Imperfect In-Vehicle Collision Avoidance Warning Systems Can Aid Drivers

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An experiment was conducted to determine the effects of an in-vehicle collision avoidance warning system (IVCAWS) on driver performance. A driving simulator was driven by 135 licensed drivers. Of these, 120 received alerts from the IVCAWS when their headway to a lead car was less than 2 s, and the other 15 (the control group) received no alerts. Drivers received varied alert interfaces: auditory, visual, and multimodal. The system had varied levels of reliability, determined by both false alarm rate and failure of the IVCAWS to alert to short headway. Results indicated that the IVCAWS led to safer (longer) headway maintenance. High false alarm rates induced drivers to slow down unnecessarily; large numbers of missed alerts did not have any significant impact on drivers. Driver acceptance of the system was mixed. Interface played a role in driver reliance on the system, with the multimodal interfaces generating least reliance. Actual or potential applications of this research include IVCAWS interface selection for greater system efficacy and user acceptance and the advisability of implementation, even of imperfect systems, for drivers who seek to maintain a safer headway.

INTRODUCTION

Intelligent transportation systems (ITSs) are increasingly becoming technically feasible and economically affordable (Lee, 1997; Walker, Stanton, & Young, 2001). Unlike in-vehicle safety systems such as air bags and safety belts, which focus on injury reduction, many new in-vehicle systems now focus on accident prevention by providing assistance to the driver during the driving task. One such driving aid is an in-vehicle collision avoidance warning system designed to alert the driver in instances of unsafe headway to a lead vehicle.

With automated driver aids, the twin issues of the impact on driver performance and user acceptability of imperfect aiding devices are increasingly important. There is good reason for caution in the use of devices that alert drivers. An alerting signal can potentially distract or annoy the driver, causing degradation in driving performance. This is especially true for a system with a high false alarm rate (Parasuraman, Hancock, & Olofinboba, 1997; Parasuraman & Riley, 1997). False alarms require allocation of attention by the driver to a situation that would ordinarily not demand attention. At best, it is annoying to the driver; at worst, the false alarm can distract the driver from real hazards. The driver can also choose to disable the system, rendering it useless.

Several recent studies on various aspects of similar systems have concluded that drivers are more cautious when using warning systems than when driving without them and that they consequently drive more slowly and maintain longer headways (e.g., Ben-Yaacov, Maltz, & Shinar, 2002; Burns, Knabe, & Tevell, 2000; Dingus et al., 1997; Shinar & Schechtman, 2002).

The degree to which the reliability of the warning system affects the driver’s usage of the system is therefore a critical issue. In one study, false alarm rates of up to 60% were found to influence younger drivers, leading them to drive with shorter headways as the number of false alarms increased, whereas older drivers were not thus affected (Dingus et al., 1997). In cases of missed alarms, overreliance on a warning system can
be hazardous; even experienced drivers can show overreliance (Young & Stanton, 2000). The cut-off point in system reliability at which the system ceases to be helpful or has adverse effects has not yet been established. In this study, we aim to further the knowledge base in the quest to define usability and acceptability of warning systems at various reliability levels.

Although it is easier to study certain driving situations in simulators rather than on the actual road, researchers are justifiably cautious when relating driver behavior in simulated scenarios to on-road behavior. The distinction between the two reflects the difference between maximal and typical behavior (Naatanen & Summala, 1976). In most experimental situations it is difficult to elicit typical behavior, and instead the driver's “best” behavior, relative to the task demands, is obtained. This shortcoming is not limited to driving simulators but extends to all studies in which the drivers are voluntary participants who are aware of the task demands and the fact that they are being measured. This limitation leads some researchers (e.g., Kiefer, 2000; Lee, McGehee, & Brown, 2000) to question some simulator studies as tools to predict driving behavior. Nevertheless, most researchers acknowledge that because of the flexibility in experimental design and creation of desired conditions, simulator studies are still beneficial in measuring various aspects of actual driving behavior (Lee et al., 2000; McGehee, Mazzae, & Baldwin, 2000).

A recent study tested the utility of an in-vehicle collision avoidance warning system (IVCAWS) on the road (Ben-Yaacov et al., 2002). It was found that the system enabled the drivers to estimate headway more effectively, that errors by the device did not impair user performance, and that the drivers’ newfound headway estimation ability persisted for as long as 6 months (the maximum duration evaluated).

One limitation of that study was that the driving scenarios could not be effectively controlled, given the dynamic nature of traffic patterns and the sometimes unpredictable behavior of nearby drivers in the real world. Consequently the purpose of this study – conducted in a driving simulator – was to relate the findings of the road study to those in a controlled driving scenario. This study, conducted on a fixed-base driving simulator running on a PC, evaluated driver performance in response to alerts to insufficient headway. Participants were presented with visual, auditory, and combination (auditory and visual) alerts. The alerts were discrete and based on the real-time headway of the simulated car to the lead vehicle displayed on the screen. The headway device emitted false alarms in order to represent occasional random device malfunctions and to allow us to compare driver performance in response to both true alerts and false alerts.

METHOD

Participants

The participants were 135 students (49 men, 87 women) who were 21 to 31 years of age (Mdn = 26 years). All of the participants were licensed drivers with 2 or more years of driving experience, and all had normal or corrected-to-normal vision (Snellen visual acuity of at least 6/9). The participants were assigned randomly to the experimental groups, as described later.

Equipment and Procedure

A “homegrown” (program written in house) fixed-base driving simulator running on a Pentium II PC with a 17-inch (43.2-cm) monitor (resolution 800 × 600) was used to simulate a simple car-following scenario. The driver’s display consisted of the dashboard of his or her car, the road ahead, and the rear view of a lead vehicle traveling in the rightmost lane of an otherwise deserted four-lane highway. Alerts were given whenever the participant’s vehicle got too close to the lead vehicle. A highway sign, initially seen as a distant rectangular object, increased in size as the participant progressed in the trial, reaching full size when the destination was reached. Figure 1 shows the display.

Participants were seated 60 cm from the screen with their hands on a noninteractive steering wheel. The rear image of a vehicle was displayed on the screen, and the participants were instructed to maintain a 2-s temporal headway (TH) from it. They were shown what 2-s headway looked like at the default cruising speed of the simulator (with no pressure on the gas or brake pedals). If the participant advanced to within the “danger zone” (<2 s TH), an alert
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was displayed and/or sounded until the driver had retreated to \( \text{TH} \geq 2 \text{ s} \). The participants were informed that the IVCAWS was not perfect and might generate false alarms as well as fail to alert them to dangerous headways. Lead vehicle speed varied randomly and was not affected by the speed of the participant or by TH. The participants’ task was to maintain a short but safe headway to the lead vehicle to avoid being overtaken and to arrive at the final destination as quickly as possible. The participants did not have steering capability and could not overtake the lead car. They could increase or decrease their speed with the “accelerator” and “brake” pedals, respectively. The accelerator and brake pedals provided continuous rather than discrete information to the simulator program and exerted a linear effect on participant speed as pressure on the pedals was increased or decreased.

The participants were alerted by the system at \( \text{TH} < 2 \text{ s} \). If braking occurred too late, a collision was simulated on the screen, after which the trial continued with the between-vehicle distance reset to \( \text{TH} = 6 \text{ s} \). In each trial the participant traveled a fixed distance to arrive at the destination, which was indicated by an overhead highway sign. The experiment consisted of a warm-up trial of approximately 3 min to familiarize the participant with the simulator, followed by six trials, each lasting approximately 3 min (depending on the individual’s driving behavior). Feedback at the end of each trial included number of crashes and time to destination. Crash frequency was not used in the analysis, given the very small number of crashes experienced by the drivers.

### Experimental Design

Three independent variables, all between participants, were included in the experiment. The first variable, collision warning alert type (or cue interface), had five alert interfaces: a visual display, an auditory tone, an auditory speech, a combination of visual warning and tone, and a combination of visual and speech warning. The speech warning was the spoken word “alert,” and the visual warning was a large white square on the vehicle’s dashboard with the word “ALERT” in red uppercase letters (shown in Figure 1), which flashed on the right side of the dashboard panel.

The other two variables were independently manipulated components of system reliability: cue-PD and cue-FAR. Cue-PD represented the probability that the warning system would alert the participants when they were in the danger zone. The values of cue-PD used for the experiment were .6, .8, and .95.

Cue-FAR represented the number of false alarms to be generated sometime during each minute of simulation time. The possible values for cue-FAR were 1 and 4. False alarms were generated when \( \text{TH} \geq 6 \text{ s} \). Thus the participants’ individual driving styles affected the number of false alarms that they actually received. In the postexperimental analysis, we found that a few participants drove more aggressively and consequently received fewer false alarms. These participants were evenly representative in both experimental conditions, so on the whole, the cue-FAR condition was indicative of the number of false alarms actually received by the two groups.

There were 30 unique combinations of the three variables – Cue-PD (3) × Cue-FAR (2) × Cue Interface (5) – and four participants assigned to each cued group, for a total of 120 cued participants. The 15 participants in the uncued (control) group received no warning alerts.

After five trials with a given cue interface, the sixth trial with a different cue interface (also about 3 min long) was run to enable collection of subjective data on driver preference for cue interface.

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**Figure 1.** Driving simulator visual display.
Analytical Methodology

Data were sampled every 300 ms. The data included distance from the lead car (TH), the state of the warning system (alert/no alert), the brake pedal position (pressed/not pressed), and the accelerator pedal position (pressed/not pressed).

We used signal detection theory (SDT) to measure the participants’ performance. SDT can explain human decision making, particularly in the trade-off between false alarms and misses. According to SDT, the task of a person faced with making a binary decision is to determine whether input received is in a “signal state” or a “noise state.” Uncertainty in the decision is caused by noise accompanying the signal state. The degree of overlap of noise and signal is symbolized as $d'$, the person’s sensitivity to the signal, or ability to distinguish between signal and noise. The person’s chosen criterion for the trade-off between false alarms and misses is depicted as $\beta$. A person who decides to limit false alarms (defining noise as signal) will set $\beta$ to a high value and consequently miss more signals; to limit misses, he or she will set $\beta$ to a low value and consequently increase false alarms (see Green & Swets, 1966, for a detailed description of SDT).

Cue dependency. Performance of a task without a cuing system can be characterized by the person’s ability or sensitivity ($d'$). A cuing system will influence $d'$ if the cues (here, the alerts) contain meaningful information. The cue dependency (CD) model (Maltz & Shinar, 2003) is used to calculate the level of human reliance on an automated system’s cues. The CD value is computed as the difference between the measured $d'$ values under conditions of accurate and faulty system conditions. The theory behind the CD model is that because $d'$ reflects performance, if $d'$ was significantly reduced when the automated system malfunctioned, compared with when it did not malfunction, then human reliance on the system’s cues was high. Alternatively, if $d'$ was not affected by system malfunction, it indicated low or no human reliance on the system’s cues.

Four types of events were defined: (a) receiving a true alert (i.e., in the danger zone: $TH < 2$ s), (b) receiving a false alert (i.e., in the safe zone: $TH \geq 2$ s), (c) entering the danger zone and not receiving a true alert, and (d) entering the safe zone and not receiving a false alert. The possible response to any of these events consisted of either slowing down (pressing on the brake pedal and/or releasing the accelerator) or not slowing down (no change, releasing the brake pedal, and/or pressing on the accelerator). A response to an event was recognized as such if it occurred within 1.3 s of commencement of the event. The proper response to being in the danger zone was to slow down, and the proper response to being in the safe zone was to not slow down. The classification of response to an event in SDT terminology depended on the headway (danger or safe zone) and on the presence or absence of an alert from the IVCAWS. Table 1 details the classification of responses into hits, misses, false alarms, and correct rejections. $P(\text{hit})$ and $P(\text{fa})$ were the experimentally observed probabilities of a hit or of a false alarm, respectively.

RESULTS

Cued versus Uncued Drivers

As expected, the IVCAWS affected the participants’ headways. The control group’s headways were too short ($TH < 2$ s) 12% of the time. Similar results were obtained for the other participant

<table>
<thead>
<tr>
<th>Event</th>
<th>Response</th>
<th>Zone</th>
<th>Alert</th>
<th>Slow Down</th>
<th>Not Slow Down</th>
</tr>
</thead>
<tbody>
<tr>
<td>Danger</td>
<td>Hit/c</td>
<td>Yes</td>
<td></td>
<td>Miss/c</td>
<td></td>
</tr>
<tr>
<td>Safe</td>
<td>FA/c</td>
<td>Yes</td>
<td></td>
<td>CR/c</td>
<td></td>
</tr>
<tr>
<td>Danger</td>
<td>Hit/nc</td>
<td>No</td>
<td></td>
<td>Miss/nc</td>
<td></td>
</tr>
<tr>
<td>Safe</td>
<td>FA/nc</td>
<td>No</td>
<td></td>
<td>CR/nc</td>
<td></td>
</tr>
</tbody>
</table>

Note: c = when cued, nc = when not cued, FA = false alarm, CR = correct rejection.
groups during the warm-up drive, before they had been exposed to the system. However, prealert versus postalert comparison of these participants showed that after they had been exposed to the IVCAWS, they had short headways (TH < 2 s) only 7% of the time, $F(1, 133) = 4.12, p = .045$.

To study driver response to the alerts, we computed a two-way analysis of variance (ANOVA) – Gender (2) × Zone (danger or safe) – on the percentage of alerts that participants responded to by slowing down. Overall, participants of both genders responded properly to the true alerts, slowing down in response to 86% of them, and slowed down inappropriately in response to only 16% of the false alerts, $F(1, 99) = 1655.04, p < .0001$. The tendency to slow down in response to an alert, whether true or false, was more marked in the female participants than in the male participants, $F(1, 99) = 9.47, p < .003$. Women slowed down more often than men in response both to true alerts (89% vs. 82%) and false alerts (19% vs. 11%). The Gender × Zone interaction was not significant.

**Warning System Reliability**

Drivers were much more responsive to changes in cue-FAR than to changes in cue-PD. A two-way ANOVA – Cue-PD (3) × Cue-FAR (2) – computed on the probability of responding to a false alert, $P(fa)$, yielded a significant main effect of cue-FAR, $F(1, 114) = 7.27, p < .0081$. Participants who received a large number of false alerts from the warning system (cue-FAR = 4) were more likely to respond incorrectly to the false alerts than were participants who received fewer false alerts (cue-FAR = 1; Figure 2). In contrast, cue-PD did not significantly affect $P(fa)$, $F(2, 114) = 1.07, p = .35$, and the interaction of the variables was not significant.

Alert reliability had a similar effect on $d'$. A high rate of false alerts reduced the drivers’ values for $d'$ from 2.8 at cue-FAR = 1 to 2.3 at cue-FAR = 4, $F(1, 118) = 4.83, p = .03$. $P(hit)$ was not significantly affected by either component of warning system reliability. The participants’ decision criterion, ln$\beta$, shifted downward from .24 at cue-FAR = 1 to -.67 at cue-FAR = 4, $F(1, 118) = 5.24, p = .02$, showing a tendency toward increased caution (slowing down more in response to alerts) when there was a large number of false alerts. Ln$\beta$ was marginally affected by cue-PD, $F(2, 114) = 2.69, p = .073$, with the highest reliability level, cue-PD = .95, causing drivers to be more “liberal” in their response to the alerts (Figure 3).

**Driver Reliance on the Warning System**

We used the cue dependency (CD) model (Maltz & Shinar, 2003) to evaluate the extent to which IVCAWS reliability affected the
participants’ reliance on it. We measured $d'$ separately under accurate IVCAWS status and faulty IVCAWS status. Accurate and faulty system statuses were defined as situations of hits and correct rejections for the former and false alerts and misses for the latter. The CD ($d' = 3.32$ under accurate system status and $d' = 2.45$ under faulty system status) was highly significant, $F(1, 119) = 21.85, p < .0001$, indicating a strong reliance on the alerts by the cued participants. We then measured the extent of reliance for the various participant groups by studying the CD under the different experimental conditions. Neither cue-PD nor cue-FAR affected driver cue dependency, $F(2, 114) = 0.67, p = .52$, and $F(1, 114) = 2.83, p = .1$, respectively. Gender also did not affect cue dependency, $F(1, 118) = 0.43, p = .52$.

**Alert interface.** Alert interface had a significant effect on the drivers’ reliance on the IVCAWS. A two-way ANOVA – Alert Interface (5) × Warning System Status (accurate/faulty) – computed on measured $d'$ values yielded a significant interaction between alert interface and system status, $F(4, 115) = 3.32, p = .014$. Figure 4 shows the values for $d'$ for the five alert interfaces under accurate and faulty warning system conditions, a graphical presentation of the components of the CD model. Reliance was greatest on the speech interface and least on the combined visual-plus-speech interface. Post hoc comparisons showed significant differences in CD values between the visual-plus-speech and the visual interfaces, between the visual-plus speech and the speech interfaces, and between the visual-plus-tone and the speech interfaces. Alert interface affected neither $P(\text{fa})$ nor $P(\text{hit})$.

**Response Time to Alerts**

We measured response time as the time from alert presentation until driver deceleration, up to a maximum of 1.3 s. The participants responded faster to true alerts (averaging 0.54 s) than to false alerts (averaging 0.67 s), $F(1, 91) = 22.57, p < .0001$. Neither cue-FAR nor cue-PD of IVCAWS reliability affected response time significantly, $F(1, 90) = 1.88, p = .17$, and $F(2, 89) = 0.23, p = .79$, respectively. As expected, alert modality did affect response time. We compared response times among the visual, auditory (tone and speech), and combined (visual-plus-tone and visual-plus-speech) interfaces. Table 2 lists the average response times measured for the different alert modalities. There was a significant difference between response times to the visual and auditory interfaces when the participants were in the danger zone, $F(1, 18) = 27.48, p < .0001$, but no significant difference was found in response time to false alerts, $F(1, 9) = 1.54, p = .25$. Hence, although the auditory interface drew the drivers into quicker desirable responses than did the visual interface, the auditory interface did not seem to induce quicker incorrect responses than did the visual interface.
There were no significant differences between response times to the auditory and the combination interfaces, which may mean that the auditory component of the combination interface, at least for response time, was prominent.

Driver preferences. To test for preferences, we exposed the participants to two different IVCAWS alert interfaces during the experiment. The combination of interfaces was a fully factorial design. Each alert interface type was used by 48 participants; 24 participants were exposed to the interface for the majority of the experiment, and 24 participants were exposed to the interface during the last trial, for comparison purposes. Consequently, 12 participants were exposed to each unique pair of interfaces.

Upon completion of the experiment, the participants were asked to name (a) which of the two interfaces that they had been exposed to helped them more in the driving task and (b) which interface would they prefer if they were to install a comparable system in their car. Tables 3 and 4 summarize the participants’ responses. Of the five interfaces, the multimodal visual-plus-tone alert interface was the only one chosen by more than half (54%) of the participants exposed to it as the more helpful interface. Overall, the participants found the multimodal alerts (visual-plus-tone and visual-plus-speech) to be more helpful. Of the unimodal alerts, the speech alert was reported as more helpful more often than either the tone

### Figure 4
Driver reliance on the IVCAWS, as shown by differences in $d'\text{ values under accurate and faulty warning system conditions, by alert interface. Note that the } d'\text{ values with the accurate system minus the } d'\text{ values with the faulty system give the cue dependency.}$

### TABLE 2: Response Times to Headway Alerts by Alert Modality

<table>
<thead>
<tr>
<th>Response to:</th>
<th>Interface</th>
<th>No. of Participants</th>
<th>Response Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Alert in the danger zone</td>
<td>Visual</td>
<td>39</td>
<td>0.66</td>
</tr>
<tr>
<td></td>
<td>Auditory$^a$</td>
<td>69</td>
<td>0.52</td>
</tr>
<tr>
<td></td>
<td>Combination$^b$</td>
<td>61</td>
<td>0.52</td>
</tr>
<tr>
<td>Alert in the safe zone</td>
<td>Visual</td>
<td>31</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>Auditory$^a$</td>
<td>63</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>Combination$^b$</td>
<td>64</td>
<td>0.61</td>
</tr>
</tbody>
</table>

Note. Each participant was exposed to two alert interfaces, and sometimes both of them were of the same modality.

$^a$Includes tone and speech interfaces. $^b$Includes tone-plus-visual and speech-plus-visual interfaces.
DISCUSSION AND CONCLUSIONS

Driving simulators are not best suited for measuring typical behavior (Kiefer, 2000; Lee et al., 2000). However, they are useful in some contexts. In the particular context under study in this paper, Shinar and Schechtman (2002) have shown that drivers actually adjust typical performance when presented with headway feedback cues. Our results also mirror those of the previous on-road study implementing an IVCAWS (Ben-Yaacov et al., 2002). Although the data are not identical, percentages of time in the danger zone versus the safe zone shifted in the same direction with the introduction of the IVCAWS in the on-road study as in the present simulator study. This study builds on the findings that driver performance was affected positively by the introduction of an IVCAWS to the driver. In this study we tested additional interfaces for the IVCAWS and performed an analysis of driver reliance on the warning system.

As expected, we found that alerted drivers spent less time in the danger zone than did those who did not receive alerts from the system. Also, drivers were mostly able to distinguish between false and true alerts; they did not automatically brake when outside of the danger zone but, rather, responded in accordance with the situation presented. Unlike the road experiments (Ben-Yaacov et al., 2002; Shinar & Schechtman, 2002), in this study we found a gender difference, with women responding more readily to the alerts than men. We have no explanation for this effect.

The reliability of the IVCAWS was not a significant factor in the responses to true alerts. This is important for actual implementation of such systems because overreliance on an IVCAWS could lead to unwarranted complacency in the event of system failure. This did not occur. An increase in the number of false alarms led to an increase in the percentage of false responses (braking when not in the danger zone); thus, although overall the drivers treated true and false alerts differently, they did make more errors when the system generated more false alerts. We believe this is not particularly worrisome. An occasional unnecessary

TABLE 3: Driver Responses on Perceived Helpfulness of Alert Interface

<table>
<thead>
<tr>
<th>Interface</th>
<th>This Interface Helped Most</th>
<th>A Different Interface Helped More</th>
<th>No Difference Seen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speech</td>
<td>17</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Visual</td>
<td>10</td>
<td>27</td>
<td>11</td>
</tr>
<tr>
<td>Tone</td>
<td>9</td>
<td>22</td>
<td>17</td>
</tr>
<tr>
<td>Visual + speech</td>
<td>21</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td>Visual + tone</td>
<td>26</td>
<td>8</td>
<td>14</td>
</tr>
</tbody>
</table>

Note. Each participant was exposed to two of the five interfaces; n = 48 for each interface.

TABLE 4: Driver Preference for Alert Interface

<table>
<thead>
<tr>
<th>Preferred This Interface</th>
<th>Preferred a Different Interface</th>
<th>No Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speech</td>
<td>20</td>
<td>24</td>
</tr>
<tr>
<td>Visual</td>
<td>19</td>
<td>29</td>
</tr>
<tr>
<td>Tone</td>
<td>19</td>
<td>26</td>
</tr>
<tr>
<td>Visual + speech</td>
<td>21</td>
<td>26</td>
</tr>
<tr>
<td>Visual + tone</td>
<td>36</td>
<td>10</td>
</tr>
</tbody>
</table>

Note. Each participant was exposed to two of the five interfaces; n = 48 for each interface.
deceleration – when it constitutes easing of the foot from the accelerator pedal or a light application of the brake (as was typical of the drivers in our study) and not an abrupt application of the brake – is not hazardous compared with a failure to respond when the driver is in the danger zone. We should note that our participants were not given the option to disable the system’s alerting mechanism, which would not be the case in a real driving situation. In the real driving environment, high rates of false alarms could lead to disuse of the device, a consequence that has been discussed in other studies (e.g., Hancock, 1993; Horowitz & Dingus, 1992; Parasuraman et al., 1997; Sorkin, 1988).

The initial finding that alert interface did not affect $P_{hit}$ or $P_{fa}$ was somewhat surprising, given the number of studies that have found that informational and warning interfaces can be significant factors in the driver response (e.g., Dingus et al., 1997; Fairclough, May, & Carter, 1997; Hirst & Graham, 1997; Kiefer, 2000). However, the cue dependency measure (CD) did show differences among the various alert interfaces. Because the standard $d’$ measure is an average of the two cases (when the warning system is accurate and when it malfunctions), $d’$ may not be sensitive enough to show existing differences in an ANOVA test. CD is less susceptible to individual differences between drivers and can better mirror changes in driver performance (Maltz, 2001). That seems to have been the case here, given that the participants were more reliant on the speech interface than on the other interfaces, causing a decline in $d’$ when the system malfunctioned.

However, with the visual-plus-speech interface, the difference in $d’$ between the different system conditions was negligible, showing little or no reliance on the system. CD was able to detect these differences and demonstrate the significance of the interface type. It is interesting that the participants preferred an interface (visual plus tone) that inspired a medium amount of reliance, rather than one of the extremes. To summarize, the alert interface can have a major effect on driver acceptance and reliance and thus should be considered a significant element in IVCAWS development.

The partial impact of IVCAWS reliability on driving performance is encouraging for implementation purposes. The drivers were able, in practice, to assess the situation independently of the warning system’s performance. Perhaps the most important consideration for the implementation of an in-vehicle automated driver aid of this type is acceptability to the driver. False alarms may have an effect on acceptability. Our drivers were not able to turn off the system; in reality, a driver would be able to deactivate the IVCAWS. This is a topic for further consideration. In-vehicle warning systems cannot compel drivers to keep safer headways; that is the driver’s personal choice. However, our results show that even an imperfect IVCAWS can aid drivers who wish to maintain safer headways.

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