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16. Abstract

This report describes the findings of three experiments that concern driver reaction to acoustic signals that might be used for backup warning devices. Intelligent warning devices are under development that will use vehicle-based sensors to warn backing drivers of the presence of objects behind the vehicle. The research described here is part of a larger project concerned with the human factors of these warning devices. Specifically, the questions of interest center around what warning information to provide, when to present it, and how to display it. Based on previous work (Lerner, Kotwal, Lyons, and Gardner-Bonneau, 1996; Huey, Harpster, and Lerner, 1996), this research focuses on acoustic signals, which are seen as more suitable for backup warnings than are visual displays. The three experiments were conducted dealing with different aspects of driver perception and response to backup warning signals, with the objective of contributing to the development of a set of recommendations for the human factors aspects of backup warning systems.

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1. Introduction

1.1. Objective

Purpose: This report describes the findings of three experiments that concern driver reaction to acoustic signals that might be used for backup warning devices. Intelligent warning devices are under development that will use vehicle-based sensors to warn backing drivers of the presence of objects behind the vehicle. The research described here is part of a larger project concerned with the human factors of these warning devices. Specifically, the questions of interest center around what warning information to provide, when to present it, and how to display it. Based on previous work (Lerner, Kotwal, Lyons, & Gardner-Bonneau, 1996; Huey, Harpster, & Lerner, 1996), this research focuses on acoustic signals, which are seen as more suitable for backup warnings than are visual displays. The three experiments deal with different aspects of driver perception and response to backup warning signals, with the objective of contributing to the development of a set of recommendations for the human factors aspects of backup warning systems.

Relation to Observational Study: Prior to these experiments, an observational study was conducted to understand how drivers normally act in a variety of common backing situations (parallel parking, backing out of an angle slot in a parking lot, backing to a wall, extended backing along a driveway, etc.). This study (Huey et al., 1996) provided a wealth of description on where and when drivers look, speeds and distances traveled, time to collision estimates, and other behavioral aspects. The logic underlying this study was that backup warning systems should be compatible with the normal behavior of drivers, so that alarms can be designed that are timely, credible, and meaningful to drivers, without being annoying and without forcing changes in normal behavior. This observational study describes the behavioral "baseline" upon which warning signals will be imposed. The three experiments described here now carry this work further by presenting warning signals to the research participant, in a manner consistent with this baseline, in order to evaluate certain aspects of signal or response. Together, the observational study and the warning signal experiments will help define desirable attributes of backup warning acoustic displays.

Experimental Approach: Three experiments were conducted. The first concerned driver brake reaction time in response to a warning signal while backing. Although there is considerable literature on driver perception-reaction time for forward driving situations, no comparable research was found for backing situations, although this is an obvious consideration in defining warning algorithms. The second experiment dealt with the preferred timing for the onset of cautionary and danger (imminent crash) warnings. An ideal warning will be consistent with driver perceptions of the urgency of the hazardous situation, so that the signal will be meaningful, perceptually valid, and well-accepted. The final experiment investigated aspects of graded warnings, where some attribute of the signal changes in a systematic way with the proximity to the hazard. Graded warnings have the potential to provide more information to the driver in a simple way, discriminate nearer from farther hazards, and be more meaningful to the perceiver. This experiment compared the advantages of varying different attributes of the acoustic signal, and different functions for that variation.

Together, the three experiments converge on a set of triggering criteria that will determine when a cautionary or imminent crash warning should be provided to the driver. They bring together data on overt vehicle control actions, subjective risk, perceived meaning, graded messages, preference and annoyance. In the sections that follow, the methods, findings, and implications of each experiment are discussed.

2. Reaction Time to Warnings During Backing

2.1. Background

The equation used to determine the latest possible time to turn on an alarm to prevent a backing accident can be expressed as follows:

Alarm Onset Time = Reaction Time + Stopping Time

In order to determine alarm onset times, reasonable estimates for reaction time and stopping time and distance must be known. Reaction times and stopping distances for drivers traveling forward have been studied extensively. However, reaction times for backing remain to be quantified.

During backing, drivers frequently shift their foot position. There is little debate that the foot position at the time of the alarm has a large impact on the reaction time. However, controlling for foot position in a field study is difficult. Forcing participants to back while with their foot in a predefined position may produce unreliable results. In the current study, participants were permitted to back in their natural manner. During their normal backing sequence an alarm was sounded. Their foot position was recorded at the time the alarm was sounded. This type of experiment determines the normal range of reaction times that can be expected during normal backing sequences, and permits the examination of foot position. Knowing the foot position at the time of the alarm allows the analysis to be done separately for each foot position.

In this experiment drivers were alerted to the fact that an alarm would be sounded. It has been shown that when drivers are aware of the possibility of an alarm their reaction times decrease. The alternative to this is to not alert the drivers and surprise them at some point during the experiment and measure their reaction time. This method has several drawbacks. Typically only one data point can be collected for each participant, and there are ethical and human participant concerns about this technique when used on public roads. The need to observe reaction times over a wide range of backing conditions (described below) in this experiment required the use of multiple warnings on practical grounds.

However, there is also reason to consider the driver who is aware that a warning might occur as an appropriate model for the backup warning situation. Drivers will of course be aware that they have the warning device in their vehicles. Immediate braking is the appropriate response to an "imminent crash" warning, but it has been recommended that a prior cautionary warning be provided at a greater distance; this provides an alerting cue. Furthermore, relative to forward driving at speed, backing is generally a very brief maneuver, and it seems likely that drivers will maintain alertness and vigilance during this short period. Finally, drivers in this study were instructed to brake quickly, but safely, and they generally did not brake in a very abrupt manner. They knew there was no actual hazard, and probably for both personal comfort and because of the presence of the experimenter in the vehicle, they rarely stopped in an extremely sharp manner as might be typical of an actual emergency stop.

2.2. Overview of Design/Procedure

This experiment was designed to measure reaction time and stopping distance under naturalistic backing conditions. To make the experimental conditions as close as reasonably possible to normal backing several steps were taken. First, participants used their own vehicles when performing the experiment. This prevented any inconsistencies because the participant was unfamiliar with the vehicle. Second, the backing sequences were performed on public roads. Using public roads with typical traffic flows required the participants to take their normal precautions in order to prevent an accident. Third, virtually all of the equipment was hidden from the view of the driver. However, it was unavoidable that the experimenter had to ride in the front seat of the vehicle and operate the equipment and direct the participant.

The participants drove their cars around Silver Spring, Maryland to six different sites, and performed three different backing sequences (extended backing, backing to a wall, and parallel parking). At different points into the backing sequence (early, middle and late) the experimenter pressed a button which set off an auditory alarm. Upon hearing the alarm the participant, as fast as safely possible, stopped the vehicle. The reaction time to the button push as well as the time until the vehicle stopped was measured. Additionally there were several trials where no alarm was sounded. This prevented the participant from anticipating when the alarm would be sounded.

Reaction Time Backing Sites

Parallel parking sites: Parallel parking was performed in a variety of urban locations. Each participant parallel parked on two-way undivided streets with parallel spaces on either side and on a median-divided, two-way street with curb-side metered parking. The particular location used for parallel parking varied with availability of suitable spots. Only spots that included vehicles fore and aft were selected.

Extended curved backing site 1: This site was located on a parkway. This location was a small parking area with an extended left curving drive provided as an exit. Participants were asked to pull through to the end of the exit and then back along the curved drive to the parking area.

Extended curved backing site 2: This site was located on a dead end section of roadway off of a minor, residential road. The drive curved left slightly near the entrance from the intersecting side street. The road was slightly uphill for the backing maneuver.

Wall site 1: This site was comprised of a wall within an apartment complex parking lot, to which participants were instructed to back. There were no parking stop blocks in front of the wall, so drivers were able to pull as close to the wall as they wished

Wall site 2: This site was comprised of a wall within another apartment complex parking lot, to which participants were instructed to back. There were no parking stop blocks in front of the wall, so drivers were able to pull as close to the wall as they wished.

2.3. Participants

Twelve participants were tested. There was an old group (mean 71.5 years, 3 males and 3 females), and a young group (mean 30.5 years, 3 males and 3 females). All participants had current drivers licenses and were active drivers.

2.4. Apparatus

The apparatus for this experiment allowed collection of both video and digital data from the vehicle and driver. All data collection equipment was controlled from a single PC located in the back seat of the vehicle with the experimenter. The figure below shows the placement of the sensor equipment in the vehicle.

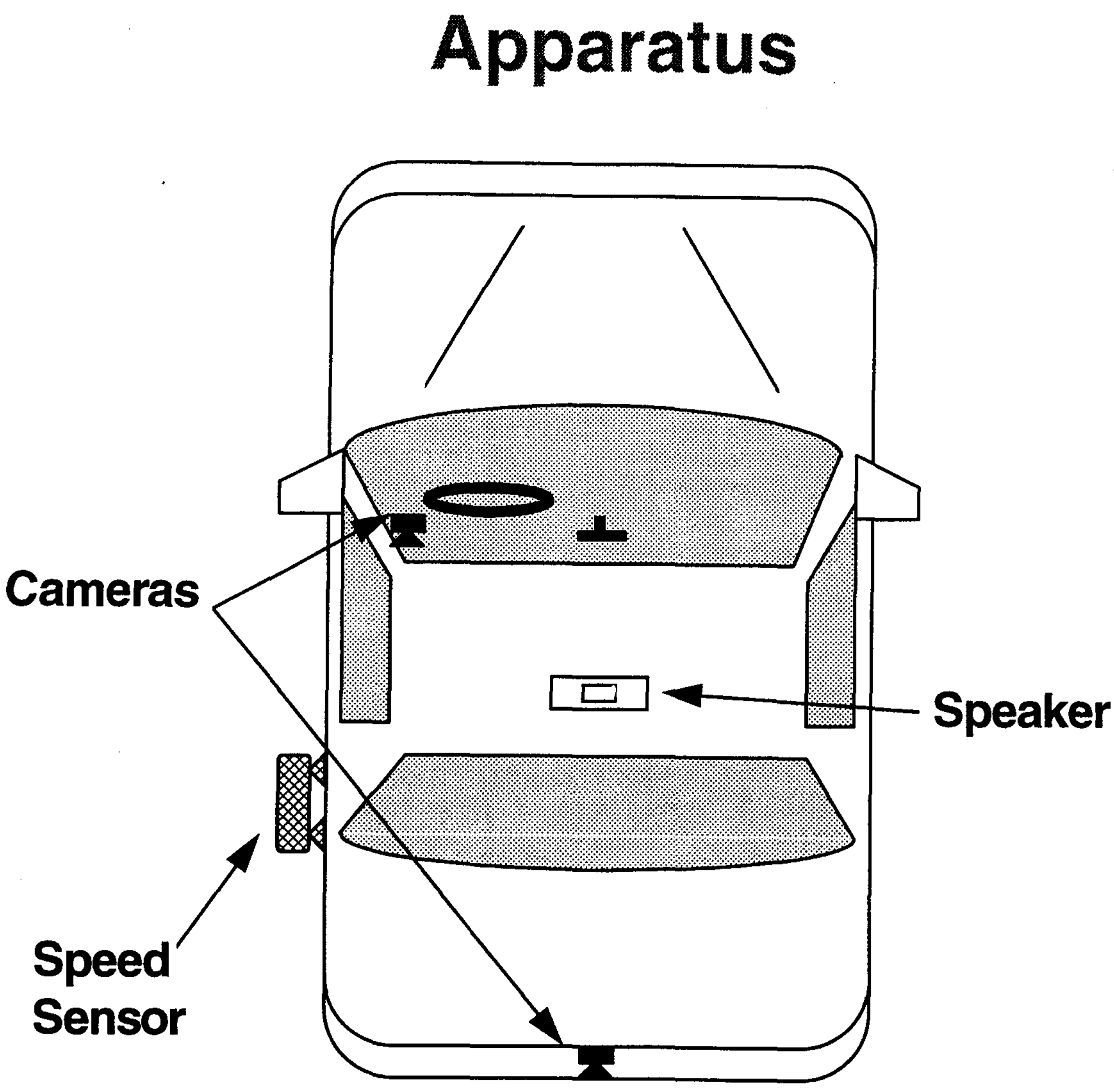

Figure 2-1 Location of equipment in vehicle

The following is a list of the major components used in the data collection.

1. **Miniature Cameras** - Two miniature cameras were used in this experiment. One miniature camera (ProVideo model CVC-300) was mounted on the rear window looking out the back of the vehicle. The

video collected from this camera was used to determine The direction of the vehicle and to verify the site. A second camera with the same make and model number was mounted near the gas and break pedals. This camera was used to determine the foot position at the time the button was pressed and to determine the reaction time through manual reduction of the data.

2. **Optical Speed Sensor** - This component, a DATRON model DLS2, allowed accurate detection and computer input of speed data. This device was mounted on the driver's side of the vehicle so the sensor would not be in the way during the parallel parking sequences.

3. **Personal Computer** - An IBM ThinkPad model 360CSE computer was used as the data collection and reduction platform. It housed boards to control the data acquisition processor and speed detector as well as controlling the recording parameters of the VCR.

4. **Computer-Controlled VCR** - A computer controlled VCR (Sony model CVD 1000) collected video data from the miniature camera. Time code was applied to the videotape to allow a frame accurate indication of events that occurred during the experiment. This time code provided the time base for all data collection and reduction activities.

5. **Data Acquisition System** - This component, an IOtech model Daqbook 100, allowed the speed data to be collected during the experiment. Speed data was collected at 10 Hz.

6. **Power Supply** - Because some of the equipment required 120 VAC power, an inverter and separate backup was required. Power was supplied by the test vehicle to the extent possible from a cigarette lighter connection. The 250 watt power inverter supplied ample power to operate the computer, VCR, and video monitor. All other components were operated directly from 12VDC power. A backup battery was used to ensure constant current levels during situation when vehicle power was insufficient.

7. **Video Monitor** - A small (2.9" diagonal) video monitor (Citizen model M329 MKII) provided a constant view of rear mounted camera to the experimenter.

8. **Quad Splitter** - This component allowed up to four video sources to be combined on a single VCR image. Only two the two video images were combined for this experiment.

9. **Sound Generation Equipment** - A small push button was provided for the experimenter to press to initiate the alarm. When the button was pressed the signal was sent to the computer so that the timecode could be recorded and simultaneously the warning alarm was played over the loud speaker.

2.5. Experimental Design

2.5.1. Independent Variables

- Alarm condition (early, middle, late or none)
- Task (back to wall, parallel and extended curvilinear)
- Age
- Gender

4 alarm conditions x 3 tasks = 12 trials per participant

No reaction time or stopping distance data was collected on the 'none' trials so there was a maximum of 9 data points for each participant. Some of the trials had to be discarded because of equipment failure.

2.5.2. Dependent Variables

- Reaction time
- Stopping time
- Foot position

The foot position was coded as being on the accelerator, brake pedal or neither at the time of the alarm.

2.6. Procedure

2.6.1. Informed Consent and Instructions to Participants

Initially, the experimenter greeted the participant and asked him or her to read and sign the informed consent form. The experimenter then read a set of instructions (see Appendix A) outlining the requirements of the participant for participation in the experiment. After the participant signed the consent form, the equipment was installed in the participant's vehicle. The experimenter then played the warning alarm sound for the participants to familiarize them with the warning sound before the experiment. Before the actual data collection began, two practice backing sequences were performed to acclimate the participant to the experimental procedure.

2.6.2. Experimental Trial

Participants drove to several locations around Silver Spring, Maryland. Once arriving at a site, the experimenter instructed the participant where they should start and stop backing. The experimenter then started the data collection equipment. This turned on the two video cameras and speed sensor. The computer controlled VCR recorded the video and the personal computer recorded the timecode and the data from the speed sensor. At a predefined point into the backing sequence (depending on the trial type, early, middle, or late), the experimenter pressed a button sounding the auditory alarm. The alarm was sounded until the vehicle came to a stop, and was the aircraft low fuel warning at 75 dBA. The early alarm occurred after the car had moved about one foot. The middle alarm occurred when the car was 50% done with the backing sequence, and the late alarm occurred when the driver was approximately 80% done with the backing sequence. The point where the alarm sounded was recorded by the computer. After hearing the alarm, the participant stopped the vehicle as quickly as possible. Completing the 12 sites took approximately 2 hours including the time to setup and teardown the equipment.

2.6.3. Data Reduction

The products produced from the experiment were the following:

1. A video tape of two images of the backing sequence. One view was on the driver's foot and the other was out the back of the car. The tape was marked with the timecode.

2. A data file with one record for each timecode. The file contained the following information (timecode, speed, cumulative distance, and alarm indicator, participant number, site, task, trial type).

The data from the file was reduced by manually looking at the foot position on the video tape. The brake time was calculated by taking the difference between the timecodes when the brake was pressed and the timecode when the vehicle first had a zero speed. If the participants foot was on the brake at the time the alarm sounded, the when the brake was deflected to its maximum position was used for reaction time purposes. The results of the data reduction were broken down into the following data fields.

a. Participant number
b. Task
c. Trial Type
d. Speed at alarm onset
e. Foot position at alarm onset
f. Time between alarm onset and brake push (Reaction Time)
g. Distance traveled between alarm onset and brake push (Reaction Distance)
h. Time between brake push and vehicle stopping (Break Time)
i. Distance traveled between brake push and vehicle stopping (Break Distance)

2.7. Results

The table below summarizes the results from this experiment. There were several main points of interest. First, the mean total time to stop the vehicle (reaction time + breaking time) was 1.47 seconds. Second, the mean total distance traveled before the vehicle was stopped (reaction distance + breaking distance) was 4.8 feet. Additionally, there was very little difference between age groups and genders.

PRT	n	Speed		Reaction Time		Stopping Time		Total Time		Reaction Dist		Stop Dist		Total Dist	
		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Overall	78	2.6	2.2	0.54	0.31	0.92	0.49	1.47	0.56	2.3	2.3	2.5	2.9	4.8	4.9
gas	43	3.1	2.7	0.66	0.31	0.94	0.50	1.60	0.57	3.2	2.6	2.9	3.5	6.1	5.9
brake	11	2.1	1.2	0.30	0.09	0.47	0.14	0.52	0.16	1.3	1.2	2.9	2.4	4.2	3.1
neither	24	1.9	1.1	0.41	0.21	0.74	0.40	1.14	0.45	1.2	1.2	1.4	1.4	2.7	2.2
Old overall	44	2.1	1.2	0.53	0.32	0.92	0.49	1.46	0.55	1.9	1.7	2.1	2.1	4.0	3.4
gas	19	2.3	1.5	0.72	0.30	0.88	0.48	1.60	0.51	2.8	1.9	2.1	2.5	5.0	4.1
brake	10	1.9	1.0	0.41	0.30	1.22	0.47	1.63	0.55	1.4	1.2	2.5	2.2	3.9	3.1
neither	15	1.8	0.8	0.38	0.23	0.78	0.44	1.16	0.51	1.1	1.1	1.7	1.5	2.8	2.2
Young overall	34	3.3	2.9	0.56	0.29	0.92	0.50	1.48	0.59	2.9	2.9	3.0	6.2	5.8	6.2
gas	24	3.7	3.2	0.62	0.32	0.99	0.52	1.60	0.62	3.5	3.1	3.5	4.1	7.0	6.9
brake	1	4.3		0.10		1.70		1.80		0.6		6.3		6.9	
neither	9	2.0	1.5	0.46	0.14	0.66	0.31	1.12	0.35	1.4	1.4	1.1	1.0	2.5	2.2
Task															
parallel (all)	17	1.2	0.4	0.53	0.37	0.62	0.40	1.15	0.52	1.1	1.1	0.7	0.9	1.8	1.6
early	7	1.4	0.4	0.80	0.42	0.82	0.44	1.61	0.36	1.9	1.4	1.2	1.2	3.1	1.6
middle	7	1.0	0.4	0.33	0.18	0.52	0.36	0.86	0.38	0.5	0.4	0.5	0.5	1.0	0.5
late	3	1.0	0.2	0.36	0.23	0.37	0.20	0.72	0.16	0.4	0.2	0.1	0.2	0.5	0.3
wall (all)	27	2.1	1.0	0.45	0.21	0.80	0.33	1.25	0.35	1.5	1.4	1.6	1.2	3.1	2.0
early	8	2.0	0.9	0.44	0.31	0.88	0.39	1.32	0.43	1.7	2.0	2.3	1.5	4.0	2.4
middle	10	2.6	1.3	0.50	0.11	0.86	0.34	1.36	0.34	2.0	1.2	1.7	1.2	3.7	2.0
late	9	1.6	0.5	0.39	0.18	0.67	0.24	1.06	0.23	1.0	0.5	0.8	0.5	1.8	0.7
ext curve (all)	34	3.7	2.8	0.63	0.32	1.17	0.52	1.80	0.55	3.6	2.7	4.0	3.7	7.6	6.0
early	12	1.7	0.7	0.81	0.38	0.76	0.34	1.58	0.54	2.7	1.6	1.5	1.1	4.2	2.3
middle	12	5.5	3.3	0.49	0.26	1.47	0.37	1.96	0.48	4.4	3.6	6.4	3.9	10.8	7.2
late	10	3.9	2.2	0.58	0.23	1.30	0.57	1.88	0.60	3.7	2.6	4.1	3.8	7.9	5.8
Gender															
male	45	2.5	2.1	0.54	0.29	1.00	0.51	1.53	0.53	3.2	2.6	2.9	3.5	6.1	5.9
female	33	2.7	2.3	0.56	0.33	0.82	0.44	1.38	0.60	2.5	2.5	2.1	2.8	4.6	5.1

Table 2-1 Summary results for reaction time experiment

Table below shows 90th percentile values.

PRT	n	Reaction Time			Total Time			Total Dist		
		90%	mean	SD	90%	mean	SD	90%	mean	SD
Overall	**78**	**0.89**	**0.54**	**0.31**	**2.17**	**1.47**	**0.56**	**10.6**	**4.8**	**4.9**
gas	43	1.04	0.66	0.31	2.52	1.60	0.57	16.3	6.1	5.9
brake	11	0.78	0.30	0.09	2.21	0.52	0.16	8.5	4.2	3.1
neither	24	0.71	0.41	0.21	1.57	1.14	0.45	5.6	2.7	2.2
Old overall	**44**	**0.97**	**0.53**	**0.32**	**2.11**	**1.46**	**0.55**	**7.7**	**4.0**	**3.4**
gas	19	1.09	0.72	0.30	2.44	1.60	0.51	10.9	5.0	4.1
brake	10	0.83	0.41	0.30	2.23	1.63	0.55	8.5	3.9	3.1
neither	15	0.80	0.38	0.23	1.50	1.16	0.51	5.2	2.8	2.2
Young overall	**34**	**0.87**	**0.56**	**0.29**	**2.41**	**1.48**	**0.59**	**16.8**	**5.8**	**6.2**
gas	24	0.92	0.62	0.32	2.52	1.60	0.62	18.9	7.0	6.9
brake	1		0.10			1.80			6.9	
neither	9	0.70	0.46	0.14	1.59	1.12	0.35	6.2	2.5	2.2
Gender (all)	**78**	**0.89**	**0.54**	**0.31**	**2.17**	**1.47**	**0.56**	**10.6**	**4.8**	**4.9**
male	45	0.87	0.54	0.29	2.20	1.53	0.53	10.8	4.9	4.8
female	33	0.98	0.56	0.33	2.08	1.38	0.60	9.4	4.6	5.1
Parallel (all)	**17**	**1.00**	**0.53**	**0.37**	**1.99**	**1.15**	**0.52**	**4.8**	**1.8**	**1.6**
early	7	1.46	0.80	0.42	2.10	1.61	0.36	5.5	3.1	1.6
middle	7	0.49	0.33	0.18	1.35	0.86	0.38	1.8	1.0	0.5
late	3		0.36	0.23		0.72	0.16		0.5	0.3
Wall (all)	**27**	**0.70**	**0.45**	**0.21**	**1.59**	**1.25**	**0.35**	**6.1**	**3.1**	**2.0**
early	8	0.92	0.44	0.31	1.71	1.32	0.43	7.7	4.0	2.4
middle	10	0.65	0.50	0.11	1.78	1.36	0.34	6.5	3.7	2.0
late	9	0.62	0.39	0.18	1.32	1.06	0.23	2.6	1.0	0.7
Ext curve (all)	**34**	**1.07**	**0.63**	**0.32**	**2.61**	**1.80**	**0.55**	**16.8**	**7.6**	**6.0**
early	12	1.30	0.81	0.38	2.26	1.58	0.54	7.2	4.2	2.3
middle	12	0.81	0.49	0.26	2.72	1.96	0.48	21.3	10.8	7.2
late	10	0.88	0.58	0.23	2.63	1.88	0.60	17.8	7.9	5.8

Table 2-2 90th percentile values for reaction time experiment

The following regression equation can be used to predict stopping distance when traveling at different speeds.

$$\textbf{stopping distance (ft)} = 2.975 * (\textbf{speed-mph}) - 0.82 \qquad R^2 = 0.85$$

Equation 1 Stopping distance regression equation.

The following regression equation can be used to predict total stopping time when traveling at different speeds.

$$\textbf{stopping time (sec)} = 0.163 * (\textbf{velocity - mph}) + 1.045 \qquad R^2 = 0.40$$

Equation 2 Stopping time regression equation.

2.8. Conclusions

Reaction times and stopping distances were measured under a range of naturalistic backing scenarios. The major finding was that on average the typical driver was able to stop the vehicle in roughly 1.5 seconds. This consistent with the imminent warning distance estimated by participants in previous experiments.

Interestingly, there was very little difference between the old and young for stopping time (1.46 seconds for the elderly and 1.48 seconds for the young). The result was obtained mainly because the average speed traveled by the elderly was 2.1 mph and 3.3 for the young and because the older drivers were far more likely to have their foot on the brake than the young. These differences may reflect compensatory behaviors in older drivers.

Stopping times and distances were influenced by the particular backing task, the point during backing that the signal occurred, and the driver's foot position at the moment the signal occurred. Brake reaction times (to initiate brake pedal depression) were quite brief if the foot was already on the brake pedal (0.3 seconds), as opposed to 0.66 seconds (across all conditions) when the foot was on the accelerator. Stopping distances were related to vehicle speed and the point during the maneuver (which is correlated with speed and foot position). Even under the least favorable conditions, however, stopping distances remained quite short; for the worst case condition, the middle portion of extended curve backing, the mean total distance was less than 11 feet. Under more typical, slower backing scenarios, mean total stopping distances were generally under 5 feet, and even 90th percentile distances were under 8 feet.

3. Preferred Timing of Collision Warnings

3.1. Background

Previous analyses (Lerner, Kotwal, Lyons, and Garder-Boneau, 1996) of backup warning systems have suggested that it might be beneficial to have two distinct backup warnings, imminent crash and cautionary. Implementing such an alarm system requires a variety of design decisions including the following:

1. When to turn on each type of alarm
2. How the alarm should vary between cautionary and imminent positions
3. The alarm acoustic characteristics

This study was designed to examine the first of these questions. Participants were asked to make judgments about when imminent crash and cautionary warnings should be presented. These subjective estimates may be compared to reaction time and stopping distance data to determine how people's expectations compare with an engineering analysis of the situation. The experiment used a small sample of participants and was not intended to provide a precise estimate of population means. Rather, its purpose was to provide an immediate order-of-magnitude estimate of subjective judgment, so that this could be considered along with objective performance criteria when designing warning algorithms.

This study was designed to serve a dual purpose. In addition to determining the expected warning zone boundaries, the study compared judgments under field and laboratory conditions. In the field condition, the participants were sitting in a car and made judgments as the car approached a target. In the laboratory condition, the participants viewed a video of the same scene and made their judgments.

Both laboratory and field measurements were made since it had been determined that laboratory studies would be required to study some of the more complex acoustic variations (see the third experiment in this report, Graded (Analog) Warning Zones) , and so an estimate was required of the generalizability of the laboratory judgments to the field situation. This experiment used the same participants to make warning zone estimates in both field and laboratory conditions. The results give a measure of warning zone estimates in both conditions using a within-subjects design.

3.2. Overview of Design/Procedure

This experiment had two parts, a field experiment and a laboratory experiment. Each experiment was repeated, once to determine the cautionary warning distance and once to determine the imminent crash warning distance. The two dependent variables were NOT measured on the same experimental trial. A trial consisted of the car backing to a target (a crash dummy suspended from the ceiling in a parking garage). During the backing sequence the participant was instructed to press a button when they were at the imminent or cautionary point. The imminent and cautionary points were defined as described below.

> An <u>imminent</u> crash avoidance situation is one in which the potential for a collision is such that it requires an immediate vehicle control response or modification of a planned response in order to avoid a collision.
>
> A <u>cautionary</u> crash avoidance situation is one in which the potential for a collision requires immediate attention from the driver, and which may require a vehicle maneuver, but does not meet the definition of an imminent crash avoidance situation.

In the field part of the study, the participants were seated in the front seat of the a Nissan Sentra and the experimenter drove the car at an approximately constant speed until the car hit the target. The participants looked over their left should to view the crash dummy out the back window of the car. When they reached the point where they believed the imminent or cautionary warning (only one per trial) should occur, the participant pushed a button and the button push was recorded by a laptop computer.

In the laboratory part of the study, the participants were seated in a chair and looked over their left shoulder at a video of the same car approaching the target from the same visual perspective. As in the field study, they pressed a button when they believed that the car was at the imminent or cautionary warning point.

3.3. Participants

Five participants were tested. Each participant was tested in both the laboratory and field conditions. There were 3 females and 2 males, aged 26-42 (mean age of 32).

3.4. Apparatus

The apparatus for this experiment allowed collection of both video and digital data from the vehicle and driver. All data collection equipment was controlled from a single PC located in the back seat of the vehicle with one of the experimenters. (One experimenter drove the car and a second operated the computerized collection equipment from the back seat.) The figure below shows the placement of the equipment in the vehicle.

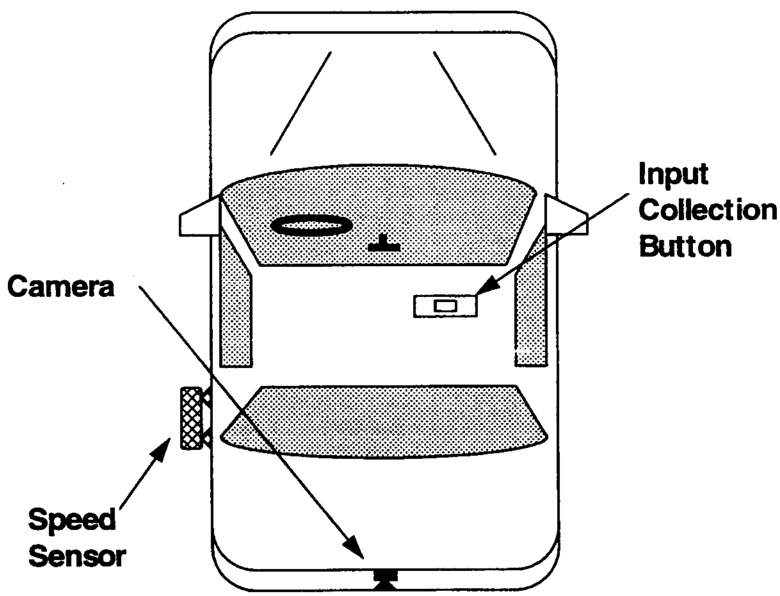

Figure 3-1 Location of equipment in vehicle

The following is a list of the major components used in the data collection.

1. **Miniature Camera** - A miniature camera (ProVideo model CVC-300) was mounted on the rear window looking out the back of the vehicle. The video collected from this camera was used to determine the time when the vehicle hit the target during the field portion. The coding of the time of the target hit was a manual process that linked the event to a video time code.

2. **Optical Speed Sensor** - This component, a DATRON model DLS2, allowed accurate detection and computer input of speed data. This device was mounted on the driver's side of the vehicle.

3. **Personal Computer** - An IBM ThinkPad model 360CSE computer was used as the data collection and reduction platform. It controlled the data acquisition processor as well as controlling the recording parameters of the VCR.

4. **Computer-Controlled VCR** - A computer controlled VCR (Sony model CVD 1000) collected video data from the miniature camera. Time code was applied to the videotape to allow a frame accurate indication of events that occurred during the experiment. This time code provided the time base for all data collection and reduction activities.

5. **Data Acquisition System** - This component, an IOtech model Daqbook 100, allowed the speed data and button presses to be collected during the experiment. Speed data was collected at 10 Hz.

6. **Power Supply** - Because some of the equipment required 120 VAC power, an inverter and separate backup battery was required. Power was supplied by the test vehicle to the extent possible from a cigarette lighter connection. The 250 watt power inverter supplied ample power to operate the computer, VCR, and video monitor. All other components were operated directly from 12VDC power. A backup battery was used to ensure constant current levels during situation when vehicle power was insufficient.

7. **Video Monitor** - A small (2.9" diagonal) video monitor (Citizen model M329 MKII) provided a constant view of rear mounted camera to the experimenter.

8. **Test Vehicle** - The test vehicle was a 1996 Nissan Sentra (4 door).

9. **Projection Video Monitor** - A projection video monitor was used to display the video during the lab portion of the study. Participants sat 10 feet from the display.

3.5. Experimental Design

3.5.1. Independent Variables

This experiment had a within-subject design with each participant receiving each of the treatments. There were three independent variables: the alarm condition (imminent and cautionary), vehicle speed (2, 4, 7, and 10 mph), and setting (field and laboratory). A table of the conditions is shown below.

Setting	Condition	Speed
Field	Imminent	2, 4, 7, 10 mph
Field	Cautionary	2, 4, 7, 10 mph
Lab	Imminent	2, 4, 7, 10 mph
Lab	Cautionary	2, 4, 7, 10 mph

Table 3-1 Experimental Conditions

Each of the 5 participants was tested in each of the conditions twice. Therefore, each participant had 16 laboratory trials and 16 field trials.

3.5.2. Dependent Variables

The single dependent variable was the distance to the target when the participant pressed the button. The time until the car reached the target was also calculated, but since the vehicle was moving at a relatively constant speed it was directly related to the distance for any given trial.

3.6. Procedure

3.6.1. Informed Consent and Instructions to Participants

Initially, the experimenter greeted the participant and asked him or her to read and sign the informed consent form. The experimenter then read a set of instructions (see Appendix A) outlining the requirements of the participant for participation in the experiment. Of major importance was the distinction between imminent and cautionary alarms. The experimenter had each participant express in their own words the meaning of each alarm condition. This confirmed the participants understood the difference between the two warnings.

3.6.2. Experimental Trial (Field)

The field study was performed on a unused level of a public parking garage. Suspended from the ceiling was a life size crash dummy (height = 73 inches). During each trial the participant rode in the passenger seat of the test vehicle. One experimenter drove the car and one experimenter controlled the equipment from the back seat. The experimenter drove the car at a constant speed (2, 4, 7 or 10 mph) toward the crash dummy. The participant's lone task was to press a button when they believed they were at the point where a cautionary or imminent (depending on the trial) warning should be given. The car continued at a relatively constant speed until it hit the crash dummy and did not slow down and stop until after contact was made with the dummy.

3.6.3. Experimental Trial (Lab)

The procedure in the lab was similar. The participant viewed a video of the backing sequence. There were four different videos, one for each of the speed conditions. Each participant saw the same four videos for both the imminent and cautionary trials. As in the field portion of the study, the participant was instructed to press a button when they believed that a cautionary or imminent warning should be sounded.

3.7. Data Reduction

Field - The following data was collected during the field study.

1. Speed
2. Cumulative distance since start of trial
3. Video of the car approaching crash dummy (out back of car)
4. Timecode
5. Button push (timecode of button push)

This data was reduced by viewing the video in parallel with the data file collected during the trial. The following parameters were derived.

1. Average speed
2. Standard deviation of speed
3. Distance from button push to crash dummy hit
4. Time from button push to crash dummy hit
5. Speed at button push
6. Speed at crash dummy hit

Lab - For the lab condition the video and data files for each run existed before the trial. The time code for the button push was captured and tied again to the video timecode. The following parameters were derived from the data file using the timecode of the button push.

1. Average speed
2. Standard deviation of speed
3. Distance from button push to crash dummy hit
4. Time from button push to crash dummy hit
5. Speed at button push
6. Speed at crash dummy hit

3.8. Results

Field condition - The following tables (3-2 through 3-5) show the results of the study for both the time and distance for the field and laboratory conditions. For the time analysis the time shown is the time between the button push and the crash dummy hit. For the distance analysis the distance shown is the distance between the button push and the crash dummy hit. The actual speed is the average speed calculated over roughly the last two-thirds of the run. This is the part of the trial after the vehicle had reached a constant speed. (SD stands for standard deviation.)

Condition	Mean Actual Speed (mph)	Mean Time (sec)	SD (sec)
Imminent - 2MPH	2.93	1.76	0.91
Imminent - 4MPH	4.68	1.69	1.04
Imminent - 7MPH	7.51	1.86	1.00
Imminent - 10MPH	10.44	1.30	0.71
Cautionary - 2MPH	2.76	5.11	2.99
Cautionary - 4MPH	4.63	3.73	2.46
Cautionary - 7MPH	7.76	3.24	1.73
Cautionary - 10MPH	10.36	2.87	1.51

Table 3-2 Mean time between button push and dummy hit field condition for all participants.

Condition	Mean Actual Speed (mph)	Mean Distance (ft)	SD (ft)
Imminent - 2MPH	2.93	7.00	4.17
Imminent - 4MPH	4.59	14.82	11.65
Imminent - 7MPH	7.51	17.16	8.49
Imminent - 10MPH	10.44	17.57	9.38
Cautionary - 2MPH	2.76	19.20	10.68
Cautionary - 4MPH	4.76	23.90	16.15
Cautionary - 7MPH	7.76	32.00	16.14
Cautionary - 10MPH	10.36	37.87	19.20

Table 3-3 Mean distance between button push and dummy hit field condition for all participants.

Condition	Mean Actual Speed (mph)	Mean Time (sec)	SD (sec)
Imminent - 2MPH	2.68	4.20	1.56
Imminent - 4MPH	4.39	2.82	1.19
Imminent - 7MPH	7.66	1.76	0.74
Imminent - 10MPH	10.56	1.59	0.61
Cautionary - 2MPH	2.68	8.86	2.44
Cautionary - 4MPH	4.39	5.63	1.62
Cautionary - 7MPH	7.66	3.88	1.02
Cautionary - 10MPH	10.56	3.48	1.09

Table 3-4 Mean time between button push and dummy hit lab condition for all participants.

Distance Analysis (lab)

Condition	Mean Actual Speed (mph)	Mean Distance (ft)	SD
Imminent - 2MPH	2.68	13.78	5.29
Imminent - 4MPH	4.39	16.74	6.90
Imminent - 7MPH	7.66	17.42	6.98
Imminent - 10MPH	10.56	22.63	8.78
Cautionary - 2MPH	2.68	27.80	7.11
Cautionary - 4MPH	4.39	32.05	8.96
Cautionary - 7MPH	7.66	37.75	10.3
Cautionary - 10MPH	10.56	50.19	15.4

Table 3-5 - Mean distance between button push and dummy hit lab condition for all participants.

The following four graphs summarize the results from the tables above.

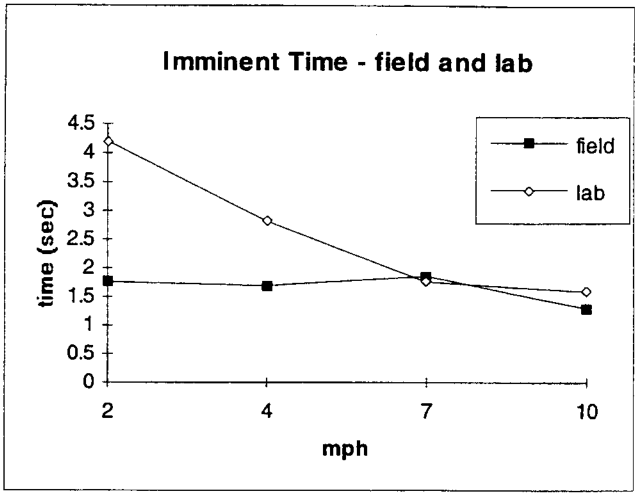

Figure 3-2 Imminent warning zone times for all participants in field and lab conditions.

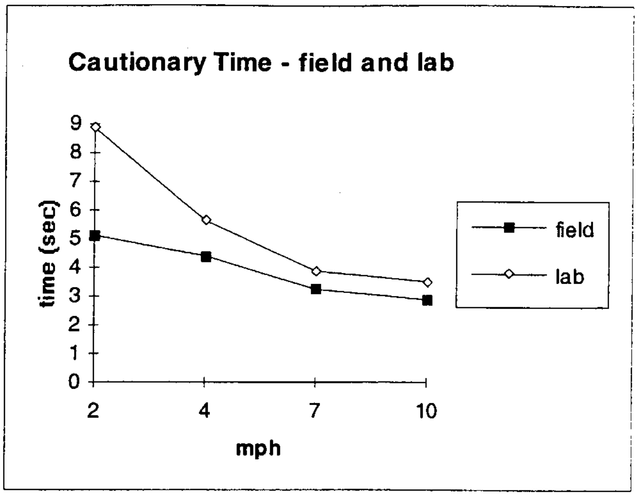

Figure 3-3 Cautionary warning zone times for all participants in field and lab conditions.

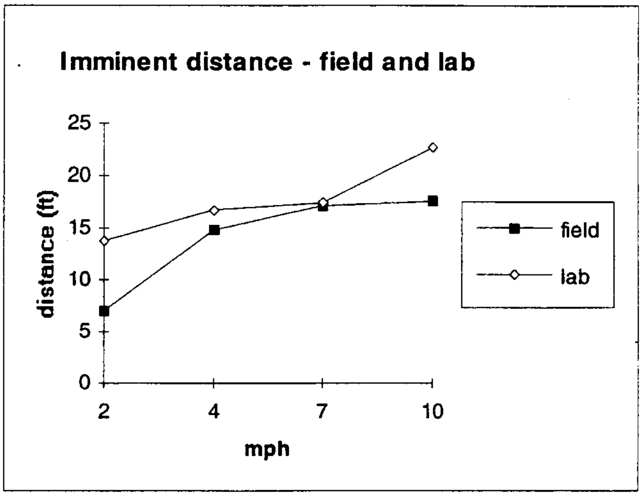

Figure 3-4 Cautionary warning zone distances for all participants in field and lab conditions.

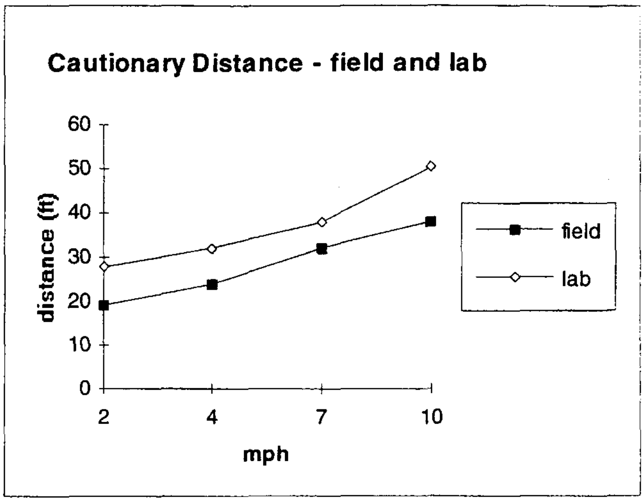

Figure 3-5 Cautionary warning zone distances for all participants in field and lab conditions.

The following tables show the time or distance for each participant across speed conditions. These tables give an indication of the variation between participants. Another measure of variation between participants is the standard deviation shown in the tables above.

field-imm	2mph	4mph	7mph	10mph
1	1.57	1.19	1.20	1.02
2	3.00	3.22	3.35	2.45
3	0.85	0.75	2.13	0.65
4	1.09	0.90	0.92	0.80
5	2.30	2.02	1.35	1.59

Table 3-6 Mean time between button push and dummy hit for each participant in the field-imminent condition.

field-caut	2mph	4mph	7mph	10mph
1	3.45	2.90	2.53	2.47
2	8.04	7.89	5.37	5.29
3	2.98	2.10	1.13	3.07
4	2.30	2.02	1.67	1.37
5	8.82	6.32	4.07	2.17

Table 3-7 Mean time between button push and dummy hit for each participant in the field-cautionary condition.

lab-imm	2mph	4mph	7mph	10mph
1	2.30	1.10	0.77	0.77
2	5.22	3.30	2.22	2.32
3	2.95	2.30	1.17	1.24
4	4.17	3.25	2.17	1.70
5	6.39	4.18	2.53	1.92

Table 3-8 Mean time between button push and dummy hit for each participant in the lab-imminent condition.

lab-caut	2mph	4mph	7mph	10mph
1	7.42	5.39	3.87	2.95
2	11.52	6.90	5.19	5.29
3	7.30	3.43	2.64	2.89
4	7.45	5.50	3.78	2.67
5	10.63	6.95	3.95	3.60

Table 3-9 Mean time between button push and dummy hit for each participant in the lab-cautionary condition.

Participant Analysis - The mean differences between the lab and the field studies (lab minus field) for each participant are shown in the following table.

(Dist C = Cautionary distance difference - lab minus field - between button push and crash dummy hit - feet)
(Dist I = Imminent distance difference - lab minus field - between button push and crash dummy hit - feet)
(Time C = Cautionary time difference - lab minus field - between button push and crash dummy hit - seconds)
(Time I = Imminent time difference - lab minus field - between button push and crash dummy hit - seconds)

sub 1				
MPH	Dist C	Dist I	Time C	Time I
2	9.7	2.0	4.0	0.7
4	14.7	-0.3	2.5	-0.1
7	11.3	-3.9	1.3	-0.4
10	9.1	-3.4	0.5	-0.3
sub 2				
MPH	Dist C	Dist I	Time C	Time I
2	4.6	5.4	3.5	2.2
4	-7.7	0.2	-1.0	0.1
7	3.0	-6.3	-0.2	-1.1
10	8.3	2.3	0.0	-0.1
sub 3				
MPH	Dist C	Dist I	Time C	Time I
2	12.2	7.1	4.3	2.1
4	8.5	6.3	1.3	1.6
7	14.4	-9.6	1.5	-1.0
10	2.8	9.5	-0.2	0.6
sub 4				
MPH	Dist C	Dist I	Time C	Time I
2	15.0	9.4	5.2	3.1
4	18.9	15.1	3.5	2.4
7	20.1	12.8	2.1	1.3
10	20.7	13.4	1.3	0.9
sub 5				
MPH	Dist C	Dist I	Time C	Time I
2	1.6	10.0	1.8	4.1
4	0.8	7.8	0.6	2.2
7	-9.6	7.8	-0.1	2.2
10	20.8	11.1	1.4	1.2

Table 3-10 Mean difference for each participant between field and lab conditions for each participant.

The graphs for the table above are shown next.

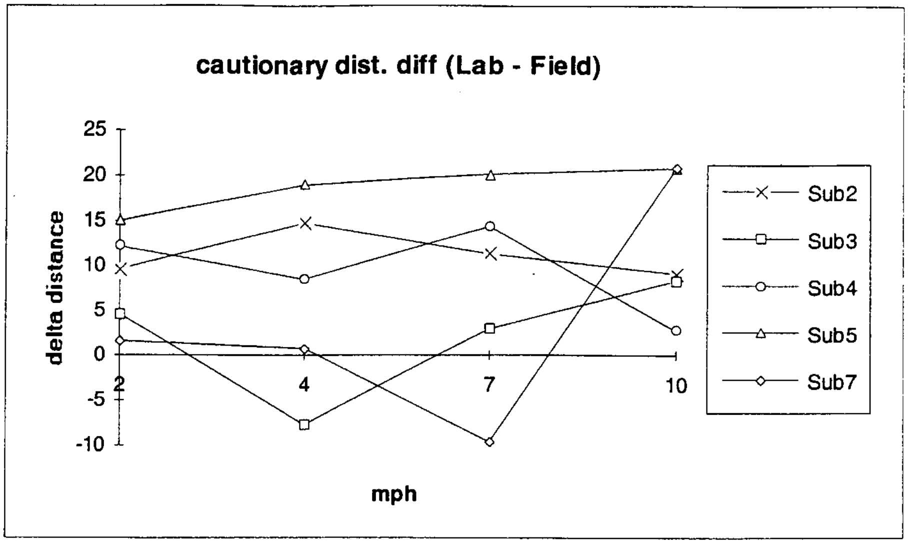

Figure 3-6 Cautionary distance difference between lab and field conditions for each participant.

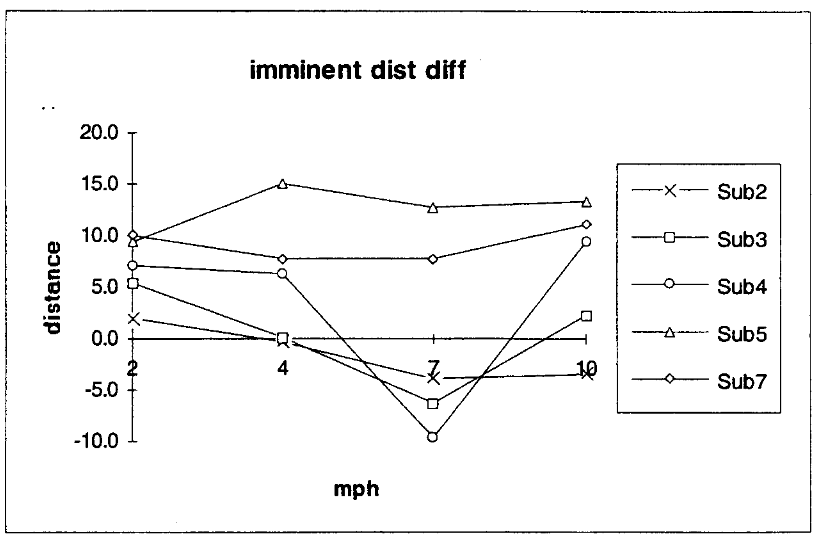

Figure 3-7 Imminent distance difference between lab and field conditions for each participant.

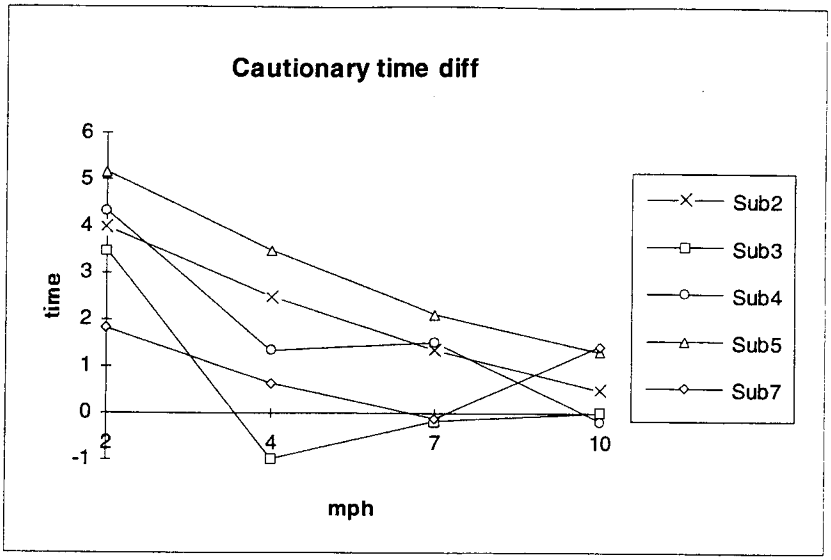

Figure 3-8 - Cautionary time difference between lab and field conditions for each participant.

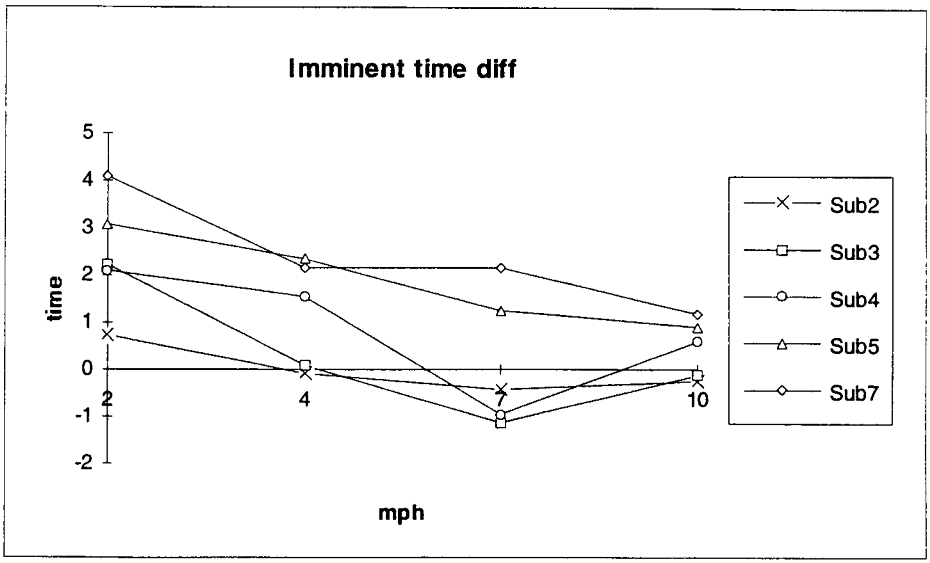

Figure 3-9 Imminent time difference between lab and field conditions for each participant.

3.9. Conclusions

This study was designed to determine where participants expect imminent and cautionary warnings when backing toward an object, and to compare these judgments under both field and laboratory conditions. In the field part of the study, the mean time for the imminent alarm time was 1.65 seconds across all speeds. The timing of the imminent alarm was fairly constant across the different speeds. On the other hand, the cautionary time in the field study varied for the different speeds from 5.11 seconds for 2 mph to 2.89 seconds for 10 mph. This would imply that imminent warnings are predominantly time-based and cautionary warnings are at least somewhat dependent upon the speed.

Since these results are mean values across the five participants, it is interesting to examine the differences between the participants. Tables 3-5 through 3-8 in the results section show the time variation between participants for each experimental condition. The differences between participants are large, typically on the order of 4 to 1 for the extreme participants. So, while the mean results seem consistent, there was a great deal of variability between the participants and the results should be used with caution.

The lab part of the study had a different pattern of results. Both the imminent and cautionary conditions had longer times for the slower speeds (similar to the cautionary field condition). Based on subjective reports that the perception of distance in the lab was 'more difficult' than in the field, a further analysis of the images was performed. This analysis revealed that there was a small difference in image's visual angle between the field and the lab. This difference is shown in the figure below.

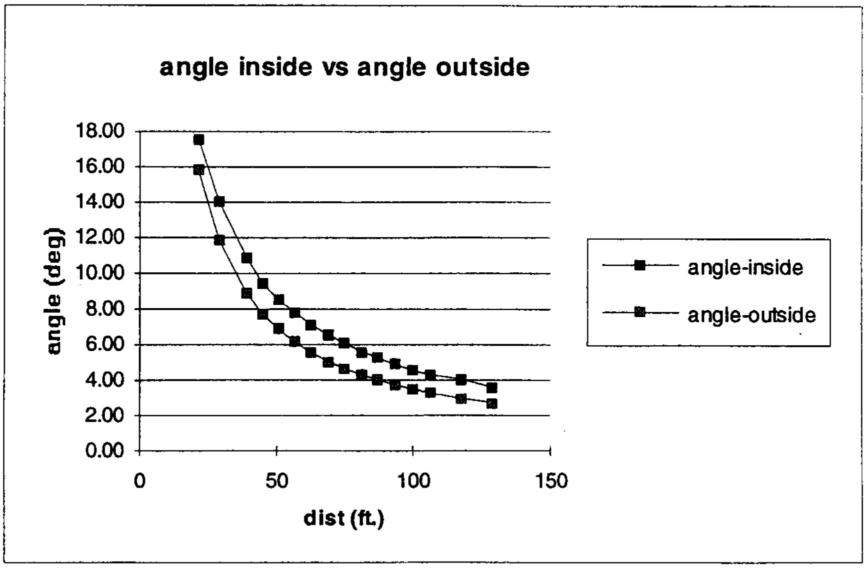

Figure 3-10 Visual angle comparison between lab and field conditions.

The figure above shows that a equal distances from the dummy the image's visual angle was bigger in the lab. The difference in visual angle corresponded to a difference in distance perception. This difference is shown the following figure.

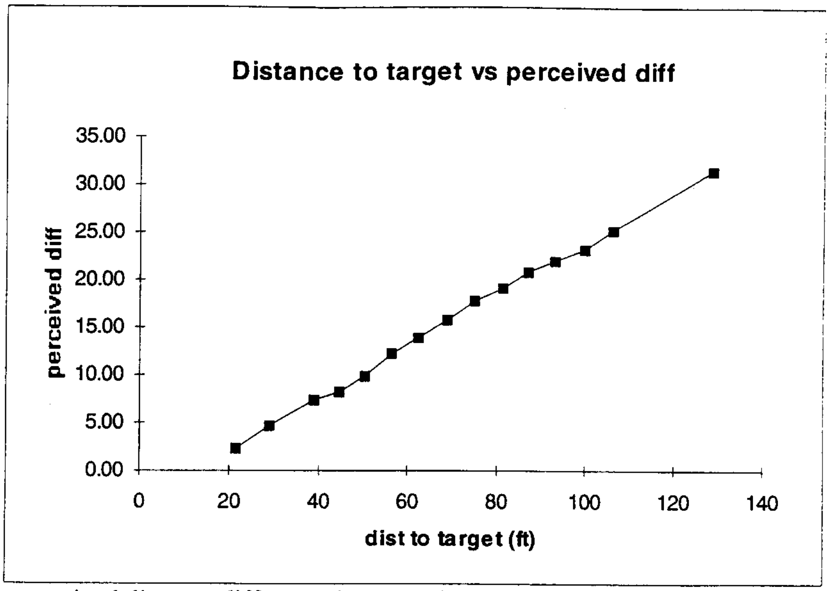

Figure 3-11 The perceived distance difference between the field and lab conditions for different distances from the target. (The target appeared closer in the lab) (ex. when the dummy was 100 feet away in the lab and the field it appeared 25 feet close in the lab).

This difference would account for much of the difference between the lab and the field studies. The following two tables shows the original and corrected distances and times based on the visual angle of the target as seen by the participant in the field and lab conditions.

Condition	Field Mean Distance (ft)	Lab Mean Distance (ft)	Lab Corrected Distance (ft)
Imminent - 2 MPH	7.0	13.8	12.5
Imminent - 4 MPH	14.8	16.7	15.0
Imminent - 7 MPH	17.2	17.4	15.5
Imminent - 10 MPH	17.6	22.6	20.2
Cautionary - 2 MPH	19.2	27.8	22.8
Cautionary - 4 MPH	23.9	32.1	26.1
Cautionary - 7 MPH	32.0	37.8	30.5
Cautionary - 10 MPH	37.9	50.2	40.1

Table 3-11 Corrected distances for the lab condition based on perceived size differences.

Condition	Field Mean Time (sec)	Lab Mean Time (sec)	Lab Corrected Time (sec)
Imminent - 2 MPH	1.8	4.2	3.7
Imminent - 4 MPH	1.7	2.8	2.5
Imminent - 7 MPH	1.9	1.8	1.6
Imminent - 10 MPH	1.3	1.6	1.4
Cautionary - 2 MPH	5.1	8.9	7.2
Cautionary - 4 MPH	3.7	5.6	4.6
Cautionary - 7 MPH	3.2	3.9	3.2
Cautionary - 10 MPH	2.9	3.5	2.8

Table 3-12 Corrected times for the lab condition based on perceived size differences.

The correction based on the size of the visual angle make the cautionary condition very similar between the lab and the field. The imminent condition still has some differences especially at the very slow speeds, but these differences are reduced with this correction. In order for the visual angle differences to be minimized the distance that the participants sat from the video image in the lab could be modified. The participants sat at 10 feet from the video screen during the lab condition. If the distance was increased to 12.5 feet the visual angle for the field and lab would be nearly identical and the above correction would not be required.

The desire for longer warning times at lower speeds is consistent with recent perceptual data, showing that viewers are more accurate in judging time-to-collision at higher speeds, with time-to-collision being underestimated at slow speeds (Sidaway, Fairweather, Sekiya, & McNitt-Gray, 1996). Because "optical flow" appears to be the primary perceptual cue for these judgments, the greater error at low speeds for the video viewing would also appear compatible, since the visual cues are more degraded than in live viewing.

In summary, this study provides estimates of the imminent and cautionary warning zones expected by drivers while backing. The study also examined the differences between field and lab perceptions of these zones. After correcting for visual angle, the lab and field data are consistent with each other with the exception of some relatively minor differences at the 2 mph condition. The desired point for imminent crash warnings, expressed in terms of time-to-collision with the dummy, was consistent across the range of vehicle speeds, with a mean of about 1.6 seconds. This suggests that time-to-collision may be an appropriate basis for warnings, one that is consistent with subjective judgments, and also consistent with the manner in which backing drivers actually perform. An earlier observational study of backing drivers found that they tended to maintain a relatively constant time-to-collision as they backed toward an object, and in fact, they generally maintained this time-to-collision at a value well above 1.6 seconds. The mean minimum-time-to-collision observed for backing drivers was on the order of 3 seconds, which is also roughly comparable to the point at which participants in this experiment felt that it would be appropriate to receive a cautionary warning (except at the slowest backing speeds). However, it should also be noted that there were substantial differences between participants in the time at which they felt the warning would be appropriate. This experiment was based on a small sample, with the purpose of obtaining a general estimate of the warning points people considered appropriate, so that this could be considered along with objective performance criteria. It does not provide a good basis for estimating the range of variation among drivers or its relationship to individual factors. The range of variation does suggest that consideration might be given to user adjustment of warning points, particularly for cautionary warnings.

4. Graded (Analog) Warning Zones

4.1. Background

Previous analyses (Lerner, et al., 1996) of crash avoidance warning suggest the benefits of having two distinct warnings, imminent and cautionary. Imminent and cautionary alarms are defined as follows.

> An <u>imminent</u> crash avoidance situation is one in which the potential for a collision is such that it requires an immediate vehicle control response or modification of a planned response in order to avoid a collision.
>
> A <u>cautionary</u> crash avoidance situation is one in which the potential for a collision requires immediate attention from the driver, and which may require a vehicle maneuver, but does not meet the definition of an imminent crash avoidance situation.

Implementing such a system for backup warnings requires a variety of design decisions including the following:

1. When to turn on each type of alarm
2. How the alarm should vary between cautionary and imminent positions
3. The alarm acoustic characteristics

This study was designed to examine questions 2 and 3.

A major concern with warning alarms is determining the sensitivity of the alarm. On one hand, if the alarm is too sensitive, many false alarms will occur. Excessive false alarms can cause drivers to ignore or disable the alarm because the device becomes a nuisance. Alternatively, if the alarm is not sensitive enough, the driver will not receive a timely alarm in situations where one is required and an accident could result.

The strategy being considered for a backup warning alarms is to have a relatively benign cautionary alarm which may or may not change in acoustic characteristics during the interval it is activated. Following the cautionary alarm is a more threatening imminent alarm. It was hypothesized that it might be useful to use a cautionary alarm that varies with the urgency of the situation. The cautionary alarm would provide information about the level of the danger as the driver approached an obstacle. This study examined variations of cautionary alarms and determined participant's preferences for the different alarms. Additionally, a measure of annoyance was obtained for several of the alarm conditions.

Although some feature of the warning (e.g. loudness, pitch, pulse rate) may increase in magnitude as the vehicle approaches an object, it is not necessarily the case that a <u>linear</u> increase with distance will provide the best match to the subjective sense of warning urgency. Therefore, this experiment included a comparison of three different functions: one that had a linear relationship to distance, one that increased more rapidly as backing progressed, and one that increased most rapidly initially.

4.2. Overview of Design/Procedure

The study was conduced in a laboratory setting. Video tapes were made of a car backing to a life size dummy suspended from the ceiling in a parking garage. The camera's perspective was from a passenger looking over the left shoulder. One tape segment was made for each of four speed conditions. (These were the same conditions used in the warning zone definition study). As the tape was played an acoustic signal was played over loud speakers. The following parameters were varied.

1. Cautionary alarm onset time- (4.5 or 1.5 seconds before imminent alarm) These values represent the approximate 5th and 95th percentile values from the warning zone definition study.
    Note: the imminent alarm was always started 1.5 seconds before contact with dummy
2. Alarm Pitch (constant, linear rise, fast rise and slow rise)
    Constant = Non-varying throughout the cautionary alarm period
    Linear Rise = Rises at a constant (linear) rate during the cautionary alarm period
    Fast Rise = Rises according to Equation 3 below (rise constant = 0.25)
    Slow Rise = Rises according to Equation 3 below (rise constant = 2.00)
3. Loudness (constant, linear rise, fast rise and slow rise)
4. Pulse Rate (constant, linear rise, fast rise and slow rise)

$$\mathbf{((((\text{Percent of rise time}) * 100)^{\text{rise constant}})/100^{\text{rise constant}}) * \text{range}}$$

where range = stop value minus start value (i.e., pitch, loudness, or pulse rate)

Equation 3 Fast and Slow rise values.

The fast rise condition changed from a low to high value very quickly at first and then changed at a slower rate. Conversely the slow rise condition started out changing only small amounts and then changing rapidly near the end of the presentation period.

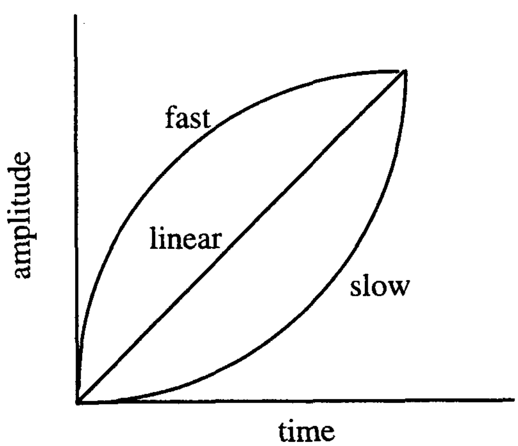

Figure 4-1 variation of fast, linear and slow conditions over time.

To summarize, the experiment had 5 independent variables

1. Cautionary alarm starting point (2 levels - early and late)
2. Vehicle speed (4 levels - 2, 4, 7 and 10 mph)
3. Pulse rate variation (4 levels - constant, linear, fast and slow)
4. Loudness (4 levels - constant, linear, fast and slow)
5. Pitch (4 levels - constant, linear, fast and slow)

A complete factorial experiment would have required (4 x 4 x 4 x 4 x 2 = 512 trials). This was too many trials for a participant to complete in a single hour session. Thus, trials were eliminated by not performing all of the combinations of the pulse rate, loudness, and pitch variables.

At each of the 8 speed by alarm onset combinations, the following 14 trials were tested.

#	Pulse Rate	Loudness	Pitch
1	constant	constant	constant
2	linear	constant	constant
3	constant	linear	constant
4	constant	constant	linear
5	linear	linear	constant
6	constant	linear	linear
7	linear	constant	linear
8	linear	linear	linear
9	constant	constant	slow
10	constant	constant	fast
11	constant	slow	constant
12	constant	fast	constant
13	slow	constant	constant
14	fast	constant	constant

Table 4-1 Speed by Onset conditions.

Therefore, there were (14 x 8) 112 trials.

The experiment included 8 additional trials in which participants rated the annoyance of the alarm. These trials were all at the 7 mph condition and employed only linear and constant change functions. The purpose was to determine weather there were meaningful differences in annoyance among the three signal characteristics being manipulated, as well as the onset point. These 8 trials can be characterized as follows:

#	Loudness	Pitch	Pulse Rate	Onset
1	constant	constant	constant	early
2	**linear**	constant	constant	early
3	constant	**linear**	constant	early
4	constant	constant	**linear**	early
5	constant	constant	constant	late
6	**linear**	constant	constant	late
7	constant	**linear**	constant	late
8	constant	constant	**linear**	late

Table 4-2 Annoyance conditions tested.

The experiment attempted to simulate a driver approaching a target and the acoustic properties that would result. The following figure shows an example of the linear variation of the loudness of a sound as a vehicle approaches a target.

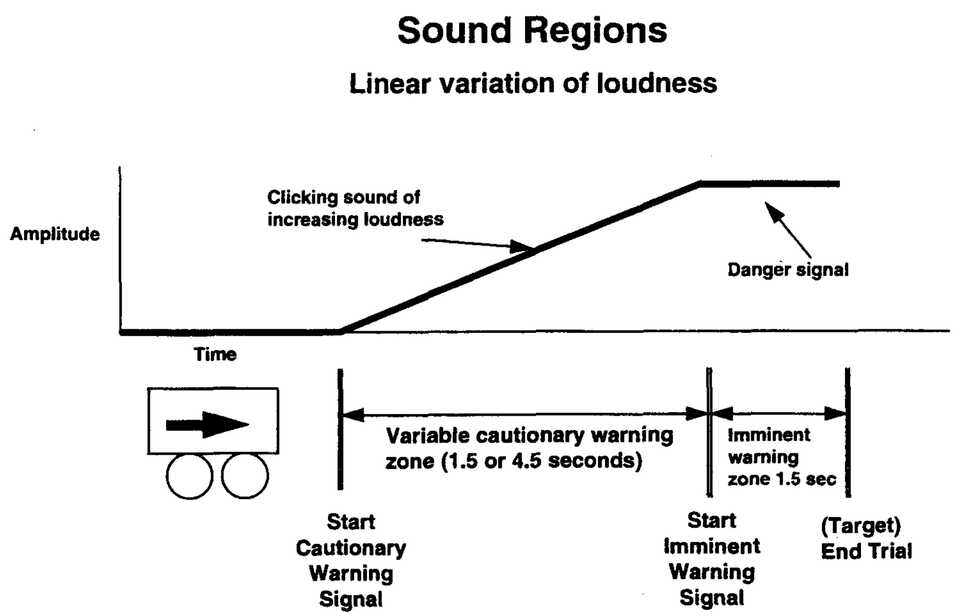

Figure 4-2 Example of linear variation of loudness.

4.3. Participants

There were 24 participants tested in this study. There were 12 each in the young (less than 55 years old) and elderly (at least 70 years old) groups. Genders were split evenly in the two groups. The mean age for the elderly group was 72.4 years, and the mean age for the young group was 34.0 years. Participants were recruited from COMSIS, other nearby businesses, and senior centers. All participants had a valid drivers license. All had normal or corrected-to-normal vision. All had normal or corrected-to-normal hearing in at least one ear.

4.4. Apparatus

A master audio/video 8 mm tape was created with each of the 122 trials (plus 5 practice trials). The video was played on a Sony VTR (model number SONY CVD-1000) and projected to a screen using a Sony Color Video Projector (model VPH-1044Q), providing an approximately 100" diagonal, life-size view of each trip toward the crash dummy. The participants were seated approximately 12' 6" from the display screen. Participants ran in groups of 5 or 6 at time. The visual angle subtended by the image at the viewer position was matched to that which would be subtended by the actual object in the field as viewed from the driver position.

4.5. Experimental Design

4.5.1. Independent Variables

The experiment had 5 independent variables

1. Cautionary alarm starting point (2 levels - early and late)

   The cautionary alarm started either 6.0 seconds (early)or 3.0 seconds (late) before the collision with the crash dummy. The cautionary alarm always stopped 1.5 seconds before the collision at which point the imminent alarm started and continued until the collision with the crash dummy.

2. Vehicle speed (4 levels - 2, 4, 7 and 10 mph)

   The vehicle speed was constant throughout each trial.

3. Pulse rate variation (4 levels - constant, linear, fast and slow)

   In the linear, fast and slow conditions the pulse rate varied from 6 Hz to 20 Hz. In the constant condition the pulse rate was fixed at 13 Hz.

4. Loudness (4 levels - constant, linear, fast and slow)

   In the linear, fast and slow conditions the loudness varied from 51 dBA to 75 dBA. In the constant condition the loudness was fixed at 63 dBA. This was approximately 18 dBA above the ambient noise level in the lab.

5. Pitch (4 levels - constant, linear, fast and slow)

   The pitch variation was done by manipulating the MIDI output on a 16-bit stereo sound card. The MIDI software allowed the choice of over 100 instruments and a wide range of frequencies. The instrument chosen for this study was called a Pizzicato String. It produces a relatively narrow band clicking sound when played for short durations (note: the length of each pulse was fixed at 25 ms.)

In the linear, fast and slow conditions the center frequency varied from 292 Hz to 1147 Hz. In the constant condition the frequency did not vary and was centered at 587 Hz.

The table below shows which combinations of the independent variables were examined. Each of the 14 conditions shown in the table were repeated for each 8 onset (early, late) by speed (2, 4, 7 and 10 mph) conditions.

#	Pulse Rate	Loudness	Pitch
1	constant	constant	constant
2	linear	constant	constant
3	constant	linear	constant
4	constant	constant	linear
5	linear	linear	constant
6	constant	linear	linear
7	linear	constant	linear
8	linear	linear	linear
9	constant	constant	slow
10	constant	constant	fast
11	constant	slow	constant
12	constant	fast	constant
13	slow	constant	constant
14	fast	constant	constant

Table 4-3 Summary of conditions.

4.5.2. Dependent Variables

There were two dependent variables in this experiment. The first was the "match to danger" rating reported by the participants. The danger rating was intended to measure how well the acoustic warning signal matched the subjective feeling of danger as the car approached the crash dummy. (The detailed instructions are given in Appendix C). The second dependent variable was the participant's report of annoyance, based on a small subset of the overall stimulus set. This was intended to capture how irritating the different alarms were. Instructions for the annoyance trials are also presented in Appendix C.

4.6. Procedure

4.6.1. Informed Consent and Instructions to Participants

Initially, the experimenter greeted the participant and asked him or her to read and sign the informed consent form. The experimenter then read a set of instructions (see Appendix C) outlining the requirements of the participant for participation in the experiment. Special emphasis was given to ensure participants understood their task. Participants were asked to rate how well the changing sense of danger in the alarm matched the send of danger they felt as the car approached the target in the video. The ratings were made on a 1 (no match) to 7 (perfect match) scale. Ample opportunity was provided for the participants to ask questions about the experimental procedure.

4.6.2. Experimental Trial

Prior to the actual data collection the participants were given detailed instructions about the task they were to perform. As part of the instruction, participants viewed several examples of the video and heard a range auditory signals. Additionally, there were three practice trials before the data collection began.

The experimental trial consisted of the participant being seated 12.5 ft. (3.81 m) from a large video projection screen. A video segment of a car backing to a crash dummy was shown on the large screen. The visual angle of crash dummy image and the actual video collection in the vehicle were matched as closely as possible. A typical video segment was about 20 seconds long. At predetermined points in the video (as described above) auditory warnings were played. At the end of the video segment, the screen would blank and the participants circled their response on the provided response forms (see Appendix C).

4.7. Results

4.7.1. Danger Ratings

The results of the 24 participants are shown below. Two data points for one of the elderly participants were coded incorrectly and are not included in the results below.

<u>Summaries of the entire data set.</u>

The experiment had 14 different conditions repeated at each speed and onset position combination. Overall mean ratings on these conditions is shown in the Table 4-4 and Figure 4-3 below. The higher the rating, the better matched a given audible characteristic was to its respective video segments.

pulse rate	loudness	pitch	mean rating
constant	constant	constant	3.58
fast	constant	constant	3.64
linear	constant	constant	3.69
slow	constant	constant	3.70
constant	constant	slow	3.81
constant	constant	linear	3.82
linear	constant	linear	3.95
constant	constant	fast	4.11
constant	slow	constant	4.22
linear	linear	linear	4.46
linear	linear	constant	4.47
constant	linear	constant	4.48
constant	linear	linear	4.51
constant	fast	constant	4.75

Table 4-4 Overall means for each of the 14 conditions.

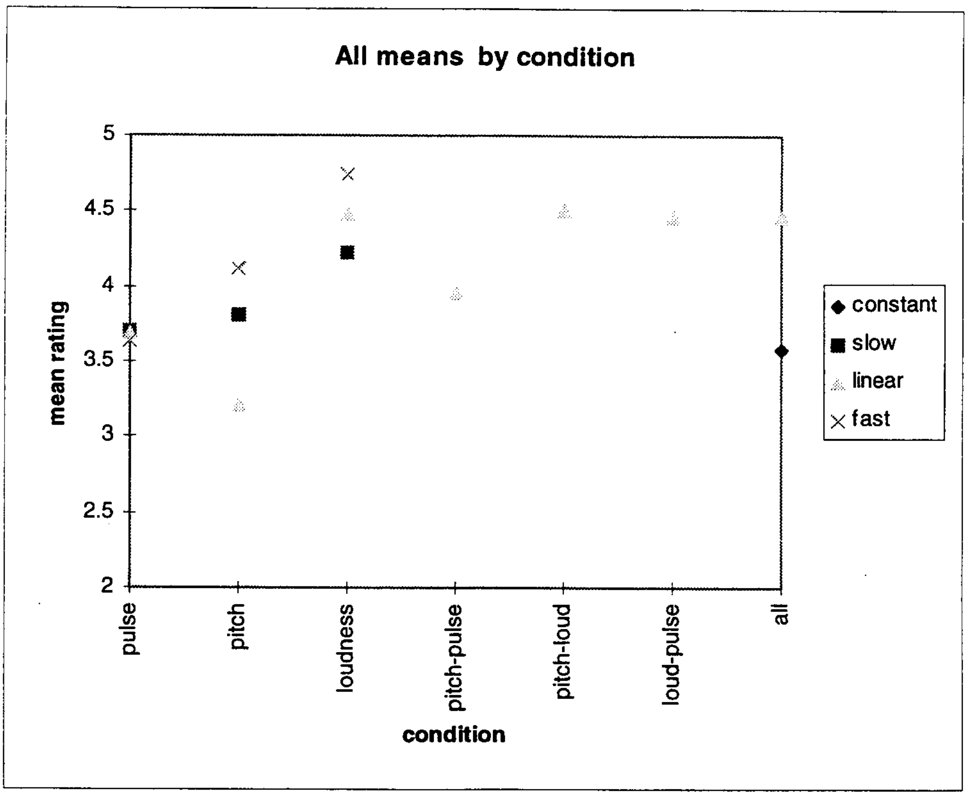

Figure 4-3 Graph of means for each condition.

The lowest ratings were for the condition where all of the sound parameters were held constant. The highest ratings were for the conditions in which loudness varied.

Early vs. Late Cautionary Alarms

Participants gave higher ratings to the early cautionary alarms than to the late ones. The means are shown in the table below.

	Mean	Standard Deviation
Early	4.72	1.64
Late	3.44	1.69

Table 4-5 Mean Ratings Of Early Vs. Late Onset Time All Participants

This difference was significant ($t = 19.81$, $p<.0001$).

This significant difference in early vs. late also holds for age and gender groups.

The tables for the early and late onset means broken down by condition are shown below.

pulse rate	**loudness**	**pitch**	**mean rating**
fast	constant	constant	4.02
constant	constant	constant	4.05
linear	constant	constant	4.32
slow	constant	constant	4.46
constant	constant	slow	4.52
constant	constant	linear	4.53
constant	constant	fast	4.57
linear	constant	linear	4.64
constant	slow	constant	4.99
constant	linear	linear	5.07
constant	linear	constant	5.08
constant	fast	cons ant	5.27
linear	linear	constant	5.28
linear	linear	linear	5.34

Table 4-6 Mean rating for early onset condition.

pulse rate	loudness	pitch	mean rating
slow	constant	constant	2.94
linear	constant	constant	3.06
constant	constant	constant	3.10
constant	constant	slow	3.10
constant	constant	linear	3.11
fast	constant	constant	3.26
linear	constant	linear	3.26
constant	slow	constant	3.46
linear	linear	linear	3.58
constant	constant	fast	3.65
linear	linear	constant	3.67
constant	linear	constant	3.89
constant	linear	linear	3.95
constant	fast	constant	4.23

Table 4-7 Mean rating for late onset condition.

Male and female rating preferences

The danger rating means broken down by gender are shown in the following two tables.

pulse rate	loudness	pitch	mean rating
constant	constant	constant	3.55
slow	constant	constant	3.69
linear	constant	constant	3.72
fast	constant	constant	3.78
constant	constant	slow	3.93
linear	constant	linear	3.98
constant	constant	fast	4.11
constant	constant	linear	4.11
constant	slow	constant	4.19
constant	linear	constant	4.40
linear	linear	linear	4.46
linear	linear	constant	4.48
constant	linear	linear	4.52
constant	fast	constant	4.61

Table 4-8 Mean rating for female participants.

pulse rate	loudness	pitch	mean rating
fast	constant	constant	3.50
constant	constant	linear	3.53
constant	constant	constant	3.60
linear	constant	constant	3.67
constant	constant	slow	3.68
slow	constant	constant	3.71
linear	constant	linear	3.92
constant	constant	fast	4.10
constant	slow	constant	4.26
linear	linear	linear	4.47
linear	linear	constant	4.47
constant	linear	linear	4.50
constant	linear	constant	4.57
constant	fast	constant	4.88

Table 4-9 Mean rating for male participants.

Rating for different speeds

The ratings for the speeds are shown in the table below. The speeds are listed on the left-hand side of the table (2, 4, 7, and 10 mph). The mean rating increased with speed, suggesting that participants believed that the warning sounds worked better at higher speeds.

MPH	N	Mean	Std. Dev.
2	671	3.23	1.76
4	672	3.99	1.73
7	671	4.40	1.66
10	672	4.73	1.52

Table 4-10 Mean rating for different speeds for all participants

Post-hoc pairwise comparisons were performed using the Bonferrioni/Dunn test. Each of the pairwise comparisons was significant. The comparison table is shown below. The speeds being compared are shown along the left side of the table. Significant differences are marked with a 'S' on the right hand side of the table.

MPH	Mean Difference	Crit. Difference	P-Value	Significant
2, 4	-.765	.245	<.0001	S
2, 7	-1.171	.245	<.0001	S
2, 10	-1.506	.245	<.0001	S
4, 7	-.407	.245	<.0001	S
4, 10	-.741	.245	<.0001	S
7, 10	-.334	.245	.0003	S

Table 4-11 Bonferrioni/Dunn test for significant differences of means

Again, the same pattern of results was exhibited by gender and age categories.

Speed by onset ratings

A consistent pattern of results was observed within the early and late cautionary warnings. The following graph shows this relationship.

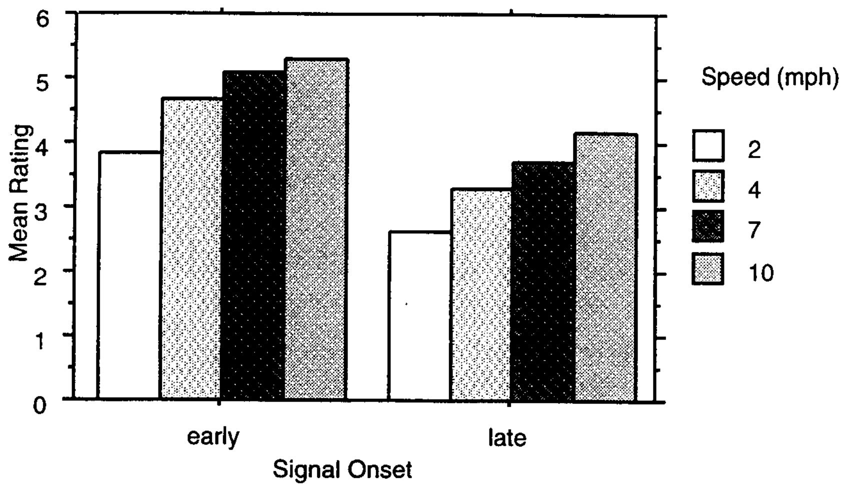

Figure 4-4 Mean rating for early and late signal onsets at different speeds.

The following ANOVA table for danger rating shows significant differences for speed and onset, but no significance for the interaction between the two variables.

	DF	Sum of Squares	Mean Square	F-Value	P-Value
speed	3	846.951	282.317	113.811	<.0001
onset	1	1095.858	1095.858	441.775	<.0001
speed * onset	3	9.942	3.314	1.336	.2608
Residual	2678	6642.989	2.481		

*Table 4-12 ANOVA Table rating for (speed * onset) all participants*

4.7.2. Summaries of partial data sets

Pulse Rate Results

The mean ratings for pulse rate across all conditions is shown below.

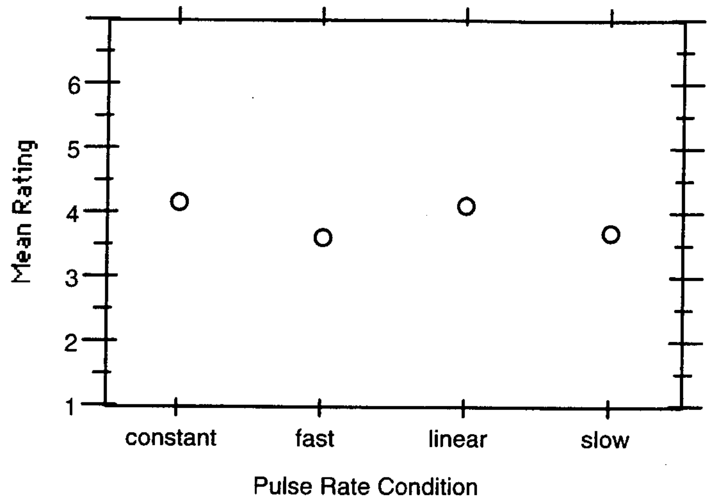

Figure 4-5 Mean rating for different pulse rate conditions - all trials.

The constant and linear variations were rated slightly higher than fast and slow variations, but none of the differences were significant. This same pattern of results was observed for age and gender comparisons.

When pitch and loudness were held constant the following danger ratings for pulse rates were observed.

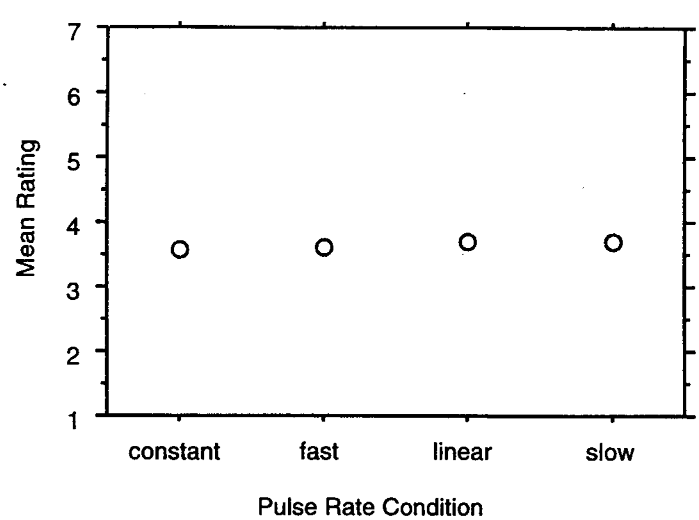

Figure 4-6 Mean rating for different pulse rate conditions with pitch and loudness held constant.

None of these differences were significant.

Loudness Rating Results

The following graphs shows the mean rating for loudness across all participants and trials.

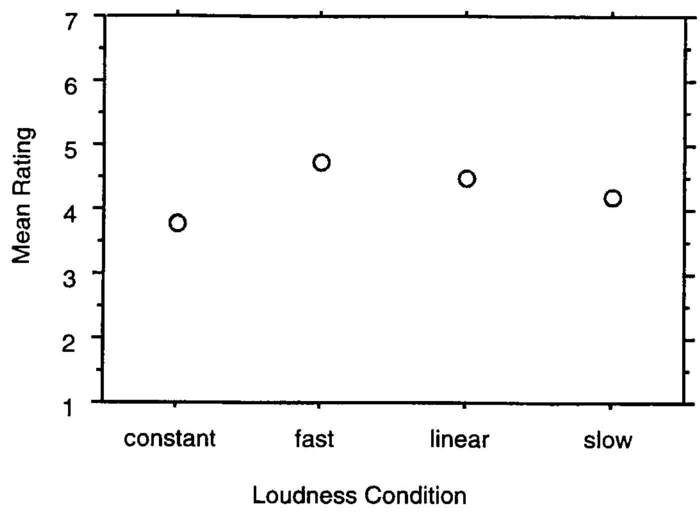

Figure 4-7 Mean rating for different loudness conditions - all trials.

Holding pulse rate and pitch constant yields the following graph.

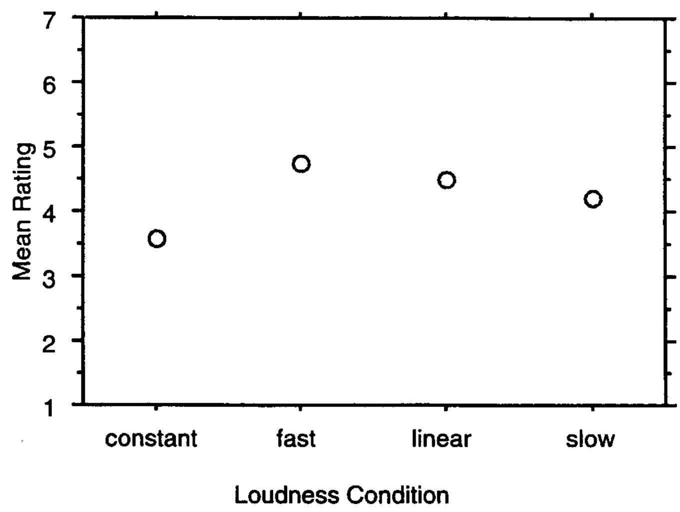

Figure 4-8 Mean rating for trials with the pulse rate and pitch held constant.

The Bonferroni/Dunn test was computed to test for significant differences between the ratings. All three variation conditions (slow, fast and linear) were preferred to the constant condition. Additionally, the fast condition was preferred to the slow, but there was no statistical difference between the fast and linear. The Bonferroni/Dunn test is shown below.

	Mean Diff.	Crit. Diff	P-Value	
constant, fast	-1.171	.478	<.0001	S
constant, linear	-.906	.478	<.0001	S
constant, slow	-.646	.478	.0004	S
fast, linear	.264	.478	.1442	
fast, slow	.525	.478	.0038	S
linear, slow	.260	.478	.1496	

Table 4-13 Bonferroni/Dunn test for mean comparisons of loudness with pulse rate and pitch held constant.

Pitch Rating Results

A plot of the mean rating for the different pitch conditions is shown below.

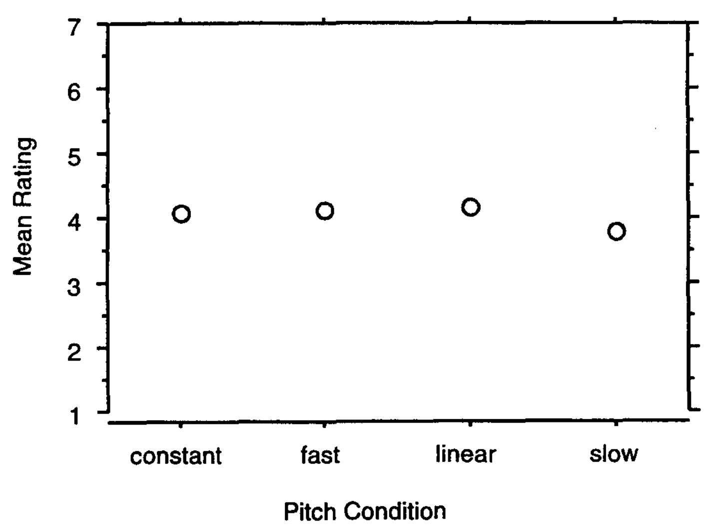

Figure 4-9 Mean rating for different pitch conditions - all trials.

None of these differences were significant. If loudness and pulse rate are held constant, the following plot is obtained.

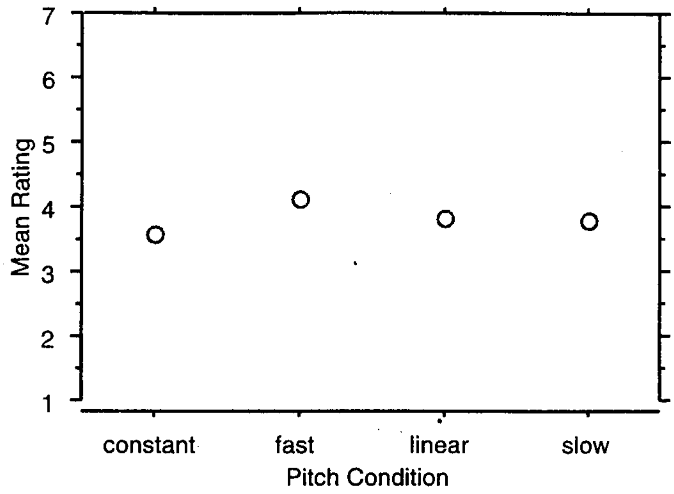

Figure 4-10 Mean rating for trials with the pulse rate and loudness held constant.

The Bonferroni/Dunn test was computed to test for significant differences between the ratings. The only significant difference was that the fast condition was rated significantly better than the constant condition. This marked by a 'S' in the table below.

	Mean Diff.	Crit. Diff	P-Value	
constant, fast	-.531	.477	.0033	S
constant, linear	-.245	.477	.1750	
constant, slow	-.228	.478	.2067	
fast, linear	.286	.477	.1125	
fast, slow	.303	.478	.0936	
linear, slow	.017	.478	.9266	

Table 4-14 Bonferroni/Dunn test for mean comparisons of pitch with pulse rate and loudness held constant.

4.7.3. Annoyance Results

Annoyance ratings were collected for early and late onsets for the 7 MPH speed condition. Pulse rate, loudness and pitch were each tested using a linear variation while the others were held constant.

One of the participants (an elderly male) apparently did not understand the instructions for the annoyance part of the experiment, and this participant's data was dropped from the analysis.

The overall annoyance ratings were as follows.

pulse rate	loudness	pitch	annoyance rating
linear	constant	constant	3.00
constant	constant	constant	3.02
constant	constant	linear	3.20
constant	linear	constant	4.70

Table 4-15 Overall annoyance results.

Statistically, the "constant - linear - constant" condition was different from the other three conditions. The other three conditions were not statistically different from one another.

The annoyance rating for the early condition is shown in the table below.

pulse rate	loudness	pitch	annoyance rating
linear	constant	constant	3.35
constant	constant	constant	3.48
constant	constant	linear	3.61
constant	linear	constant	5.04

Table 4-16 Annoyance results early condition.

The annoyance rating for the late condition is shown in next table.

pulse rate	loudness	pitch	annoyance rating
constant	constant	constant	2.57
linear	constant	constant	2.65
constant	constant	linear	2.78
constant	linear	constant	4.35

Table 4-17 Annoyance results late condition.

The mean annoyance ratings for early and late onsets are shown in the following table.

	N	Mean	Std. Dev
early	92	3.87	1.72
late	92	2.63	1.62

Table 4-18 Mean table early vs. late onset.

A t-test revealed that this difference was significant ($t=3.179$, $p = 0.0017$) indicting that late alarms are less annoying the early ones.

4.8. Conclusions

4.8.1. Dimension variation

The main purpose of this experiment was to determine how people expected a cautionary alarm to vary as a vehicle approached a target. Three acoustic variations and combinations of these variations were examined. The three main variations were pulse rate, loudness and pitch. Examination of the results indicate that loudness was the most useful dimension to vary. Each condition that varied loudness had a higher rating than each condition that did not. In other words, participants felt the greatest match between their sense of danger in the backing scene and the danger portrayed by the alarm when the loudness increased as the car approached the target. The best overall condition was constant pulse rate, constant pitch and fast variation of loudness.

Examining each dimension individually, the following conclusions can be made.

Pitch: When holding the pulse rate and loudness constant only the fast variation of pitch was effectively different then the other three conditions (constant, linear and slow). This suggests that pitch alone is not a strong candidate for the coding of danger. Additionally, adding pitch variation to a signal that already has loudness variation did not significantly improve its rating.

Pulse Rate: When holding loudness and pitch constant, none of the pulse rate conditions were significantly different from one another. This indicates that pulse rate is not strongly associated with the perception of danger.

Loudness: When pitch and pulse rate were held constant the loudness trials showed significant variation. All of the loudness variations conditions (linear, fast and slow) were significantly different than the constant condition. Additionally, the fast variation of loudness was significantly better than the slow. This experiment showed no benefit from adding pulse rate or pitch variation to loudness variation.

In addition to varying each of the acoustic dimensions, the onset of the cautionary alarm was varied from 4.5 seconds before the collision (early) to 1.5 seconds before the imminent alarm. Participants rated the early warning condition, as more closely matching their sense of risk.

One consistent finding in this experiment was that the slower the backing speed, the lower the rating. Our previous studies indicated that participants experienced some difficulty accurately estimating slow speeds in a laboratory setting. The findings of this experiment are consistent with the previous research.

There were no significant differences between the danger ratings for the young and elderly or the males and females.

4.8.2. Annoyance rating

The annoyance ratings paralleled the danger ratings. Alarms that were perceived as appropriate for a danger warning were rated as being more annoying. To a large extent that is what was expected, since alarms are typically designed to grab the driver's attention often at the expense of being annoying. The alarms that had the highest annoyance were alarms with early onset and loudness variation. Conversely, alarms with the lowest rating were the ones with a late onset and constant loudness.

Although loudness variation was rated a most annoying, it should be noted that the ultimate amplitude of the signal was higher in the loudness varying conditions than in the loudness constant condition (ranging from 51-75 dBA, verses fixed at 63 dBA). Since loudness is known to be a dominant factor in the annoyance of acoustic signals, it is likely this peak loudness, rather than the variance in loudness, that cause it to be rated as more annoying than the other conditions. Under normal backing condition, a warning system with variable loudness would typically not reach its highest level.

4.8.3. Design implications

1. Loudness variation is most useful for coding danger.
2. Pulse rate and pitch variation did not code subjective danger well and should not be used.
3. Drivers prefer early onset times when rating danger.
4. Drivers find loudness variation more annoying than other dimensions
5. Drivers prefer late onset times when rating annoyance.
6. There were no gender or age differences in either danger or annoyance ratings.

4.8.4. Data limitations

The range of values over which loudness, pulse rate, pitch, onset time and backing speed were selected as reasonable. More extreme variation could be looked at for any of these. The experiment also focused on constant speed backing, and needs to be extended to actual backing actions.

5. References

Huey, R., Harpster, J., & Lerner, N. (1995). *Field measurement of naturalistic backing behavior.* (Report under contract DTNH22-91-C-07004) National Highway Traffic Safety Administration.

Lerner, N. D., Kotwal, B. M., Lyons, R. D., Gardner-Bonneau, D. J. (1996). *Preliminary human factors guidelines for crash avoidance warning systems* (Report under contract DTNH22-91-C-07004) National Highway Traffic Safety Administration.

Sidaway, B., Fairweather, M., Sekiya, H, & McNitt-Gray, J. (1996). Time-to-collision estimation in a simulated driving task. *Human Factors*, 38(1), 248-282.

APPENDIX A: FORMS AND INSTRUCTIONS FOR REACTION TIME TO WARNINGS DURING BACKING.

INSTRUCTIONS

COMSIS Corporation is conducting this study for the U.S. Department of Transportation. The purpose of this study is to test the effectiveness of a warning device. I will be asking you to drive in your normal manner and go through a number of backing up and parking maneuvers in urban, residential and suburban settings around Silver Spring.

The drive will include various kinds of parking lots, driveways and on-street parking. In each of these places, you will need to back up your car in order to park. Will you be comfortable with that kind of driving? [**if not, stop here and dismiss participant**]

Like I said, you will be backing up and parking your car. We are interested in the ways that average drivers stop their cars when backing up or parking. At random times during backing or parking, you will hear an alarm. This alarm is intended to simulate a warning that you are about to hit an object behind you. However, the alarm you will hear is only a simulation--the timing of the alarm is in no way tied to actual objects or events inside or outside of the car.

The alarm will only sound when you are backing up or parking. When you hear this alarm, you should react by stopping the car quickly and safely, just as you would if this were a real, functioning warning device. Safety is of paramount concern in this experiment. Please do *not* respond to the warning if you believe that it will put you or your vehicle in any danger.

Do you have any questions at this point?

Equipment

After we go over the instructions and necessary forms, I will install the study equipment on your car. The bulk of the equipment fits in your trunk with small wires running from there to the sensors or to the back seat where I'll be sitting. A speed sensor will be attached to the outside of your car with suction cups. We will be collecting two different video views, including one on the rear window to get the view behind you and another underneath your seat to get a view of the brake and accelerator pedals while you are driving. We have used this method before with success, and there should be absolutely no damage to your car from this mounting system.

Consent

This is the consent form that we use in this study. It explains the study and your rights as a research participant. If at any time you decide you don't want to participate, just say so and we'll stop without any penalty to you. You will still be paid based on the amount of time that you participated.

Do you have any questions?

Okay, then I'll need you to read and sign this consent form.

GIVE CONSENT FORM.

Thanks. I'll get started with the installation of the equipment on your car. It should take me about 30 minutes to get everything hooked up. You may either stay here to watch or go into the COMSIS building to have a seat and a cool drink or cup of coffee while I get started. You'll just need to return here in 30 minutes.

INSTALL EQUIPMENT, MEET PARTICIPANT AGAIN AT THE CAR.

<u>Purpose</u>

As you read in the consent form, the purpose of this study is to assess how effective a signal device is for capturing drivers' attention. Devices that operate in a similar manner to the equipment we will be installing in your car today may, in the future, be used to alert drivers of objects behind the car when backing or parking. However, the system that we will be evaluating in your car today is *not* a functioning system. It *cannot* detect any objects outside your car and in no way is intentionally tied to any real hazards that might occur. This is test equipment only.

<u>Research Procedure</u>

The way we will test this equipment is by asking you to perform a number of different driving maneuvers. We are interested in how quickly average drivers can safely stop their cars after they have been presented with an alarm. You will drive to a number of sites and perform different parking maneuvers.

Sometimes during the parking sequence, an alarm will sound. This alarm is intended to simulate a warning that means you are about to hit an object behind you. When you hear the alarm, respond by stopping the car. You will need to stop the car as quickly and as accurately as possible. That is, you will need to maintain complete control of the car for safety *and* to stop as quickly as possible. Keep in mind that sometimes while you are backing up or parking, no alarms will sound, and you will then need to stop the car on your own in your normal manner.

Safety is of paramount concern in this experiment. Do not respond to the warning if you believe that it will put you, your vehicle, or anyone else in danger. Before we begin the study, I will demonstrate the alarm to you so you can become familiar with its sound. We'll also run a couple practice trials so you can be accustomed to stopping the car in response to the alarm.

Driving instructions

I will be guiding you around a predefined route that takes us through a variety of driving situations including city and residential areas within Silver Spring. I will give you plenty of notice before stops and turns. If for some unforeseen reason I don't give you enough notice to turn or stop at a given location, just go on by. We will not get lost and there is no penalty for having to turn around in a safe place and come back to a site.

I want to stress that you should drive just as you normally would. We want to use this system in typical driving situations, so you must drive in your normal fashion in order to adequately test it. I will try to be very clear in the way that I describe each driving maneuver that I want you to complete to avoid confusion. However, if you are unsure about any instruction I give you or if you don't feel comfortable performing it, please let me know and we will try to work around it. You should not perform any maneuver that you feel unsafe about. Do you have any questions at this point?

APPENDIX B: FORMS AND INSTRUCTIONS FOR PREFERRED TIMING OF COLLISION WARNINGS.

Instructions to participant (in vehicle - field portion):

Thanks for offering to participate in this study. This experiment will last approximately 30 minutes, and we'll meet again in about a week for the second session. In this experiment we're collecting information that will be useful in designing warning systems. In the future, cars may be able to alert drivers of hazards that the driver might not see. For example, when a driver backs up, an alarm might alert a driver of an object behind the car. Today, you'll ride as a passenger while I drive the car. We'll take a number of short rides in reverse right here in the garage. You'll press a button when you feel the alarm should be sounded, and I'll give you more specific information about your task in a couple minutes, but first, do you have any questions? Alright, before we continue, I need you to read and sign this consent form.

CONSENT

Thanks. Like you read, if at any time during the experiment you feel uncomfortable or you do not wish to continue, tell us and the experiment will be stopped immediately.

We're collecting data about when an alarm should be turned on to prevent a collision. I will back the car towards the target at a constant speed. The target is that big dummy. During the experiment you'll hold a small device with a single button. As the car approaches the target, you should look over your left shoulder out the back of the vehicle and observe the target as the vehicle approaches it. Each time we back up, the car will come in contact with the target, which was designed to be hit with a car, and it doesn't pose any threat to the vehicle or its occupants.

Warning systems often have two levels. There may be a cautionary warning to tell you that you should be alert to a nearby hazard, and a danger signal that you are about to hit something. You can think of these as a "warning" alert and a "danger" alarm. We want to study when people expect these warnings to occur.

On the [first 8 trials/second 8 trials] you should push the button when you believe that the driver should first be alerted that they are on a path for a collision. This is called a cautionary alarm. This type of alarm does not mean that the driver must immediately stop the car, but means be alert to the object behind you or you might hit it. Remember that this alarm should provide a relatively early warning, but that you (or other drivers) may become aggravated if it occurs too far away from an object for you or others to be concerned during normal backing.

On the [second 8 trials/first 8 trials] you should push the button when you believe that situation is critical and the driver must stop at once to avoid a collision. This is called an imminent crash alarm. This type of alarm means stop the car <u>now</u> or you will hit something. As mentioned earlier, during the experiment the car will hit the target on each approach.

There will be two test trials before the actual data collection begins. This will allow you to become familiar with the equipment and the movement of the car.

Before we start, I want to make sure you understand the distinction between the 2 types of signals. Do you have any questions? (no) Ok, then just tell me in you own words, what each signal is supposed to mean.

Instructions to participant (lab session):

Once again, thanks for offering to participate in this study. Like the first session, this session will last approximately 30 minutes. As before, if at any time during the experiment you feel uncomfortable or you do not wish to continue, tell us and we'll terminate the experiment.

Just to refresh your memory, in this study we're collecting data about when an alarm should be turned on to prevent a collision. Last time when we were in the test car across the street, you indicated with a pushbutton when you felt an alarm should be presented to the driver. Your task will be the same today.

You will watch a video that shows a car backing to a target, which again will be the big dummy. As the car approaches the target, your view in the video will be as if you are looking out the back of the vehicle. Each time the car backs up, it will come in contact with the target. You should always be able to see the video monitor. If you have a problem glare, viewing angle or for some reason cannot see the video monitor properly, please inform

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On the [second 8 trials/first 8 trials] you should push the button when you believe that situation is critical and the driver must stop at once to avoid a collision. This is called an imminent crash alarm. This type of alarm means stop the car now or you will hit something. As mentioned earlier, during the experiment the car will hit the target on each approach.

There will be two test trials before the actual data collection begins. This will allow you to familiarize yourself again with the equipment and the movement of the car. Before we start, I want to make sure you understand the distinction between the 2 types of signals. Do you have any questions? (no) Ok, then just tell me in you own words, what each signal is supposed to mean.

APPENDIX C: FORMS AND INSTRUCTIONS FOR GRADED (ANALOG) WARNING ZONES

Instructions: Alarm Variations Study

Dangerousness Session

Thank you for your participation in this study. This study will last approximately one hour. If at any time during the study you feel uncomfortable or you do not wish to continue, just let me know and I'll stop the study immediately. You will still be paid for the part of the experiment that you complete.

We are studying warning systems that may present alarms to drivers who are backing up their cars. In the future, auditory warnings may be presented inside average drivers' cars to alert drivers of unseen objects behind the car when they are backing up or parking. Today, we will evaluate several different alarms to determine which alarm provides the best warning with the least annoyance to drivers.

As you approach an object while backing, the danger of striking the object increases as you get closer to the object. We want to develop a warning alarm that informs drivers of this increased danger. You will see a video of a car backing to a target. Your perspective will be that of a passenger sitting in the front seat and looking out the rear window of the car. The target will be a crash dummy suspended from the ceiling of the garage where the car is backing. Let me show you how this will look.

PLAY EXAMPLE OF VIDEO WITHOUT SOUND

Assuming you are aware of the object behind the car, you will begin to feel a sense of danger as you approach it. As you get closer and closer, your sense of danger may change. We want to design a warning that matches the changing sense of danger you feel. That way, if a driver hears the sound in a situation where he did not notice the person or object behind him, the warning will give an appropriate sense of the danger.

In each video segment that you watch, the car will back up towards the crash dummy. An auditory alarm will be presented that is intended to warn the driver of the danger of hitting the dummy. The sounds you hear will be played at a volume that should be comfortable for you. We want you to rate how well the alarm matches your sense of the increased danger as the car approaches the target.
Let me play you an example of the kind of alarm you will hear.

PLAY SOUND ONLY EXAMPLE

Were you able to hear the alarm?
Did you notice how the warning sound had two different parts? First there was a low pulsing sound, then there was a high beeping sound.

IF NECESSARY, PLAY SOUND ONLY EXAMPLE AGAIN

The first part of the alarm cautions you that you are getting closer to an object. The last, high pitched part comes on at the point where the driver has just enough time to stop; it means "STOP RIGHT NOW!" That last part--the stop right now alarm--will be the same on every example you hear. It will always come on at the same point, which is about the last instant most drivers can stop safely. It is the other, earlier part of the warning that is going to vary from example to example. That is the part you need to pay special attention to as you view the car backing toward the dummy, so that you can make a good rating on each trial. We will let you hear a few examples of how these sounds can vary before we actually start collecting your opinions for real.

PLAY SOUND & VIDEO EXAMPLE 1, EXAMPLE 2

Could you tell the difference between the earlier part of the alarm and the later, stop-right-now part of the alarm?

The early part of the alarm may change in subtle ways from one backing sequence to the next, so you will need to listen very carefully to evaluate them. Take any aspect of the alarm into account in making your ratings. Many aspects of the alarms may contribute to a sense of danger, including onset time, loudness, type of sound, or any other aspect. You should rate how well the alarm's sense of danger matches your sense of danger.

For each backing sequence, you will give a single rating of the alarm on a scale from 1 to 7. You will use the rating scale on your response sheet to make these ratings. A response of 1 means that the alarm does <u>not</u> match your perception of danger at all. A rating of 7 indicates that the alarm matches your feelings of danger <u>perfectly</u>.

We want to know how well each signal corresponds to <u>your</u> sense of danger. You may just have a "gut feeling" about the dangerousness of the alarm and how well it matches your sense of danger in the backing sequence. There are no right or wrong answers in this study. We're interested in your personal opinions about these sounds.

In a later part of the study today, you will have a chance to rate the annoyance of the alarms, so for now you will need to keep separate the idea of dangerousness and the idea of annoyance. Until I tell you otherwise, you will <u>only</u> be rating how closely the alarm's sense of danger matches your sense of danger in the video.

It's important that you give a considered response, because the information you give may affect the design of backup alarms in real drivers' cars. Designing alarms that correspond to drivers' perceptions will be very important in making sure that future warning systems are meaningful to drivers.

Periodically, I will tell you the trial number that we are on. On your response sheet, the trial numbers on the left correspond to the trial numbers that I will say. Be sure to circle your response in the correct row. If you ever find that you have missed a trial number or that you are on the wrong row, let me know and I can help get you back to right point. After you have made a rating for a trial, you may NOT go back to that trial to change your rating.

There will be several practice trials before the actual data collection begins. This will allow you to become familiar with the equipment and viewing the video image.

Do you have any questions about the procedure we're going to follow?
Let's practice now.
RUN PRACTICE SESSION 1 (Three backing sequences)

Any questions?
Please be sure to watch the video during the entire backing sequence rather than looking back and forth between your rating form and the screen. Plenty of time should be available to make your rating after each backing sequence. If you need more time or if you lose your place, let me know immediately.
Let's begin. (Begin Data Collection)

Annoyance Session

Now, we are no longer going to make ratings of how well the alarm corresponds to your sense of danger. We're now going to consider the annoyance of the alarms. Imagine you were backing up your car and sounds like those you've heard came on as you approached the object behind you. If you are already well aware of the object behind you, the sound might be annoying. Also, drivers may find certain sound qualities of the alarm more annoying than others.

In the next set of trials, I'd like you to rate the annoyance of the alarm on a scale from 1 to 7. A rating of 1 indicates that the warning is not annoying at all. A rating of 7 means that the alarm is very annoying. Please watch the video and rate the annoyance of the cautionary alarm for each backing sequence you view. You may take any aspect of the alarm into account in making your ratings of its annoyance.

Do you have any questions about the procedure we're going to follow?

Just remember that you are no longer rating how well the alarm expresses your sense of danger. Now you are only rating how annoying each alarm is in each backing sequence that you view.

Let's practice now.
RUN PRACTICE SESSION 2

Any questions?
BEGIN DATA COLLECTION

Data Collection Form Alarm Variation Experiment

The first two pages are shown (not to scale).

Participant ID______________

Session Number______________

PRACTICE SESSION 1

How closely does the alarm match your sense of danger in this scene?

TRIAL	Does NOT Match My Sense of Danger At All	Perfectly Matches My Sense Of Danger
P1)	1 . . . . . .2 . . . . . .3 . . . . . .4 . . . . . .5 . . . . . .6 7	
P2)	1 . . . . . .2 . . . . . .3 . . . . . .4 . . . . . .5 . . . . . .6 7	
P3)	1 . . . . . .2 . . . . . .3 . . . . . .4 . . . . . .5 . . . . . .6 7	

	Does NOT Match My Sense of Danger At All	Perfectly Matches My Sense Of Danger
TRIAL		
1)	1 . . . . . .2 . . . . . .3 . . . . . .4 . . . . . .5 . . . . . .6 7	
2)	1 . . . . . .2 . . . . . .3 . . . . . .4 . . . . . .5 . . . . . .6 7	
3)	1 . . . . . .2 . . . . . .3 . . . . . .4 . . . . . .5 . . . . . .6 7	
4)	1 . . . . . .2 . . . . . .3 . . . . . .4 . . . . . .5 . . . . . .6 7	
5)	1 . . . . . .2 . . . . . .3 . . . . . .4 . . . . . .5 . . . . . .6 7	
TRIAL		
6)	1 . . . . . .2 . . . . . .3 . . . . . .4 . . . . . .5 . . . . . .6 7	
7)	1 . . . . . .2 . . . . . .3 . . . . . .4 . . . . . .5 . . . . . .6 7	
8)	1 . . . . . .2 . . . . . .3 . . . . . .4 . . . . . .5 . . . . . .6 7	
9)	1 . . . . . .2 . . . . . .3 . . . . . .4 . . . . . .5 . . . . . .6 7	
10)	1 . . . . . .2 . . . . . .3 . . . . . .4 . . . . . .5 . . . . . .6 7	

Annoyance Data Collection Form

	Not Annoying At All						Very Annoying
TRIAL							
119)	1	2	3	4	5	6	7
120)	1	2	3	4	5	6	7
121)	1	2	3	4	5	6	7
122)	1	2	3	4	5	6	7
123)	1	2	3	4	5	6	7
TRIAL							
124)	1	2	3	4	5	6	7
125)	1	2	3	4	5	6	7
126)	1	2	3	4	5	6	7