

Mitigating Heavy Truck Rear-End Crashes with the use of Rear-Lighting Countermeasures

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ABSTRACT

In 2006, there were approximately 23,500 rear-end crashes involving heavy trucks (i.e., gross vehicle weight greater than 4,536 kg). The Enhanced Rear Signaling (ERS) for Heavy Trucks project was developed by the Federal Motor Carrier Safety Administration (FMCSA) to investigate methods to reduce or mitigate those crashes where a heavy truck has been struck from behind by another vehicle. Visual warnings have been shown to be effective, assuming the following driver is looking directly at the warning display or has his/her eyes drawn to it. A visual warning can be placed where it is needed and it can be designed so that its meaning is nearly unambiguous. FMCSA contracted with the Virginia Tech Transportation Institute (VTTI) to investigate potential benefit of additional rear warning-light configurations as rear-end crash countermeasures for heavy trucks. This paper will describe the dynamic closed-track testing performed and overall countermeasure performance of two rear warning-light configurations as compared to the baseline brake lights. The key metric of effective performance was the rear warning-light configurations' ability to draw the following-vehicle driver's eye forward during an in-vehicle distraction task. Thirty participants were coached to maintain a following distance of approximately 120 ft (36.58 m) during multiple closed-track loops. Results indicated a strong trend for improved eye-drawing performance of both rear warning-light configurations over that of normal brake lights. The rear warning-light configurations had significantly better attention-getting ratings, as compared to baseline brake lights, while the participants were fixating either directly ahead or 30 deg off-axis. Participants gave discomfort glare ratings while (1) positioned directly behind the test trailer and fixating on the vehicles rear-lighting (i.e., acting as a

following vehicle) and (2) positioned in the adjacent lane and looking past the rear-lighting (i.e., acting as a passing vehicle). The results indicated that there were no significant differences in discomfort glare ratings for the two rear warning-light configurations and brake lights. The helpfulness and usefulness ratings showed that overall participants perceived both rear warning-light configurations positively. In conclusion, both rear warning-light configurations appear to be good candidates to move forward to the follow-on real-world data collection effort.

INTRODUCTION

In 2006, there were approximately 23,500 rear-end crashes involving heavy trucks (i.e., gross vehicle weight greater than 4,536 kg). Of these crashes, 135 resulted in fatalities and 1,603 resulted in incapacitating injuries [1]. The Enhanced Rear Signaling (ERS) for Heavy Trucks project was developed by the Federal Motor Carrier Safety Administration (FMCSA) to investigate methods to reduce or mitigate those crashes where a heavy truck has been struck from behind by another vehicle. This project investigated a variety of rear-end crash countermeasures which included passive conspicuity markings, visual signals, and auditory signals. The focus of this paper is the dynamic closed-track testing performed and overall countermeasure performance of two rear warning-light configurations as compared to the baseline brake lights.

BACKGROUND

Visual warnings have been shown to be effective, assuming the following driver is looking directly at the warning display or has his/her eyes drawn to it. A visual warning can be placed where it is needed and it can be designed so that its



meaning is nearly unambiguous. Based on these principles, researchers have found great promise in using enhanced rear signaling as a rear-end crash countermeasure. For many years, research involving light vehicles has been ongoing regarding how to use rear lighting to help prevent rear-end crashes[2, 3, 4]. This work was conducted by the National Highway Traffic Safety Administration (NHTSA) with Virginia Tech Transportation Institute (VTTI) serving as the prime research organization. More recently, rear-end crash avoidance research has shifted towards commercial trucking. General Dynamics and Freese Enterprises were involved the development of a prototype ERS system that incorporated countermeasures generated from a General Estimates System (GES) database analysis of heavy truck rear-end crashes [5, 6, 7, 8]. Each element of the prototype was evaluated and rated by 25 volunteers (licensed drivers) and by limited field testing (approximately 10 h on public roads). The evaluation of these countermeasures found potential benefits of using such countermeasures for heavy trucks. This project's ERS used both areas of research as a foundation for countermeasure development and test methodology. Namely, this project used lighting technology similar to that developed for light vehicles; multiple high-output LED units that flash simultaneously at a 5-Hz frequency as well as dynamic testing protocols. The purpose of all testing was to determine how well various rear-lighting configurations would provide improved eye-drawing capabilities of drivers in a following vehicle; thus, reducing the potential for rear-end crashes involving heavy trucks.

METHOD

STUDY DESIGN

The primary objective of this study was to assess the eye-drawing capability of rear-lighting configurations on the rear of a trailer. Three experimental conditions were investigated: baseline (normal brake lights), main bumper rear warning-light configuration, and main bumper combined with 12-light ICC bumper rear warning-light configuration. The normal brake lights were not activated in conjunction with the rear warning-lighting configurations. Performance results from the two rear warning-light configurations were analyzed in comparison to the baseline brake lighting.

The experimental paradigm was for the following driver to perform a secondary task while following the lead tractor trailer. The in-vehicle experimenter coached each driver to maintain the approximate target distance of 120 ft (36.58 m) behind the lead tractor trailer during each loop around the Virginia Smart Road, a 2.2 mile closed-test track. While maintaining a constant speed, the lead tractor trailer's brake lighting and rear warning-light configurations were independently activated at various points along the route. These points were preselected, and the brake lights and warning lights on the lead vehicle were activated both when

the following driver looked away from the forward view to attend to the secondary task as well as when the driver was looking forward. Rear-lighting configurations for these uninformed trials were treated as a between-subjects factor.

A total of 30 naïve drivers (no previous exposure to the lighting configurations) were tested to investigate trends in rear-lighting performance. Half of the participants were males and the other half were females. Candidate participants were screened over the phone with a verbal questionnaire to determine whether they were licensed drivers, were of the appropriate age, and whether they had any health concerns that might exclude them from participating. Individuals who participated in previous rear-signaling studies or other surprise event studies at VTTI were considered ineligible to participate. Approval for participant experimentation was given by the Virginia Tech IRB Human Assurances Committee. The age of participants ranged between 20 and 65 years old (mean of 39.27). Counterbalancing of two conditions was performed (i.e., gender and lighting configuration). Data was collected during the day from 8:30am EST to 5:00pm EST. Time of day was not considered in the counterbalancing; however, participants were randomly assigned to the available time slots in order to avoid potential sunlight angle bias.

This study collected both performance and opinion data. The time taken for a participant to redirect his/her gaze from the in-vehicle display to the forward roadway was measured and served as the main dependent measure. This measure was computed during video analysis using time stamp data. Other objective measures included were the time to accelerator release and the rate of change in accelerator position. The use of a between-subjects design was necessary because after each participant was exposed to the surprise event (uninformed event) re-exposure would not provide the same effect. Attention-getting and discomfort-glare rating scales were administered at multiple light-vehicle positions behind the tractor trailer to those participants who received the warning-light configuration and the normal brake light condition (32 participants in total). Helpfulness and usefulness ratings were administered to the 16 participants that received the rear warning-light configurations (not the baseline condition). These helpfulness and usefulness ratings were administered upon returning to the VTTI building at the completion of the study.

APPARATUS

Two warning-light configurations and one baseline configuration mounted on the rear of a tractor trailer were used during testing on the Smart Road. The prototype rear warning-light configurations were made up of 4 inch high-output LED units. Previous light-vehicle research by VTTI has shown that by ganging LED units together, eye-drawing performance is greatly improved [2]. Therefore, these two

Table 1. Preliminary Analysis of Vertical and Horizontal Aim of LED Units Using 6 deg Beam Width

Position on Trailer	Approximate Height Above Roadway	Vertical Aim Angle	Horizontal Aim Angle
Main bumper	45 in (114.3 cm)	2.64 deg upward	2.5 deg inward
ICC bumper (Sides)	22.5 in (57.15 cm)	3.75 deg upward	2.5 deg inward
ICC bumper (Center)	22.5 in (57.15 cm)	3.75 deg upward	0.0 deg inward
Lower unit on door	56 in (142.24 cm)	1.33 deg upward	2.5 deg inward
Middle unit on door	97 in (246.38 cm)	1.45 deg downward	2.5 deg inward

rear warning-light configurations contained LED units ganged closely together on the main bumper. Each high-output LED unit was aimed appropriately, both vertically and horizontally, according to the location on the back of the trailer (table 1).

The baseline lighting configuration was made up of two original equipment manufacturer (OEM) LED units already installed on the trailer. These three rear-lighting configurations are summarized as follows: (1) two LED-unit normally positioned brake light configuration [baseline condition] (figure 1); twelve high-output LED units ganged and positioned on main bumper (figure 2); and twelve high-output LED units ganged and positioned on main bumper combined with 12 high-output LED units positioned on the ICC bumper (figure 3).

During the experiment, participants drove a late model sedan directly behind the tractor trailer. Participants were instructed by the lead experimenter (sitting in the passenger seat) to follow along and complete in-vehicle tasks using the radio and navigation system. These tasks were intended to distract the participant's gaze away from the forward roadway. Tractor trailer rear-lighting activation was controlled by the lead experimenter in the passenger seat of the light vehicle. Upon activation of the rear warning-light configuration, only the rear-warning lights, and not the brake lights, would flash simultaneously at a 5-Hz frequency for a period of 5 s. Upon activation of the baseline configuration, only steady brake lighting (no simultaneous flashing), and not the rear-warning lighting, was initiated for a period of 5 s. Four camera views were recorded in the light vehicle by the DAS. A radar unit was installed on the rear of the trailer to provide data on following-vehicle closing rates and distances.

PROCEDURE

Upon arrival at VTTI, participants read and signed an initial information sheet and informed consent form. After all

questions were addressed, both the participant and lead experimenter signed the form. Next, participants were asked to show a valid driver's license and two brief vision tests were administered. The first vision test was a Snellen test to ensure that vision acuity was within the legal driving limit (corrected to 20/40).



Figure 1. Two LED-unit Steady Brake Light Configuration (Baseline Condition)



Figure 2. Twelve High-output LED-unit Ganged Main Bumper Configuration

Immediately following, the Ishihara Color Vision test was also administered. The experimenter recorded participants' ability to detect color, but it was not part of the eligibility criteria. No participants were dismissed due to ineligibility (all participants had sufficient vision).

After the screening session was complete, each participant was escorted to the sedan parked in front of the VTTI building. The participant was instructed to adjust the seating position and mirrors to a normal, comfortable, and safe position. As soon as the participant was ready, he/she were instructed to drive the light vehicle on to the Smart Road to the start position (as guided by the experimenter). Although participants were aware that they would be following a tractor trailer during the experiment, they were not aware that it was in any way associated with the in-vehicle display tasks to be performed. At the start position on the Smart Road, the light vehicle was positioned at the safe distance of 120 ft (36.58 m) directly behind the lead tractor trailer. While the sedan was parked, participants were instructed on the use of the controls and displays of the vehicle's standard navigation system. Once the participants were comfortable with use of

the controls, each was instructed to follow the lead heavy vehicle at the demonstrated safe distance of 120 ft (36.58 m) and to keep that distance at all times. Participants were provided feedback to help them maintain this approximate target distance. The lead heavy vehicle maintained a speed of approximately 25 mph (11.8 m/s) for safety reasons, which also allowed enough time for multiple tasks to be performed during each loop.



Figure 3. Twelve High-output LED Units Ganged and Positioned on Main Bumper Combined with Twelve High-output LED Units on ICC Bumper

Each participant drove a total of three loops around the Smart Road. The first loop consisted of a training loop only and any data collected were excluded from all analyses to follow. The second loop was a data-collection loop in which multiple tasks were performed by each participant. During this loop, there was only one event when both a rear-lighting configuration and a distraction task were initiated simultaneously. This occurred on the uphill portion of the Smart Road. The uphill portion of the Smart Road was used for events because it was much easier for a driver to maintain a certain speed and following distance. Immediately following this event, both vehicles were stopped and the