3.8 Study 3 Experimental Methodology and Approach

Unexpected Braking Event with "Unexplained" FCW Crash Alerts

Building upon the solid foundation provided by the results obtained from CAMP Study 1 and Study 2, this study further examined how and when to present crash alert information to a relatively inattentive driver. An overview of the experimental methodology and approach used in this study is shown in Table 3-11, and an overview of the order of experiment events (or procedures) in this study is shown in Table 3-12. Unlike Study 2, a completely new set of test drivers was tested who had not previously participated in CAMP Study 1. In sharp contrast to Study 2, drivers in this study were not informed at the beginning of the study that the purpose of this research was to address the usefulness of FCW system crash alerts for helping drivers avoid rear-end collisions.

In this study, the Surprise Moving Trial occurred during the first phase of the study. In this early phase, the on-board computer was allegedly "learning" driver's normal following behavior for a later "automatic distance control" phase. Drivers were simply asked to follow the lead vehicle at their "normal" following distance. The backseat experimenter was engaging the driver in a structured Question and Answer (Q & A) background information dialogue when the Surprise Moving Trial was introduced. Prior to this event, these (naïve) drivers were completely unaware the vehicle was equipped with a FCW system crash alert.

After the Surprise Moving Trial, drivers were asked a series of questions about whether they noticed anything coming on or happening inside the car before they began braking. This trial was then followed by two Follow-On Moving Trials using the same alert type used for the Surprise Moving Trial, and then two Follow-On Moving Trials with a comparison alert type. As in Study 2, immediately after both the Surprise Moving Trial and the Follow-On Moving Trials, drivers were asked judge the appropriateness of the FCW system crash alert timing on a 7-point scale ranging from "much too early" to "much too late".

The timing of the crash alert information was again based on modeling results from CAMP Study 1, and utilized the most conservative crash alert timing approach used in Study 2 (i.e., the RDP timing). For both the Surprise Moving Trial and the Follow-On Moving Trials, driver RT was assumed to be 1.50 seconds.

Five different 1-stage FCW system crash alert types were evaluated, three of which were "carryovers" from Study 2. These carryovers included the HUD + Non-Speech, HHDD + Non-Speech, and HHDD + Speech crash alert type conditions. The two new crash alert types tested included a HHDD + Non-Speech condition in which the HHDD was flashed, which was added in an attempt to increase the noticeability of the HHDD alert. This alert is subsequently referred to as the *Flashing HHDD + Non-Speech* condition. The second new crash alert type tested involved adding the non-speech tone component to the HHDD + Brake Pulse crash alert type tested in Study 2, forming a 1-stage, tri-modality alert. This alert is subsequently referred to as the *HHDD + Brake Pulse + Non-Speech* condition. The non-speech tone component was added in an attempt to reduce the relatively slow brake RTs associated with the HHDD + Brake Pulse condition in Study 2, and to reduce any ambiguity associated with the brake pulse by simultaneously providing a non-speech alert.

3.8.1 Subjects

Test participants consisted of 15 males and 15 females in each of two different age groups; 40-57 and 60-66 years old. Corresponding mean ages for these two groups were 45 and 63 years old, respectively. Each driver was tested individually in one approximately 1 ½ hour session and paid $150 for their participation. It should be noted that drivers finished 1 hour earlier than they were led to believe, in order to be consistent with the test instruction rouse used in Part 1 of this study. Drivers were recruited by an outside market research recruiting firm, and were required to be "naive" drivers who had not previously participated in CAMP Study 1 or Study 2. Drivers who were ultimately allowed to participate were mailed the information letter shown in Appendix A8 prior to testing. A copy of the informed consent statement is provided in Appendix A9, which describes the various conditions that ruled out potential drivers from participating (which were nearly identical to the conditions used in CAMP Study 1).

3.8.2 Test Site

Data was gathered on the same straightaway used in CAMP Study 1 and Study 2. The road was closed to all other traffic during testing. All testing was conducted under daytime conditions under dry road and dry weather conditions.

3.8.3 Test Vehicles and the "Surrogate" (Lead Vehicle) Target

The SV, surrogate target, and POV were identical to that used in CAMP Study 1 and Study 2. Both the SV front seat, passenger-side experimenter and POV driver were trained General Motors Milford Proving Ground test drivers who had previous experience conducting brake tests. The SV and the POV test drivers communicated during the study via digital radio communication.

3.8.4 Data Acquisition System

The data acquisition system used was identical to that used in CAMP Study 2, with the exception of the following crash alert changes. The capability of flashing the HHDD was added. When flashed, the HHDD was flashed at a 4 Hz rate, with a 50% duty cycle (i.e., repeated cycles of 125 ms on and 125 ms off). In addition, the loudness of the alert sounds were increased such that the dBa levels (averaging over left and right channels) were approximately 74.8 and 72.6 dBa for the non-speech and speech sounds, respectively.

3.8.5 Procedure and Design

Procedures Before and After Test Trials

The procedures used were identical to those used in Study 2, with the exception of the test instructions (shown in Appendix A10). Prior to the start of the test session, subjects in the HUD + Non-Speech condition were instructed to adjust the HUD while viewing a “CAMP” logo, since HUD visibility is dependent on the driver’s seated eye position. Subjects were told the HUD would be used in later testing. This HUD adjustment procedure was necessary to help ensure the HUD would be visible to the driver (i.e., the driver’s eyes would be within the HUD eye box or viewing area) during the Surprise Moving Trial.

Test Phases / Driver Instructions

Unlike in Study 2, the Surprise Moving Trial in this study occurred during the first phase of the study. In this first phase, the computer was allegedly “learning” driver’s normal following behavior for a later “automatic distance control” phase. Drivers were simply asked to follow the lead vehicle at their “normal” following distance. The backseat experimenter engaged the driver in a structured *Question & Answer* (*Q & A*) background information dialogue. The last two questions of the dialogue were as follows:

1. Can you tell me the make and model of the last three vehicles you owned prior to your current vehicle?

2. In your opinion, what is the best car you ever owned and why?

During this last question, the surprise braking event was introduced under the same conditions (30 mph POV speed, -0.37 g POV deceleration, and no brake lights) used in Study 2. This surprise trial technique will be referred to as the “*Background Q & A*” surprise technique. After this event, drivers were asked a series of questions shown below about whether they noticed anything coming on or happening inside the car before they began braking.

1. “Did you notice anything come on or happen inside the car before you began braking?”
   If yes, please describe what came on (please be as specific as possible).

2. Did you notice anything else come on or happen inside the car before you began braking?
   If yes, please describe what came on (please be as specific as possible).

If the driver did notice any of the crash alerts components coming on, they were asked a series of additional questions about the alert components that they did notice, which are shown below. If the driver did not report in an open-ended fashion any of the crash alerts components coming on, they were asked more specifically (one at a time) if they noticed a visual indicator, sound, or vehicle braking or jerk. Based on this experimenter prompting, if the driver then reported noticing any of the crash alerts components coming on, they were asked the questions below about the alert components that they did notice.

- If the driver noticed visual alert:

→ What color was the indicator?
→ Where was this indicator located?
→ Were there letters or a picture, or letters and a picture on the indicator?
If you saw letters, what word or words did they spell?
If you saw a picture, please draw or describe the picture?
What does this picture mean to you?

- If the driver noticed the auditory alert:

→ What was the type of sound you noticed?
→ Was the sound a tone or a word, or both?
If you heard a tone, please describe the sound.
If you heard a word, please say the word.

If drivers noticed the brake pulse alert, they were asked to describe the sensation.

In addition, after this Surprise Moving Trial, drivers were asked to judge the appropriateness of the crash alert timing using the same rating scale used during Study 2.

The Surprise Moving Trial was then followed by two comparable alerted trials using the same alert type, and then two comparable alerted trials with the comparison HHDD + Non-Speech alert type. In the condition in which the driver experienced the HHDD + Non-Speech alert during the Surprise Moving Trial, the comparison alert was a HHDD + Speech alert. During these Follow-On Moving Trials (the second phase of the study), drivers were instructed to brake immediately in response to the crash alert in order to avoid colliding with the artificial car.

In this study, five separate, 1-stage, multi-modality crash alert types were evaluated, which are indicated below:

- Head-Up Display (HUD) + Non-Speech Tone
- High Head-Down Display (HHDD) + Non-Speech Tone
- High Head-Down Display (HHDD) + Speech
- High Head-Down Display (HHDD) + Non-Speech Tone + Brake Pulse
- Flashing High Head-Down Display (HHDD) + Non-Speech Tone

For crash alert timing, the RDP crash alert timing was employed with a 1.5 second driver brake RT assumption. The “bail-out” auditory alert for the front seat, passenger-side experimenter was also triggered based on the RDP crash alert timing approach, with assumed inputs of a 0.52 second driver (test driver) brake RT, and an assumed constant deceleration in response to the crash alert of -0.55 g’s. The “bail-out” sound, which was distinct from the non-speech tone employed, signaled the experimenter to take over braking using the add-on brake. A black cardboard visual barrier was placed between the driver and front seat experimenter which prevented the driver from anticipating (or being distracted by) the foot (braking) behavior of the experimenter, and allowed the experimenter to discretely let their foot hover over the add-on brake during a test trial.

Independent Variables Examined

For the Surprise Moving Trial and Follow-On Moving Trials, the between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, HHDD + Brake Pulse + Non-Speech, or Flashing HHDD + Non-Speech), age (middle-aged or older), and gender (male or female).

It should be noted that originally, additional analysis were planned for the Follow-On Trials to compare the first pair of trials, using the crash alert type experienced during the Surprise Moving Trial, to the second pair of Follow-On Moving Trials experienced with the comparison crash alert type (which in 4 of the 5 cases was the HHDD + Non-Speech condition). However, a strong order effect was found with the only two crash alert type conditions during which such an effect could be assessed (HHDD + Non-Speech/HHDD + Speech order versus the HHDD + Speech/HHDD + Non-Speech order). Hence, any comparisons between the first and second pair of Follow-On Moving Trials were deemed inappropriate, and all analyses were performed on the first pair of Follow-On Moving Trials in order to avoid confounding potential order effects.

Objective (Or Performance) Measures Examined

Same as those used in the Surprise Moving Trial and the Follow-On Moving Trials conditions of Study 2.

Subjective Measures / Questionnaire Data.

As in Study 2, immediately after each trial, drivers were asked to judge the appropriateness of the FCW system crash alert timing using the 7-point scale ranging from “much too early” to “much too late. These ratings were analyzed for each phase of the study using the same independent variables and analysis approach that was used to analyze the driver performance measures.

In addition, after the Surprise Moving Trial, drivers were asked various questions about what they noticed coming on or happening inside the car before they began braking. This is referred to as the *“alert noticeability”* questionnaire. These questions were previously described above in the “Test phases / Driver instructions” section.

At the end of the study, drivers were asked to fill out three separate questionnaires. First, drivers were administered the alert modality appropriateness questionnaire previously used in Study 2 after each pair of Follow-On Moving Trials. Second, drivers were administered the crash alert appropriateness questionnaire used in Study 2. Third, drivers were administered the rank order portion of the name the system questionnaire used in Study 2. This revised questionnaire is shown in Appendix A11. Unlike Study 2, drivers were informed that the feature they were to name was not designed to detect pedestrians, and that this feature would occasionally alert or warn the driver under conditions which pose no threat to the driver. This change was made in order to be more consistent with current CAMP assumptions about FCW system performance. Drivers were asked to rank order the top three names from the following set of proposed system names, which are shown below. The eight system name choices below were compiled by selecting the top four choices found in Study 2 (see Table 3-21), and adding four identical system name choices which used the word “alert” rather than “warning.”

Proposed System Names

- Forward Collision Warning System
- Forward Collision Alert System
- Forward Crash Warning System
- Forward Crash Alert System
- Front-End Collision Warning System
- Front-End Collision Alert System
- Rear-End Collision Warning System
- Rear-End Collision Alert System

3.8.6 Results and Discussion

Overview of Statistical Analysis Approach for Objective Measures

For the analysis of the objective (or performance) measures, a factorial Analysis of Variance (ANOVA) was performed for each relevant performance measure (i.e., when the lead vehicle was moving) used in Study 1, along with the brake reaction time measure defined in Study 2. Data from the Surprise Moving Trial and Follow-On Moving Trials were analyzed separately during the statistical analysis. The criterion set for statistical significance was $p<0.05$. Unless otherwise noted, all statistically significant results indicated met (and often exceeded) these adopted criterion.

Objective (or Performance) Measures

Surprise Moving Trial

The between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, HHDD + Brake Pulse + Non-Speech, or Flashing HHDD + Non-Speech), age (middle-aged or older), and gender (male or female). During 2 of these 60 Surprise Moving Trials, the passenger-side experimenter intervened to assist the driver in coming to a stop, but the driver contacted the brake first. This occurred once in the HUD + Non-Speech condition, and once in the Flashing HHDD + Non-Speech. It remains unclear whether these drivers could have avoided impact with the surrogate target without the assistance of the passenger-side experimenter. In these two cases, the data obtained at onset of braking was included in the analysis, but any measures obtained throughout or at the end of braking were excluded from the analysis.

The brake RT findings are shown in Figure 3-35. Unlike Study 2, these results did not indicate a main effect of crash alert type on brake RTs. However, a planned comparison test did find there was a significant effect of faster brake RTs in the HHDD + Non-Speech relative to the HHDD + Speech condition. One hypothesis for these findings is that the use of the non-speech component across 4 of the 5 crash alert types examined in effect neutralized any differences between the various crash alert types. Partial support for this hypothesis comes from a planned comparison of brake RTs in the HHDD + Speech condition relative to the remaining four crash alert types combined, all of which have a non-speech component. Although, results did not quite reach statistical significance ($p<0.11$), this comparison does provide some support for this “non-speech tone neutralization” hypothesis.

Figure 3-36 provides the brake RT distribution (based on 60 RTs) during these Surprise Moving Trials for all drivers. It is worth noting that no subject yielded a brake RT higher than the 1.5 second brake RT assumed for crash alert timing purposes. This distribution is overall quite similar to the upper-percentile distribution found in Study 2 (see Figure 3-32), with a 0.13 second lower 85th %tile value and a 0.16 second lower 95th %tile value.

There were also significant main effects of crash alert type on a number of dependent measures, which are shown in Table 3-22, along with brackets indicating significant differences between pairs of conditions found from follow-up tests. These results generally indicate that the driver was in a more conservative (less aggressive) kinematic scenario in the HHDD + Brake Pulse + Non-Speech scenario relative to the HUD + Non-Speech and HHDD + Speech conditions (i.e., lower speed, TTC, and required deceleration values), and for a few variables (minimum headway and range) relative to the Flashing HUD + Non-Speech condition. There were no differences found between the HHDD + Brake Pulse + Non-Speech and the (steady) HHDD + Non-Speech condition.

For the dependent measures shown in Table 3-22, there was only one higher order interaction involving the crash alert type variable, and this was an Age x Crash Alert Type interaction with the minimum range measure. For the middle-age group, mean minimum ranges in the HUD + Non-Speech, HHDD + Non-Speech, HHDD + Brake Pulse + Non-Speech, HHDD + Speech, and Flashing HHDD + Non-Speech conditions were 16, 13, 27, 10, and 6 feet, respectively. The corresponding mean minimum ranges for the older age group were 11, 13, 19, 23, and 17 feet, respectively. (For a point of reference, as mentioned in the CAMP Study 1 report, 1 mid-size car length is about 16 feet.). These minimum range data are not straightforward to interpret, since a small minimum range can be obtained within the context of a hard stop or more of a coasting, rolling stop.

In summary, as in Study 2, results from the Surprise Moving Trial indicate that the fastest mean brake reactions times occurred in the HUD + Non-Speech and HHDD + Non-Speech conditions, and brake RTs were significantly faster in the HHDD + Non-Speech relative to the HHDD + Speech condition. It is also worth noting that, in comparing mean brake RTs from Study 2 to those in the current study, brake RTs were reduced by 30% by adding a non-speech component to the HHDD + Brake Pulse crash alert type examined in Study 2. It is also interesting to note that, overall, the distribution of all brake RTs observed during these trials is very similar (albeit with times slightly lower in the upper percentiles) to those observed in Study 2. Finally, results found for the TTC-based and required deceleration measures suggest that the vehicle slowing, resulting from the brake pulse cue, resulted in the driver being in a more conservative kinematic scenario at SV braking onset relative to the HUD + Non-Speech and HHDD + Speech conditions (but not relative to the HHDD + Non-Speech and Flashing HHDD + Non-Speech conditions).

For reference and comparison purposes, Table 3-28 provides a list of various percentile values for key variables, along with the corresponding values for Study 2 Surprise Moving Trials for comparison purposes (previously shown in Table 3-17).

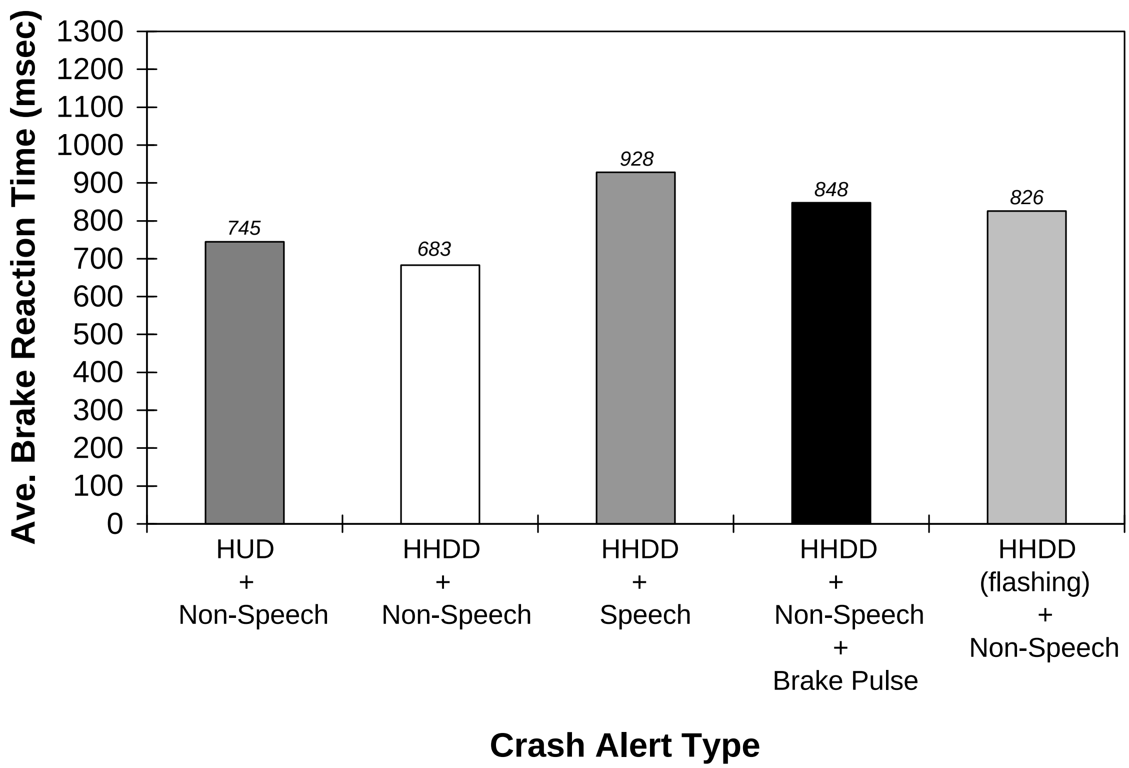

Figure 3-35 Ave. Brake Reaction Times During Surprise Trials as a Function of Crash Alert Type (Study 3)

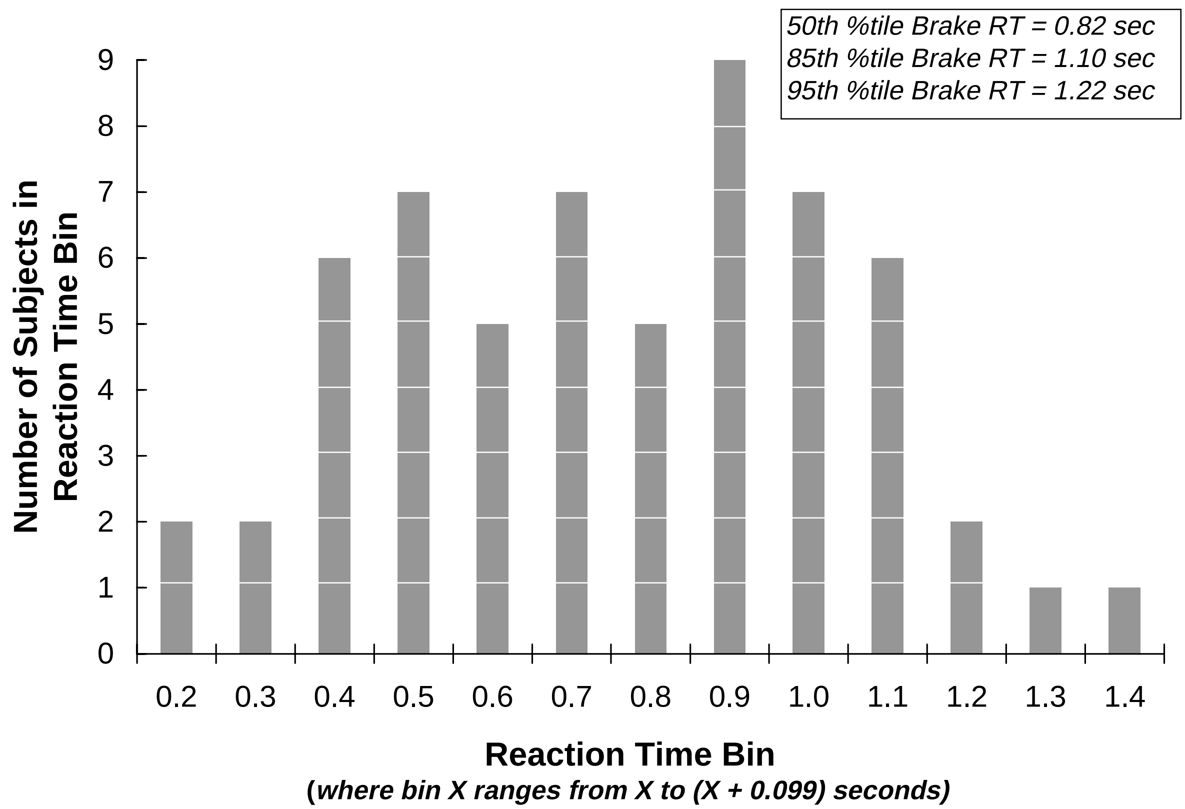

Figure 3-36 Brake Reaction Time Distribution During Surprise Moving Trials (Study 3)

Table 3-22 Significant Main Effects of Crash Alert Type on Various Driver Performance Measures During the Surprise Moving Trials, as well as Results from Follow-Up Tests (Study 3)

	At SV Braking Onset				Throughout Braking			
Crash Alert Type	**SV Speed (mph)**	**TTC / Case 1 (sec)**	**TTC / Case 2 (sec)**	**Req. Decel. (g)**	**Peak Decel. (g)**	**Min TTC / Case 2 (sec)**	**Min. Head-way (sec)**	**Min. Range (feet)**
HHDD + Non-Speech	31.1	7.1	2.7	-0.31	-0.52	2.6	1.3	13.5
HUD + Non-Speech	31.2	6.3	2.4	-0.34	-0.62	2.3	1.0	13.0
HHDD + Non-Speech + Br. Pulse	30.0	8.2	2.9	-0.28	-0.51	2.9	1.6	23.0
HHDD + Speech	31.3	5.3	2.4	-0.36	-0.60	2.2	1.1	16.2
HHDD Flashing + Non-Speech	30.8	6.2	2.5	-0.34	-0.53	2.5	1.1	11.2

Note: Brackets indicating significant differences between pairs of conditions found from follow-up tests.

Table 3-23 Percentile Values for Key Driver Performance Measures During Surprise Moving Trials for Study 3 (Across All Combinations of Age, Gender and Crash Alert Type Variables)

Time During Which Variable was Measured	Dependent Measure (unit)	15th %tile Value	50th %tile Value	85th %tile Value
At POV Braking Onset	Time Headway (sec)	1.1 *(1.0)*	1.6 *(1.5)*	2.1 *(1.9)*
At SV Braking Onset	Brake Reaction Time (sec)	0.46 *(0.59)*	0.82 *(0.84)*	1.10 *(1.23)*
	Required Deceleration (g)	-0.26 *(-0.28)*	-0.32 *(-0.33)*	-0.40 *(-0.42)*
Throughout Braking	Braking Distance (feet)	86 *(75)*	103 *(94)*	115 *(105)*
	Actual Deceleration (g)	-0.30 *(-0.35)*	-0.36 *(-0.42)*	-0.44 *(-0.47)*
	Peak Deceleration (g)	-0.44 *(-0.53)*	-0.55 *(-0.60)*	-0.64 *(-0.77)*
	Minimum Headway (sec)	0.5 *(0.6)*	1.3 *(1.2)*	1.7 *(1.6)*
	Minimum Range (feet)	4 *(5)*	15 *(17)*	23 *(28)*

Note: Numbers shown in parenthesis indicate corresponding values from Study 2 Surprise Moving Trials.

Follow-On Moving Trials

The between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, HHDD + Brake Pulse + Non-Speech, or Flashing HHDD + Non-Speech), age (middle-aged or older), and gender (male or female). As in Study 2, results indicated no statistically significant effects on driver brake RTs during Follow-On Moving Trials. Across the crash alert type conditions examined, mean brake RTs ranged from 485 to 579 ms. Once again the lack of differences observed may be due to difficulties reported by the experimenter in getting the drivers focused on performing during these trials which were experienced immediately after the Surprise Moving Trial.

However, there were significant main effects of crash alert type on a number of dependent measures, where are shown in Table 3-24, along with brackets indicating significant differences between pairs of conditions found from follow-up tests. These results indicate that the driver was in a more conservative (less aggressive) kinematic scenario in the HHDD + Brake Pulse + Non-Speech scenario relative to the remaining crash alert type conditions (i.e., lower TTC, and required deceleration values). Unlike during the Surprise Moving Trial phase of this study, there were differences found between the HHDD + Brake Pulse + Non-Speech and the steady/flashing HHDD + Non-Speech conditions during this Follow-On Moving Trials phase.

For the dependent measures shown in Table 3-24, there was only one higher order interaction involving the crash alert type variable, and this was an Age x Gender x Crash Alert Type interaction with the minimum range measure. This interaction indicated that for each of the five crash alert types tested, the direction of the change in the mean minimum range from the middle-aged to older groups (i.e., either an increase or decrease in minimum range) was the exact opposite for the male relative to female groups. Of the 20 cells formed by this 3-way interaction, 3 of the 4 longest minimum ranges occurred in the HHDD + Brake Pulse + Non-Speech condition. However, as was mentioned earlier, these minimum range data are not straightforward to interpret, since a small minimum range can be obtained within the context of a controlled stop.

There were also Age x Gender x Crash Alert Type interaction effects on the following measures: range at POV braking onset, SV Speed at POV braking onset, headway at POV braking onset, range at SV braking onset, headway at SV braking onset, POV Speed at SV braking onset, and SV actual deceleration at SV braking onset. These 3-way interactions generally indicated that for the majority of the five crash alert types tested, the direction of the change in the measure of interest from the middle-aged to older groups (i.e., either an increase or decrease in the measure) was the exact opposite for the male relative to female groups. For both the range and headway measures at both POV braking onset and SV braking onset, the nature of this Age x Gender x Crash Alert Type interaction was very similar. For the male drivers, with the exception of the HHDD + Brake Pulse + Non-Speech crash alert type, the mean values were *lower* for the middle-aged relative to the older-aged group. In contrast, for the female drivers, with the exception of the HHDD + Brake Pulse + Non-Speech and HHDD + Non-Speech crash alert types, the mean values were *highe*r for the middle-aged relative to the older-aged group for 3 of the 5 crash alert types tested. For 4 out of the 5 crash alert types tested, (the exception being the HHDD + Non-

Speech condition), the direction of change in the measure of interest from the middle aged to older groups (i.e., either an increase or decrease in the measure) was the exact opposite for the male relative to female groups.

There were also a few statistically significant effects not involving the crash alert type variable. There was a main effect of age on mean peak deceleration values. For the middle-aged and older-aged groups, the mean peak deceleration values were -0.49 and -0.56, respectively. There was also an Age x Gender interaction for the TTC-Case 2 measure at SV braking onset. For the middle-aged group, the mean TTC-Case 2 values for male and female drivers were 2.8 and 3.1 seconds, respectively. The corresponding mean values for the older age group were 3.1 and 3.0 seconds, respectively.

In summary, as with the Surprise Moving Trial, results from the Follow-On Moving Trials indicate that the driver was in a more conservative (less aggressive) kinematic scenario in the HHDD + Brake Pulse + Non-Speech scenario relative to the remaining crash alert type conditions (i.e., lower TTC, and required deceleration values). Although there were differences found between the HHDD + Brake Pulse + Non-Speech and the steady/flashing HHDD + Non-Speech conditions (unlike results found for the Surprise Moving Trial phase of this study), these differences were not apparent for the required deceleration measure.

Table 3-24 Significant Main Effects of Crash Alert Type on Various Driver Performance Measures During Follow-On Moving Trials, as well as Results from Follow-Up Tests (Study 3)

	At SV Braking Onset			Throughout Braking		
Crash Alert Type	**Mean Current Dec. (g)**	**TTC / Case 2 (sec)**	**Req. Decel. (g)**	**Min TTC / Case 1 (sec**	**Min TTC / Case 2 (sec)**	**Min. Range (feet)**
HHDD + Non-Speech	-0.02	3.0	-0.27	3.1	3.0	25
HUD + Non-Speech	-0.02	2.8	-0.30	2.2	2.6	17
HHDD + Non-Speech + Br. Pulse	-0.10	3.4	-0.25	5.1	3.2	42
HHDD + Speech	-0.02	2.9	-0.29	3.7	2.8	29
HHDD Flashing + Non-Speech	-0.02	2.8	-0.30	2.9	2.7	22

Subjective Measures / Questionnaire Data

Crash Alert Timing Ratings

Surprise Moving Trial

The between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, HHDD + Brake Pulse, or Flashing HHDD + Non-Speech), age (middle-aged or older), and gender (male or female). Recall, in this study phase, the RDP crash alert timing was used. Results indicated no statistically significant effects, with an overall rating of 4.1 (closest to "just right"). A histogram provided in Figure 3-37 shows the percent of responses at each point along the crash rating scale. Across all drivers, 58 total ratings were made. These data indicate that 69% of the timing responses were "just right", and 24% of the timing responses were either "slightly early" or slightly late."

Follow-On Moving Trials

The between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, HHDD + Brake Pulse, or Flashing HHDD + Non-Speech), age (middle-aged or older), and gender (male or female). Once again, in this study phase, the RDP crash alert timing was used. Results indicated an overall rating of 3.9 (closest to "just right"), and an Age x Gender interaction. For male drivers, the mean crash alert timing ratings for the middle-aged and older groups were 3.6 and 4.3, respectively. For female drivers, the corresponding mean ratings were 3.8 and 3.7, respectively. Hence, the largest difference in ratings between gender groups occurred for the older age group.

The histogram provided in Figure 3-38 shows the percent of responses at each point along the crash rating scale. Across all drivers, 116 total ratings were made. These data indicate that 59% of the timing responses were "just right", and 32% of the timing responses were either "slightly early" or slightly late."

Summary of Crash Alert Timing Ratings Findings

In summary, these crash alert timing ratings are consistent with those found in Study 2, and provide further evidence that the crash alert timing approach directly derived/modeling from the CAMP Study 1 findings (i.e., the RDP crash alert timing) does an excellent job from a driver preference perspective under a wide range of driver expectancy conditions.

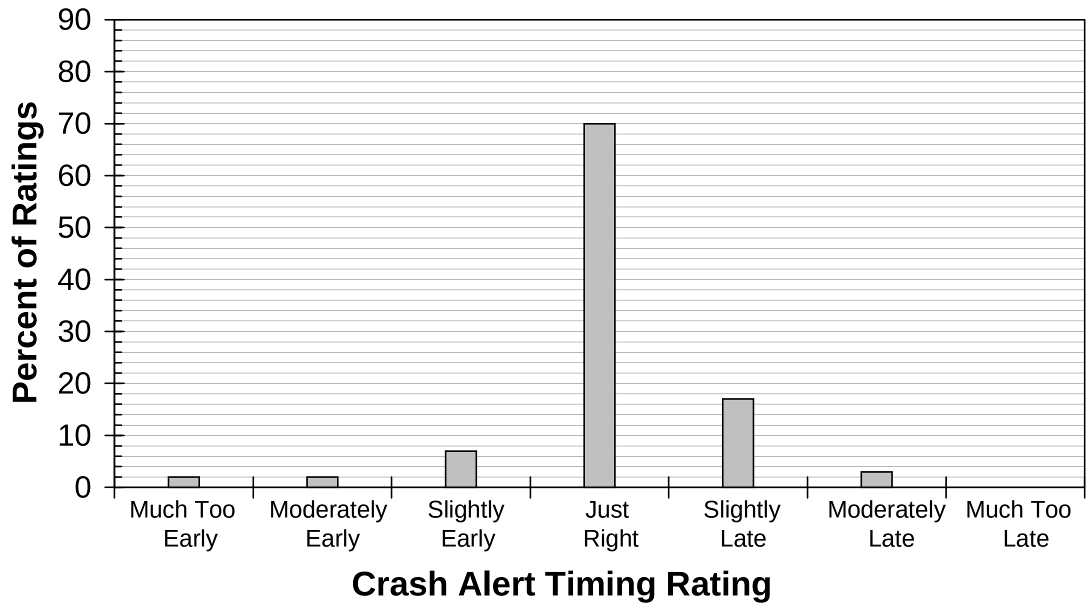

Figure 3-37 Histogram of Subjective Crash Alert Timing Ratings During Surprise Moving Trials (Study 3)

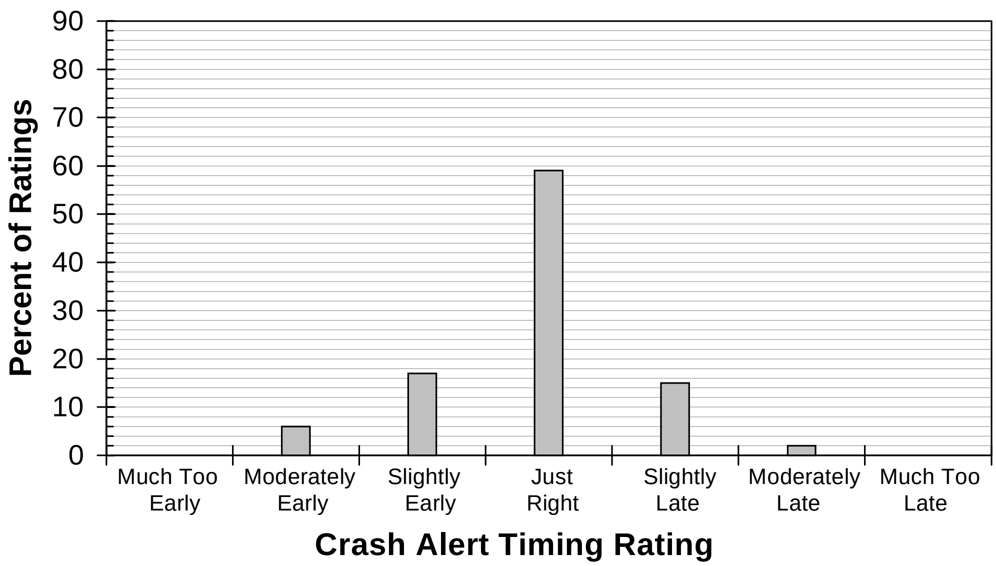

Figure 3-38 Histogram of Subjective Crash Alert Timing Ratings During Follow-On Moving Trials (Study 3)

Alert Noticeability Questionnaire

Results from this questionnaire (administered immediately after the Surprise Moving Trial) are shown in Table 3-25. The criterion for "noticeability" of these alerts during this first experience the driver had with each of these crash alert components were as follows. For the visual alert, noticeability was defined as correctly reporting either the presence of a flashing light, the HHDD location, the yellow/orange color, or the correct word or picture following either an open-ended report of the presence of a visual indicator or following an experimenter prompting if the driver noticed a visual indicator. For the auditory non-speech alert, the criterion for the noticeability was defined as correctly reporting the sound following either an open-ended report of the presence of the sound or following an experimenter prompting if they noticed a sound. For the speech alert, the criterion for the noticeability was defined as correctly reporting the word "Warning" following either an open-ended report of the presence of the speech alert or following an experimenter prompting if they noticed a sound. (It should be pointed out that nearly all drivers correctly described whether the sound was a tone versus speech message). For the brake pulse alert, the criterion for the noticeability was defined as correctly reporting a pulse-like sensation following either an open-ended report of or following an experimenter prompting if they noticed such a sensation (even if drivers were not sure of the source of the sensation during this initial experience with this alert). For the interested reader, a more detailed breakdown of these data beyond this high-level "noticeability" criterion is provided in Appendix A17. The decision to include experimenter-prompted responses to assess whether the noticeability criterion was met during subject's initial experience with the crash alert was due to the intentional vagueness of the open-ended questions (i.e., "Did you notice anything come on or happen inside the car?"), the ability to verify whether responses given by the driver were correct by examining their comments, and to perhaps facilitate driver recollections which may have been impacted by the surprise braking event and the driver's braking maneuver.

Across each of the three alert types combining a visual and auditory alert (HUD + Non-Speech, HHDD + Non-Speech, Flashing HHDD + Non-Speech), the non-speech component of the alert was noticed by all drivers. For the HHDD + Non-Speech + Brake Pulse and HHDD + Speech crash alert types, 11 of 12 drivers noticed the auditory component of the alert. In the one crash alert type including a brake pulse (HHDD + Non-Speech + Brake Pulse), the pulse was noticed by all drivers. This data provides direct evidence that the auditory alert and brake pulse profile established during pilot testing met the goal of providing crash alert components which would be clearly noticed by naive drivers. In summary, across all crash alerts, the auditory and brake pulse components of the alerts examined were noticed by a very high percentage of drivers, all of whom were completely unaware the vehicle was equipped with a FCW system crash alert during this first phase of testing. The descriptions provided by drivers of the brake pulse alert proved interesting. Two of the 12 drivers reported experiencing a bump. All of the remaining 10 of 12 drivers experiencing this alert reported a pulse-like sensation. Seven of these 10 drivers attributed the vehicle as the source of this sensation (using responses such as "vehicle hesitation", "braking", "jerk", and "like ABS" in their descriptions), whereas 3 of these 10 drivers could not readily identify the source of this pulse-like sensation (the vehicle, their own braking, or the road). These data suggest that when implementing a brake pulse alert, an additional alert modality component (visual and/or auditory) is merited to "explain" the source of the pulse-like sensation experienced by the driver (5 of the 12 drivers failed to quickly identify the vehicle as the source of this sensation) . However, it should be noted that under more typical conditions in which the driver would be aware his/her vehicle was equipped with a brake pulse crash alert, the driver may have little difficulty unambiguously identifying this pulse-like sensation as a crash alert.

In contrast, the noticeability of the visual alerts varied considerably across the crash alert types. In the (steady) HUD + Non-Speech and the Flashing HHDD + Non-Speech conditions, the visual alerts were noticed by 9 of 12 drivers and 8 of 12 drivers, respectively. In the three remaining crash alert type conditions (HHDD + Non-Speech, HHDD + Non-Speech + Brake Pulse, and HHDD + Speech), all of which employed a steady HHDD, the visual alerts were noticed by less than half of the drivers. In addition, it should be noted that, in general, drivers had great difficulty reporting any information with respect to the visual display format (i.e., the icon or word) based on this first experience with a visual crash alert, particularly in the HHDD (relative to the HUD) condition (see Appendix A17). As with the brake pulse alert, under more typical conditions in which the driver would be aware that his/her vehicle was equipped with a visual crash alert, the probability of noticing these visual alerts may increase.

These visual alert data suggest that flashing the HHDD may be prudent in order to improve the noticeability of the HHDD (which is also likely to be true for the HUD). This flashing issue was further examined in Study 4 under Surprise Moving Trial conditions in which the driver was asked to search for a (non-existent) indicator light located at the head-down, conventional instrument panel. These conditions tested this flashing hypothesis under conditions in which the anticipated visual angle between the driver's eyes and both the visual crash alert location and the lead vehicle braking event location were substantially increased relative to the current study.

Table 3-25 Noticeability of Visual, Auditory, and Brake Pulse Alerts Across Various Crash Alert Types (Study 3)

Crash Alert Type	Visual Alert Noticed?	Auditory Alert Noticed?	Brake Pulse Alert Noticed?
HUD + Non-Speech	9 / 12	12 / 12	N/A.
Flashing HHDD + Non-Speech	8 / 12	12 / 12	N/A.
HHDD + Non-Speech	5 / 12	12 / 12	N/A.
HHDD + Non-Speech + Brake Pulse	4 / 12	11 / 12	12 /12
HHDD + Speech	2 / 12	11 / 12	N/A.

Alert Modality Appropriateness Questionnaire

Results from this questionnaire (administered at the end of the Follow-On Moving Trials) are shown in Table 3-26. For comparison purposes, also provided are corresponding ratings from the previous Study 2. However, unlike Study 2, these ratings were between-subjects, and were made with much less experience with both the crash alerts experienced and alternative crash alert types. Hence, in general, these ratings are considered less valuable than those found in Study 2. The ratings provided in Table 3-26 are based on the Surprise Moving Trial and the next two Follow-On Moving Trials (all conducted with the same crash alert type).

Across crash alert types, the visual alerts were rated on average from “fair” to “good”. As in Study 2, the HUD generally received higher attribute ratings than the HHDD crash alert component (particularly for the intensity and size attributes). Across crash alert types, the auditory alerts were rated on average “just right”, with the speech alert, as in Study 2, receiving slightly higher mean loudness and mean duration ratings than the non-speech alert. Note that the actual dBa sound level of the speech alert was slightly lower. Also, it is worth noting that the loudness ratings were higher in this study relative to the previous Study 2, which could be explained by the approximately 6 dBa sound level increase in the auditory sounds employed in this study. In addition, overall, 70% of drivers (ranging between 50%-83% across all crash alert types tested) indicated the radio should be muted during the alert. For the brake pulse alert, the strength of jerk was rated on average between “slightly weak” and “just right” and the duration was rated between “slightly short” and “just right.”

Overall, these findings are very consistent with those found in Study 2. The crash alert modalities tested were overall rated good/just right, with the exception of the HHDD which again received low ratings on size and intensity. The loudness ratings for the auditory alerts increased over Study 2, most likely due to the increase in sound levels employed in this study. Finally, across both Study 2 and Study 3, overall, about 3 of 4 drivers indicated that the radio should be muted during the crash alert sound presentation.

Table 3-26 Mean Ratings from Alert Modality Appropriateness Questionnaire Findings (Study 3)

	Crash Alert Type				
Modality/Attribute	**HUD + Non-Speech**	**HHDD + Non-Speech**	**HHDD + Speech**	**HHDD + Non-Speech + Brake Pulse**	**Flashing HHDD + Non-Speech**
Visual					
Intensity	3.8 (*4.0*)	3.0 (*3.0*)	2.8 (*3.0*)	3.0 (*2.7*)	3.9
Size	3.8 (*3.9*)	3.7 (*3.0*)	3.0 (*3.2*)	3.3 (*3.0*)	3.4
Color	4.0 (*4.0*)	3.4 (*3.6*)	2.8 (*3.5*)	3.2 (*3.4*)	3.9
Location	4.0 (*3.8*)	4.2 (*3.6*)	3.3 (*3.5*)	3.7 (*3.3*)	3.5
Auditory					
Loudness	4.3 (*3.8)*	4.1 (*3.8)*	4.5 (*4.0*)	4.4 (*N/A.*)	4.5
Duration	4.3 (*3.9)*	4.2 (*3.9)*	3.9 (*4.1*)	3.8 (*N/A.*)	3.9
Brake Pulse					
Strength of Jerk	N/A.	N/A.	N/A.	3.5 (*3.8*)	
Duration	N/A.	N/A.	N/A.	3.5 (*3.6*)	

Note: See Appendix A4 for excerpts of a questionnaire identical to the one used in this Study. Above ratings are based on the Surprise Moving Trial and first two Follow-On Moving Trials (all experienced with the same crash alert type). Hence, relative to Study 2, these ratings are based on much more limited experience with the crash alert type being rated, as well as other crash alert types. With the exception of the HHDD + Non-Speech + Brake Pulse crash alert type, all italicized numbers shown in parentheses are corresponding ratings found for the same crash alert type in Study 2. For the HHDD + Non-Speech + Brake Pulse condition, the italicized numbers are corresponding ratings found for the HHDD + Brake Pulse conditions in Study 2 provided for comparison purposes. On the attribute rating scale, for visual alerts, 2=Poor, 3=Fair, 4=Good, and 5=Excellent. For the loudness attribute, 3=Slightly Soft, 4=Just Right, and 5=Slightly Loud. For the auditory duration attribute, 3=Slightly Short, 4=Just Right, and 5=Slightly Long. For the strength of jerk attribute, 3=Slightly Weak and 4=Just Right. For the brake pulse duration attribute, 3=Slightly Short and 4=Just Right. N/A=Not applicable.

Crash Alert Appropriateness Questionnaire

An Analysis of Variance (ANOVA) was performed on each of the 14 statements employed in this questionnaire. The between-subjects variables analyzed were crash alert type (HUD + Non-Speech, HHDD + Non-Speech, HHDD + Speech, HHDD + Brake Pulse + Non-Speech, or Flashing HHDD + Non-Speech), age (middle-aged or older), and gender (male or female). Due to the relatively large number of statistical tests carried out (which increases the probability of spuriously significant results, (Hays, 1981)), the criterion set for statistical significance was $p<0.01$. Unlike Study 2, these ratings were made between-subjects, and were made with much less experience with both the crash alerts experienced and alternative crash alert types. Hence, in general, these ratings are considered less valuable than those found in Study 2. The ratings analyzed were based on the Surprise Moving Trial and the next two Follow-On Moving Trials (all conducted with the same crash alert type).

Across all 64 cells formed by combining the 5 crash alert types by 14 sound statements, the mean statement ratings (averaging over both age and gender) ranged from 3.0 to 6.8 (where 3=perhaps disagree, 4=neutral, 5=perhaps agree, 6=moderately agree, and 7=strongly agree). There were no statistically significant differences found between the five crash alert types examined. It should be also noted that with the exception of Question #11 (danger), either the HUD + Non-Speech or HHDD + Brake Pulse + Non-Speech conditions received the highest (most desirable) mean rating for each of the statements examined. This pattern of results for the HUD + Non-Speech condition is largely consistent with those found in Study 2, and the pattern of these ratings provides evidence that adding the non-speech component to the HHDD + Brake Pulse crash alert type tested in Study 2 substantially improved driver’s subjective ratings of this crash alert type including a brake pulse component.

Name the System Questionnaire

This questionnaire was administered at the end of testing, after the Follow-On Moving Trials. Results for this questionnaire are shown in Table 3-27. The proposed system name choices are listed in the order of the total number of votes received in the top three choices (shown in the rightmost column of Table 3-27. There are several interesting trends that can be observed. First, there was no clear preference between including “Warning” versus “Alert” as part of the system name. Second, there appears to be a slight preference for including “Collision Alert” as part of the system name relative to “Collision Warning.” However, the interpretation of both these results is somewhat unclear, since during the driver’s testing session, the various crash alerts tested were referred to simply as “alerts”, and these references may have influenced drivers’ naming judgments. Third, as in Study 2, the top name included “Forward Collision” as part of the system name, in spite of instruction that the system was not designed for detecting pedestrians.

It should be stressed once again that this naming data is strictly based on driver preferences, and does not provide direct data on what driver expectations (in terms of system performance) would be associated with each of these proposed names. An "open-ended" questionnaire employing naive drivers would provide more direct data for assessing the association between system name and driver expectations.

Table 3-27 Name the System Questionnaire Findings (Study 3)

	Number of Votes			
Proposed System Name	**Best Choice**	**Second Choice**	**Third Choice**	**In Top Three**
Forward Collision Alert System	12	10	7	29
Front-end Collision Alert System	7	11	9	27
Rear-end Collision Warning System*	6	10	10	26
Front-end Collision Warning System*	10	7	8	25
Forward Collision Warning System*	9	4	9	22
Rear-end Collision Alert System	8	4	7	19
Forward Crash Alert System	5	10	1	16
Forward Crash Warning System*	3	4	9	16

Note: See Appendix A11 for a copy of the questionnaire. "*" denotes proposed system name carried over from Study 2. 60 subjects provided ratings. It should be noted that unlike Study 2, subjects in this study were informed that feature is not designed to detect pedestrians, and that this feature would occasionally alert or warn the driver under conditions which pose no threat to the driver.