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The Effectiveness of Auditory Side- and Forward-Collision Warnings in Winter Driving Conditions

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Because the snowplow operator's tasks are predominately visual, warnings presented visually may interfere with critical tasks. Auditory warnings could reduce visual load if they are meaningful, effectively signal danger, and are not annoying. We conducted a driving simulation experiment—using a 210-degree forward field-of-view driving simulator—and a field test to investigate using auditory icons as side- and forward-collision avoidance warnings. Participants in the experiment drove on simulated snow-covered roads in 105-meter (344-feet) visibility conditions. Analysis of data from 28 participants showed the side-collision avoidance warnings were equally effective; lane change response times were approximately 1.1 seconds for both a single- and double-beep car horn warning—although participants said the double-beep warning sounded more urgent. Analysis of the forward-collision avoidance warning data, obtained from 32 participants, showed the mean response time with a warning consisting of two bursts of screeching-tire sounds was significantly faster than with a single-screech warning—with both warnings significantly faster than the mean time obtained when no warning was given. The poorest collision outcomes occurred with no warning—outcomes were better with the single-screech warning, and better still with the double-screech warning (which the participants said sounded more urgent than the single-beep warning). In the field test, six of seven snowplow operators preferred the double-beep side-collision warning. We recommend an auditory icon sounding like the double-beep of a car horn be used as a side-collision avoidance warning and an auditory icon sounding like two successive bursts of screeching tires should be used as a forward-collision avoidance warning.

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0.1 Introduction

The overall objective of this study was to determine how *auditory* side- and forward-collision avoidance warnings affect drivers traveling on snow-covered roads in poor visibility conditions. The intent was to identify warnings that are effective and sufficiently urgent but cause minimal annoyance.

The majority of the tasks the snowplow operator performs are visual in nature. Warnings presented visually may place additional demands on visual attention that, in turn, interfere with the performance of critical tasks. Using auditory displays to communicate important information may reduce visual load. For auditory warnings to be successful they must (i) be meaningful, (ii) effectively signal danger, and (iii) not annoy the listener. When auditory warnings are designed for use in snowplows, the possibility that they will be perceived as annoying should be limited—otherwise the operators may not accept them in their vehicles.

It is extremely important for auditory warnings to capture the attention of the listener. The meaning of a particular warning should be unambiguous so that it is correctly understood. Because of its intuitive nature, Harder, Bloomfield, and Chihak investigated the use—in specialty vehicles (snowplow, ambulance, and patrol car)—of an auditory warning resembling the sound of a vehicle passing over a rumble strip (1). Drivers easily recognized this message ("Return to the lane") conveyed by the rumble strip sound and responded to it quickly (1).

Belz, Robinson, & Casali found that using auditory icons as warnings produced significantly improved driver performance compared to conventional auditory warnings (2). Belz et al. did not compare differing types of auditory icons to identify which one is the more effective warning. In the current study, which involved a simulation experiment and a brief field test, we compared two different configurations of auditory icons for both side- and forward-collision avoidance warnings. The icons used as side-collision avoidance warnings were (i) a single-beep car horn, and (ii) a double-beep of a car horn. The icons used as forward-collision avoidance warnings resembled the sound of screeching tires during emergency braking—we used (i) one screeching-tire-like sound and (ii) two successive screeching-tire-like sounds.

0.2. Method—Driving Simulator Experiment

The study participants were between 18 and 65 years of age. The comparison of side-collision avoidance warnings was made with data from 28 participants (16 males and 12 females), the comparison of forward-collision avoidance warnings, involved 32 participants (19 males and 13 females), and, 43 participants (29 males and 14 females) completed a questionnaire.

Each participant drove in an advanced driving simulator, with a 210-degree forward field-of-view. The simulator vehicle's controls are equipped with sensors that relay the driver's inputs to the steering wheel, transmission, and accelerator and brake pedals to the simulation computer, which provides a real-time interface with the virtual environment. Road and traffic noise, and vehicle engine sounds are delivered through four speakers placed near the base of the forward screen. The virtual position of the simulator vehicle relative to the scenario being driven was recorded at 20 Hz—allowing us to determine steering performance and vehicle speed.

Each participant drove in three experimental drives, which were undertaken in poor visibility conditions—the road surface was snow-covered and fog limited visibility to 105 meters (344 feet). In the first two drives, we investigated responses to side-collision avoidance warnings. In the third, the participant experienced one of three forward-collision warning conditions—as well as the single- and double-screech warnings, there was a no-warning control condition. After completing the third experimental drive, the participant filled out a short questionnaire.

0.3 Results—Driving Simulator Experiment

Side-Collision Warnings—An Analysis of Variance (ANOVA) indicated that there was no statistically significant difference in the response of the participants to the two side-collision warnings. They were equally effective—the Lane Change Response Times were 1.113 seconds and 1.173 seconds for the single- and double-car-horn-beeps, respectively.

Forward-Collision Avoidance Warnings—Three aspects of the response to the forward collision warnings were investigated: (i) the time from the onset of the warning to the moment at which the participant's foot comes off the accelerator (Classical Response Time); (ii) the time from the moment at which the participant's foot comes off the accelerator to the moment at which his or her foot touches the brake (Control Transition Time); (iii) the Success/Failure of the Outcome. An ANOVA showed the forward-warning collision avoidance conditions had a statistically significant effect on the Classical Response Time. The double screech was most successful, producing a mean response time that was significantly faster than the mean response time obtained from those who received the single-screech warning. Both forward-collision warnings produced mean response times that were significantly faster than the mean time obtained in the no warning control condition. However, the type of forward-collision warning had no effect on the mean Control Transition Times, which were in the 0.31 to 0.49 second range—these may be the fastest transition times that can be achieved—especially in the warning conditions. When considering the Success/Failure of the Outcome, the speed when the warning was issued must also be taken into account. The poorest outcomes occurred with no warning, outcomes were better with the single-screech warning, and better still with the double-screech warning. In the no-warning condition, participants driving slower than 72 km/h (44.7 mph) stopped successfully—those driving faster than 75.5 km/h (46.9 mph) collided with a stationary vehicle in the lane ahead. In the single-screech condition, participants driving slower than 75 km/h (46.6 mph) stopped successfully—those driving faster than 78.5 km/h (48.8 mph) crashed. And, in the double-screech condition, participants driving slower than 82 km/h (51.0 mph) stopped successfully, while those driving faster than 86.0 km/h (53.4 mph) crashed.

Questionnaire—There were virtually no differences in the participants' preferences for the Side-Collision Avoidance Warnings—22 out of 43 participants chose the single-beep, while the remaining 21 chose the double-beep warning. The single-beep warning seemed a little less annoying than the double-beep warning; in contrast the double-beep warning sounded slightly more urgent than the single-beep warning.

The single-screech Forward-Collision Avoidance Warning was judged to be less annoying and less urgent than the double-screech warning. Although the double-screech warning sounded more urgent, only 2/14 participants remembered they had heard that warning—7/14 could not remember which warning they heard, and 5/14 thought they heard the single-screech warning.

When the driving experience of the 43 participants was explored, while changing lanes none had hit another vehicle, although 29 of them had experienced a near misses—these 29 thought the side-collision avoidance warnings tested in the study would have helped. In contrast to their lack of experience with side collisions, eight participants had rear-ended a vehicle ahead—five of these eight did not believe that a forward-collision warning would have helped them.

0 4: Field Test

Snowplow operators were not available for the simulation experiment. However, we conducted a brief field test to discover what operators thought about the auditory icons used in the simulation experiment. A shortened form of the questionnaire from the experiment was used to gather the opinions of snowplow operators about the side- and forward-collision avoidance warnings. Seven snowplow operators took part in the field test. Each drove for approximately 50 minutes. During the drive, the participants were asked which side- and forward collision warnings they preferred, as well as how annoying and how urgent they were.

Side-Collision Avoidance Warnings—The operators assessed the two side-collision avoidance warnings similarly in terms of annoyance, with a relatively low score. They gave the double-beep warning a higher urgency rating than the single-beep warning. Six out of the seven operators preferred the double-beep warning—the other operator expressed a preference for the single-beep warning.

Forward-Collision Avoidance Warnings—The two forward collision warnings were also assessed similarly in terms of annoyance. The single-beep warning had a higher urgency rating than the double-beep warning. The urgency ratings were different from those obtained in the simulator experiment—perhaps because the double screech was of a lower pitch than the single screech, and may not have stood out against the low frequency noise emanating from the snowplow. Four operators preferred the single-screech warning, while two preferred the double-screech warning (while the seventh operator expressed no preference).

0.5 Discussion

The average Lane Change Response Times (1.1 seconds) obtained with the side-collision warnings are similar to data obtained by Harder et al., who found Lane Change Response Times of approximately 1.4 seconds when a warning (resembling the sound of a rumble strip) was presented—they were 0.7 seconds longer when no warning was given. Together these two experiments suggest that an auditory warning will be useful in reducing collisions when vehicles are changing lanes. Because six of the seven snowplow operators preferred the double-beep warning, and higher urgency ratings were obtained in both the simulation experiment and the field test (coupled with low annoyance ratings), the double-beep warning is recommended.

With regard to the forward-collision avoidance warnings, the double screech warning was most successful—although the single screech warning was also significantly better than the no warning condition. The subjective ratings of the urgency of these warnings were in line with the Classical Response Time data— the double screech warning received a higher urgency rating than the single screech warning. The differences in “safe speeds” for the forward-collision avoidance warning conditions derived from the analysis of outcomes mirror the effects on the Classical Response Time. The reduction in response time from 1.69 seconds, with no warning, to 0.54 seconds with a double screech warning increased the “safe speed” from 72 km/h (44.7 mph) to 82 km/h (51.0 mph).

In the field test, four operators preferred the single-screech warning, while two preferred the double-screech warning (while the seventh operator expressed no preference). The urgency ratings were different from those obtained in the simulator experiment—perhaps because the double screech was of a lower pitch than the single screech, and may not have stood out against the low frequency noise emanating from the snowplow.

The current study confirms the suggestion made by Belz et al that auditory icons are excellent candidates for use as warning signals (2). We extended their finding by comparing different configurations of auditory icons for both side- and forward-collision avoidance warnings. As a result of this study, we suggest that:

- An auditory icon that is the double-beep of a car horn should be used as a side-collision avoidance warning.
- An auditory icon that is the sound of two short bursts of screeching tires during emergency braking should be used as a forward-collision avoidance warning (with a higher frequency mix than was used in this study).

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Chapter 1
Introduction

1.1 Objective

When traveling on snow-covered roads in poor visibility conditions, drivers are in danger of colliding both with vehicles that are traveling more slowly in-lane ahead of them and, if they attempt to change lanes, with vehicles traveling in adjacent lanes. In such conditions side- and forward-collision avoidance warnings are likely to be of assistance to them.

The overall objective of this study was:

- To determine how *auditory* side- and forward-collision avoidance warnings affect drivers traveling on snow-covered roads in poor visibility conditions. The intent was to identify warnings that are effective and sufficiently urgent but cause minimal annoyance.

1.2 Background

As Hancock and Parasuraman have pointed out, driving is a complex task composed of three levels of inter-related activity—(i) vehicle control; (ii) navigation; and (iii) collision avoidance (1). These activities are at the heart of the highly demanding work environment of snowplow operators who are charged with clearing roads in what are often extremely challenging conditions. The snowplow operator must make sure that his or her snowplow is clearing the snow adequately from the road surface. In addition, the operator may be applying sand or salt (or other topical road application) to the road surface. In this case, the operator must make sure that it is being applied correctly, while at the same time he or she must remember that the box being used to apply the sand or salt is in an elevated position. If the box is elevated it must be lowered as the snowplow approaches any overpass so that it does not strike the overpass as the plow attempts to pass under it. Further, snowplow operators must be careful not to plow into stranded or moving vehicles. During snowy winters a challenging work environment confronts snowplow operators on an almost daily basis.

It should be noted that the majority of the tasks the snowplow operator encounters in this complex work environment are visual in nature. This presents a problem because of the finite amount of the operator's cognitive resources that can be effectively devoted to visual tasks at any one time. Because snowplow driving is a predominately visuospatial task, warnings presented via a visual display are likely to place additional demands on visual attention, which in turn can interfere with the performance of critical tasks.

One way to reduce the visual load of snowplow operators is to introduce an auditory display to communicate important information. The way in which the operator distributes his or her visual attention is crucial to the successful execution of the task of clearing roads. However, the use of redundant information presented in the auditory channel to aid certain activities is likely to reduce stress for the operator. This, in turn, will likely help the operator to perform his or her job more effectively and safely.

Unlike visual warning signals, auditory warnings are omnidirectional. This is a major advantage. Because they are omnidirectional, auditory signals are perceived regardless of the driver's orientation. Unlike eyes, ears cannot be closed—auditory warnings are attention-demanding warnings.

Auditory warning signals have not been systematically investigated in a snowplow context--although they have been investigated in a variety of environments ranging from aircraft cockpits to medical operating rooms—e.g., Patterson (2); Edworthy and Adams (3), Stanton and Edworthy (4), If auditory warning cues are to be successful in communicating warnings, it is critical that the sounds used are (i) meaningful in the context in which they are applied, (ii) effectively signal danger, and (iii) do not annoy the listener. It is important to discover which acoustic properties best facilitate safe driving behavior.

We know that warnings presented in an auditory format result in higher levels of compliance than those presented in a visual format—see Edworthy (5). Most of the research on auditory warnings to date has been in very different environments from that provided by snowplows—e.g., it has been conducted in aircraft cockpits and hospital operating rooms. Because the context provided by snowplows is very different from these other environments, investigators exploring the snowplow environment need to be cautious in using research findings obtained in them.

In developing guidelines for the design and evaluation of auditory warning systems used in commercial aircraft, Patterson focused on the following issues—(i) overall sound level; (ii) temporal characteristics; and (iii) spectral characteristics (6).

With regard to the *overall loudness of warnings*, Patterson found that continued loud sounds tend to incapacitate the listener (6). His findings led him to conclude that auditory warnings should be between 15 dB and 30dB above the masked threshold. They need to be at least 15 dB above the masked threshold in order to ensure that they are noticed. And they should be no more than 30 dB above the masked threshold, otherwise they may interfere with communication. There is nothing to be gained and much to lose if the warning is over 30 dB above masked threshold. The listener, for example, may disable the warning, may be interrupted at a critical time, or may be startled—all of which could affect his or her performance.

Considering the *temporal characteristics of warnings*, Patterson suggested that when used in commercial aircraft their onset and offset times had tended to be too abrupt, thus startling the listeners (6). He recommended that warnings should last long enough to ensure that they are noticed, but not go on long enough to interfere with speech communications.

As to the *spectral characteristics of warnings*, Patterson suggested they had a decisive role in the response (6). If the lower frequency components of an auditory warning have a significant proportion of energy, then the warning will sound "smooth, sonorous, and full." Alternatively, if the higher frequencies hold much of the energy, then the resultant warning will sound more urgent. Thus, there is a tradeoff with auditory warnings; warnings with higher frequencies are perceived to be more urgent, but are also perceived to be more annoying [see Preis (7), and

Edworthy, Loxley, and Dennis (8)], with the subsequent risk that listeners will disable the auditory alarm.

When auditory warnings are designed for use in snowplows, the possibility that they will be perceived as annoying should be taken into consideration and limited as far as possible—otherwise the operators may not accept auditory warnings in their vehicles. Currently, the auditory warnings used in snowplows are simple high frequency, sinusoidal tones. These tones are inherently aversive and, because of this, are highly likely to annoy the operators.

Berglund, Harder, and Preis suggest that there are several elements of warnings that contribute to perceived annoyance (9,10). These elements include the following.

- Loudness-based intrusiveness (i.e., when the sound is perceived as too loud)
- Quality-based intrusiveness (i.e., when the sound spectrum is perceived to be too harsh or too rough)
- Information-based intrusiveness (i.e., when the sound interferes with attempts to extract information)

It is important that when the designer of a set of auditory warnings is considering the sound space to be used, he or she should be aware of these potentially annoying qualities of sounds, both individually and collectively.

Edworthy points out that the ease with which a sound can be localized should be considered when warnings are designed (5). The localizability of a warning will increase if many, rather than few, frequencies are present in the warning sound—this is particularly true if the frequencies are in the 500 Hz to 5000 Hz range. Single, continuous sinusoids (typical of hospital equipment alarms) should be avoided if possible, since they are among the hardest sounds to localize and, in addition, are hard to discriminate from each other because of the way humans encode pitch information.

Digital technology has made it possible to produce almost any kind of warning sound. However in spite of this, little research has been directed toward finding the optimal subset of suitable warning sounds in most applications. Most research conducted on auditory warnings has focused on the detectability of individual warnings, and the ways to produce distinctive auditory icons and patterns. Even though it is more important than other issues, designers have until recently, largely ignored the way in which listeners respond to the warning—see Edworthy and Stanton (11). First, it is extremely important for an auditory warning to capture the attention of the listener. Next, the meaning of the particular warning should be unambiguous—so that the listener correctly understands it. The interpretation and understanding of an auditory warning depends on more than the physical structure of the sounds—it also depends on what those sounds mean to the listener.

When developing *lane departure* warnings for specialty vehicles (snowplow, ambulance, and patrol car), Harder, Bloomfield, and Chihak implemented an auditory warning that resembled the sound of a vehicle passing over a rumble strip because of the intuitive nature of the sound's message (12). Rumble strips are frequently used along road edges just outside the lane edge markers to alert drivers who have drifted over the markers. In Harder et al.'s experiment, drivers easily recognized this message (return to the lane) conveyed by the rumble strip sound and they responded to it quickly (12).

Research by Belz, Robinson, and Casali on the use of auditory warnings in commercial trucks may also be relevant to snowplow applications (13). Belz et al. used a fixed-base driving simulator that had been modified to mimic the vehicle dynamics and control configuration of a heavy truck and that had acoustics configured to match those found within a commercial truck cab (13). They used forward- and side-collision avoidance warnings that were (i) auditory icons; (ii) more conventional auditory warnings; (iii) dash-mounted visual warnings; and (iv) combined auditory and visual warnings. The forward-collision avoidance warnings were a tire-skid sound presented for 0.7 sec for the auditory icon, and a multi-frequency signal (comprised of 500, 1000, 2000, and 3000 Hz frequencies presented concurrently for 0.7 sec—2 pulses, 0.35 sec each) for the conventional auditory warning. The side collision avoidance warnings were a 0.7-sec long horn honk for the auditory icon, and positive "sawtooth" waveform (with a 500-Hz pure tone that was presented for 0.7 sec—2 pulses, 0.35 sec each) for the conventional auditory warning.

Belz et al. found that for both the forward- and side-collision scenarios, the auditory icon warnings prompted significantly improved driver performance when compared with the conventional auditory warnings (13). For both the forward- and side-collision scenarios, the multimodal displays (with the visual dash-mounted display plus either the auditory icon or the conventional auditory warning) produced significantly faster response times than the visual dash-mounted display alone. But, there was no significant difference between the response times for the auditory icon alone and the multimodal display (with the dash-mounted display and the auditory icon).

1.3 Current Study

Belz et al's study suggests that auditory icons are excellent candidates for use as warning signals in heavy vehicle platforms (13). And while their study determined that auditory icons are superior to more conventional auditory warnings, they did not compare differing types of auditory icons to identify which one is the more effective warning. In the current study, which includes a driving simulation experiment and a field study, we compared two different configurations of auditory icons for both side- and forward-collision avoidance warnings. The icons used as side-collision avoidance warnings were (i) a single-beep car horn, and (ii) a double-beep car horn. The icons used as forward-collision avoidance warnings resembled the sound of screeching tires during emergency braking—we used (i) one screeching-tire sound and (ii) two short bursts of screeching-tire sounds.

Chapter 2
Method

2.1 Participants

Forty-eight participants took part in the experiment. All were between the ages of 18 and 65 and all had a valid driver's license. At the end of the experiment, the participants were reimbursed $15 for their participation.

This was the first experiment run on a new driving simulator and because of various problems with the simulator we were unable to collect complete sets of data from some of the participants. The major problems were (i) simulator failure or excessive downtime between drives—these affected seven participants; and (ii) errors in the simulator data collection system—these affected 13 participants. In addition, the data from one participant were lost because of experimenter error, the data from another participant were unusable because of participant error, one participant was non-compliant, and one subject crashed during a side-collision avoidance warning drive, rendering the data unusable. We used as much of the data that we obtained as possible. This means, for example, that although in some cases errors in the data collection system occurred in the side-collision avoidance warning drives, in some cases we still were able to obtain data in the forward-collision avoidance warning condition.

With regard to the comparison of side-collision avoidance warning conditions, we obtained usable data sets from 28 participants (16 males and 12 females). With regard to the comparison of forward-collision avoidance warning conditions, we obtained usable data sets from 32 participants (19 males and 13 females). In addition, 43 participants (29 males and 14 females) completed a questionnaire.

2.2 Driving Simulator

Each participant drove in an advanced driving simulator, located in the University of Minnesota's HumanFIRST laboratory. The main elements of this simulator are as follows.

Simulator Vehicle—The simulator vehicle is a full-body 2002 Saturn SC1 coupe.

Simulator Visuals—The driver of the simulator vehicle has a 210-degree forward field-of-view. This 210-degree forward field of view is provided by five flat-panel screens—each of which is 4.7-ft high and 6.5-ft-wide. There is a central flat panel in front of the simulator vehicle. The center of this panel is aligned with the line of sight of the driver of the simulator vehicle. Next, there are two flanking panels—one to the right, the other to the left. They are set at 138-degrees to the central panel. Finally, there are two outer panels—again, one to the right, the other to the left. And they are set at 138-degrees to the flanking panels. All five flat-panel screens are elevated 16 inches from the ground. Five projectors are used to project a coordinated, high fidelity, virtual environment onto the five flat-panels, which comprise the 210-degree forward field-of-view. [The simulator also has the capability to provide rear-view imagery, via an additional 10-ft high by 7.5-ft wide rear-view screen and two 5-inch LCD screens installed in the place of the simulator vehicle's side-view mirrors. However, no rear view imagery was provided to the participants during this experiment.]

Simulator Vehicle Controls—The vehicular controls in the simulator vehicle are equipped with sensors that relay the participant's inputs to the steering wheel, transmission, and accelerator and brake pedals to the driving simulator computer, which provides a real-time interface with the virtual environment. Force feedback is applied to the steering wheel, using a high-torque motor attached to the steering column. A vacuum assist pump is connected to the brake pedal to simulate realistic braking. The simulator vehicle is equipped with an automatic transmission, which is functional and is controlled by the simulator computer.

Simulator Sound System—Road and traffic noise, and the vehicle engine sounds are delivered through four speakers placed around the car's exterior near the base of the forward screen. Each speaker receives independent inputs from the simulator's 3D sound generation system. Low frequencies are delivered using a 10-inch subwoofer placed inside the simulator vehicle's engine compartment. In addition, for this particular experiment, auditory warnings and experimenter instructions were delivered through the four speakers placed at the base of the forward screen.

Simulator Vehicle Movement—A bass shaker mounted to the underside of the car's frame provides additional low-frequency vibration. Servo-motors attached to the suspension components at each of the rear tires provide a partial motion base.

Data Recording—The virtual position of the simulator vehicle relative to the scenario being driven was recorded throughout each experiment drive at 20 Hz. From this record, it is possible to determine the steering performance and speed of the vehicle. In addition, three micro-video cameras positioned in the cab of the Saturn were used to record the participant's face, foot position, and steering wheel response through the course of the experimental session. A video display at the experimenter's station enabled the experimenter to monitor the participant throughout the experiment.

2.3 Experimental Design

The participants drove in three experimental drives. All three drives were undertaken in poor visibility conditions—the road surface was snow-covered and fog limited visibility to 105 meters (344 feet). In the first two of these drives we investigated the responses of the participants to side-collision avoidance warnings; in the third we investigated their responses to forward collision avoidance warnings.

Auditory icons were used as warning signals for both side- and forward-collision avoidance warnings. Please see Appendix C for specification of the warnings.

Side-Collision Avoidance Warnings—There were two side-collision avoidance warning icon conditions. The icons were (i) a single-beep of a car horn (Side-Collision Avoidance Warning #1), and (ii) a double-beep of a car horn (Side-Collision Avoidance Warning #2). Each participant had one experimental drive under each of these conditions—the order in which the two conditions were presented was counterbalanced across subjects.

Both of the experimental drives took place on a divided highway with two lanes in each direction. Each participant was instructed to perform seven lane change maneuvers—five shifts to the left lane, and two shifts to the right lane. Three of the five instructions to shift to the left lane were given when a Jeep in the left lane, traveling 10 km/h (6.09 mph) faster than the participant's vehicle, was about to overtake the vehicle. For each of these events, a side-collision avoidance warning was presented when the participant attempted to change lanes. The warning was triggered when, after receiving the lane-change instruction, the participant's vehicle crossed the lane marker separating the right and left lanes. On hearing the warning, the participant returned to the right lane, and the Jeep passed in the left lane. Two of the five instructions to shift to the left lane were used as catch trials, meaning that no warning was actually given for them. On these two occasions the participants shifted to the left lane. No warning was given and subsequently they were instructed to move back to the right lane which they did.

Forward-Collision Avoidance Warnings—There were three forward-collision avoidance warning conditions. The auditory icons used in the conditions were (i) one screeching-tire sound (Forward-Collision Avoidance Warning #1), or (ii) two short bursts of screeching-tire sounds (Forward-Collision Avoidance Warning #2), or (iii) no warning (No Forward-Collision Avoidance Warning). The participants were randomly assigned to one of three groups. Each group received one of the three forward-collision avoidance warnings in the third experimental drive.

During the third experimental drive, all the participants encountered a vehicle in-lane ahead—those assigned to the first two forward-collision avoidance warning conditions heard the warning when they were 107 meters (351 feet) away from this vehicle, while no warning was given to the participants assigned to the third condition.

2.4 Driving Scenarios

Each participant took part in one experimental session. At the start of that session, the participant drove one practice drive followed by three experimental drives.

Practice Drive—The practice drive was on an 8.85-km (5.5-mile) stretch of highway through uneven terrain. Snow covered the road surface and fog restricted visibility to approximately 105 meters (344 feet). The first 5.63-km (3.5-mile) section of the practice drive was on a divided highway with two lanes in each direction; the final 3.22-km (2-mile) section of the practice drive was on an undivided highway with one lane in each direction. The posted speed throughout both sections of the drive was 90 km/h—the participants were told that in the practice drive and all three experimental drives they would be driving on roads in Canada.

Side-Collision Avoidance Warning Drives (First and Second Experimental Drives)—The first and second experimental drives, in which the side-collision auditory warnings were investigated, took place on a 13.52-km (8.4-mile) long section of divided highway with two lanes in each direction. As in the practice drive, heavy snow covered the roadway, fog restricted visibility to approximately 105 meters (344 feet), and the posted speed was 90 km/h. The distances from the start of the drive at which instructions to change lanes and the distances at which Side-Collision avoidance warning #1 and Side-Collision avoidance warning #2 were given differed in the two drives. The distances are presented in Table 2.1. The order of presentation of the two drives was counterbalanced across subjects.

Table 2.1. Distance (from start of drive) at which (i) lane-change instructions, and (ii) warnings were given, for two side-collision avoidance warning conditions.

Distance from Start (in miles)	**Side-Collision Avoidance Warning Condition #1 (single beep)**	**Side-Collision Avoidance Warning Condition #2 (double beep)**
0.0	—	—
0.4	—	—
0.8	—	—
1.2	—	Instruction (Left)
1.6	Instruction (Left)	—
2.0	—	—
2.4	Instruction (Right)	Instruction (Right)
2.8	—	—
3.2	Instruction (Left) plus Warning #1	Instruction (Left)
3.6	—	—
4.0	Instruction (Left)	Instruction (Right)
4.4	—	—
4.8	—	Instruction (Left) plus Warning #2
5.2	Instruction (Right)	—
5.6	—	—
6.0	—	—
6.4	Instruction (Left) plus Warning #1	—
6.8	—	Instruction (Left) plus Warning #2
7.2	—	—
7.6	—	—
8.0	—	—
8.1	Instruction (Left) plus Warning #1	Instruction (Left) plus Warning #2

Forward-Collision Avoidance Warnings Drives (Third Experimental Drive)—In the third experimental drive the forward-collision avoidance warnings were tested. The roadway for this drive was a 5.63-km (3.5-mile) segment of an undivided highway with one lane in each direction. As with the practice drive and the first two experimental drives, heavy snow covered the roadway, the visibility was approximately 105 meters (344 feet), and the posted speed was 90 km/h. After driving 4.92 km (3.06 miles) of the third experimental drive, the participant encountered a Jeep that was stationary in the middle of the lane ahead. For the two forward-collision avoidance warning conditions, when the participant was 107 meters (351 feet) from the stationary vehicle, the forward collision avoidance warning was given.

2.5 Procedure

Consent Form—Before the start of the experimental session, each participant read and signed a consent form.

Practice Drive—The participant sat in the simulator vehicle and took a practice drive in order to become familiar with driving the simulator vehicle. The practice drive was on an 8.85-km (5.5-mile) stretch of highway through uneven terrain. Snow covered the road surface and fog restricted visibility to approximately 105 meters (344 feet). The first 5.63-km (3.5-mile) section of the practice drive was on a divided highway with two lanes in each direction; the final 3.22-km (2-mile) section of the practice drive was on an undivided highway with one lane in each direction. The participants were told that in the practice drive and all three experimental drives they would be driving on roads in Canada, and that for all the drives, the posted speed would be 90 km/h—also, they were informed that 90 km/h is equivalent to 55 mph. Each participant was asked to drive as he or she normally would when facing poor driving conditions.

Throughout the practice drive, the experimenter sat in the passenger seat of the simulator vehicle. From time to time during the drive, the experimenter instructed the participant to practice making lane changes, to rapidly accelerate and rapidly decelerate. Also during the practice drive, the participant was introduced to the auditory collision avoidance warnings that he or she would hear later in the experimental drives. The participant heard one example of each of the side collision avoidance warnings. The first of these warnings was presented 3.22 km (2 miles) after the start of the practice drive; the second was presented 0.8 km (0.5 miles) after the first warning. After each of the warnings was presented, the participant was told that this warning would be heard if, when he or she was changing lanes, there was a danger of colliding with a vehicle if he or she continued the lane-changing maneuver. The experimenter explained that the appropriate response on hearing the warning was to stop the lane-changing maneuver and return to the original lane. The participant was informed that during the experimental drives he or she would be given instructions to perform a number of lane change maneuvers.

With regard to forward-collision avoidance warnings, the participants were assigned to one of three groups. Also during the practice trial, each participant heard the forward-collision avoidance warning appropriate to the condition to which he or she had been assigned. Before the warning was presented, the participant was told that he or she would hear it in the experimental drives if there was an obstruction ahead with which he or she was in danger of colliding. On hearing the forward collision avoidance warning, the participant was instructed to stop as quickly as possible—even if he or she was unable to see the obstruction ahead. During the practice scenario when he or she heard the forward-collision avoidance warning, the participant was instructed to stop, although in this case there was no obstruction. The forward-collision avoidance warning was presented 2.90 km (1.8 miles) after the roadway narrowed to two-lane undivided highway. The participants who were in the "no warning" group did not hear either forward-collision avoidance warning and were given no instructions about emergency stopping.

After the practice drive was completed, the experimenter reminded each participant that the warnings he or she had experienced during practice would occur during the experimental drives. The experimenter also reminded the participant of the appropriate response for each warning, and then answered any questions the participant had.

First Experimental Drive—As the first experimental drive was being brought up on the simulator computers, the participant heard recorded instructions for the experimental drives. [These instructions are presented in Appendix A]. Immediately after the instructions were delivered, the experimenter answered any remaining questions, and then presented the first experimental drive. It took place on a 13.52-km (8.4-mile) long section of divided highway with two lanes in each direction. The roadway was snow covered, fog restricted visibility to approximately 105 meters (344 feet), and the posted speed was 90 km/h. During the experimental drive, participants heard pre-recorded instructions asking them to change lanes seven times—five were shifts from the right to the left lane, and two were shifts from the left to the right lane. Table 2.1 indicates the distances along the roadway at which these instructions were given. They were given at different distances in the two side-collision avoidance warning conditions.

Three of the five instructions to shift from the right to the left lane were presented when a vehicle was approaching in the left lane at a speed that was 10 km/h (6.09 mph) faster than the speed at which the participant was driving. When this happened, a side collision avoidance warning was triggered as soon as the participant's vehicle crossed over the lane marker separating the right and left lanes—Table 2.1 also indicates, the distances along the roadway at which these warnings were given. One group of participants received the Side-Collision Avoidance Warning #1 (the single-beep warning) in the first experimental trial and Side-Collision Avoidance Warning #2 (the double-beep warning) in the second experimental drive; a second group received Side-Collision Avoidance Warning #2 during the first drive, and Side-Collision Avoidance Warning #1 in the second drive. As soon as the participant returned to the right lane, the vehicle in the left lane passed the participant. The participant was then instructed to remain in the right lane. At the end of the drive, the participant was instructed to stop the simulator vehicle.

Second Experimental Drive—The second experimental drive was similar to the first experimental drive, except that if the participant had received Side-Collision Avoidance Warning #1 in the first experimental drive, now in the second he or she received Side-Collision Avoidance Warning #2. And alternatively, if he or she had received the double-beep warning first, now he or she received the single-beep warning in the second experimental drive. At the end of the second experimental drive, the participant was instructed to stop the simulator vehicle.

Third Experimental Drive—In the third experimental drive, the participant drove a 5.63-km (3.5-mile) segment of undivided highway with one lane in each direction. After driving for 4.92 km (3.06 miles) on a snow-covered roadway, with visibility that was approximately 105 meters (344 feet), the participant encountered a Jeep that was stationary in the middle of the lane ahead. If the participant was in one of the two forward-collision avoidance conditions (i.e., Forward-Collision Avoidance Warning #1, or Forward-Collision Avoidance Warning #2), he or she heard the auditory icon when 107 meters (351 feet) from the stationary vehicle. If the participant was in the No Forward-Collision Avoidance Warning condition, he or she was not given a forward-collision avoidance warning, although the threshold distance at which something could be seen in the lane ahead was similar—i.e., at 105 meters (344 feet)—to the distance at which the forward collision avoidance warnings were presented. Whichever forward-collision group the participant was in, after coming to a stop, the experimenter instructed them to turn off the vehicle.

Questionnaire—After completing the third experimental drive, the participant left the simulator vehicle. He or she was then asked to fill out a short questionnaire. The questionnaire asked about the participant's experience in the simulator, and his or her attitudes toward the warning sounds they had encountered. The participants who received one of the two forward-collision avoidance warnings in the third experimental drive, received the first form of the questionnaire. The participants in the No Forward-Collision Avoidance Warning condition received the second form of the questionnaire—it omitted questions about the forward-collision avoidance warnings. [The two forms of the questionnaire are presented in Appendix B.] After completing the questionnaire, each participant was debriefed and reimbursed $15 for their participation.

Chapter 3
Results

3.1 Side-Collision Avoidance Warnings

There were two side-collision avoidance warning conditions—one for Side-Collision Avoidance Warning #1, with a single-beep of a car horn as the auditory icon; the other for Side-Collision Avoidance Warning #2, with a double-beep of a car horn as the icon. For each participant, there was one experimental drive under each of these conditions. In each of these drives, there were three events—i.e., occasions in which an instruction to change from the right lane to the left lane was given and then, when the participant attempted to change lanes, followed by a side-collision avoidance warning that was presented because a vehicle, traveling 10 km/h (6.09 mph) faster than the participant's vehicle, was approaching in the left lane. For each of these three events, the warning was triggered when the participant's vehicle crossed the lane marker separating the right and left lanes. On hearing the warning, the participant returned to the right lane, and the Jeep passed in the left lane.

For each of the three events during both experimental drives that a side-collision avoidance warning was given, we determined the Lane Change Response Time (LCRT)—i.e., the time from the onset of the warning to the moment at which the participant's vehicle began to return to the right lane.

Upon completing the experiment, we had obtained LCRT data from 28 participants (16 males and 12 females). However, after an initial inspection of these data, we omitted the data for two of these participants. The reasons for these omissions were as follows. First, one participant drove extremely fast in all drives—when asked if that was how she normally drove in the poor driving conditions that had been simulated in the experiment, she responded that she had recently arrived from Texas and had never driven in the conditions being simulated—as a result her data were omitted from the analysis. Second, there was a problem with one response from a second subject—when the third lane changing event in one of his experimental drives, was about to occur, he anticipated the warning, so that his "response" preceded the warning. Since this appears to be an experimental artifact, LCRT data from this participant were also omitted from the analysis.

Inspection of the distribution of the Lane Change Response Times (LCRT) obtained from the remaining 26 participants in both warning conditions, indicated that these data were positively skewed (the skew was 1.214, and the kurtosis was 2.997). Because of this, the data were transformed using a log (1 + LCRT) transform. This transformation normalized the distribution (skew and kurtosis had dropped to 0.705 and 1.276, respectively).

A two-way Analysis of Variance (ANOVA) was conducted using data from 26 participants (after S101 and S103 were excluded as described above). The effects of the side-collision auditory warnings and the order of the events in the drives were the primary variables in this analysis. Because participant S101 appeared to have anticipated the warning when the third lane changing event in one of his experimental drives was about to occur, we were concerned that other participants might also have "learned" to anticipate warnings—if they were able to do this, the two-way (Warning Condition X Event) ANOVA would produce either a statistically significant Event main effect or a significant interaction between Warning Condition and Event. In fact, as can be seen in Table 3-1, which gives a summary of this ANOVA, neither the Event main effect nor the Warning Condition by Event interaction were statistically significant—so the "learned" response by participant S101 appears to have been an anomaly.

Table 3-1. Summary of two-way ANOVA conducted on transformed lane change response times obtained with side-collision avoidance warnings

Source of Variation	**Degrees of Freedom**	**Sum of Squares**	**Mean square**	**F-value**	**P-Value**
Participants (P)	25	0.182	0.007	--	--
Type of Warning (W)	1	0.006	0.006	2.171	0.1531
P x W	25	0.064	0.003	--	--
Event (E)	2	0.001	0.001	0.407	0.6679
P x E	50	0.069	0.001	--	--
W x E	2	0.001	0.001	0.708	0.4975
P x W x E	50	0.044	0.001	--	--

Table 3-2 makes the lack of effect of the order of the events even clearer. It shows that the mean times for Event #1, Event #2, and Event #3 are very similar. [For purposes of clarity, the means and standard deviations of the transformed data used in the ANOVA have been transformed back to seconds—i.e., each value in the table is equal to the antilog of the mean of log (1 + LCRT) - 1]

Table 3-2. Mean and standard deviation (in seconds) of lane change response times for the events in the first two experimental drives

	Mean	**Standard Deviation**
Event #1	1.163	0.125
Event #2	1.128	0.104
Event #3	1.138	0.127

Table 3-1 also shows that there was no statistically significant difference in the Lane Change Response Times obtained with the two Side-Collision Avoidance Warnings. Table 3-3 shows they were equally effective—the Lane Change Response Times were 1.113 seconds and 1.173 seconds for Warning #1 and warning #2, respectively.

Table 3-3. Mean and standard deviation (in seconds) of lane change response times for the two side-collision avoidance warnings.

Side-Collision Avoidance Warnings	Mean	Standard Deviation
Warning #1	1.113	0.107
Warning #2	1.173	0.130

3.2 Forward-Collision Avoidance Warnings

Upon completing the experiment, we had obtained responses to the Forward-Collision Avoidance Warnings from 32 participants (19 males and 13 females).

The following three aspects of each participant's response to the forward collision avoidance warnings are of interest:

- The time from the onset of the warning to the moment at which the participant's foot came off the accelerator (Classical Response Time).
- The time from the moment at which the participant's foot came off the accelerator to the moment at which the participant's foot touched the brake (Control Transition Time).
- The Success/Failure of the Outcome.

Classical Response Times—The distribution of Classical Response Time was normal—there was no need to transform these data. An ANOVA of these data, summarized in Table 3-4 shows that there was a statistically significant effect of forward collision avoidance warning condition on the Classical Response Time.

Table 3-4. Summary of two-way ANOVA of classical response times obtained with forward-collision avoidance warnings.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean square	F-value	P-Value
Type of Warning (W)	2	5.758	2.879	53.764	< 0.0001
Residual	22	1.178	0.054		

Table 3-5 presents the mean response times for the three forward-collision avoidance warning conditions. First, the Forward-Collision Avoidance Warning #2 (the double screech) was most successful—it produced a mean response time of 0.54 seconds. This was significantly faster than the mean response time of 0.86 seconds that was produced by the participants who received Forward-Collision Avoidance Warning #1 (the single-screech warning). Also, both forward collision avoidance warnings produced mean response times that were much faster than the mean response time of 1.69 seconds that was obtained in the "No Forward-Collision Avoidance Warning" condition. [It should be noted that it is legitimate to make this comparison because the visibility distance threshold for the stationary vehicle, 105 meters (344 feet) was approximately the same as the distance—i.e., 107 meters (351 feet—at which the auditory warnings were given.]

Table 3-5. Mean of classical response times obtained with forward-collision avoidance warnings

Forward-Collision Avoidance Warnings	Mean	Standard Deviation
Warning #1	0.864	0.090
Warning #2	0.541	0.272
No Warning Condition	1.693	0.255

Control Transition Time—While there was a statistically significant effect of forward collision avoidance warning condition on the Classical Response Time, this effect did not carry over to the second aspect of interest. The distribution of Control Transition Times was normal—so there was no need to transform these data. Table 3-6 presents the ANOVA summary table for these data.

Table 3-6. Summary of two-way ANOVA of control transition times obtained with forward-collision avoidance warnings.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean square	F-value	P-Value
Type of Warning (W)	2	0.149	0.075	1.477	0.2502
Residual	22	1.113	0.051	--	--

As Table 3-6 shows there were no statistically significant effects of the forward collision avoidance warning conditions on the Control Transition Time. For the simulator vehicle the mean Control Transition Time was in the 0.31 seconds for both warning conditions and 0.49 seconds for the no warning condition. It should be noted that these are extremely fast mean Control Transition Times, and may represent the fastest transition times that can be achieved—especially in the warning conditions. It is likely that only an equipment change in the simulator vehicle—that would reduce the physical distance between the accelerator and break pedals—could lower the Control Transition Time further. It is possible that the Control Transition Time would be statistically significantly slower in the no warning condition than the two warning conditions if a larger sample size were used.

Success/Failure of Outcome—When looking at the third aspect of the participant's response to the forward-collision avoidance warning (i.e., the Success/Failure of the Outcome) an additional variable must be considered. The speed at which the participant was driving when he or she was 107 meters (351 feet) away from the stationary vehicle is crucial in determining the outcome. Analysis of the Success/Failure of the Outcome shows, like the Classical Response Time data, that the poorest Outcomes occurred with the No Forward-Collision Avoidance Warning group, that the outcomes were better with Forward-Collision Avoidance Warning #1 (the single screech warning), and that they were better still with forward-Collision Avoidance Warning #2 (the double screech warning). The way in which these conditions interact with the speed at which the participant was traveling is as follows:

- In the No Forward-Collision Avoidance Warning group, participants who were driving below 72 km/h (44.7 mph) were able to stop successfully—in contrast, participants driving at more than 75.5 km/h (46.9 mph) all failed to stop successfully and collided with the stationary vehicle.

- In the Forward-Collision Avoidance Warning #1 (“single screech”) group, participants who were driving below 75 km/h (46.6 mph) were able to stop successfully—in contrast, participants driving at more than 78.5 km/h (48.8 mph) all failed to stop successfully and collided with the stationary vehicle.
- In the Forward-Collision Avoidance Warning #2 (“double screech”) group, participants who were driving below 82 km/h (51.0 mph) were able to stop successfully—in contrast, participants driving at more than 86.0 km/h (53.4 mph) all failed to stop successfully and collided with the stationary vehicle. [In this condition there was also one participant who drove at 83.4 km/h (51.8 mph) who was able to stop successfully, and one who drove at 82.2 km (51.1 mph) who collided with the stationary vehicle]

3.3 Questionnaire Data

Upon completing the experiment, we had obtained responses to one of the forms of the questionnaire from 43 participants (29 males and 14 females). The questionnaire included general questions about (i) the driving behavior of the participants, (ii) the side-collision avoidance warnings, (iii) the forward-collision avoidance warnings (if they had received one), and (iv) their experience of crashes or near misses. The responses of the participants to these questions are presented in the following subsection.

General Driving Questions—The first questions were about the frequency with which the participants drove, and with how often they knowingly drove faster than the posted speed limit. The participants were asked to respond, by giving a number between 1 and 7. The responses to these two questions are presented in Table 3-7.

Table 3-7. Responses to general driving questions.

General Driving Questions	**Participants Receiving Forward-Collision Avoidance Warning #1 (n = 14)**	**Participants Receiving Forward-Collision Avoidance Warning #2 (n = 14)**	**Participants Who Did Not Receive Forward-Collision Avoidance Warning (n =15)**	**Average of All Participants (n = 43)**
How often do you drive?	1.93	2.79	2.40	2.37
How often do you knowingly drive faster than posted speed?	3.64	2.93	3.40	3.33

For the question, about the frequency with which the participants drive, a response of 1 meant that they drive very frequently; while a response of 7 meant that they almost never drive—a mid-range score would be 4. Table 3-7 shows that, on average, the responses of all three groups of participants were similar—the overall average score was 2.37 (with the group means ranging from 1.93 to 2.79) indicating that the participants drive fairly frequently.

For the second question in Table 3-7, regarding how often the participants knowingly drive faster than the posted speed, a response of 1 meant that they always knowingly drive faster than the posted speed, while a response of 7 meant that they never knowingly drive faster than the posted speed. Again, a mid-range score would be 4. Table 3-7 shows that, the overall average of the participants was 3.33 (with the group means ranging from 2.93 to 3.64) —which would indicate on average, the participants knowingly drive above the posted speed a little more than half the time.

Side-Collision Avoidance Warnings—The next three tables present an assessment of the participants' preferences about the Side-Collision Avoidance Warnings, and then their judgments about the degree of annoyance and of urgency engendered by those warnings. Table 3-8 gives the preference data.

Table 3-8. Side-collision avoidance warning preferences.

Side-Collision Avoidance Warning Preference	**Participants Receiving Forward-Collision Avoidance Warning #1 (N = 14)**	**Participants Receiving Forward-Collision Avoidance Warning #2 (N = 14)**	**Participants Who Did Not Receive Forward-Collision Avoidance Warning (N =15)**	**Average of All Participants (N = 43)**
Prefer warning #1 (single beep)	35.7 %	71.4 %	46.7 %	51.2 %
Prefer warning #2 (double beep)	64.3 %	28.6 %	53.3 %	48.8 %

As Table 3-8 shows, overall there was little difference in the preference (22 out of 43 participants chose Warning #1 (single beep), and 21 out of 43 chose Warning #2 (double beep). Although there were more pronounced differences in preferences among the different groups of participants—with those who received Forward-Collision Avoidance Warning #2 preferring the single beep side collision avoidance warning almost 3 to 1 over the double-beep warning—it is difficult to read any significance into this.

The next two tables deal with how annoying the side-collision avoidance warnings were and how urgent they seemed to be. Table 3-9 deals with Warning #1 (the single-beep warning) and Table 3-10 with Warning #2 (the double-beep warning), with a response of 1 meaning the warning had a low degree of annoyance or urgency, and a response of 7 meaning the warning had a high degree of annoyance or urgency, and with a response of 4 being a mid-range score.

Table 3-9. Annoyance and urgency of side-collision avoidance warning #1 (the single-beep warning).

Side-Collision Avoidance Warning #1 (single beep)	**Participants Receiving Forward-Collision Avoidance Warning #1 (single screech) (N = 14)**	**Participants Receiving Forward-Collision Avoidance Warning #2 (double screech) (N = 14)**	**Participants Who Did Not Receive Forward-Collision Avoidance Warning (N =15)**	**Average of All Participants (N = 43)**
Degree of annoyance	2.14	2.21	2.67	2.35
Degree of urgency	4.64	4.21	4.60	4.49

Table 3-10. Annoyance and urgency of side-collision avoidance warning #2 (the double-beep warning).

Side-Collision Avoidance Warning #2	**Participants Receiving Forward-Collision Avoidance Warning #1 (N = 14)**	**Participants Receiving Forward-Collision Avoidance Warning #2 (N = 14)**	**Participants Who Did Not Receive Forward-Collision Avoidance Warning (N =15)**	**Average of All Participants (N = 43)**
Degree of annoyance	3.57	3.29	2.67	3.16
Degree of urgency	5.29	4.07	5.00	4.79

When Tables 3-9 and 3-10 are considered together, they indicate that Side-Collision Avoidance Warning #1 seems to be less annoying than Warning #2—their overall averages are 2.35 and 3.16, respectively. On the other hand, it seems that Warning #2 sounds slightly more urgent than Warning #1—in this case, their overall averages are 4.49 and 4.79, respectively.

Forward-Collision Avoidance Warnings—The 43 participants were randomly assigned to one of three forward-collision avoidance warnings groups. Each group received one of the three forward-collision avoidance warnings in the third experimental drive—one of which was the No Warning control condition. Because they only experienced one condition, it is not appropriate to average across the groups. Table 3-13 shows the participants' responses to questions about the Forward-Collision Avoidance Warning.

Table 3-11. Annoyance and urgency of forward-collision avoidance warnings, and ability to remember warning.

	Participants Receiving Warning #1 (single screech) (N = 14)	**Participants Receiving Warning #2 (double screech) (N = 14)**
Degree of annoyance	2.86	3.29
Degree of urgency	5.43	6.07
Correctly remembered warning received	64.3 %	14.3 %
Incorrectly remembered warning received	—	35.7 %
Unable to remember warning received	35.7 %	50.0 %

With regard to the first two questions in Table 3-11, a response of 1 meant the Forward-Collision Avoidance Warning had a low degree of annoyance or urgency, a response of 7 meant the warning had a high degree of annoyance or urgency, and a response of 4 was a mid-range score. The table shows that, as with the Side-Collision Avoidance Warnings, the Forward-Collision Avoidance Warning which was judged to be less annoying (i.e., Warning #1) was also judged to be less urgent. Perhaps more surprisingly, although the participants who received warning #2 judged that warning as sounding very urgent (with an average rating of 6.08), only two of them (14.3 %) remembered what warning they heard—seven (50 %) could not remember which warning they heard, and interestingly the remaining five (35.7 %) thought they heard Warning #1.

Real-world experience of side collisions—Table 3-12 presents responses given by all participants about their real-world experience of side collisions.

Table 3-12. Side-collision experience of participants

Experience of side collisions	**Participants Receiving Forward-Collision Avoidance Warning #1 (single screech) (N = 14)**	**Participants Receiving Forward-Collision Avoidance Warning #2 (double screech) (N = 14)**	**Participants Who Did Not Receive Forward-Collision Avoidance Warning (N =15)**	**Average of All Participants (N = 43)**
When changing lanes have you hit another vehicle?	Yes—0/14 No—14/14	Yes—0/14 No—14/14	Yes—0/15 No—15/15	Yes—0/43 No—43/43
When changing lanes have you almost hit another vehicle?	Yes—9/14 No—5/14	Yes—9/14 No—5/14	Yes—11/15 No—4/15	Yes—29/43 No—14/43
If yes to either question, do you think side-collision warning would have helped?	Yes—9/9 No—0/9	Yes—9/9 No—0/9	Yes—11/11 No—0/11	Yes—29/29 No—0/29

Table 3-12 shows that, when changing lanes, none of the 43 participants had ever hit another vehicle. However, 29 of the 43 responded that, when changing lanes, they had almost hit another vehicle. All 29 of those who had almost hit another vehicle thought that one of the side-collision avoidance warnings they had experienced would have helped.

Real-world experience of forward collisions—Table 3-13 presents the participants' responses about their real-world experience of forward collisions.

Table 3-13. Forward-collision experience of participants.

Experience of forward collisions	Participants Receiving Forward-Collision Avoidance Warning #1 (N = 14)	Participants Receiving Forward-Collision Avoidance Warning #2 (N = 14)	Participants Who Did Not Receive Forward-Collision Avoidance Warning (N =15)	Total (N = 43)
Have you ever rear-ended a vehicle ahead?	Yes—4/14 No—10/14	Yes—3/14 No—11/14	Yes—1/15 No—14/15	Yes—8/43 No—35/43
Have you had a near miss involving a vehicle ahead?	Yes—5/14 No—9/14	Yes—8/14 No—6/14	Yes—11/15 No—4/15	Yes—24/43 No—19/43
If yes to either question, do you think a forward-collision warning would have helped?	Yes—6/10 No—4/10	Yes—4/8 No—4/8	Yes—9/11 No—2/11	Yes—20/29 No—9/29

In contrast to their lack of experience with side collisions, Table 3-13 shows that eight of the 43 participants had rear-ended a vehicle ahead. Interestingly—and not specifically highlighted in the table—five of these eight participants did not believe that a forward-collision avoidance warning would have helped them.

The table also shows that 24 of the 43 participants responded that they have had a near miss involving a vehicle ahead—and four of them did not believe that a forward-collision avoidance warning would have helped them either.

Chapter 4
Field Test

4.1 Introduction

Unfortunately, snowplow operators were not available for the driving simulation experiment described in the previous two chapters of this report. However, in order to discover what operators thought about the auditory icons that were used in the experiment, we conducted a brief field test. In the field test, a shortened form of the questionnaire administered during the experiment was used to gather the opinions of snowplow operators about the side-collision avoidance warnings, and the forward-collision avoidance warnings.

4.2 Method

Seven snowplow operators took part in the field test. All seven were male. They had an average of 18 years experience driving in snowplows—with a range between one and 34 years.

Each of the seven operators drove with an investigator for approximately 50 minutes. After approximately 25 minutes, the operator turned the snowplow around and drove back to the starting point. During the outbound portion of the drive, the investigator presented one of the side-collision avoidance warnings on seven separate occasions. Each time, the warning was presented via two speakers located in close proximity to the operator. The investigator presented the warning on occasions when there was relatively little other traffic on the road. At the end of the outbound portion of the drive, the investigator asked the operator to rate how annoying and how urgent the warning had been.

Then, during the inbound portion of the drive, the investigator presented the second of the side-collision avoidance warning warnings—also on seven separate occasions, and again when there was relatively little other traffic on the road. The order in which the side-collision avoidance warnings were presented was alternated between operators—the first, third, fifth, and seventh operators heard the single-beep warning on the outbound portion of the drive and the double-beep warning on the inbound portion; while, the second, fourth, and sixth operators heard the double-beep warning on the outbound portion of the drive and the single-beep warning on the inbound portion. At the end of the inbound portion, the operator stopped the snowplow—but kept the engine running. The investigator asked the operator to rate how annoying and how urgent the second warning been. Then the operator was asked which of the two side-collision avoidance warnings he preferred.

Next with the engine still running, the investigator presented one of the forward-collision avoidance warnings twice. If requested by the operator, the investigator presented the forward-collision avoidance warning again. Then the operator was asked to rate how annoying and how urgent the warning was.

After this the investigator presented the second forward-collision avoidance warning twice—again presenting it additional times if requested to by the operator. The operator was asked how annoying and how urgent that warning was. As with the side-collision avoidance warnings, the order in which the forward-collision avoidance warnings were presented was as follows—the first, second, and fifth operators heard the single-screech warning first, followed by the double-screech warning, while, the third, fourth, sixth and seventh operators heard the double-screech warning first, followed by the single-screech warning. Finally, the operator was asked which of the two forward-collision avoidance warnings he preferred.

By the time all the questions had been asked and answered, each operator had spent approximately an hour with the investigator.

4.3 Results

As mentioned above, a shortened form of the questionnaire used in the main study was used to gather information from seven snowplow operators. The questions dealt with the side-collision avoidance warnings, and the forward-collision avoidance warnings [Omitted from the questionnaire were the questions used in the main study about the driving behavior of the participants, and their experience of crashes or near misses.] The responses of the seven operators are presented below.

Side-Collision Avoidance Warnings—Table 4-1 presents the opinions of the snowplow operators about the degree of annoyance and of urgency engendered by the two Side-Collision Avoidance Warnings, and which of the warnings they preferred. The operators were asked to assess the degree of annoyance and urgency of the two side-collision avoidance warnings using a seven-point scale—a response of 1 meant the warning had a low degree of annoyance or urgency, a response of 7 meant the warning had a high degree of annoyance or urgency, and a response of 4 was a mid-range score.

Table 4-1. Seven snowplow operators' assessment of annoyance, urgency, and preference, of two side-collision avoidance warnings.

	Annoyance	**Urgency**	**Preference**
Side-collision avoidance warning #1 (single beep)	2.00	3.29	1/7
Side-collision avoidance warning #2 (double beep)	2.00	4.71	6/7

Table 4-1 shows the two warnings were assessed similarly in terms of annoyance, with a relatively low score of 2.00. The snowplow operators gave Warning #2 (the double-beep warning) a higher urgency rating than the Warning #1 (the single-beep warning). Given these annoyance and urgency assessments it is not surprising that six out of the seven operators preferred Warning #2, with only one operator expressing a preference for Warning #1.

Forward-Collision Avoidance Warnings—Table 4-2 deals with the two forward-collision avoidance warnings. It presents the opinions of the snowplow operators about the degree of annoyance and urgency engendered by these warnings; the table also presents the preference data. Again, the degree of annoyance and urgency of the two side-collision avoidance warnings were assessed using a seven-point scale—with a response of 1 meaning that the warning had a low degree of annoyance or urgency, a response of 7 meaning that the warning had a high degree of annoyance or urgency, and a response of 4 being a mid-range score.

Table 4-2. Seven snowplow operators' assessment of annoyance, urgency, and preference, of two forward-collision avoidance warnings.

	Annoyance	**Urgency**	**Preference**
Forward-collision avoidance warning #1 (single screech)	4.14	5.29	4/7*
Forward-collision avoidance warning #2 (double screech)	4.14	4.64	2/7*

[*Please note, one subject, who did not like either warning, did not express a preference for either of the forward-collision avoidance warnings.]

Table 4-2 shows the two warnings were assessed similarly in terms of annoyance, with a score of 4.14. The operators gave Warning #1 (the single-screech warning) a higher urgency rating than Warning #2 (the double-screech warning)—these urgency ratings are differ from those expressed by the participants in the simulator experiment. A possible reason for this is suggested by the comment of one of the snowplow operators who pointed out that the double screech had a lower pitch than the single-screech warning, and because of this may not have stood out as well as the higher-pitched single-screech warning against the low frequency noise emanating from the snowplow, particularly when the blade is down. When it came to preferences, four operators preferred Warning #1 (the single-screech warning), while two preferred Warning #2 (the double-screech) warning.

Chapter 5
Discussion

5.1 Side-Collision Avoidance Warnings

The overall objective of this study, which included a driving simulation experiment and a field test, was to determine how auditory side- and forward-collision avoidance warnings affect drivers traveling on snow-covered roads in poor visibility conditions. The intent was to identify warnings that are effective and sufficiently urgent but cause minimal annoyance.

With regard to side-collision avoidance warnings, the two-way ANOVA that examined the effects of these warnings in the driving simulation experiment, and that is summarized in Table 3-1, showed no statistically significant effects. In addition, as Table 3-10 shows, the participants expressed no clear preference for either Warning #1 (the single-beep warning) or Warning #2 (the double-beep warning). The average Lane Change Response Times were approximately 1.1 seconds for both auditory warnings.

These results are in line with the related experiment conducted by Harder et al. looking at the effect of lane departure warnings when drivers drifted out of lane (12). Those data were also positively skewed and required a log transform to normalize them. In that case, when an auditory *lane departure* warning (resembling the sound of a rumble strip) was presented, Lane Change Response Times were on the order of 1.4 seconds and were approximately 2.1 seconds (0.7 seconds longer) when no warning was given.

Taken together these two experiments suggest that an auditory warning will be of use in reducing collisions when vehicles are changing lanes.

While the participants in the driving simulation experiment expressed no clear preference for either side-collision avoidance warning, six of the seven operator's who took part in the field test preferred Warning #2 (the double-beep warning) to Warning #1 (the single-beep warning). In addition, both the participants in the experiment and the operators in the field test gave the double-beep warning a higher urgency rating than the single-beep warning (the ratings were 4.79 for the double-beep warning versus 4.49 for the single-beep warning for the experimental participants; and 4.71 for the double-beep versus 3.29 for the single-beep for the snowplow operators). Based on the preferences expressed by the snowplow operators in the field test and the urgency ratings (coupled with low annoyance ratings) the double-beep side-collision avoidance warning is recommended.

5.2 Forward-Collision Avoidance Warnings

With regard to forward-collision avoidance warnings, three aspects of each participant's response to these warnings are of interest:

- The time from the onset of the warning to the moment at which the participant's foot came off the accelerator (Classical Response Time).

- The time from the moment at which the participant's foot came off the accelerator to the moment at which the participant's foot touched the brake (Control Transition Time).
- The Success/Failure of the Outcome.

The ANOVA conducted on the effects of forward-collision avoidance warnings on the Classical Response Time showed that there were statistically significant differences in the response to all three forward collision avoidance warning conditions:

- The double screech warning was most successful—it produced a mean response time of 0.54 seconds.
- The single screech warning was next most successful—it produced a mean response time of 0.86 seconds.
- The "no warning" conditions was least successful—it produced a mean response time of 1.69 seconds.

The subjective ratings of the urgency of these warnings—obtained with the questionnaire and reported in Table 3-11—are in line with the Classical Response Time data. The participants gave an urgency rating of 6.07 to the double screech warning (and an urgency rating of 5.43 to the single screech warning).

The ANOVA conducted on the effects of forward-collision avoidance warnings Control Transition Time showed no statically significant differences—the Control Transition Time was in the 0.31 to 0.49 second range. These are extremely fast mean Control Transition Times, and may represent the fastest transition times that can be achieved—especially in the warning conditions.

When looking at the Success/Failure of the Outcome, an additional variable must be considered. The speed at which the participant was driving when he or she was 107 meters (351 feet) away from the stationary vehicle was crucial in determining the outcome. Analysis of the speed data shows the following.

- In the "no warning" group, participants who were driving below 72 km/h (44.7 mph) were able to stop successfully—in contrast, participants driving at more than 75.5 km/h (46.9 mph) all failed to stop successfully and collided with the stationary vehicle.
- In the "single screech" group, participants who were driving below 75 km/h (46.6 mph) were able to stop successfully—in contrast, participants driving at more than 78.5 km/h (48.8 mph) all failed to stop successfully and collided with the stationary vehicle.
- In the "double screech" group, participants who were driving below 82 km/h (51.0 mph) were able to stop successfully—in contrast, participants driving at more than 86.0 km/h (53.4 mph) all failed to stop successfully and collided with the stationary vehicle. [In this condition there was also one participant who drove at 83.4 km/h (51.8 mph) who was able to stop successfully, and one who drove at 82.2 km (51.1 mph) who collided with the stationary vehicle]

The differences in the "safe speeds" for the three forward-collision avoidance warning conditions mirror the statistically significant effects of the Classical Response Time. The reduction in response time, from 1.69 seconds in the "no warning" condition to 0.54 seconds in the "double screech" condition, results in an increase in "safe speeds" from 72 km/h (44.7 mph) to 82 km/h (51.0 mph), respectively.

Based on these results from the driving simulation experiment the double-screech forward collision avoidance warning should be recommended. But, the data obtained in the field test suggest some modification should be made to this recommendation. In contrast to results of the driving simulation experiment, in the field test the double screech warning was not rated as sounding more urgent than the single-screech warning and was only preferred by two of the seven operators as compared to four of seven preferring the single-screech warning (with one operator expressing no preference). However, as one snowplow operator pointed out, the double screech had a lower pitch than the single-screech warning. Because of this, it may not have stood out as well as the higher-pitched single-screech warning against the low-frequency noise emanating from the snowplow. We believe that a double-screech forward collision avoidance warning should be recommended, but that it should have a higher frequency mix than the double-screech warning tested in this study.

5.3 Conclusion

The current study confirms the suggestion made by Belz et al. that auditory icons are excellent candidates for use as warning signals (13). We extended their finding by comparing different configurations of auditory icons for both side- and forward-collision avoidance warnings. As a result of this study, we suggest that:

- An auditory icon that is the double-beep of a car horn should be used as a side-collision avoidance warning.
- An auditory icon that is the sound of two short bursts of screeching tires during emergency braking should be used as a forward-collision avoidance warning (with a higher frequency mix than was used in this study).

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APPENDIX A

RECORDED INSTRUCTIONS

APPENDIX A. RECORDED INSTRUCTIONS

During the experimental sessions, each participant heard the general instructions for the experimental drives. These instructions were recorded prior to the start of the experiment. They were played back to the participant via the simulator's sound system after the practice drive was completed and before the first of the three experimental drives. A transcript of the instructions is presented below.

Transcript of Instructions—"During your time here there will be three separate drives. When you drive, please drive as you normally would in the real world. In the three drives you will hear either side collision avoidance warnings or forward collision avoidance warnings. When you are asked to change lanes you should do so. However, if there is a vehicle that you could collide with in that lane, you will be given a side collision avoidance warning and you should not complete the lane change. Instead, stay in lane and wait for the next instruction. When you hear a forward collision avoidance warning, it means that there is a vehicle ahead. Even if you can't see the vehicle, you should stop as quickly as you can. In all three drives the speed limit will be 55 mph. Also, the visibility will be poor because of fog and there will be snow on the road surface. In all three drives please drive as you normally would in poor conditions. If you have any questions please ask the experimenter now."

APPENDIX B

QUESTIONNAIRES

APPENDIX B. QUESTIONNAIRES

At the end of each experimental session, after completing the third experimental drive, each participant was asked to fill out a short questionnaire. There were two forms of this questionnaire—the first form was given to the participants who were in one of the two groups of participants who were given an auditory forward-collision avoidance warning in their third experimental drive; while the second form was given to the participants who were in the group of participants who did not receive an auditory forward-collision avoidance warning in their third experimental drive. These two forms of the questionnaire are presented on the following pages. (In addition, as in all our simulator studies, the questionnaire included questions about the experience of driving in the simulator vehicle.)

Form 1 (Presented to participants who received auditory forward-collision avoidance warnings)

POST-EXPERIMENT QUESTIONNAIRE

(1) How often do you drive? (Please answer on a scale from 1 - 7. An answer of 1 reflects that you drive very frequently and an answer of 7 reflects that you almost never drive.)_________

(2) How often do you knowingly drive faster than the posted limit?(Please answer on a scale from 1 - 7. An answer of 1 reflects that you always knowingly drive faster than the speed limit and an answer of 7 reflects that you never do.) _________

(3) Is there anything else you would like to tell us about the way you drive?

____

____

Simulator and Simulator Controls

(4) Did driving in the simulator make you feel ill? (Please answer on a scale from 1 - 7. An answer of 1 reflects that you didn't feel at all ill and an answer of 7 reflects that you felt very ill.)

____

(5) How similar was driving in the simulator to driving in your car? (Please answer on a scale from 1 – 7 for each item below. An answer of 1 reflects that driving in the simulator was exactly like driving in your car and an answer of 7 reflects that it was not at all like driving in your car.)

the steering _________
the acceleration _________
the brakes _________
the feel of the car _________

Trial/Condition Information

Side Collision Avoidance Warnings

In this experiment you heard two different types of side collision avoidance warnings. Questions 6 through 10 refer to them.

(6) In one drive you heard a shorter one-beep horn warning and in another drive you heard a longer two-beep horn warning. Which of the warnings did you prefer (please place a check beside your answer):

(a) shorter one-beep warning _________

(b) longer two-beep warning _________

(7) On a scale from 1 – 7, please circle a number that best reflects how annoyed the *one-beep horn* warning made you feel. (For example, an answer of 1 reflects that you were not at all annoyed and an answer of 7 reflects that you were highly annoyed.)

1	2	3	4	5	6	7
Not at all Annoyed						Highly Annoyed

(8) On a scale from 1 – 7, please circle a number that best reflects how annoyed the *two-beep horn* warning made you feel. (For example, an answer of 1 reflects that you were not at all annoyed and an answer of 7 reflects that you were highly annoyed.)

1	2	3	4	5	6	7
Not at all Annoyed						Highly Annoyed

(9) On a scale from 1 – 7, please circle a number that best reflects how urgent the *one-beep horn* warning sounded. (For example, an answer of 1 reflects that the warning did not sound at all urgent and an answer of 7 reflects that the warning sounded extremely urgent.)

1	2	3	4	5	6	7
Not at all Urgent						Extremely Urgent

(10) On a scale from 1 – 7, please circle a number that best reflects how urgent the *two-beep horn* warning sounded. (For example, an answer of 1 reflects that the warning did not sound at all urgent and an answer of 7 reflects that the warning sounded extremely urgent.)

1	2	3	4	5	6	7
Not at all Urgent						Extremely Urgent

Forward Collision Avoidance Warning

In this experiment you heard a forward collision avoidance warning.
Questions 11 through 13 refer to it.

(11) On a scale from 1 – 7, please circle a number below that best reflects how annoyed the *braking* warning made you feel. (For example, an answer of 1 reflects that you were not at all annoyed and an answer of 7 reflects that you were highly annoyed.)

1	2	3	4	5	6	7
Not at all Annoyed						Highly Annoyed

(12) On a scale from 1 – 7, please circle a number below that best reflects how urgent the *braking* warning sounded. (For example, an answer of 1 reflects that the warning did not sound at all urgent and an answer of 7 reflects that the warning sounded extremely urgent.)

1	2	3	4	5	6	7
Not at all Urgent						Extremely Urgent

(13) The braking sound was either a *one-screech* or *two-screech* sound. Which one did you hear? (Please place a check after your response.)

one-screech braking sound _______
two-screech braking sound _______
do not remember________________

Prior Driving Experience

Questions 14 – 21 pertain to your prior driving experience.

(14) When changing lanes, have you ever hit another vehicle? Yes ______ No ______

(15) When changing lanes, have you almost hit another vehicle? Yes ______ No ______

(16) If you answered "yes" to Question 14 or Question 15, do you think it would have helped if you had had one of the side collision avoidance warnings that you experienced today?
Yes ______ No ______

(17) If you answered "no" to Question 16, why do you think these side collision avoidance warnings would not have helped?

____
____
____
____

(18) When driving, have you ever rear ended a vehicle ahead? Yes ______ No ______

(19) When driving, have you ever had a near miss involving a vehicle ahead?
Yes ______ No ______

(20) If you answered "yes" to Question 18 or Question 19, do you think it would have helped to have the forward collision avoidance warning you experienced today?
Yes ______ No ______

(21) If you answered "no" to Question 20, why do you think the forward collision avoidance warning would not have helped?

____
____
____
____

Form 2 (Presented to participants who did not receive auditory forward-collision avoidance warnings)

POST-EXPERIMENT QUESTIONNAIRE

(1) How often do you drive? (Please answer on a scale from 1 - 7. An answer of 1 reflects that you drive very frequently and an answer of 7 reflects that you almost never drive.)_________

(2) How often do you knowingly drive faster than the posted limit?(Please answer on a scale from 1 - 7. An answer of 1 reflects that you always knowingly drive faster than the speed limit and an answer of 7 reflects that you never do.) _________

(3) Is there anything else you would like to tell us about the way you drive?

____

____

Simulator and Simulator Controls

(4) Did driving in the simulator make you feel ill? (Please answer on a scale from 1 - 7. An answer of 1 reflects that you didn't feel at all ill and an answer of 7 reflects that you felt very ill.)

____

(5) How similar was driving in the simulator to driving in your car? (Please answer on a scale from 1 – 7 for each item below. An answer of 1 reflects that driving in the simulator was exactly like driving in your car and an answer of 7 reflects that it was not at all like driving in your car.)

the steering _________
the acceleration _________
the brakes _________
the feel of the car _________

Trial/Condition Information

Side Collision Avoidance Warnings

In this experiment you heard two different types of side collision avoidance warnings. Questions 6 through 10 refer to them.

(6) In one drive you heard a shorter one-beep horn warning and in another drive you heard a longer two-beep horn warning. Which of the warnings did you prefer (please place a check beside your answer):

(a) shorter one-beep warning _________

(b) longer two-beep warning _________

(7) On a scale from 1 – 7, please circle a number that best reflects how annoyed the *one-beep horn* warning made you feel. (For example, an answer of 1 reflects that you were not at all annoyed and an answer of 7 reflects that you were highly annoyed.)

1	2	3	4	5	6	7
Not at all Annoyed						Highly Annoyed

(8) On a scale from 1 – 7, please circle a number that best reflects how annoyed the *two-beep horn* warning made you feel. (For example, an answer of 1 reflects that you were not at all annoyed and an answer of 7 reflects that you were highly annoyed.)

1	2	3	4	5	6	7
Not at all Annoyed						Highly Annoyed

(9) On a scale from 1 – 7, please circle a number that best reflects how urgent the *one-beep horn* warning sounded. (For example, an answer of 1 reflects that the warning did not sound at all urgent and an answer of 7 reflects that the warning sounded extremely urgent.)

1	2	3	4	5	6	7
Not at all Urgent						Extremely Urgent

(10) On a scale from 1 – 7, please circle a number that best reflects how urgent the *two-beep horn* warning sounded. (For example, an answer of 1 reflects that the warning did not sound at all urgent and an answer of 7 reflects that the warning sounded extremely urgent.)

1	2	3	4	5	6	7
Not at all Urgent						Extremely Urgent

Prior Driving Experience

Questions 11 – 18 pertain to your prior driving experience.

(11) When changing lanes, have you ever hit another vehicle? Yes ______ No ______

(12) When changing lanes, have you almost hit another vehicle? Yes ______ No ______

(13) If you answered "yes" to Question 11 or Question 12, do you think it would have helped if you had had one of the side collision avoidance warnings that you experienced today?

Yes ______ No ______

(14) If you answered “no” to Question 13, why do you think these side collision avoidance warnings would not have helped?

____
____
____
____

(15) When driving, have you ever rear ended a vehicle ahead? Yes ______ No ______

(16) When driving, have you ever had a near miss involving a vehicle ahead?
Yes ______ No ______

(17) If you answered “yes” to Question 15 or Question 16, do you think it would have helped to have had a forward collision avoidance warning?
Yes ______ No ______

(18) If you answered “no” to Question 17, why do you think a forward collision avoidance warning would not have helped?

____
____
____
____

APPENDIX C

SPECIFICATIONS OF WARNINGS

APPENDIX C. SPECIFICATIONS OF WARNINGS

The specifications of the side- and forward-collision avoidance warnings that were used in this study are presented in the sub-sections below.

C.1 Side-Collision Avoidance Warnings

Tables C-1 and C-2 give the duration and sound intensity levels of the side-collision avoidance warnings used in both the simulation experiment and the field test.

Table C-1. Duration of side-collision avoidance warnings

Type of warning	Duration
Single-beep	0.61 seconds
Double-beep	1.37 seconds

Table C-2. Sound intensity levels of side-collision avoidance warnings

Sound source	Sound intensity level
Masked threshold	61.0 dB(A)
Single-beep warning	78.0 dB(A)
Double-beep warning	76.5 dB(A)

C.2 Forward-Collision Warnings

Tables C-3 and C-4 give the duration and sound intensity levels of the forward-collision avoidance warnings used in both the simulation experiment and the field test.

Table C-1. Duration of forward-collision avoidance warnings

Type of warning	Duration
Single-screech	1.52 seconds
Double-screech	1.77 seconds

Table C-2. Sound intensity levels of forward-collision avoidance warnings

Sound source	Sound intensity level
Masked threshold	61.0 dB(A)
Single-screech warning	83.0 dB(A)
Double-screech warning	76.5 dB(A)