TOPIC CHOICE: SURFACE TRANSPORTATION SYSTEMS (driver behavior)

Effects of Single versus Multiple Warnings on Driver Performance (9 words OK)

RUNNING HEAD: Effects of Single versus Multiple Alarms (35 chars w/spaces OK)

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DARCY: They are listed in the order of importance.

Keywords: driver warnings, collision avoidance, multiple alarms, alarm reliability, master alarm, auditory alarms

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ABSTRACT (212 words OK)

Objective: To explore how a single master alarm system affects drivers' responses when compared to multiple, distinct warnings. **Background**: Advanced driver warning systems are intended to improve safety, yet inappropriate integration may increase the complexity of driving, especially in high workload situations. This study investigated the effects of auditory alarm scheme, reliability, and collision event-type on driver performance. **Method**: A 2x2x4 mixed factorial design investigated the impact of two alarm schemes (master vs. individual) and two levels of alarm reliability (high and low) on distracted drivers' performance across four collision event-types (frontal collision warnings, left and right lane departure warnings, and follow-vehicle fast approach). **Results**: Participants' reaction times and accuracy rates were significantly affected by the type of collision event and alarm reliability. The use of individual alarms, rather than a single master alarm, did not significantly affect driving performance in terms of reaction time or response accuracy. **Conclusion**: Even though a master alarm is a relatively uninformative warning, it produced statistically no different reaction times or accuracy results when compared to information-rich auditory icons, some of which were spatially located. In addition, unreliable alarms negatively impacted driver performance, regardless of event type or alarm scheme. **Application**: These results have important implications for the development and implementation of multiple driver warning systems.

INTRODUCTION

Driving is a complex task, requiring human operators to make decisions, visually track objects, monitor dynamic driving and road conditions, and manage traditional in-vehicle activities as well as telematic interactions. Adding to this complexity is the introduction of advanced warning systems including forward collision warnings (FCW), lane departure warnings (LDW), and blind spot indication system warnings (BLIS) (Campbell, Richard, Brown, & McCallum, 2007). Introducing additional alarm systems, even advanced ones, into existing vehicles could further complicate the driver's task. One particular concern involves the sheer number of alerting events conveyed via advanced driver warning systems, each requiring different responses by the driver. A large number of in-vehicle alerts, with various reliabilities, could lead to increased numbers of nuisance, ambiguous, or false alarms, all of which may adversely affect driver reactions.

Previous research has demonstrated that degraded alarm reliability can significantly impact operator performance. For example, Parasuraman et al. (1997) demonstrated that because of the low base rate of collisions, alarms must have accurate posterior probabilities to convey useful warning information. While it has been shown that imperfect advanced systems can improve driver performance, particularly with training (e.g., Ben-Yaacov, Maltz, & Shinar, 2002; Maltz & Shinar, 2004), driver acceptance, compliance, and trust are likely to decline with unreliable systems (Bliss & Acton, 2003; Cotte, Meyer, & Coughlin, 2001; Lee & See, 2004). For these reasons, it is imperative that alarms are sufficiently informative, without overwhelming or confusing drivers.

Several studies have assessed collision warning effectiveness including the impact on different age groups (Maltz, Sun, Wu, & Mourant, 2004), and different modality effectiveness. These include visual (General Motors Corporation and Delphi-Delco Electronic Systems, 2002), auditory icons and tonal signals (Graham, 1999), and haptic feedback (Tijerina et al., 2000). Multi-staged alert strategies for impending collisions have been investigated (Lee, Hoffman, & Hayes, 2004), as well as warning timing for potential rear-end collisions (Lee, McGehee, Brown, & Reyes, 2002). While these studies have examined a number of advanced warning issues in the driving domain, little research has focused on the impact of the number of alarms and whether drivers benefit from a single master alarm. In this study, we investigate the effectiveness of a single master alarm as compared to multiple, distinct alarms for four different collision warning events under high and low reliability.

Master vs. Individual Alarms

The use of a master alarm is commonplace in the aviation domain. Previous research has found that aircrew have difficulty recalling the meaning of the large number of auditory signals used in military aircraft (Doll & Folds, 1986). Inconsistencies in alert utilization philosophies, lack of standardization, and a rapid increase in the number of alarms are major problems contributing to pilot confusion (DOT/FAA Systems research and development service, 1977). With the explosion of in-vehicle intelligent systems and telematics, these aviation-domain alerting problems are now applicable to the driving domain.

However, the impact of a master alarm system as opposed to individual, unique alarms is not well understood, with little previous research. Alarms, as intentional disruptive signals, represent exogenous auditory orienting cues that direct attention. However, coded cues, such as tones, require operators to search their memory for the meaning of these codes. In the case of individual alarms, operators must map each auditory code to a unique meaning. In contrast, a master alarm requires operators to visually search the external environment for the cause of the alarm. While the master alarm condition represents an exogenous control case, the individual alarm condition requires modulated exogenous response (Spence & Driver, 1994), in that it depends on external auditory orienting cues, as well as on the driver's internal diagnostic strategies.

In terms of human performance, it is not clear which of these two alarm paradigms, individual or master, promotes faster or more accurate responses. Auditory cue informativeness, as in the case of the individual alarms, is thought to enhance performance, particularly when using spatial localization (Spence & Driver, 1994). In addition, if the coding is directly perceived (such as a virtual rumble strip sound), endogenous search time is minimized. However, if the alarm is not perceptually obvious and long-term memory must be accessed for diagnosis, divided attention allocation may lead to significantly longer identification times than if the driver simply searches the visual field for anomalies, as in the case of the master alarm.

In terms of performance benefits of single master alarms, Spence and Driver (1994) and Klein, et al. (1992) have demonstrated that even uninformative cues, those that provide a non-specific warning, can improve performance. Thus the master alarm, a relative uninformative cue that identifies an anomalous state but gives no other causal information, could be just as beneficial as individual alarms by orienting the driver and reducing memory search time. In an attempt to shed light on this issue, a laboratory experiment was conducted, described in the next section.

METHOD

Two important research questions were addressed in this study: 1) Does the use of multiple, distinct aural alarms improve drivers' recognition of, and subsequent reaction to, different hazardous driving events, in contrast to a single master alarm?; and 2) What is the low reliability impact for these two alarm schemes?

Participants

Forty licensed drivers (17 female, 23 male) participated in this experiment, ranging in age from 18 to 40 years (mean = 25.8 years, standard deviation (SD) = 5.4 years). Driving experience averaged 7.2 years (SD = 5.0 years). All participants received $15, and could "win" an additional $5 for good performance, which included avoiding traffic violations such as running red lights or speeding.

Experimental Design

The 2x2x4 mixed factorial experimental independent variables included the alarm scheme, alarm reliability, and the collision event-type, described below.

Alarm Scheme Participants experienced one of two possible alarm schemes: single master alarm and multiple individual alarms. Half of the participants were alerted to all potential collisions by the use of a single master alarm, while the other half were alerted by a specific alarm signal for each type of potential collision, discussed below.

Alarm Reliability. Two Alarm Reliability conditions were used, low and high alarm reliability, which were within-participants across two test scenarios and counterbalanced. Alarm reliability was defined as the ratio of true-positive to false-positive (TP:FP) alarm events. For the high reliability condition, the TP:FP ratio was 3:1 across the four types of collision events. In contrast, the TP:FP ratio for low reliability was 1:3.

Collision Event-Type. The four types of collision events included frontal collision warnings (FCW), follow vehicle fast-approach warnings (FVFA), and left lane and right lane departure warnings (Left and Right LDW). The four collision event-types were within-participants and randomized within each of the two test scenarios. All four alarms sounded for either a maximum of four seconds, or until corrective action was taken, as noted below.

- *Frontal Collision Warning Triggers*: Frontal collision events were triggered by one of three conditions: (a) an oncoming vehicle attempting to pass a vehicle, resulting in an impending head-on collision; (b) a lead vehicle suddenly braking; (c) a parked vehicle pulling into the driver's path. The proper corrective action was either decreasing the closing velocity by braking or swerving laterally away from the threat vehicle.
- *Left and Right Lane Departure Warning Triggers*: In reality, lane departure warnings are intended to alert drivers who are inattentive, distracted, or drowsy. Such conditions are extremely difficult to reproduce in controlled experiments. For this reason, left and right LDWs were triggered by a single condition, in which a "wind gust" forced a gradual heading change and subsequent lane departure. The proper corrective action was swerving back into the lane by a compensating lateral steering motion.
- *Follow Vehicle Fast-Approach Triggers*: This last alarm category was a novel warning included to represent a distinctly different alarm system that required a visual search beyond the forward visual field. FVFA warnings were triggered when a vehicle quickly approached from the rear with a closing velocity of greater than 50 feet per second. The threat vehicle then passed the participant when the two vehicles were separated longitudinally by less than two feet. The proper corrective response

was to either increase the distance from the following vehicle through acceleration, or swerve to avoid an impending collision.

Secondary Task

Previous research has shown that drivers performing a secondary task benefited more from a collision warning system (Lee, McGehee, Brown, & Reyes, 2002), thus a secondary task was included in this study to distract drivers' visual attention from the roadway, similar to that of telematics. The secondary task in this study required drivers to look inside the car and perform a computational problem using an internal LCD display and keypad apparatus. Participants read a number string comprised of six zeros and one non-zero number in a random order. After mentally calculating the sum of the non-zero number and its position in the number string, participants responded via a keypad located below the LCD screen. For example, if "0 0 4 0 0 0 0" was displayed, the participant added '4' to '3' (the third position in the string), to calculate the correct response of '7.' This secondary task was presented at random intervals (between 30-45 seconds) throughout the experiment. If participants did not respond within four seconds, the task disappeared and was considered an incorrect answer.

Dependent Variables

Alarm Response Time. One of the primary dependent variables was the response time to true positive alarms. For a FCW event, this was recorded as the time taken by the driver to initiate an emergency braking action or sharp steering action. Emergency braking action was defined as approximately 2.5 times the braking force of normal braking. A steering command was considered sharp if the steering angle input exceeded 5 degrees, which generally resulted in a heading angle of greater than 28.6 degrees. For both left and right LDW events, response time was recorded as the time taken by the driver to initiate a steering correction in a direction opposite to that of the lane departure, with the same steering angle parameters above. For a FVFA event, response time was recorded as the time to depress the accelerator pedal at twice the normal acceleration force, or to initiate an evasive steering action defined by the 5 degree steering threshold.

Alarm Response Accuracy. A true-positive alarm accurate response occurred when the correct action was initiated to avoid collisions or mitigate lane departures, as discussed above. When participants were presented with false-positive alarms, the absence of corrective actions during the period of the alarm duration was also considered correct.

Since speed control can indicate how well overall subjects attend to the driving task (Green, 2000), it was included as a dependent variable. In addition, participants' secondary task scores, calculated as the percentage of correct responses, was included. Although previous research has indicated that lane position and steering behavior are important indicators of drivers' responses to warning systems, these measures were not explicitly used as independent variables since they were indirectly used to calculate evasive steering reaction times.

Auditory Stimuli

The five auditory alarms (one master and four individual) were audio clips provided by the Ford Motor Company, and represent realistic warnings currently in use. All alarms were presented at ~87dBA, which compares to the background road noise of ~73dBA, which was not silenced during a warning event.

The Single Master Warning alarm consisted of a repeating four-pulse tone pattern, with a fundamental frequency of 885 Hz of approximately 1.0 s. Each of the four pulses lasted ~200 ms, with a 40 ms pause between the first and second, and third and fourth pulses, and a longer 80 ms pause between the second and third pulse. The four-pulse pattern was repeated after a 255 ms pause.

For the multiple alarm scheme, the FCW was also a four-pulse tone pattern, but with a greater prominent frequency (2555 Hz), a shorter pulse duration (~100 ms), a reduced between-pulse pause (8 ms, with a 20 ms onset and offset ramp), and a shorter pause between pattern repetition (113 ms). The corresponding FVFA Warning was a repeating two-pulse pattern with appreciably longer pulse duration (220ms), and no pause between pulses. The fundamental frequencies of these two tones used were approximately 1300 Hz and 650 Hz.

Both the FCW and the FVFA alarms were presented equally across the left and right in-vehicle speakers. In contrast, identical audio clips were used for the Left and Right LDW alarms: a simulation of a low frequency rumble caused by driving on a highway rumble strip. This sound consisted of three repeated rumble patterns, each ~130 ms in length, with a prominent frequency near 80 Hz. The alarm was presented from either the left or right in-vehicle speaker, corresponding to the side on which the lane departure occurred.

Apparatus

The experiment was conducted on a fully instrumented, fixed-based driving simulator, which incorporated a production model 2001 Volkswagen™ Beetle and STISIM *Drive*™ software. Participants interacted with the simulator using the actual brake and accelerator pedals and steering wheel, which were all augmented with tactile force feedback. Auditory output, primarily comprised of vehicular engine sounds and the auditory warning stimuli, was presented to participants through the in-vehicle stereo sound system. The simulator's virtual driving environment was projected onto a large, wall-mounted screen (eight feet long and six feet high and located approximately six feet in front of the seated driver, creating a roughly 65° horizontal field of view.) The simulator’s rearview mirror was displayed as a screen projection inset. Both urban and highway settings were simulated, using only daylight and dry road conditions. Completed distance, speed, and steering, throttle, and braking inputs were captured at a sampling rate of 20 Hz.

Procedure

Each participant experienced three practice and two test scenarios, which lasted approximately 90 minutes total. In the three practice scenarios, which lasted 15-20 minutes and used pre-recorded instructions, participants were told to place priority on successfully completing the driving task, and to attend to the secondary task only when it did not interfere with critical driving events. The drivers were also informed that they would experience some alarm failures, but no failure rates were expressly communicated. During the practice scenarios, participants encountered impending collisions, heard their respective alarms for all four types of potential collision events, experienced false alarms, and practiced driving while performing the secondary task.

Each participant completed two test scenarios, one for each level of Alarm Reliability, but with the same level of Alerting Scheme. In each test scenario, participants were presented with eight warning stimuli for each of the four potential collision event-types. These 32 warnings were randomly interspersed in each driving scenario. Depending on the reliability level of the test scenario, participants were subjected to either 24 true warning events and 8 false alarms, or 8 warning events and 24 false alarms. These warning events occurred approximately 30-45 seconds apart and were triggered when participants crossed predetermined locations on the ~42,000 feet of straight roadway.

RESULTS

Alarm Response Time

The effects of auditory alarm scheme, reliability, and collision event-type on drivers' response times to true-positive auditory alarms were evaluated using a general linear repeated measures model. All data met normality and homogeneity assumptions, and _ = .05.

Significant main effects were found for both the collision event-type and the reliability of the alarm system (F[3, 114] = 91.24, p < .001 and F[1, 38] = 9.69, p = .004, respectively). Overall response times tended to be greatest for FVFA events (Figure 1). Response times tended to be shorter for both left and right LDW events, and shorter still for FCW events. According to Bonferroni pairwise comparisons, the reaction times were significantly different for *all* pairings of the four potential collision event-types (p < .001). In addition, there was a significant interaction effect between collision event type and alarm reliability (F[3, 114] = 8.56, p < .001). Response times for FCW and left and right LDW events were found to be similarly short for both the high and low alarm reliability conditions. Response times for FVFA events, however, tended to increase when alarm reliability was reduced (Figure 2).

The effect of alarm scheme (master versus multiple individual alarms) was not statistically significant (power = .83, means 1.079/1.078s, standard error .048/.050s respectively). Thus there was no experimental evidence to conclude that one system was superior to the other. In addition, neither the interaction between alarm scheme and alarm reliability, nor the interaction between alarm scheme and event type were statistically significant. The three-way interaction between alarm scheme, alarm reliability, and potential collision event-type was not investigated. Rather, the experimental model was partitioned to include the three-way interaction in the error in order to increase degrees of freedom.

Alarm Response Accuracy

Participants were generally accurate in determining the correct response to a given alarm stimulus. This was true whether the alarm required intervention, as in the case of a true-positive event, or no action, as in the case of a false-positive event. Over all test scenarios, 72% responses were correct. For the four collision event-types, accuracy rates were only significantly different for the FVFA alarms (Table 1). As with reaction time, reduction in alarm reliability yielded a dramatic decrease in overall response accuracy to FVFA events, from 86% in the high reliability condition to 58% in the low reliability condition.

As demonstrated in Table 1, there were occasional problems with the event logging that led to some missing data, affecting approximately 7% of the experimental driving events. The most significant problem was detecting FVFA responses, where 20% of the data were inconclusive. The data were not missing per se, but the threshold for correct response was ambiguous. If participants were already fully depressing the acceleration pedal at the closest point of approach and they did not perform a steering action, the simulator did not detect a response, even though the driver may have correctly identified the problem.

Because of the dichotomous nature of the accuracy dependent variable (either correct or incorrect), a chi square test was used. The results were very similar to those previously discussed for reaction times. Alarm scheme was not found to be significant (_^{2} = .25, df = 1, p = .62), while collision event-type and reliability of the alarm system both had significant effects (_^{2} = 14.12, df =3, p = .003, and _^{2} = 548.0, df = 1, p < .001, respectively).

While participants generally responded correctly, error rates significantly increased in the low reliability condition (Figure 3). When examining just the responses to false-positives, the chi-square results followed the same trends as overall accuracy results. Most notably, correct rejection of false alarms dropped from 98.3% for the high reliability condition to only 60.7% for the low reliability condition. Moreover, in a post-experiment survey, participants were generally overconfident in their ability to detect false alarms, as seen by the consistent large gap between subjective self- assessments and objective performance criteria (Table 2).

Speed Control

The percentage of the overall distance drivers were speeding was analyzed to determine whether speed control was representative of actual driving scenarios. Drivers were told to obey 55mph speed limits and would be "speeding" if they exceeded 60mph. Overall, drivers exceeded the 55mph limit only 5.9% of the roadway distance (SD = 6.1%). Drivers' speed control was statistically no different across the alarm schemes (multiple vs. single, p = .908), but was statistically significant across the low and high reliability factor (F(1,76) = 13.7, p < .001). Drivers tended to speed less under low reliability conditions (Low: mean = 3.4%, SD = 3.8%, High: mean = 8.5%, SD = 6.9%). Drivers apparently were more conservative under the low reliability condition.

Secondary Task Score

The secondary task score was based on the percentage of correct answers to the task described previously. A Wilcoxon-Sign test indicated that reliability had a marginal significant effect on the secondary task (Z = -1.798, p = .072), and participants performed better on the secondary task in low reliability scenarios as compared to high. The effect of each alarm scheme on high and low reliability conditions was analyzed using a non-parametric Mann-Whitney U test, which showed that the alarm scheme did not affect secondary task performance in the high reliability scenario (Mann-Whitney U = 185.5, p=.693), but it showed a main effect under low reliability (Mann-Whitney U = 128, p = .049). Participants performed the secondary task better with the master alarm scheme than with the multiple distinct alarms when the reliability was low.

DISCUSSION

Although alarm scheme did not affect response times and accuracies, the collision event-types and alarm reliabilities affected both driver response times and accuracies. In terms of secondary performance, participants did better in the low reliability scenario than in the high, particularly with the master alarm. These findings are discussed below.

Different Collision Event-Types

Drivers' response times to true-positive alarms were significantly affected by the type of collision event. Response times to the FCW events were the shortest, while those for the left and right LDWs were not different. The longest response times occurred for the FVFA warning condition. This is a somewhat expected result; as events in the forward visual scene are the most salient, an impending frontal collision potentially elicits the quickest response. Moreover, when participants heard the alarm for a FVFA warning, they were required to determine the rear vehicle's potential behavior before selecting an appropriate evasive action (e.g. accelerating or swerving).

Multiple Alarms vs. Master Alarm

Results showed no significant difference in drivers' response times or accuracies under the different alarm schemes, regardless of whether they were responding to true-positive or false-positive events. Assuming that the LDWs conveyed the most information in the individual alarm scheme condition (due to spatial localizing and auditory icon use), a post-hoc cell comparison of the LDW responses and accuracies between the master alarm and multiple individual alarm schemes was conducted, which revealed no statistical difference. Thus in the case of the LDW individual alarm with iconic and spatial information, participants correctly responded no differently that those with the relative uninformative LDW master alarm.

This result supports previous assertions that uninformative cues can still be beneficial, likely because, in the case of FCW and LDW, events are more easily perceived in the forward visual field. Thus, all that was needed was a general alarm which did not specific spatial or semantic meaning. While an important finding, it should be noted that only auditory alarms were used in this experiment, and results may differ with haptic, visual, or multimodal alarms. For example, previous research has indicated that for detection of unexpected changes, tactile feedback can improve performance for concurrent visual tasks (Sklar & Sarter, 1999), but more research is needed to determine how this kind of feedback would complement audio feedback.

One artifact of this study is that participants experienced an artificially high incidence of collision events within a compressed time period. For this reason, participants may come to expect alarms and accordingly assume a higher state of mental alertness. In reality, the incidence of collision events, and thus alarms, should be drastically lower. Since true-positive events would be rare occurrences, whether drivers would maintain an ability to diagnose the meaning of distinct alarms remains an open question. Nonetheless, it is encouraging that a single master alarm appears to work as well as multiple alarms, even within a laboratory setting.

Alarm Reliability

As seen in Figure 2, lower reliability increased response times, but only to those events in which a vehicle rapidly approached from the rear. Since such events were likely more difficult to detect and correct, it is probable that the addition of an unreliable alarm system caused participants to even further delay decisions to brake while assessing their environment.

There also was a significant difference in response accuracies across the two alarm reliability levels. Responses to the high reliability alarms were much more accurate than the less reliable alarms. With high reliability, there was no difference between participants' response accuracies across the four different collision events. However, when alarm reliability was low, the percentage of correct responses for both true and false positives dropped dramatically.

While overall the accurate responses rates were generally high, most inaccuracies were associated with false-positive alarm events. These problems were particularly prevalent in the low reliability condition, causing drivers to aggressively brake or steer without real cause. While this experiment focused only on single drivers, such inappropriate responses could quickly lead to chain reactions in dense traffic. The significant increase in error rate across all four types of collision events for low-reliability alarms further supports previous research that alarm reliability is of great importance in ensuring desired human performance.

Although a high percentage of participants reported on the post-survey that they knew when an alarm was a false one (Table 2), a consistently lower percentage of participants correctly rejected false alarms by not responding. Either participants were not able to accurately assess false alarms, or if they were, they still tended to respond to them. One reason might be that participants responded regardless of alarm validity, which is an indication of a "better-safe-than-sorry" risk-averse attitude, as no perceived negative costs were incurred for responding to a false alarm.

Limitations

These results should be interpreted in light of the narrow scope of this experiment, as well as the inherent constraints of driving simulation. The primary limitation of this study is the large alarm event rate, which is higher than would normally be experienced. In generating enough data for sufficient power, there is a trade-off between external validity (representing realistic alarm rates) as well as access to and comfort of participants (i.e., longitudinal studies are difficult and longer test scenarios can exacerbate simulator sickness).

Given the high event rate limitation of this study, further research is needed to determine the effects of time latencies and low base rates before the results can be further generalized. However, the results provide insight into multiple alert impacts during a tracking task under high workload, which is representative of other complex, time-pressured domains such as piloting and air traffic control. In these domains, high event rate occurrence is not unusual. Moreover, using similar experimental event rates, other studies have examined multiple alarm presentation schemes and reliabilities in the driving spatial audio (Bliss & Acton, 2000) and aviation verbal alarm (Bliss, 1997) domains. As in these previous studies, while specific behaviors are difficult to generalize due to experimental constraints, the comparative information gleaned about the alarm presentation modalities is helpful for general design considerations.

CONCLUSIONS

This study investigated alarm scheme (single master alarm versus multiple distinct alarms), alarm reliability (high versus low), and collision event-types (forward collision, left and right lane departure, and following vehicle fast-approach). The single master alarm scheme represents a relatively uninformative non-directional, non-specific alarm system, whereas the multiple distinct alarm scheme represents a more informative directional, threat-specific alarm system. An important finding from this study is that objective driving performance showed no difference in reaction times and accuracy of responses between multiple individual alarms and the uninformative single master alarm. Moreover, the results also demonstrate that low alarm reliability can negatively influence driving performance, suggesting that if there is a high incidence of false alarms for warning systems, drivers may be better served by not having such advanced alerts at all.

[DARCY I ALREADY PROMPTED THEM ABOUT THE ISSUE NUMBERS AND THEY REMOVED ALL THE ONES APPROPRIATELY EXCEPT FOR DOLL WHICH WAS ADDED AFTERWARDS]

REFERENCES

Ben-Yaacov, A., Maltz, M., & Shinar, D. (2002). Effects of an In-Vehicle Collision Avoidance Warning System on Short- and Long-Term Driving Performance. *Human Factors, 44,* 335–342.

Bliss, J. P. (1997). Alarm Reaction Patterns by Pilots as a Function of Reaction Modality. *International Journal of Aviation Psychology, 7*, 1–14.

Bliss, J. P., & Acton, S. A. (2000). *An evaluation of the safety, utility, and reliability of three-dimensional alarm systems for automotive use.* UTCA Report No.99-324, Tuscaloosa, AL: University Transportation Center for Alabama.

Bliss, J. P., & Acton, S. A. (2003). Alarm mistrust in automobiles: how collision alarm reliability affects driving. *Applied Ergonomics, 34*, 499–509.

Campbell, J. L., Richard, C. M., Brown, J. L., & McCallum, M. (2007). *Crash Warning System Interfaces: Human Factors Insights and Lessons Learned* (No. HS 810 697). Washington DC: National Highway Traffic Safety Administration.

Cotte, N., Meyer, J., & Coughlin, J. F. (2001). *Older and younger drivers' reliance on collision warning systems.* In *Proceedings of the 45th Annual Meeting of the Human Factors and Ergonomics Society* (pp. 277–280). Santa Monica, CA: Human Factors and Ergonomics Society.

Doll, T. J., & Folds, D. J. (1986). Auditory signals in military aircraft: ergonomic principles versus practice. *Applied Ergonomics, 17*(4), 257–264.

DOT/FAA Systems research and development service. (1977). *Aircraft alerting systems criteria study* (No. FAA-RD-76-222). Washington D.C.: Department of Transportation.

General Motors Corporation and Delphi-Delco Electronic Systems. (2002). *Automotive Collision Avoidance Operational Field Test Warning Cue Implementations Summary Report* (No. DOT-HS-809-462). Washington D.C.: National Highway Transportation Safety Administration.

Graham, R. (1999). Use of Auditory Icons as Emergency Warnings: Evaluation within a Vehicle Collision Avoidance Application. *Ergonomics, 42*, 1233–1248.

Green, M. (2000). How Long Does it Take to Stop?: Methodological Analysis of Driver Perception-Brake Times. *Transportation Human Factors, 2*, 195–216.

Klein, R. M., Kingstone, A., & Pontefract, A. (1992). Orienting of visual attention. In K. Rayner (Ed.), *Eye movements and visual cognition: Scene perception and reading* (pp. 46–65). New York: Springer-Verlag.

Lee, J. D., Hoffman, J. D., & Hayes, E. (2004). Collision Warning Designed To Mitigate Driver Distraction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing* (pp. 65–72). New York: ACM Press.

Lee, J. D., McGehee, D. V., Brown, T. L., & Reyes, M. L. (2002). Collision Warning Timing, Driver Distraction, and Driver Response to Imminent Rear-End Collisions in a High-Fidelity Driving Simulator. *Human Factors, 44,* 314–334.

Lee, J. D., & See, K. A. (2004). Trust in technology: Designing for appropriate reliance. *Human Factors, 46,* 50–80.

Maltz, M., & Shinar, D. (2004). Imperfect in-vehicle collision avoidance warning systems can aid drivers. *Human Factors, 46,* 357–366.

Maltz, M., Sun, H., Wu, Q., & Mourant, R. (2004). *In-Vehicle Alerting System for Older and Younger Drivers: Does Experience Count?* Transportation Research Record, Vol. 1899, 64-70.
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Parasuraman, R., Hancock, P. A., & Olofinboba, O. (1997). Alarm effectiveness in driver-centred collision-warning systems. *Ergonomics, 40*, 390–399.

Sklar, A. E., & Sarter, N. B. (1999). Good Vibrations: Tactile Feedback in Support of Attention Allocation and Human-Automation Coordination in Event-Driven Domains. *Human Factors, 41,* 543–552.

Spence, C. J., & Driver, J. (1994). Covert spatial orienting in audition: Exogenous and endogenous mechanisms. . *Journal of Experimental Psychology: Human Perception and Performance, 20*, 555–574.

Tijerina, L., Johnston, S., Parmer, E., Pham, H. A., Winterbottom, M. D., & Barickman, F. S. (2000). *Preliminary Studies in Haptic Displays for Rear-end Collision Avoidance System and Adaptive Cruise Control Application* (No. DOT-HS-809-151). Washington, DC: National Highway Transportation Safety Administration.

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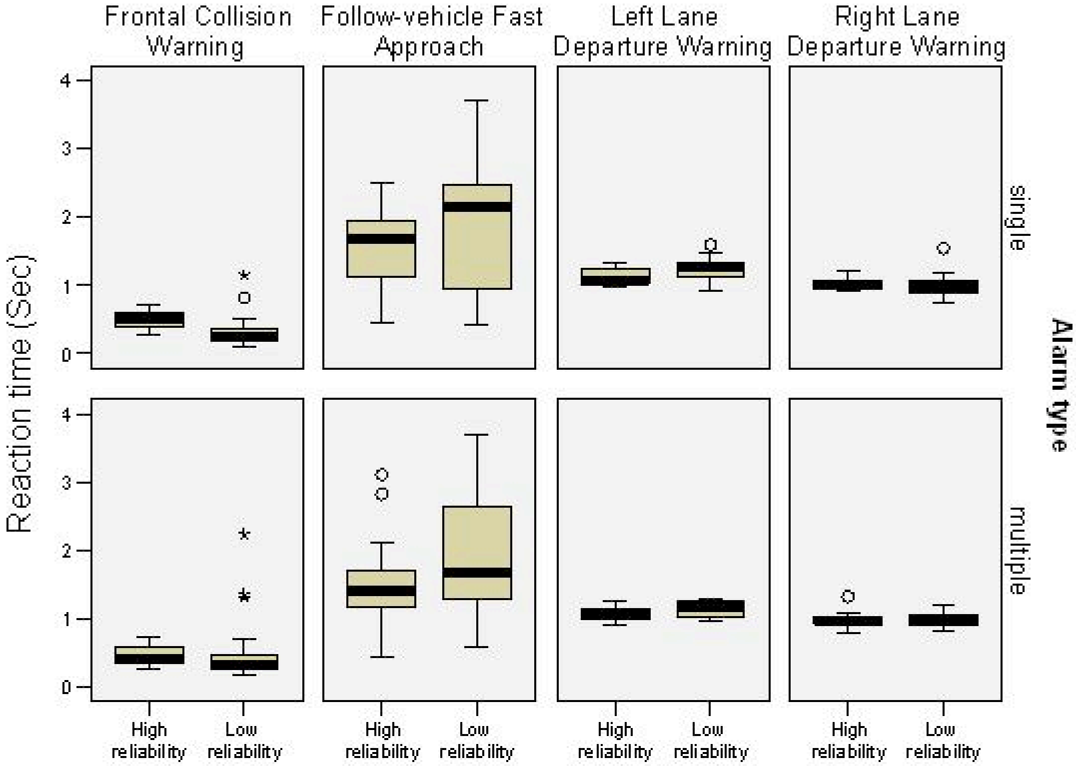
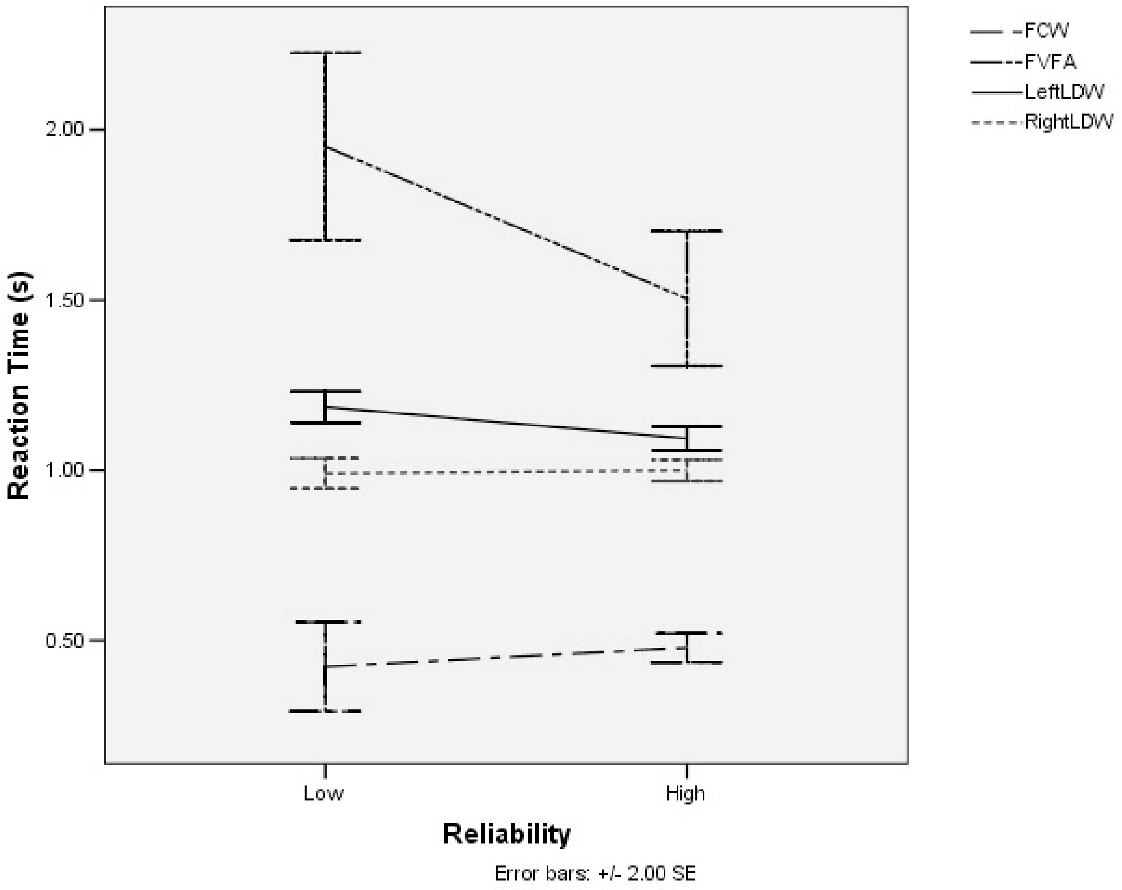
FIGURES

Figure 1 – Response times across experimental factors

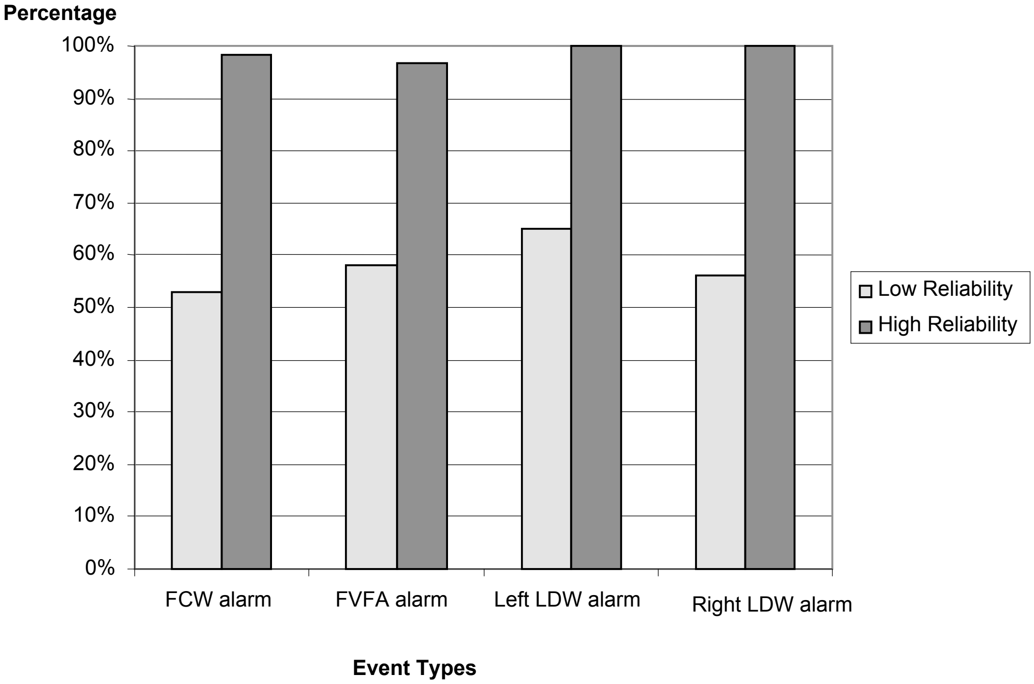
Figure 2 – Reliability x event type interaction for response times

Figure 3 – Percent correct response by event type and reliability


Frontal Collision Warning
Follow-vehicle Fast Approach
Left Lane Departure Warning
Right Lane Departure Warning
Reaction time (Sec)
Alarm type
single
multiple
0
1
2
3
4
High reliability
Low reliability



FCW
FVFA
LeftLDW
RightLDW
Reaction Time (s)
2.00
1.50
1.00
0.50
Low
High
Reliability
Error bars: +/- 2.00 SE


Percentage
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
FCW alarm
FVFA alarm
Left LDW alarm
Right LDW alarm
Event Types
Low Reliability
High Reliability

TABLES

Factor	**Level**	**Correct Response Rate**	**Inconclusive Data Rate**	**Total events**
Overall		72%	7%	2480
Alarm Scheme	Single	72%	7%	1240
	Multiple	72%	6%	1240
Potential Collision Event Type	Frontal Collision	73%	3%	640
	Following Vehicle Fast-Approach	**58%**	20%	640
	Left Lane Departure	81%	1%	600
	Right Lane Departure	77%	2%	600
Alarm Reliability	Low	**58%**	1%	1240
	High	86%	13%	1240

Were participants able to identify false alarms?	**Subjective Yes**	**Objective Yes**
Frontal Collision Event	92%	49%
Following Vehicle Fast-Approach Event	88%	52%
Left Lane Departure Event	82%	66%
Right Lane Departure Event	88%	53%

Author Biographies

Mary Cummings received her Ph.D. in Systems Engineering from the University of Virginia in 2003. She is currently an assistant professor in the MIT Aeronautics & Astronautics Department and is the director of the Humans and Automation Laboratory.

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