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Effects of an In-Vehicle Collision Avoidance Warning System on Short and Long-Term Driving
Performance

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Intelligent transportation systems (ITS) have enhanced the way we can deal with road safety issues. Many new in-vehicle systems focus on accident prevention by facilitating the driving task. One such driving aid is an in-vehicle collision avoidance warning system (IVCAWS), used to alert the driver to an impending collision. Our study evaluated the effects of an imperfect IVCAWS both on driver headway maintenance, and on driver behavior in response to warning system errors. Our results showed that drivers tend to overestimate their headway and consequently drive with short and potentially dangerous headways, and that IVCAWS are a useful tool for educating drivers to estimate headway more accurately. Moreover, our study showed that after a relatively short exposure to the system, drivers were able to maintain longer and safer headways for at least six months. Drivers responded properly for the most part to the system alerts, slowing down when necessary, and ignored false alerts. The practical implications of these results are that the use of an IVCAWS should be considered for inclusion in driver education and training programs.

Running Title: Driving with IVCAWS

Key words: Driver performance, temporal headway, collision avoidance, in-car safety systems, IVCAWS, CAS

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INTRODUCTION

In the U.S., rear-end collisions represent approximately 30% of all car crashes on public roads [NHTSA, 1999]. One of the major causes of such accidents is the failure of the following car to maintain the proper distance from the lead car. In most cases, failure to maintain safe headway can be attributed to driver inattention and/or misjudgment of distance [Knipling et al., 1993].

Two measures are commonly used for converting the distance between vehicles traveling in the same direction into a unit of time. One is time-to-collision (TTC), or the time it will take for two cars at their present speeds to collide. The second measure, the one used in this study is temporal headway (TH): the time it will take for the following car to reach the position of the lead car. A two-second TH has been recommended as the minimum safe distance between vehicles [National Safety Council, 1992]. However, several studies have shown that drivers have difficulty estimating the two-second TH and do not, in practice, maintain it [e.g. Evans, 1991; McGehee et al., 1992; Mortimer, 1997; Taieb and Shinar, 2001]. On the highway, drivers rely on the fact that sudden deceleration by the lead car rarely occurs. They view the lead vehicle speed as a constant; so that if they match its speed, an accident will not occur. One reason why drivers tend to misjudge other vehicles' speeds may be related to the difficulty in perceiving external objects' movement in relation to one's own movement [Rumar, 1990]. There have also been numerous instances of drivers reporting that they simply did not see the other vehicle until it was too late, commonly referred to as 'looking but not seeing' [Treat et al., 1977; Storie, 1977], the cause of which is most likely error in perceptual or cognitive recognition [Crundall and Underwood, 1997; Rumar, 1990; Storie, 1977].

Driver errors in headway judgment and in the detection of other vehicles' movement lead to the possibility of using technological devices both as a way to educate the driver and as a

means to alert the driver to situations that s/he may not have perceived. Such a device measures the TH and sounds a warning beep when the headway to the lead car is shorter than a predefined threshold.

There are two human factors issues in the implementation of in-vehicle collision avoidance warning systems (IVCAWS). The first is the interface to use in relaying the information from the automatic system to the driver. Some studies compared different methods of warning (visual, auditory, and combinations of the two) and found that most were effective to some degree [Dingus et al, 1997], with an auditory tone being the most effective interface [Maltz et al, 1999; Hirst and Graham, 1997].

The second issue is how to analyze the interaction between the driver and the automated warning system when both are capable of error. Sorkin and Woods [1985] recommended that analysis of human performance with an automated aid should be considered a combination of the performance of the automatic system and of the human's subsequent behavior. The automatic system's performance is defined by its probability of detection (of an unsafe headway) and by its probability of a false alarm. The human's behavior is based both on his/her own processing of the event and on the information provided by the automatic system. Some researchers found that human operators will ignore or even disable extremely faulty automatic aids [e.g. Seminara et al., 1977; Sorkin 1988; Horowitz and Dingus, 1992], although users can be influenced by the faulty systems even if they mostly ignore them [Maltz and Meyer, 2001].

In previous research, Taieb and Shinar [2001] found that drivers instructed to drive at a comfortable distance behind a lead car chose a temporal headway (TH) of approximately one second, irrespective of speed. In the present study, drivers were instructed to maintain one-second TH to determine whether they were aware of the TH actually maintained. We examined driver response to a headway detection system's warning tone that was sounded whenever the

driver's headway decreased to less than one second from the lead car. The warning system was programmed to randomly malfunction by generating false alarms (i.e. sounding a tone when TH was longer than one second) and by missing true events (i.e. not sounding the tone when TH was shorter than one second).

The following hypotheses are addressed in this paper: 1) Drivers have a poor sense of safe TH and tend to drive too closely to the lead car. 2) An IVCAWS will assist a driver in maintaining the proper TH. 3) Use of an IVCAWS can teach a driver to maintain good TH. This learning process will remain long after s/he no longer uses the automatic system. 4) The more reliable the IVCAWS, the better the drivers' performance will be with the system.

METHOD

Participants: Thirty subjects, fifteen females and fifteen males, ranging in age from 25 to 50, participated in the experiment. All subjects were licensed drivers with five or more years of driving experience (mean driving experience was 10 years). The subjects were evenly divided into three experimental groups. The grouping was based on the reliability level of the warning system.

Equipment: The subjects drove an automatic compact car (1997 Hyundai Accent) equipped with a laser-based headway detection device (Control-Laser model CL200, by Silicon Heights, Ltd.) The device measured TH to the lead car and signaled whenever a pre-determined headway has been breached. The system provided data, collected by a Pentium-grade laptop (166 MHz) at a rate of about 10 Hz, including self and lead car speed, distance to the lead car, and TH. The computer sounded the alarm whenever the device detected $TH < 1.0$ sec., and generated false alarms, triggered by the experimenter seated in the passenger seat. In addition,

the experimenter muted the alarm at random periods (commensurate with the reliability level of the system for that experimental group) to generate missed alarms.

Procedure: The experiment took place on a six-lane divided highway, in the late afternoons under clear skies. Prior to the experiment, the participants drove without instruction for about ten minutes to the starting point to help familiarize them with the vehicle. Then, they were instructed to reach the destination point in minimum time given the following conditions: 1) stay on the tail of some vehicle as much as possible, keeping a one-second distance to the lead car, 2) stay in the right lane without overtaking unless instructed to do so, and 3) stay within the speed limit.

The experiment was divided into four trials. In the first trial, the subjects drove 20 kilometers (about 15 minutes), with the warning system muted. Before the second trial, the subjects were made aware of the headway detection device and its use as a warning system. For this portion of the experiment, subjects were randomly assigned to the three experimental groups, which had warning systems with reliability levels of 60%, 80%, and 95%. The subjects were informed of the system reliability. The second trial was a 70-kilometer drive (about 50 minutes), consisting of 35 kilometers in each direction along the same route. The third trial was the 20-kilometer drive back to the starting point, with the warning signal, again, muted. The fourth trial of the experiment took place six months after the subjects' initial exposure to the Control-Laser. The subjects drove for 20 kilometers in the same vehicle as before, along the same road, under the same conditions, and with the same instructions. The warning system was muted for the fourth trial.

RESULTS AND DISCUSSION:

The state of the driver-car-warning system was recorded every 300 milliseconds. Four parameters: temporal headway to the lead vehicle, driver speed, driver response, and the state of the warning system (beep or no beep) were grouped into categories. We divided TH into six categories: 0-0.4, 0.4-0.8, 0.8-1.2, 1.2-1.6, 1.6-2.0 and greater than 2 seconds TH. We excluded the last TH category from all but analyses involving false alarms since it included long stretches with no lead car. Since participants were asked to maintain a one-second TH, the first two categories were classified as within the danger zone, the last two categories as out of the danger zone and the 0.8-1.2 second TH category as the requested driving performance (allowing for noise in either direction). The warning system's state was either sounding an alert (beep) or not (no beep). The potential driver responses were: to slow down (noted whenever vehicle speed decreased by at least 3% for at least 1.5 seconds), to speed up (in which speed similarly increased), or to maintain current speed. Driver speed was assigned to two categories: fast (> 90 kilometer/hr) or slow (≤ 90 kilometer/hr).

Figure 1 presents the percentage of time spent by the participants in each TH category on each of the trials. A two-way ANOVA was run (trial (4) X TH (5)) with percentage of time in the TH category as the dependent variable. The two-way interaction was significant ($F_{(12,348)}=24.86$; $p<0.0001$). Driver headway maintenance during the last three trials was noticeably different from the first trial before exposure to the Control-Laser. In the first trial, the drivers spent an average of about 40% of the time in the danger zone ($TH \leq 0.8$ sec.). During and after the use of the Control-Laser, this percentage dropped to about 5%, with TH being between 0.8 and 1.6 seconds for an average of about 45% of the time, compared with about 20% before exposure to the device. The key result was that there were no statistical differences between the latter two trials – immediately after exposure to the device, and six months later [$F_{(1,29)}=.19$; $p<.66$], showing a long term learning effect of headway maintenance.

< Insert figure 1 about here>

To test whether the system's reliability level influenced the headway maintenance, we measured the percentages of time spent in the different TH categories as a function of the reliability of the system both during exposure to and for the trial immediately following exposure to the device (TH (5) X reliability (3)). No significant effects of system reliability were found in driver performance in either of the trials [$F_{(8,108)}=1.07$; $p<.39$ and $F_{(8,108)}=.78$; $p<.63$ respectively].

We included the TH category of >2 seconds when studying the effects of driver speed on driver behavior during and after exposure to the Control-Laser. This was done because we assumed that an open roadway gave the drivers an opportunity to increase their speed, and we wished to see if drivers who tended to exceed the speed limit would exhibit different headways when actually receiving alerts than when not receiving alerts. A 3-way ANOVA (driver speed (2) X TH (6) X trial (2)) with trial treated as a repeated measure was run on percent time in each TH condition. There were no effects of driver speed on headway maintenance [$F_{(5,290)} = 0.88$, $p<.5$], indicating that the effects of the IVCAWS were consistent across driving speed categories.

We defined four IVCAWS conditions of interaction between the independent variables TH and warning state: 1) true sounding of the alert (TH in the danger zone and warning state of 'beep') 2) false alarm (FA) alert (TH outside of the danger zone and warning state of 'beep') 3) warning system miss of an event (TH in the danger zone and warning state of 'no beep') 4) proper non-alert (TH outside of the danger zone and warning state of 'no beep'). We measured the relative frequencies of these conditions for all categories of TH except TH 0.8-1.2 seconds since this TH included the desired headway and could not be classified as totally within or totally outside of the danger zone.

Figure 2 shows the driver behavior (excluding response=no speed change) in response to the warning system's alert or non-alert when in the danger zone. A 3-way ANOVA was run with the two short TH categories (warning state (2) X TH (2) X driver response (2)). A significant interaction between warning system state and response [$F_{(1,29)}=17.98$; $p<.0002$] showed that drivers rarely speeded up in response to the warning and were more likely to decrease their speed when the system alerted them to their short headways than when the system did not alert them. Under conditions of true warning (i.e. $TH<0.8$ and warning beep on), the drivers slowed down in response to the 'beep' an average of approximately 45% of the time compared to accelerating an average of 5% of the time (for the remaining time, speed remained constant). This contrasted with the cases in which there were no warning beeps and the drivers were within the danger zone. Here, the drivers only slowed down an average of 23% of the time. Accelerating remained the same as for true alerts. Thus, the alarm doubled the rate of correct responses to short THs.

< Insert figure 2 about here >

To examine driver response to false alarms, a 3-way ANOVA was run with the three long TH categories (warning state (2) X TH (3) X driver response (2)). There was a significant interaction between warning system state and response [$F_{(1,29)}=6.14$; $p<.02$]. As can be seen in figure 3, false alerts did not particularly cause unnecessary speed reductions. Speed reductions remained at about 10%, regardless of the activation (FA) or non-activation (correct non-alerting) of the IVCAWS. However, false alerts affected the drivers' tendency to speed up. Without alerts, drivers speeded up about 20% of the time when they were outside of the danger zone, but with the FA alerts they speeded up only 11% of the time.

<Insert figure 3 about here>

An examination of the 0.8-1.2 second TH category - a 'borderline' condition that encompassed the typical headway and the one that the participants were instructed to maintain - yielded significant difference in driver behavior before and after exposure to the warning system. A 2-way ANOVA (driver slow down or speed up (2) x trial (4)) was run on the time spent in the borderline headway zone, yielding a significant interaction between driver behavior and trial [$F(3,87)=22.07$; $p<.0001$]. As illustrated in figure 4, whereas in the trial before exposure to the warning system, the percentages of time that the drivers slowed down and accelerated while in the borderline zone were approximately equivalent (around 14%), during all other trials, drivers slowed down more often than they sped up, showing a heightened sensitivity to the headway. Note, that in this TH category, the alarm was sounded whenever $TH < 1.0$ second so that as far as the drivers were concerned, they were getting a true alert.

SUMMARY and CONCLUSIONS

Most of our hypotheses, stated above, were confirmed by our results. First, we found that drivers are generally poor at estimating temporal headway. Prior studies reported driver error in estimation of TH at between 20-42% [McLeod and Ross, 1983; Cavallo et al., 1986; Hoffman and Mortimer, 1994]. The reports, based on laboratory studies, were confirmed in our study, and in the study by Taieb and Shinar, which were performed under actual road conditions. Drivers' headway estimation, however, can be improved with an IVCAWS like the one that we employed. During use of the headway detection device, the drivers' headway increased dramatically.

In addition, the use of the IVCAWS taught the drivers to correctly assess TH, and they were able to maintain safer headways, both immediately after being exposed to the system, and after six months; a significant period of time considering the lack of feedback during the period. While we cannot verify if our participants actually changed their habitual THs after their

exposure to the headway detection system, in the post-driving debriefing, all commented on the changes in their habits with statements like “I keep much longer headways now” or “now I know what headway I should be maintaining.” Thus, the delayed fourth trial demonstrated that their newfound ability to estimate and maintain TH was firmly established.

It is reassuring to note that the warning system did not have to be perfect to be useful. Dingus et al. [1997] showed that a warning system of less than 60% accuracy was not effective. Our results (contrary to our hypothesis) showed that there were no significant differences between 60%, 80% and 95% reliable systems. The drivers were somewhat affected by the false alarms, slowing down unnecessarily, and they occasionally did not slow down when TH was in the danger zone and the alert was not sounded. However, overall, the headways maintained by the drivers were not significantly different with the different levels of IVCAWS reliability. Apparently, the combination of the warning system and the natural perception of the driver concerning where s/he was located in relation to the lead vehicle provided enough input for the driver to process headway maintenance information optimally. These results were independent of driver speed.

Since maintaining adequate safe headway is universally defined as a desired characteristic of safe driving, it appears that a training period with a warning system like the one we used in the study, followed by constant and significant encouragement to maintain a safe temporal headway, should lead to safer driver behavior.

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Figure 3. Percent of response to false alarms/correct non-alerting – in the safe zone (TH $>$ 1.2. sec).

Figure 4. Driver behavior in the 'borderline' zone (0.8-1.2 sec TH).







