PRELIMINARY STUDIES OF MONO-PULSE BRAKING HAPTIC DISPLAYS FOR REAR-END COLLISION WARNING

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Summary: This paper summarizes two studies of mono-pulse braking for rear-end collision avoidance applications. The first study was a single-vehicle parameter-setting study without a lead vehicle that produced recommended pulse braking display duration and jerk rate. However, results also indicated that pulse braking display magnitude influenced the magnitude of driver braking behavior. A second study examined the impact of this driver interface concept both when a lead vehicle was braking to a stop and when the display came on even though the lead vehicle was not slowing down. The results indicated that in the first case drivers modulated their response according to the constraints of the situation rather than the magnitude of the haptic display. On approximately one-third of false positive trials, brief and mild inappropriate braking responses were recorded.

INTRODUCTION

Driver collision warnings might be given through haptic displays that are felt rather than seen or heard.

This paper reports on two small-scale studies of a mono-pulse braking display that might be used as the driver-vehicle interface for rear-end collision avoidance systems. Such a display concept has been recently tested by the Crash Avoidance Metrics Partnership (CAMP). Also, a recently completed USDOT-sponsored project used haptic cues for collision avoidance through braking use a series of short pulses (analogous to the feel of rumble strips). However, that system concept required an auxiliary brake system. In contrast, the mono-pulse brake display used in studies described below was accomplished through use of the standard foundation brakes of the test vehicle.

STUDY 1: MONOPULSE BRAKING PARAMETER SETTING STUDY

Method

Test Participants: Three females (ages: 27, 36, and 50 years) and three males (ages 25, 39, and 56 years) employed by the Transportation Research Center (TRC) Inc. served as volunteer test participants. Test participants were unaware of the nature of the research prior to participation.

Apparatus: The test vehicle was an instrumented, 1995 4-door Chevrolet Lumina with automatic transmission. To induce driver distraction, the driver entered address destinations during a portion of the data collection session into a route guidance system mounted within easy reach by the driver. All trials were conducted on the TRC skid pad, a 5-lane concrete course, with approximately 1 mile (1.6 km) of straightaway and banked turnaround loops (310 ft or 94 m radius curves) at either end.

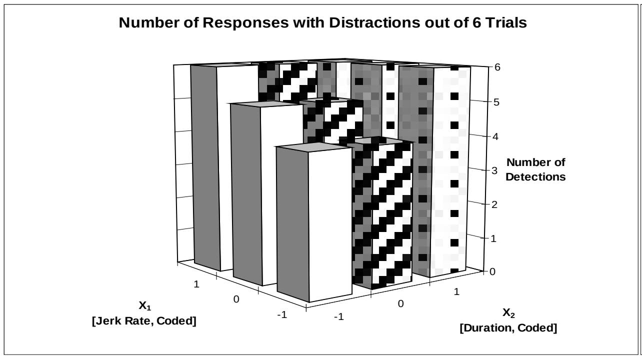
A torque motor was attached by means of a wire cable and pulley to the arm of the brake pedal of the Lumina. Upon application of a command signal provided by means of a laptop computer, the torque motor provided a force on the brake pedal that generated the nominal jerk rate and duration required for a given trial. Each test participant wore headphones over which ocean surf sounds were played by means of a CD player in order to mask sounds generated by the torque motor assembly.

Procedure: The test participant was informed of the general purpose of the study and was given an opportunity to ask questions. The test participant was oriented to the test vehicle and provided with instructions on how to enter street address destinations into the route guidance system. The test vehicle was then driven to the TRC skid pad for testing. Upon reaching the skid pad the test participant was read carefully worded instructions that emphasized a quick response to bring the vehicle to a controlled stop when the a pulse braking event was detected.

The test participant then drove 45 mph (72 kph) through one circuit of the skid pad for familiarization. Two blocks of 12 trials each (of 9 trials with various haptic pulse braking events and 3 ‘catch trials’, i.e., trials in which no pulse braking display was presented) then followed. A single trial consisted of travel in one direction on the skid pad. After the vehicle was brought to a complete stop, the test participant rated the acceptability of the pulse braking display as a rear-end collision warning. For all participants, one block of trials was carried out while driving only and one block while the driver was entering street addresses into a route guidance system.

Results

Three levels of jerk rate (J) and three levels of duration (D) were the pulse braking display parameters manipulated for this study and analyzed through response surface modeling using coded levels. The nominal levels and codes for jerk rate (J) were: 0.08 g/s (code: -1), 0.20 g/s (code: 0), and 0.32 g/s (code: +1). The nominal levels and codes for duration (D) were: 0.25 s (code: -1), 0.65 s (code: 0); and 1.0 s (code: +1). These were crossed to create 9 conditions. A third factor, distraction condition (driving only vs. destination entry while driving), was manipulated as a blocking variable.



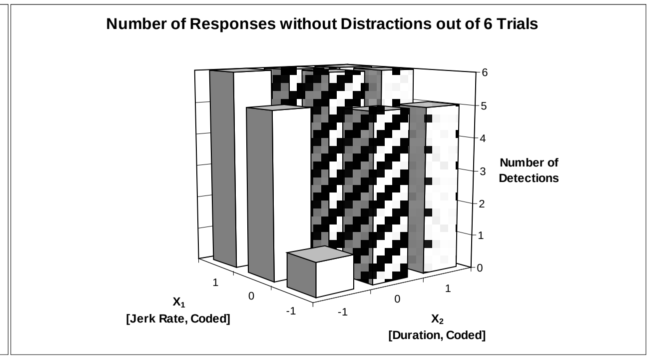


Figure 1. Monopulse Braking Event Detections out of 6 Participants with and without distraction.

Figure 1 presents 3-D bar charts indicating the number of test participants out of six who responded correctly to each of the nine pulse braking events. Consistent across both distracted and non-distracted trials is a number of missed detections at the lowest levels of jerk rate and duration. Across both conditions only the highest jerk rate and the middle or highest event duration produced perfect detection. Surprisingly, the block of trials without distraction was associated with more missed detections than the block of trials completed with the destination entry distraction task. One possible explanation for this was that test participants exerted more effort to attend to a possible pulse braking event when they were obviously under greater distraction. This is considered to be an artifact of the experimental methods used; it cannot be assumed that being distracted while driving will always promote greater sensitivity to pulse braking or other types of warning displays. It nonetheless remains an interesting hypothesis for future evaluation

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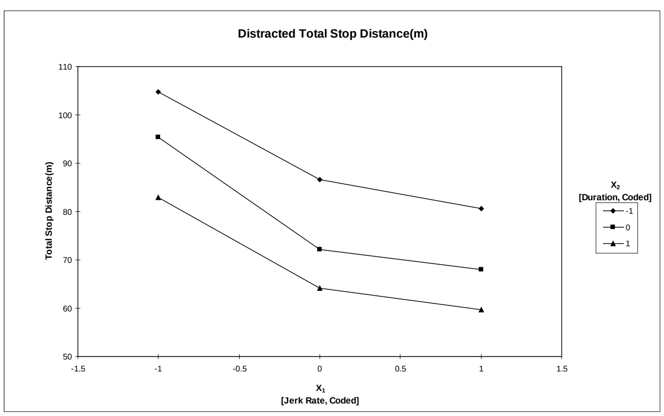

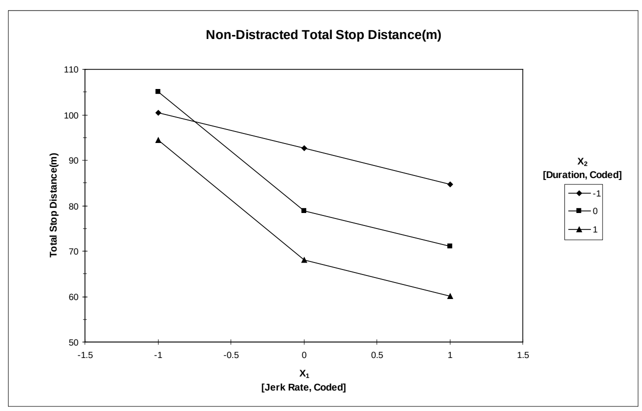

Figure 2. Total stopping distance as function of pulse braking display jerk rate and duration for distracted and non-distracted conditions.

Test participants were instructed ahead of time to bring the vehicle to a “controlled stop” if they noticed a pulse braking display. Figure 2 shows the mean stopping distances as a function of jerk rate and duration (coded values) for both distraction and non-distraction trials. The figure suggests linear trends toward shorter stopping distances as jerk rate and duration increase.

Regression analysis revealed there was no appreciable interaction between jerk rate and duration; variations from parallel lines represent chance variation. This pattern holds for both distraction and non-distraction data sets. Indeed, the least-squares first-order regression model of total stopping distance as a function of coded jerk rate and duration had an $R^2 = 0.38$ without subject effects and an $R^2 = 0.80$ with subject effects. For the non-distraction condition, the first-order regression model yielded an $R^2 = 0.37$ without subject effects and an $R^2 = 0.86$ with subject effects. In general, then, the higher the jerk rate and the longer the pulse braking event duration, the harder the driver braked to bring the vehicle to a controlled stop. This arose even though care was taken in the instructions provided to the test participant to be neutral about the nature of the braking maneuver. This prompted a follow-on study to determine how drivers would respond to the same displays in car following both in true positive and false positive states.

STUDY 2: MONOPULSE BRAKING DISPLAY EFFECTS IN CAR FOLLOWING

Method

Test Participants: Seven (7) individuals served as volunteer test participants: three females (ages: 21, 41, and 61 years) and four males (ages 20, 22, 42, and 65 years). All individuals were in the employ of the TRC. Test participants were unaware of the nature of the research prior to participation and had not participated in previous pulse braking studies.

Apparatus: The same subject vehicle (SV) used in the previous study was used in this study as well. A ControlLaser 2000™ headway sensor was used to capture range and range rate information during car following. The SV followed behind a towed surrogate lead vehicle (LV), a fiberglass mockup of the rear end of a 1997 Taurus. The surrogate LV was towed behind a 1996 4-door Honda Accord, equipped with conventional cruise control, and both drove with brake lights disabled. To induce driver distraction, the driver entered address destinations during a portion of the data collection session into a route guidance system mounted within easy reach by the driver.

An adaptive cruise control system was implemented on a laptop computer to help ensure that similar initial conditions of car following were achieved from trial to trial. The adaptive cruise control system was set for a speed of approximately 45 mph and a car following time headway of 2.0 seconds, nominal. Time headway variations were generally in the range of 1.9 to 2.1 seconds.

All lead vehicle braking events were staged to occur with a nominal 0.35 g braking. This braking event was executed by a TRC driver who monitored a calibrated brake pedal force meter installed in the towing vehicle. Once a braking event began, the haptic brake warning was initiated when the time-to-collision (TTC) value was 25 seconds or less.

Procedure: All trials were conducted on the TRC skid pad. Instructions were carefully worded to emphasize a quick response and avoid collision with the surrogate vehicle while leaving undefined the magnitude of the braking response. The test participant was informed that, during car following, the adaptive cruise control system would maintain an initial separation but that in the event the lead vehicle braked to a stop, the test participant was responsible for bringing the host vehicle to a safe stop. After familiarization trials, the test participant then car followed at approximately 45 mph (72 kph) for a series of 24 trials nominal, where a single trial constituted travel in one direction on the skid pad. These included 9 true positive (TP) trials (i.e., trials in which the surrogate lead vehicle braked, pulse braking display came on), 9 false positive (FP) trials (i.e, trials in which the surrogate lead vehicle did not brake, but pulse braking display came on), and 6 true negative (TN) trials (i.e., trials in which the surrogate lead vehicle did not brake, pulse braking display did not come on). Drivers were always given a destination entry task to perform while car following.

After the pulse braking display was presented (in true positive and false positive trials), the test participant was asked to indicate whether or not he or she noticed the display and, if so, rate the appropriateness of the pulse braking display as a rear-end collision avoidance system warning.

Analysis and Results

The same combinations of jerk rate and duration as in Study 1 were used in Study 2. Figure 3 presents 3-D bar charts indicating the number of test participants out of seven who reported noticing a specific pulse braking event. Data are presented separately for TP and FP trials. It can be seen that the number of reported detections generally increases with increasing jerk rate and duration. For FP trials, the number of reported detections is 7 of 7 for the four combinations of middle and high jerk rate and the middle and high duration. However, the reported number of detections is never higher than 5 out of 7 for similar display conditions in the TP trials. The reasons for this are unclear. In some cases, the test participant was more sensitive to the lead vehicle braking than the warning onset rule and braked in anticipation of the display onset. The display system was structured to display even if the test participant was already braking at warning onset. Thus, unless the test participant was braking beyond the magnitude programmed for the display, it is possible that he or she might still have noticed the display even though the test participant "anticipated" it somewhat in time. Examination of the number of anticipated braking responses in TP trials unfortunately revealed no systematic relationship between number of detections and number of anticipations.

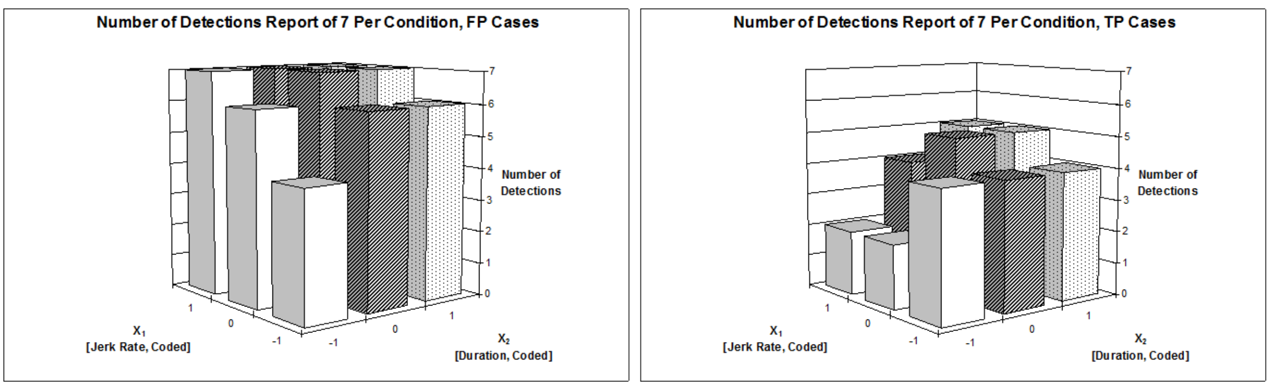

Figure 3. Monopulse Braking Event Detections out of 7 Participants, False Positive (FP) and True Positive (TP) conditions.

Analysis revealed no systematic effects of pulse braking display parameters on any of the measured variables such as total stopping distance, maximum pedal force, minimum time-to-contact, or maximum deceleration for TP trials. For FP trials, jerk rate reliably increased the speed difference from driver brake onset to release of the brake (average speed changes of 0.78, 0.98 and 3.17 kph from smallest to largest jerk rate). However, the largest average speed reduction was only 3.17 kph (about 2 mph), minor considering a nominal travel speed of 72 kph (45 mph). A similar trend in the effects of jerk rate on driver peak deceleration was also interpreted as minor.

CONCLUSIONS

The first parameter-setting study, conducted in the absence of a lead vehicle, uncovered an effect of haptic display parameters on subsequent driver braking behavior. In the presence of a decelerating lead vehicle, drivers appear to modulate their braking in response to it rather than pulse braking display parameters. On the other hand, unnecessary braking occurred on approximately one-third of false positive trials. Interestingly, 40% of these were from just one of the 7 test participants. Furthermore, such false positive braking actions were mild and brief. This suggests guarded optimism that haptic braking displays may be useful to drivers. Adaptive cruise control (ACC) with braking authority in fact presents haptic braking cues (though not pulse braking) to the driver in situations where maximum braking authority is reached and the driver must intervene. Further research is needed to more fully understand the effects (including driver acceptance) that such displays have on drivers, both singly and in combination with visual or auditory displays.

ACKNOWLEDGEMENTS

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REFERENCES

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