needing to pass slower moving vehicles.

Data collection occurred in three blocks, each block under a different ambient noise condition. The sequence of the three noise conditions was counterbalanced within each vehicle condition. The first block included only the core set of 15 auditory signals (see Table 2). The second and third blocks each began with two novel auditory signals (one voice, one non-voice). Different novel sounds were used for the second and third blocks. This was done to help preclude the participant from assuming that the same set of signals occurs for each block. The novel signals were then followed by the 15 signals of the primary set in a random order.

During the drive, the experimenter was seated in the right rear seat and had a laptop computer for experimental control and data entry. The computer program indicated the sequence of blocks and the sequence of trials within blocks. The program indicated to the experimenter when they were authorized to initiate the next trial. The experimenter triggered that trial once they confirmed that the roadway situation was appropriate (e.g., proper speed, no unusual surrounding vehicles, proper road surface). Triggering a trial first initiated a 5-second interval, which served as a basis for post hoc confirmation of appropriate ambient noise levels. At the end of 5 seconds, the auditory signal was activated. When the participant pressed the microswitch the response time was automatically recorded and the sequence of rating and meaning questions appeared on the experimenter's screen. The experimenter then read each question to the participant, who gave a verbal response. The experimenter then entered the response on the computer. Once the data for all questions were entered, the controlling software began timing the interval for the next trial. If the participant did not activate the microswitch within 8 seconds of activation of the auditory signal, the trial was recorded as a failure to detect the sound. In the case of this event, the experimenter was presented with an option from the computer, asking them if the sound had been heard by the participant. If the experimenter clicked "no", the software began the timing for the next trial. If the participant verbalized that they heard the sound but forgot or mis-clicked the microswitch, the experimenter clicked "yes" and proceeded to ask the participant questions about the sounds. (Events of this type were rare.) Participants were not given any feedback if they failed to hear a sound, so if they did not verbalize that they heard the sound on their own, the rating questions were not asked.

When the "Music On" block of trials was scheduled to begin, the experimenter had the participant turn on the CD player and adjust the sound level of the music to the volume they would choose for listening to their own music when driving alone in their own vehicle. This adjustment was made while traveling at the target speed of 60 mph. Once the participant had set the music at their chosen level, the experimenter instructed them to skip to the next track, which was a pink noise track calibrated to the level of the music. A 10-second recording was made near the driver's head position to document the SPL inside the vehicle with the pink noise playing. The experimenter also documented the digital volume knob setting selected by the participant. After sound level measurement, the participant skipped back to the music track and the stimuli were presented as they were in the other two noise conditions. If the participant had the music volume set loud, the experimenter asked them to turn the music off while answering the ratings questions. Note that the level of the music selected by participants had no effect on the level of the acoustic alerts presented during this block.

The entire session took approximately 90 to 120 minutes, with the data collection portion taking approximately 60-80 minutes.

3 Results

Ambient noise conditions had a substantial effect on all dependent measures in this experiment. Three factor (alerting signal, ambient noise background, and vehicle type) analyses of variance were conducted for the measures of rated noticeability, rated urgency, and response time. The conclusions of these three ANOVAs were identical and are presented in Tables 4, 5, and 6. In each case, there was a statistically significant effect of alerting signal, noise condition, and the signal-by-noise interaction. There was no main effect of vehicle type and no interaction of vehicle type with ambient noise condition. There was a statistically significant interaction of alerting signal with vehicle type, although the effects were not pronounced. Some such interaction may be expected due to the complex and varied geometry of the vehicle cabin space and the nature of the reflective and absorbing materials in the car. Such differences in the acoustic space could idiosyncratically affect some particular sound. There was no statistically significant three-way interaction.

Table 4. Summary of ANOVA for noticeability

Effect	DF	F Value	Prob > F
Ambient Noise	2	228.38	<.0001
Alerting Signal	14	94.24	<.0001
Vehicle	2	1.74	0.1918
Ambient Noise X Alerting Signal	28	6.35	<.0001
Ambient Noise X Vehicle	4	1.27	0.2786
Alerting Signal X Vehicle	28	2.83	<.0001
Ambient Noise x Signal X Vehicle	52	0.70	0.9501

Table 5. Summary of ANOVA for urgency

Effect	DF	F Value	Prob > F
Ambient Noise	2	59.90	<.0001
Alerting Signal	14	60.73	<.0001
Vehicle	2	2.58	0.0908
Ambient Noise X Alerting Signal	28	3.98	<.0001
Ambient Noise X Vehicle	4	0.73	0.5714
Alerting Signal X Vehicle	28	2.35	<.0001
Ambient Noise x Signal X Vehicle	52	0.75	0.9010

Table 6. Summary of ANOVA for response time

Effect	DF	F Value	Prob > F
Ambient Noise	2	16.67	<.0001
Alerting Signal	14	13.66	<.0001
Vehicle	2	0.38	0.6843
Ambient Noise X Alerting Signal	28	2.99	<.0001
Ambient Noise X Vehicle	4	1.90	0.1083
Alerting Signal X Vehicle	28	2.05	0.0011
Ambient Noise x Signal X Vehicle	52	0.96	0.5643

Figures 2, 3, and 4 illustrate the effects of alerting signal, ambient noise, and their interaction. Figure 2 shows the group mean ratings of noticeability for each of the 15 sounds for each of the three ambient noise conditions. The overall main effect of noise condition is evident, with alerts being rated highest under baseline noise and lowest under the windows-down condition. However the differences between these three conditions varied among the 15 sounds. The main effect of alerting signal is evident in the substantial difference in rating from one signal to another. On the 7-point rating scale, some alerts were rated near 7, even under high noise conditions. Others were rated about only 2 for noticeability under windows-down noise.

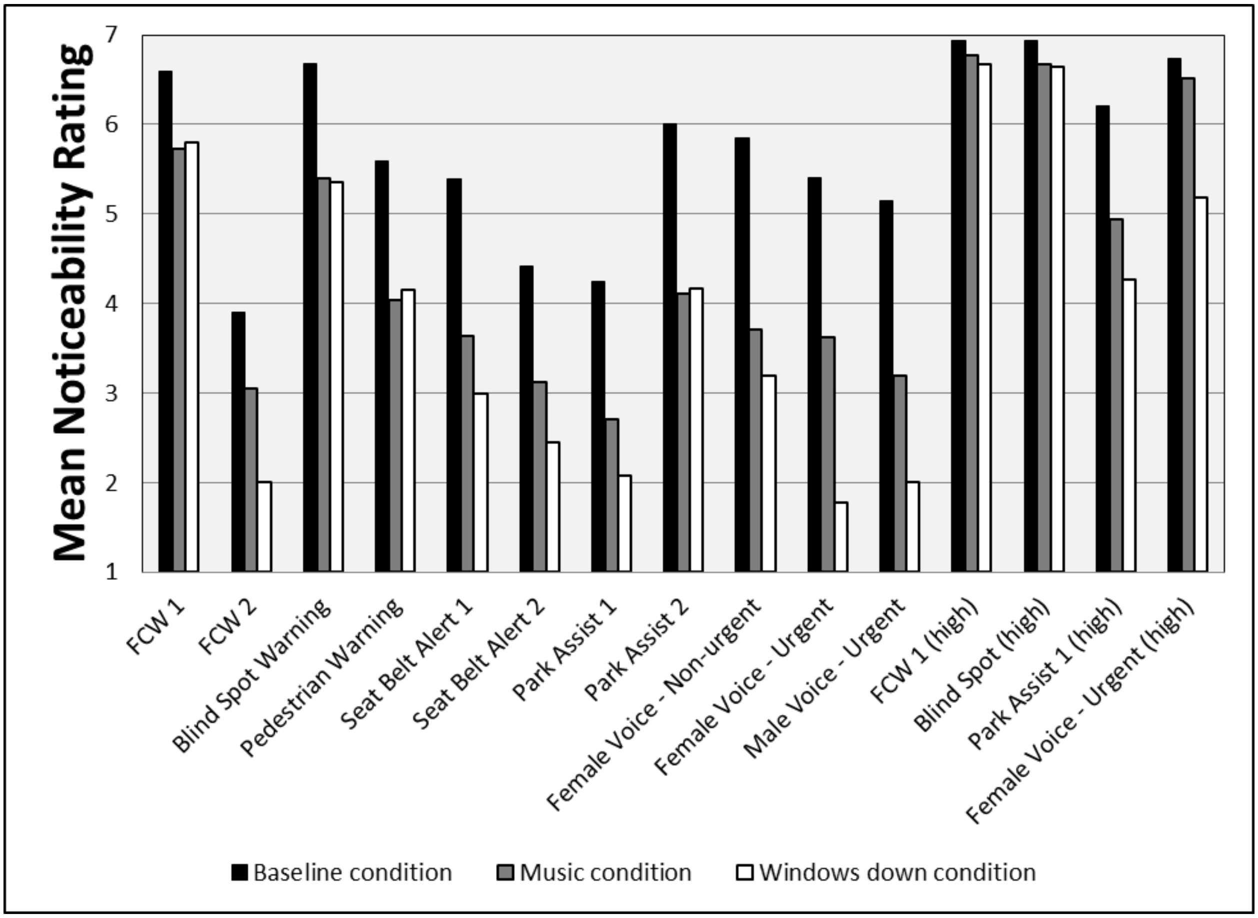


Figure 2. Mean noticeability rating for each combination of signal and ambient noise condition

Figure 3 shows a similar pattern for the group mean ratings of urgency. It may be noted that sounds presented at the 75 dBA level tended to preserve their urgency even under the high ambient noise conditions. Degradation of perceived urgency by ambient noise varied considerably among the 65 dBA sounds. As Figures 2 and 3 illustrate, even among sounds equated for approximately equal loudness under relatively quiet listening conditions, there are substantial differences in noticeability and urgency under moderate noise conditions (baseline noise) and even greater differences under higher noise conditions.

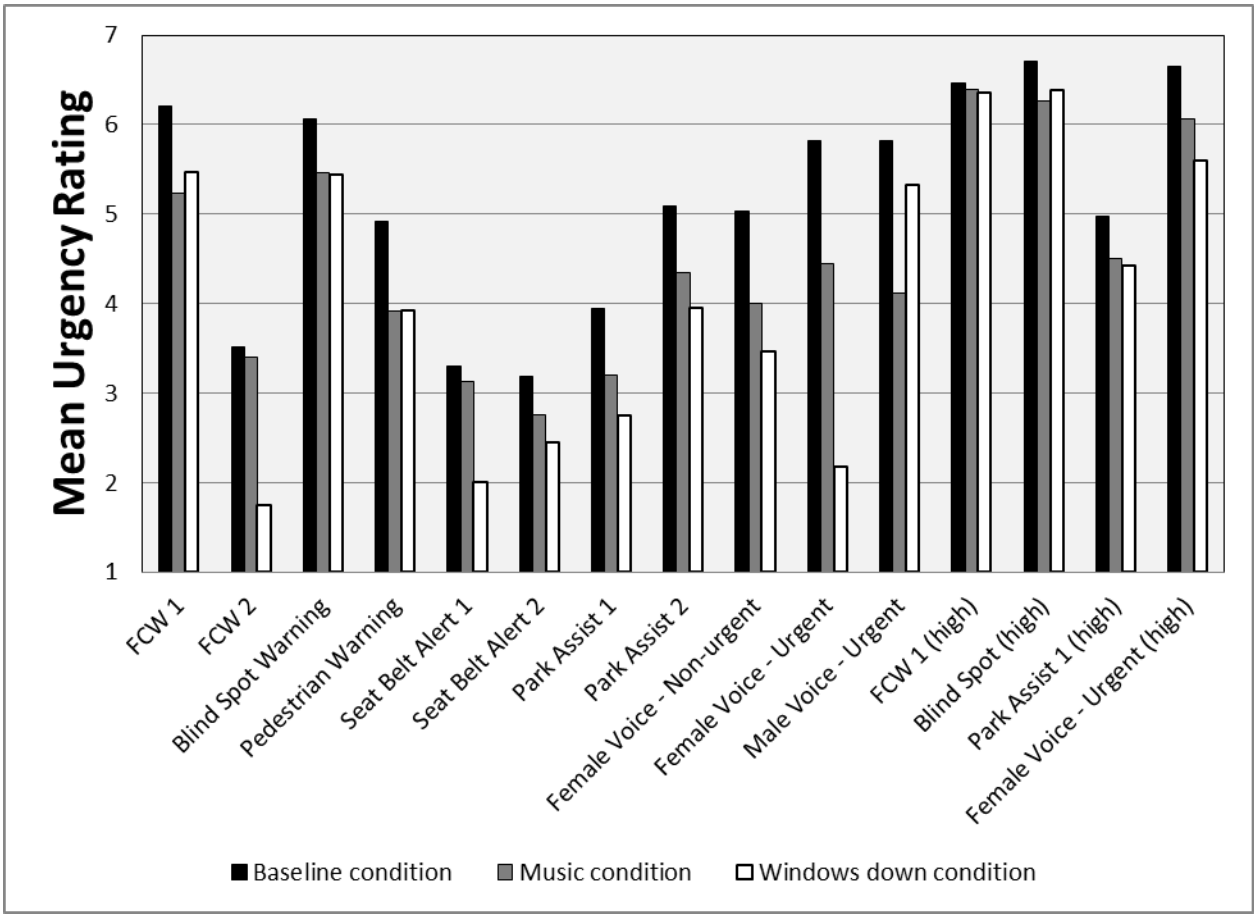


Figure 3. Mean urgency rating for each combination of signal and ambient noise condition

Figure 4 shows the mean response time data. Differences among alerting sounds are again evident. The differences among the ambient noise conditions are not as consistent, but response times tend to be somewhat faster in the baseline condition.

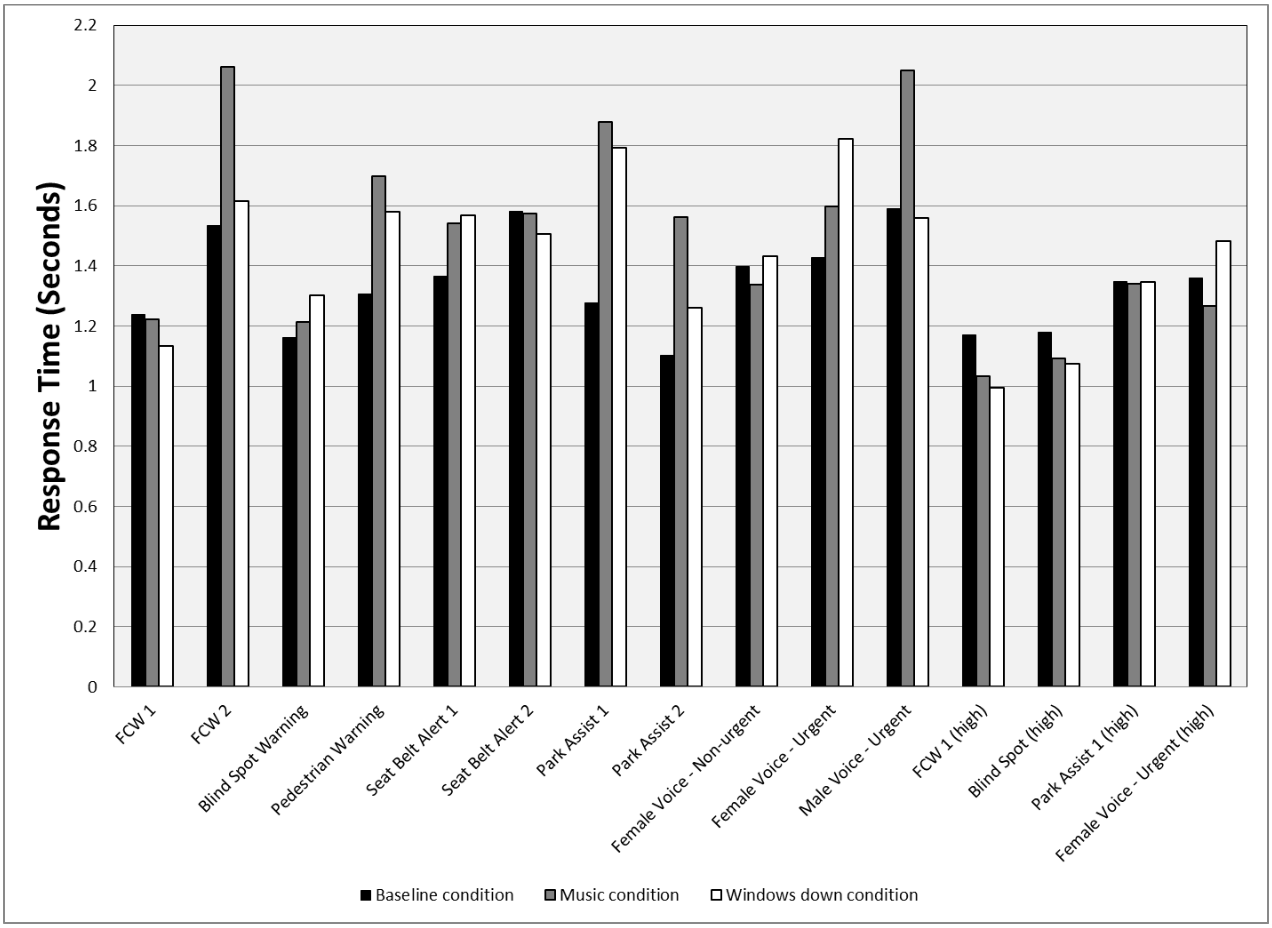


Figure 4. Mean response time for each combination of signal and ambient noise condition

In order to assess the effects of sound level, post hoc tests were conducted to compare each of the four alerts presented at 75 dBA with the identical alert presented at 65 dBA. For the measures of perceived noticeability and perceived urgency, in each case the rating for the 75 dBA sound was statistically significantly higher than for the 65 dBA sound (at $p<.0001$ in all cases). For the response time measure, responding was significantly faster to the 75 dBA sound for park assist 1 ($p<.0001$) and female voice - urgent ($p<.0005$). Sound level did not significantly speed response time for FCW 1 or blind spot warning.

The analyses and figures above represent the findings on participant responses to alerting signals, given that they were able to detect the signal. Under moderate (baseline) noise, participants rarely failed to hear an alert. Under higher noise conditions, missed signals were more frequent. Across all 15 alerting sounds, only about 1% were missed under the baseline condition, 15% under the music condition, and 36% under the windows-down condition. Under the windows-down condition, some alerts were missed in a majority of cases. Figure 5 shows the percent of times each alerting signal was detected, under each of the three ambient noise conditions. As with the ratings and response time measures, it is evident that even though the 65 dBA alerts were equated to be of similar loudness under relatively quiet listening conditions, they differed substantially in detectability once noise levels rose above the baseline condition. Music had a detrimental effect for most of the alerts, with 10-50% misses. A few 65 dBA alerts continued to be well detected even in the windows down condition. However, others were missed around 90% of the time with the windows down. The four alerts presented at 75 dBA were all well detected, even under the higher noise conditions.

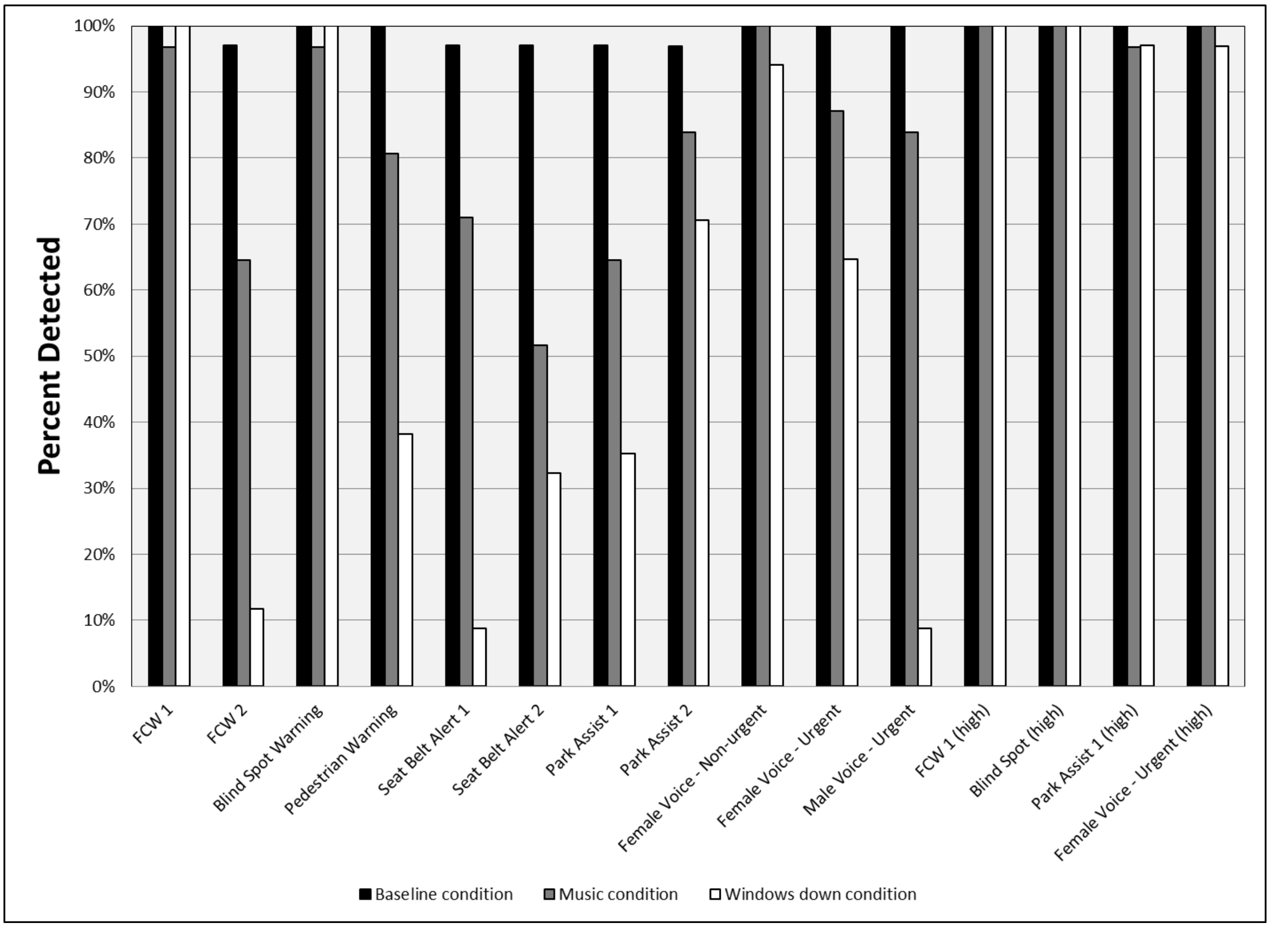


Figure 5. Percentage of participants who detected alerts under each ambient noise condition

In considering the effects of music on the detection of the alerting signals, it should be kept in mind that the participant set the volume of the music to the volume they would typically use for their own music while driving alone in their own car. Thus the actual volume varied from participant to participant. The sound intensity (measured near the driver's ear position while traveling at 60 miles per hour) ranged from 66 to 81 dBA, with a mean of 71.4 dBA and a standard deviation of 3.7 dBA.

This setting may actually be rather conservative as an estimate of how loud some drivers may adjust their music, since the "Café Amore" track is "smooth jazz" and people may adjust their preferred music, in other genres, to louder volumes in actual practice. In order to determine whether the volume at which a particular participant adjusted the music influenced the magnitude of observed noise effects, a difference score was computed between the baseline condition and the music condition, for the measures of rated urgency, response time, and percent of alerts detected. There was no meaningful correlation of music loudness with the difference score for urgency ratings (R=-0.18) or response times (R=0.22). There was a moderate correlation (R=0.70) of music loudness with the difference score for detection rate of the alerting signals. While there was not a highly consistent relationship, 5 of the 6 participants with the largest difference scores for signal detection were among the top third of the group in terms of music volume.

The ambient noise condition influenced the category of meaning that a listener assigned to a particular alert. Participants had the option of classifying a given alert as "urgent crash warning," "safety information," "information not related to safety," and "incoming personal communication." As expected, the various alerts differed in terms of how they were interpreted, with some predominantly viewed as urgent crash warnings and others predominantly view as unrelated to safety at all. Multinomial logistic regression was used to analyze the perceived meaning classifications. Multinomial logistic regression is used to predict the probability of category membership on a dependent variable based on multiple independent variables. This approach is an extension of binary logistic regression that allows for $k>2$ categories of a dependent variable. Maximum likelihood estimation is used to evaluate the probability of category membership. It is an attractive approach due not assuming normality, linearity, or homoscedasticity. In addition, it assumes non-perfect separation of the outcome variables by the predictor variables. The current model analysis was performed in SAS and used a cumulative logit model with Fisher's scoring as an optimization technique. Differences of least square means are reported with Sidak adjusted p-values. The Wald Chi-Square statistics are presented in Table 7.

Table 7. Summary of analysis for perceived meaning

Effect	**DF**	**Wald Chi-Square**	**Prob > Chi Sq**
Ambient Noise	2	11.23	0.0036
Alerting Signal	14	318.29	<.0001
Ambient Noise X Alerting Signal	28	42.38	0.0399
Subject	33	161.07	<.0001

As Table 7 indicates, there were significant effects of ambient noise, alerting signal, and their interaction. Table 8 presents the actual distribution of choices among meaning categories for each alert under each noise condition. The effects of ambient noise were complex and depended upon the particular alert, as the significant interaction term suggests.

Table 8. Distribution of meaning categories for alerts under each ambient noise condition

Alert	Ambient Noise Condition	Meaning Category (%)			
		Urgent Crash Warning	Safety Information	Non-Safety Information	Personal Communication
1 FCW 1	Baseline	18	56	12	15
	Music	17	33	23	27
	Windows Down	26	44	9	21
2 FCW 2	Baseline	3	21	36	39
	Music	0	30	35	35
	Windows Down	0	0	25	75
3 Blind spot warning	Baseline	26	50	12	12
	Music	17	53	7	23
	Windows Down	9	56	21	15
4 Pedestrian warning	Baseline	12	41	35	12
	Music	16	28	44	12
	Windows Down	0	31	54	15
5 Seat belt alert 1	Baseline	0	12	27	61
	Music	0	5	50	45
	Windows Down	0	33	67	0
6 Seat belt alert 2	Baseline	0	24	48	27
	Music	0	31	56	13
	Windows Down	0	36	13	18
7 Park assist 1	Baseline	3	27	42	27
	Music	0	25	40	35
	Windows Down	0	25	50	25
8 Park assist 2	Baseline	6	41	31	22
	Music	4	38	31	27
	Windows Down	0	25	42	33
9 Female voice - non urgent	Baseline	0	65	29	6
	Music	10	42	39	10
	Windows Down	3	44	34	19
10 Female voice - urgent	Baseline	44	50	6	0
	Music	37	37	15	11
	Windows Down	9	36	36	18
11 Male voice - urgent	Baseline	41	53	0	6
	Music	35	42	19	4
	Windows Down	67	0	0	33
12 FCW 1	Baseline	47	24	18	12

Alert	Ambient Noise Condition	Meaning Category (%)			
		Urgent Crash Warning	Safety Information	Non-Safety Information	Personal Communication
(high)	Music	55	16	3	26
	Windows Down	35	47	3	15
13 Blind spot (high)	Baseline	65	29	0	6
	Music	61	16	6	16
	Windows Down	47	32	12	9
14 Park assist 1 (high)	Baseline	3	44	38	15
	Music	3	37	40	20
	Windows Down	9	33	45	12
15 Female voice – urgent (high)	Baseline	82	15	3	0
	Music	58	42	0	0
	Windows Down	38	47	9	6

To illustrate the effects of ambient noise on perceived meaning of the alert, several examples are presented in Figures 6-9. Figure 6 shows the percentage of participants choosing each category of meaning for the blind spot warning presented at the higher (75 dBA) level. Under baseline noise conditions, a majority of participants viewed this sound as an "urgent crash warning," and 94% of participants put it in one of the two safety-related categories ("urgent crash warning" or "safety information"). However, only 61% classified this sound as an "urgent crash warning" under the music ambient noise condition and only 47% under the windows down condition. Figure 7 shows data for the same blind spot warning when presented at 65 dBA. Most participants interpret the sound as safety-related, but only about 26% interpret it as an "urgent crash warning." The percentage reduces under the higher noise conditions, so that only 9% view the sound as an "urgent crash warning" under the windows down condition. Figures 6 and 7 illustrate a trend seen for a number of alerts in which an alert is predominantly perceived as a safety-relevant message under the baseline condition but this aspect weakens under noise. Figure 8 shows another example, this time for the female voice – urgent, at the higher (75dBA) level. The drop in the percentage viewing this as an "urgent crash warning" is particularly dramatic, dropping from 82% in the baseline noise condition to 38% in the windows down condition. This may be because the degree of urgency is conveyed by the content of the speech ("warning"), more so than any sound quality of the voice. Figure 9 shows data for seat belt alert 2. Under baseline noise conditions, relatively few participants (24%) interpreted this sound as being safety-related. Unlike the other examples shown, under higher noise conditions, this percentage did not shrink, but actually increased somewhat (36% in the windows down condition). These examples are intended to illustrate the interaction of ambient noise conditions with specific alerts in terms of what meaning is conveyed. Table 8 may be referred to for all such comparisons.

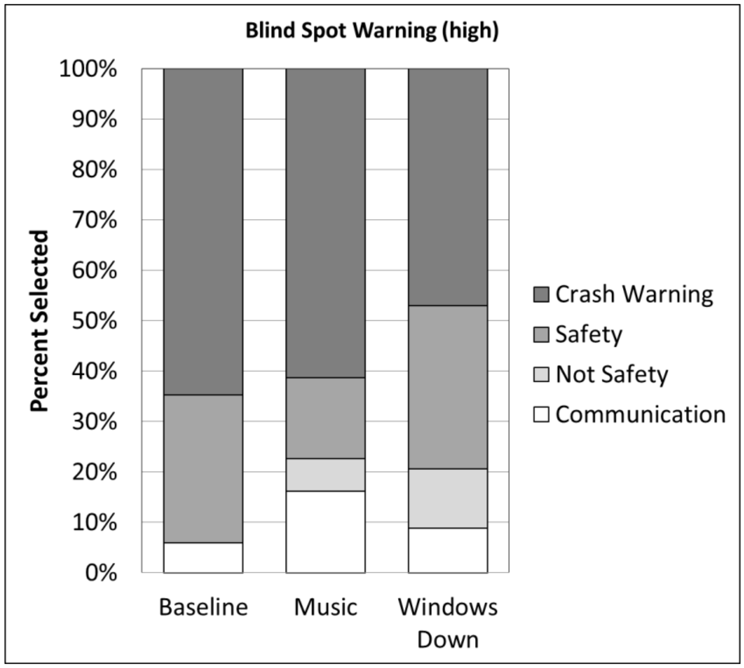


Figure 6. Categorization of signals by ambient noise condition for blind spot warning (high)

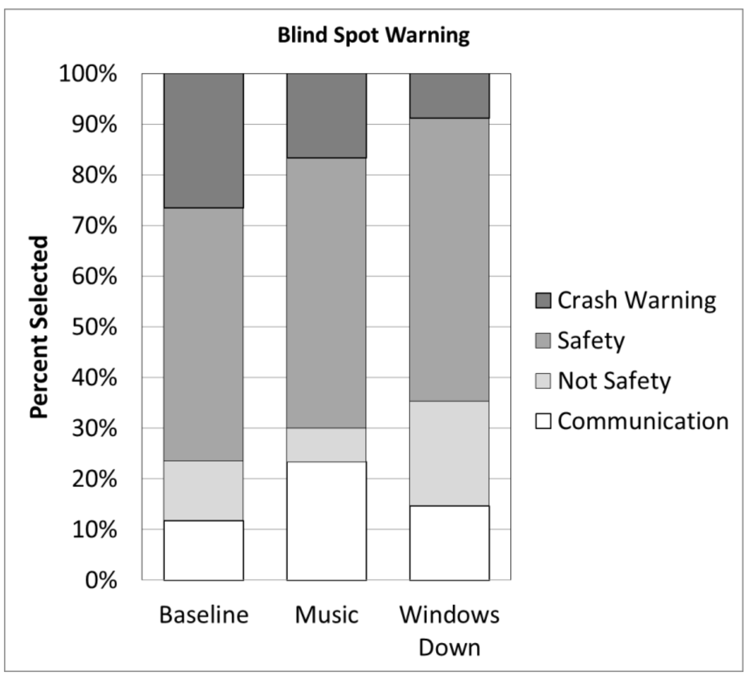


Figure 7. Categorization of signals by ambient noise condition for blind spot warning

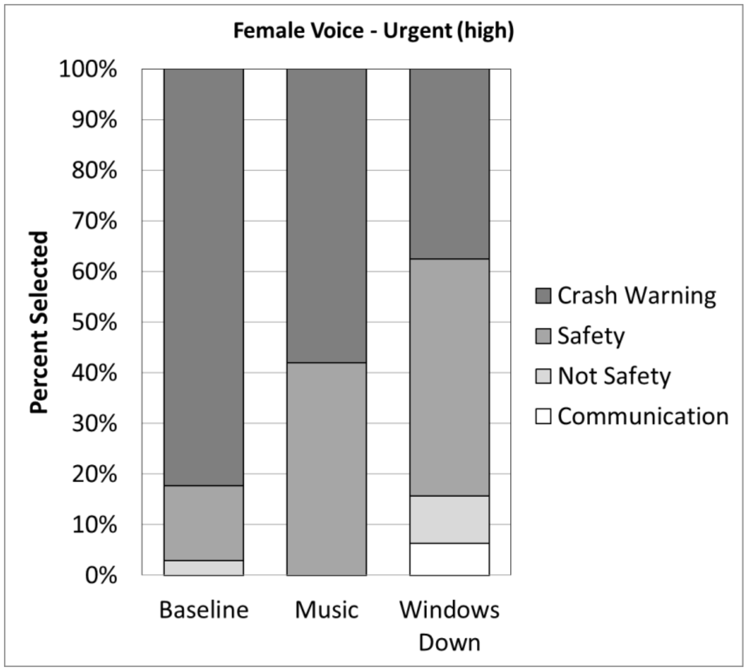


Figure 8. Categorization of signals by ambient noise condition for Female Voice – Urgent (high)

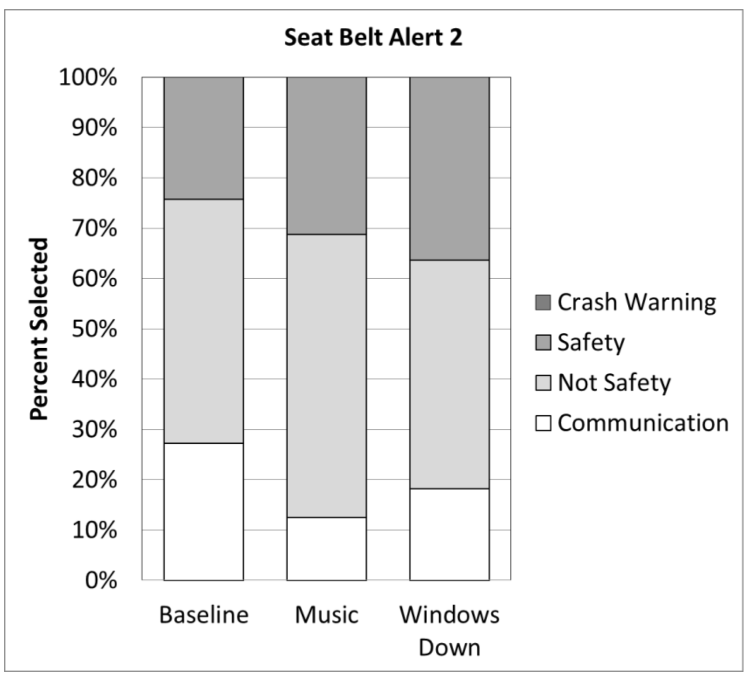


Figure 9. Categorization of signals by ambient noise condition for Seat Belt Alert 2

4 Discussion

This research was motivated by the concern that auditory urgent crash warnings may lose their effectiveness under foreseeable ambient noise conditions in passenger vehicles. Imminent crash alerts that appear effective in moderate ambient noise levels may not be reliably detected in higher noise, or may lose their subjective sense of urgency, may be confused with other categories of messages, or may be responded to more slowly. Little research basis exists to understand the nature and magnitude of these possible effects. It is not known under what naturally occurring ambient noise conditions such effects may be meaningful. It is not known what features of an auditory alert may make it more or less susceptible to noise effects. The existing literature on in-vehicle warnings is primarily based on the presentation of the auditory signals under quite moderate ambient noise conditions. This experiment was intended to provide initial findings on the nature of these effects.

Background noise from music, and especially from open windows, interfered with the perception of auditory signals presented at 65 dBA. Interference was not very pronounced for the set of 75 dBA signals, although only four signals were included at this level. The set of sounds and voice messages equated for approximately equal loudness under relatively quiet listening conditions differed substantially in noticeability and urgency even under the baseline condition and even more under the music and open windows conditions. Under noise conditions, 65 dBA signals typically lost much of their perceived urgency, which may compromise their effectiveness for crash warnings, assuming they are even detected. Some sounds suffered low detection rates under noise, particularly the windows down ambient condition.

This experiment was designed to provide an initial examination of the extent to which possible ambient noise conditions might interfere with signal detection and meaning. It was not intended to provide any systematic evaluation of signal features or parameters regarding their resistance to noise effects. However, it appeared that the predominant frequencies that characterize a signal may relate to perceived urgency under noise. Sounds with predominant frequencies below 1000 Hz generally performed worst and those with primary or significant components above 1500 Hz performed best. However, this observation is based on a very limited sample of sounds that also differed in a number of other respects, and so should be considered tentative.

Following this on-road experiment, a series of three laboratory experiments were conducted to replicate and extend these findings. The first experiment provided a successful replication of the on-road results using headphone playback of recorded ambient noise conditions and alerts in a lab setting. The second experiment investigated additional ambient noise conditions, including different pavement conditions and environmental factors (e.g., rain). The third experiment investigated the effects of varying alert loudness, and added alert annoyance and consumer acceptability as dependent variables. These experiments are described in a separate report (Singer, Lerner, & Kellman, 2014). Complementary research is being conducted by NHTSA and others on the characteristics of auditory signals that make them effective as crash warnings and that distinguish them from other sorts of messages (e.g., Lerner et al., 2014). Consideration of background noise effects should be incorporated into such research. A greater range of ambient noise conditions than those included in this experiment should also be assessed. For example, traveling at higher speeds on worn concrete roads will generate a quite different noise condition than traveling at 60 mph on smooth asphalt (as in this experiment). Other potentially significant noise conditions might include loud adjacent large vehicles (e.g., tractor trailer), rain, or road surfaces under repair. Although the present experiment did include a music condition, this only addresses a single piece of music and a broader and more representative range of music, including listening volumes, would be appropriate, given how common this activity is.

Another research need concerns methodology. This experiment was conducted under realistic field conditions, presenting acoustic signals in an actual vehicle while operating at speed on functional roadways. While this provides a strong degree of face validity, on-the-road methods are less efficient than laboratory methods for collecting perceptual data. On-road methods require a period of sufficient training and vehicle familiarization for each participant so that the participant is comfortable and safe while engaged in driving an unfamiliar vehicle. Non-productive time is required to drive to and from test sites and for engaging in maneuvers such as exiting, merging, and turning. On-road methods are also subject to scheduling limitations and problems, broken sessions, or data loss due to weather, road maintenance activity, or traffic conditions. Certain noise conditions may be difficult to obtain for extended listening periods, such as loud passing vehicles or rough pavement conditions. Furthermore, in any on-road experiment there is some degree of variability in conditions from session to session. Therefore it would be valuable to develop an efficient and valid means of collecting perceptual data for ambient noise conditions in a laboratory setting. Such methods must be careful to maintain accurate replication of acoustics and should be validated against comparable data from on-road methods. Once developed, such laboratory methods could make use of high-quality field recordings to allow efficient evaluation of a broad range of noise conditions and alerting signals.

In summary, the present experiment demonstrated that comparing auditory signals under "typical" moderate background noise conditions may fail to discriminate important differences in how well alternative signals might function under more demanding, but still realistic, noise conditions. Ambient noise conditions influence how well signals will be detected, how quickly they are responded to, and how they are interpreted (urgency, meaning). Some of these effects can be quite large. Signal characteristics and noise characteristics interact to influence driver perception of alerts.

Alerts at a level of about 75 dBA maintained their detectability and perceived urgency quite well under the noise conditions included in this experiment, but those at 65 dBA varied considerably from one another. Designers and evaluators of driver interfaces for FCW and other types of in-vehicle alerts and messages will need to consider how a given auditory signal will perform under an appropriate range of possible in-vehicle noise conditions.

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Appendix A: Recruitment ad

Title: Participants needed for Driving Safety Study (receive $75 compensation)

Compensation: $75 for a 2-hour session

Location: Rockville

Westat is seeking participants for a federally-funded research study on drivers' ability to detect and recognize sounds and voice messages under different driving conditions.

If you participate in the study, you will take part in a 2-hour session in Rockville. You will drive a vehicle that Westat provides you on highways and local roads. You will hear occasional sounds and messages while you are driving and you will be answer questions about what you hear. The actual driving portion of the session will take about one hour.

Sessions will take place on weekday mornings and afternoons. Occasional weekend sessions may be available.

To be eligible to participate:

- You must have had a valid U.S. driver's license for at least 2 years and no major driving violations in the past few years.
- You must drive a car on a regular basis
- You must be between 21 and 50 years old
- You must have normal hearing; hearing aid users or those with functional hearing loss are not eligible.

If are interested in participating or would like to learn more about this study, please call […].

Appendix B: Recruitment screener

Thank you for your interest in the Ambient Vehicle Noise Driving Study. If you participate in this study, you will drive a vehicle provided by Westat on local roads and on the Inter County Connector while providing feedback about various sounds that will be played in the vehicle. You will drive with the car windows closed, car windows open, and with music playing.

I have a few questions I need to ask to verify your eligibility. Your ability to participate will depend on your eligibility and our need for participants with a variety of characteristics. If you are invited to participate, we will first need to verify your driving records to ensure that you have not had any major driving violations in the past few years.

1. In what year were you born? __________
2. For how many years have you had a valid U.S. driver's license?
3. Has your license ever been suspended or revoked within the past five years __Yes __No
4. What is the year, make, and model of the vehicle you drive most often?

   ____

5. How many days per week do you typically drive? ______
6. How often do you drive a small compact car such as a Ford Fiesta, Toyota Yaris, or Honda Fit? Would you say… [frequently, occasionally, rarely, or never]
7. How often do you drive a full size sedan such as a Chevy Impala, Dodge Charger, Ford Taurus, or Nissan Maxima? Would you say… [frequently, occasionally, rarely, or never]
8. How often do you drive a SUV? Would you say… [frequently, occasionally, rarely, or never]
9. Have you ever been diagnosed with a hearing impairment? __Yes __No
10. Do you have any reason to believe you have a hearing impairment? __Yes __No
11. Do you use a hearing aid? __Yes __No
12. Which statement best describes your hearing (without a hearing aid)? [good, a little trouble, or a lot of trouble]
13. What times can you be available for a 2-hour session in Rockville?
    a. ___weekday mornings
    b. ___weekday afternoons
    c. ___weekend mornings
    d. ___weekend afternoons

14. If eligible: It looks like you are eligible to participate. Before we schedule you for a session, we will need to confirm that you have a valid driver's license and that you have not had any serious driving violations. We will mail you a form that you will sign and return to us that allows Westat's Security Services office to receive your motor vehicle records. This information will be kept confidential and is used only for purposes of qualifying to participate in this study. Are you willing to allow us to obtain that information, after you read and sign the records release consent form? __Yes __No
15. What is your full name? ___________________________
16. What is your daytime phone number? _______________________
17. What is your mailing address? ____
18. Is there an email address I can use to contact you about this study? _________________________

Thank you for your interest in this study. We will mail the driving records release form to you shortly. Please sign and return it to us at your earliest convenience. Once we verify your driving records we can schedule you for a session.

Appendix C: Instructions to participants

Intake (in lobby)

- Check driver's license and confirm information vs. driving record check
- Have participant read and sign consent form, offer copy for their records
- Offer use of restroom before starting session

Instruction and Practice

Purpose and Procedure: This is a study about how people hear sounds and messages while they are driving. Some new vehicles can use sounds or voice messages to inform drivers about safety-related issues, the status of their vehicle, traffic conditions, incoming calls, and many other things. One important question is how well drivers can perceive these sounds under realistic driving conditions. Under noisy conditions, it might be harder to hear and understand sounds and messages. In today's study, I am going to ask you to drive on roads in this area including the ICC. The noise conditions are going to vary. Every so often, I will present a sound. Your job will be to let me know as soon as you hear the sound, and then make ratings about what you hear.

Adjustments and calibration: Before we get started, please silence your cell phone. You can also adjust the seat and mirrors to get comfortable in the car. [*wait for participant to make adjustments*] Are you comfortable with your seat and mirror positions? During this session, please do not turn up the air conditioning fan speed – we need to keep the fan low so it doesn't make much noise. However, you can change the temperature control or aim the vents if you get too warm or cold. To the right of your head is a microphone that I will be using to measure sound levels in the car. This mic will also record audio from this session. Before we get started I need to calibrate the sound level in the car. Please sit quietly for a few seconds while I calibrate. [*Click COMP WHITE NOISE button in program and adjust volume level from computer tray until meter steadily reads 65 dB +/- 1 dB*]

Safety precautions. During today's session, safety is the top priority. You will be required to wear your seat belt at all times while driving and obey posted speed limits and other traffic laws. I will be giving you navigation directions while you drive, but please only make driving maneuvers when it is safe to do so. I would prefer you to miss a turn rather than do something risky to make a quick maneuver. Remember that it is *your* responsibility to drive safely.

Vehicle familiarization: First, let's get you familiar with driving this vehicle. We will take a minute to drive around the parking lot. Please pull out of the parking space when it is safe to do so. I'll give you directions around the parking lot. [*Drive one lap around parking lot, return to parking space, put car in Park*]

Now let's make sure you are comfortable with some of the things you will do while driving. Please lower both front windows all the way down using the controls on your door.

Now please turn the car stereo on, and try adjusting the volume up and down. Now skip forward to Track 2, now skip backwards to Track 1 [*instruct as necessary*]. *When done*: OK, please turn off the stereo.

Now let's go over what you will do when you hear a sound or voice message coming from the car. When you hear a message, the first thing you have to do is click this little button [*give finger button to participant*]. That lets us know how quickly you recognized that there was a sound. You will attach it to your finger so you can click it easily without looking at it. *Attach the microswitch and have them operate it; have them adjust it so that they can quickly and comfortably operate the switch but where it will not likely be accidentally activated*] Once you push the button, I will ask you some questions about the sound. You can take your time with these answers. I'll play a practice sound for you, and then we will go through the ratings you will make about that sound. [*play kazoo practice sound*]

The first question I will ask you is "how NOTICEABLE was the sound?" Noticeability means that the sound is easily noticeable among other sounds and noises in the vehicle. You will rate the sound you just heard on a scale from one to seven. A "one" means that the sound is not very noticeable. A "seven" means that the sound is extremely noticeable. How would you rate this sound?

The next question I will ask you is "how URGENT was the sound?" Urgency means that the sound conveys a sense of importance, motivating you to make an immediate response. A "one" means that the sound is not very urgent. A "seven" means that the sound is extremely urgent. How would you rate the urgency of the sound you just heard?

Next, I will read you a list of four possible meanings for this sound. Choose the one the most closely matches the meaning conveyed by this sound. I'll read you the list of possible meanings, then I'll go back and explain what each one means. The options will be:

- <u>Urgent crash warning</u>… means that there is a situation in which you must react immediately to avoid a crash. For example, imagine you are about to hit a pedestrian or about to run off the road.
- <u>Safety information</u>… means that there is a safety issue that you need to pay attention to, but you are not in immediate danger of a crash. For example, imagine that you are approaching a work zone where two lanes are closed or there are reports of icy roads ahead.
- <u>Information not related to safety</u>… means exactly what it says – you are receiving information, but the information is not safety-related. This could include various types of information, such as traffic congestion several miles ahead, prices at nearby gas stations, or a navigation system telling you to make the next turn.
- <u>Incoming personal communication</u>… means that you are receiving an incoming call, text message, email, or other direct communication.

Any questions? Which meaning would you choose for the sound you just heard? [*record answer*] The list of options will be the same for all of the sounds you hear today. I'll read the list to you for each sound you hear. If you can't remember what a category means, let me know and I can try to clarify. Also, please remember that there isn't necessarily a correct or incorrect answer to this question – I want to know what the sound conveys to <u>you</u>.

Now let's try another sound for practice. [*play voice message; go through NOTICEABILITY and URGENCY; read full definitions again and indicate 1-7 scale*] Now the next rating that comes up is INTELLIGIBILITY. You did not make this rating before. That is because it will only come up when the sound is a voice message. "Intelligibility" means that the spoken words can be easily understood. A "one" means that the voice message was not very intelligible. In other words, you could not understand the words clearly. A "seven" means that the message was extremely intelligible. How would you rate this voice message for intelligibility? [*have participant say choice; go through meaning question; read full definitions again*] Do you have any questions about how to do the ratings and choices?

Would you like to make any more adjustments before we go out on real roads? Now let's start driving toward I-270, which will take us to the ICC. I'll give you step by step directions. [*give directions toward I-270*] *Once on I-370*: We're on I-370 now which will eventually become the ICC. While on the ICC, please try to maintain your speed close to the speed limit, which is 60 miles per hour. Be aware that the police frequently pull over speeders on this road. Stay in the right lane unless you need to pass a slower vehicle. If you need to pass, please let me know before you change lanes, use your turn signals, and always look carefully to make sure it is safe to change lanes. When we get close to the end of the ICC, I'll give you directions to exit onto Briggs Chaney Road and get back on in the other direction. Do you have any questions before we start the real experiment?

[wait until you reach the Shady Grove Rd/Metro exit, then begin data collection]

Data Collection

- *Look for upcoming concrete sections/overpasses before triggering*
- *Click button quietly and avoid giving any subtle triggering cues*
- *If participant fails to hear a sound, you can trigger the next one without waiting for the countdown*
- *Try to be silent in back seat at all times*
- *Keep an eye on participant speed*
- *Do not allow cruise control use*
- *Do not allow driver to lean forward to hear better*
- *Watch for signs to exit onto Briggs Chaney Rd (shortly after Route 29); and then Shady Grove Rd.*
- *During final block, choose turnaround spot to minimize drive back to Westat at end of session.*

<u>Prior to Condition 2 (windows down)</u>: For the next set of sounds, you will have the front two windows opened all the way. After each time you click the finger button, I'll ask you to close the windows so we can talk to each other more easily.

<u>Prior to Condition 3 (music on)</u>: For the next set of sounds, you will turn the stereo on and set the volume to the level that you would usually set your own music while driving by yourself. Whether or not you like the music that we have in the car, it is important that you set it to the volume you would choose for your own music and leave it at that volume until we get through this full set of sounds. Having the music on might make it harder to hear some sounds, but that's OK. For this experiment it is <u>much</u> more important that you have the music at your own typical volume than it is for you to be able to hear all of the sounds. Pretend I'm not here when you choose your volume level. Go ahead and turn the stereo on now and set the volume to the level that you would usually set your own music while driving by yourself.* Now please skip forward to track two on the CD player so I can take a sound measurement. Please try not to make any noise until I tell you that the measurement is complete. [*Check for white concrete/tunnels ahead before starting recording. Wait 10 seconds for sound to ramp up, then click to start recording. Write down digital volume level on session info sheet. Max sound level allowed is 90 dB – have participant reduce if necessary.*]

**MINIMUM VOLUME ALLOWED:* *Accent: 7 … Terrain: 14 … Camry … 21*

Now that I have taken a sound level measurement, it's important that you not change the music volume until we finish this set of sounds. [*If they have the music set loud, say "After each time you click the finger button, I'll ask you to turn off the music so we can talk to each other more easily"*]. Please skip back to Track 1 now and we'll get started.

[If the participant presses the button when there is no actual signal:]

If this happens during a non-trial period, ask the participant what sound they heard, then record on paper as accidental or false alarm. If this happens during the 5 s pre-signal period of a trial, ask if they heard something or if it was an accidental button press. Then follow program prompts to redo the trial.

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