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Enhanced Rear Lighting and Signaling Systems
Project Final Report
Emphasizing Task 3 Results:
Test Road Experiment on Imminent-Warning Rear Lighting and Signaling

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16. Abstract

Task 3 of the Enhanced Rear Lighting and Signaling project was directed toward refinement and initial field testing of two “imminent-warning” signals. These signals are intended to direct the following driver’s visual glance to the lead vehicle as it brakes rapidly to a stop. The signals can also be used to warn of an impending rear-end crash. Task 3 consisted of a preliminary experiment and a main experiment. In the preliminary experiment, modifications to an alternating pair of lamps were tested in a static situation using human-factors experts. Results of the experiment indicated that use of greater drive voltage and kick voltage improved the attention-getting capability of the alternating pair. Results also showed that an alternating frequency of 4.0 Hz was optimal. Previously, the TCL (traffic clearing lamp) had been selected as the most promising imminent-warning signal. Consequently, in the main experiment, the TCL and the IAP (improved alternating pair) were compared to ordinary rear lighting.

The main experiment was conducted on the Virginia Smart Road in Blacksburg, Virginia, using a surrogate vehicle (drawn by a lead vehicle) containing conventional lighting and the two new, imminent-warning lighting configurations. Seventy-two ordinary drivers, split into three groups, participated. Driver subjects were purposely distracted by in-vehicle tasks as the lead (surrogate) vehicle underwent hard braking. Responses were compared for the conventional and two enhanced lighting groups. Results showed improvements in brake activation times of 0.25 to 0.35 seconds, corresponding to 15 to 30 feet (4.6 to 9.1 m) of additional stopping distance for the enhanced lighting. The TCL was just slightly better than the IAP. The results also demonstrate a learning effect between the first and second exposures, with braking performance improving with second exposure. Other measures suggested the eyes are drawn to the forward view more quickly with the enhanced lighting.

This report fully describes the experiments and results. It then recommends additional refinements and fleet testing because of the promise shown by the results thus far.

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ABSTRACT

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This report fully describes the experiments and results. It then recommends additional refinements and fleet testing because of the promise shown by the results thus far.

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The opinions expressed in this report are those of the authors and do not necessarily reflect the official positions of NHTSA or of any other organizations, or the opinions of other individuals, including those acknowledged on this page.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
CAMP	Crash Avoidance Metrics Partnership
CHMSL	Center High-Mounted Stop Lamp
CMOS	Complementary Metal-Oxide Semiconductor
CNV	Conventional Rear Lighting
IAP	Improved Alternating Pair
LED	Light Emitting Diode
LV	Lead Vehicle
NHTSA	National Highway Traffic Safety Administration
SNK	Student Newman-Keuls tests
TCL	Traffic Clearing Lamp
TVA	Time from the first view of the brake lights to accelerator release
TVB	Time from first view of the brake lights to brake activation
TVFS	Time from first view of the brake lights to a full stop
TVPB	Time from first view of the brake lights to peak braking
VTTI	Virginia Tech Transportation Institute

EXECUTIVE SUMMARY

Background

The Enhanced Rear Lighting and Signaling Project had three major tasks. The first involved information gathering and development of new rear-lighting concepts. Solicitation of expert opinions was included in Task 1. The second involved static testing of numerous selected concepts, using ordinary drivers and a flexible test rig. Based on the results of Task 2, both an imminent-warning signal and a stopped/slowly-moving signal were recommended. The imminent-warning signal was intended to warn the following driver of either hard braking by a lead vehicle or of an imminent rear-end crash. Task 3, which is reported in the current document, involved further static refinement of imminent-warning signals and subsequent controlled test-road evaluation of the signals.

At the completion of Task 2, a device called the Traffic Clearing Lamp (TCL) was recommended as an imminent-warning signal because it equaled or outperformed all other devices tested and was relatively simple. The TCL is a lamp with a motorized reflector that moves in an "M-sweep" pattern. However, the decision was made to test a second device as an imminent-warning signal so that the possibilities for success in field trials would be increased. The second device selected was an alternating pair of lamps that were separated by 15.7 cm (6.2 in.), measured from inner edge to inner edge. The device was then improved in the early phase of Task 3 and is subsequently referred to as the Improved Alternating Pair (IAP) in this report.

Task 3 Preliminary Experiment

A preliminary static, controlled experiment (described fully in the current document) was performed at the beginning of Task 3. Its purpose was to optimize the parameters of the alternating pair using a group of eight experts. The experimental results showed that the optimum frequency for the alternating pair was 4 Hz and that a lamp kick circuit was effective in increasing the attention-getting capability of the alternating pair by turning the lamps on with sharper rise-times. In addition, the "brightness" of the lamps could be increased by using a slightly higher drive voltage, which was used for both the TCL and the alternating pair. The final result was an improved alternating pair (referred to as IAP) with greater attention-getting capability. A comparison of the TCL and IAP by the experts indicated that the TCL remained superior but that the IAP had substantial attention-getting and peripheral-detection capabilities.

Task 3 Main Experiment

In the main experiment of Task 3, both the TCL and the IAP were tested by comparing them with ordinary rear lighting. In this experiment, performed on the Virginia Smart Road in Blacksburg, Virginia (an instrumented, closed roadway), 72 ordinary driver subjects were divided into three equal-sized groups. The first group received only conventional rear lighting (CNV), the second received both conventional lighting and the TCL (called the TCL group), and the third group received both conventional lighting and the IAP (called the IAP group). The lighting was installed in a surrogate vehicle made of fiberglass. The vehicle was essentially a lightweight trailer with a 40-foot (12.2-meter) collapsible boom, resembling the rear of a sedan.

It was designed to minimize damage to the following vehicle (driven by the driver subjects) in the event of an inadvertent collision. The trailer was pulled by a lead vehicle driven by a confederate experimenter. Power electronics for the lighting were installed in the trunk of the lead vehicle. Experimental runs took place during full daylight and good weather.

Initially, the driver subject was instructed to follow at a distance of 120 feet (36.6 m) and to maintain that distance at all times. The driver practiced this following distance procedure prior to being given any in-vehicle tasks to perform. Thereafter, the paradigm was to present a situation in which the driver subject was preoccupied with an in-vehicle task while the lead vehicle simultaneously performed a hard braking maneuver. There were two replications of this for each driver subject, the first being an "uninformed" exposure (in which there had been no previous explanation of the enhanced lighting) and the second being an "informed" exposure (in which the purpose of the enhanced rear lighting had been explained). Drivers in the CNV group received the same tasks and parallel instructions intended to minimize instructional biases. The two data-gathering events were embedded in a group of other in-vehicle tasks and low-level braking maneuvers so that driver subjects would not know when concurrent events involving an in-vehicle task and hard braking would occur.

The following vehicle, driven by the driver subject, was heavily instrumented. It included multi-channel video and numerous sensors, including forward-looking radar that measured the distance and closing rates to the surrogate vehicle. The experimenter sat in the front passenger's seat and gave instructions. The experimenter also provided a transmitted tone to the confederate experimenter in the lead vehicle when hard braking was to occur (during the two critical data gathering events). The experimenter gave the tone when the driver subject diverted his or her attention to perform the selected in-vehicle task. The tone was inaudible in the following vehicle and was sent secretly.

Task 3 Main Experiment Results

Following data gathering, data for the two critical events were extracted. Measures believed to be sensitive to driver reactions were extracted and analyzed statistically. Initially, all data were examined in a 3-condition (CNV/TCL/IAP) by 2-exposure (Uninformed/Informed) analysis. Thereafter, the data were treated in different ways to gain a better understanding of the results. In all, four groups of analyses were performed on the performance data, and additional analyses were performed on the opinion data.

Group I analyses of the performance data demonstrated an overall improvement for each of the two enhanced lighting conditions. Group I analyses did not take eye-glance position into account; thus, the results are general. Most importantly, brake response time and time to a full stop were shorter for these two conditions. The TCL appeared to produce slightly better results than did the IAP; however, the difference was not statistically significant. Other measures showed favorable results as well, and the descriptive statistics similarly pointed to improvements.

Later Group I analyses accounted for experimenter braking. There were 11 cases out of a possible 144 in which the experimenter had to brake to avoid a rear-end collision with the surrogate vehicle. These data were removed prior to statistical testing. The results were generally similar to those obtained earlier in Group I.

Group II analyses pre-selected the data based on driver eye position. These analyses were intended to examine cases in which the driver had an early glance to the forward view. Specifically, if the driver had a short glance forward within the first half second, the data were included. The results once again showed trends of improvement in brake response times and times to a full stop for the enhanced lighting. The results are applicable to the case in which the driver is looking at or near the lead vehicle.

Group III analyses investigated what happened when the drivers returned their glances to the forward view. Four new measures were evolved that evaluated the driver's response times once the driver looked forward. The results showed that times from first view to brake response and from first view to a full stop were shorter for the enhanced lighting. These results are in line with the earlier results.

The Group IV analyses used a single additional measure: time from brake-light activation to first forward glance. This analysis was intended to determine the eye-glance drawing effect of the enhanced lighting, if any. These analyses were carried out in two different ways to deal with drivers who were looking forward at the time that the brake lighting was activated. In the first analysis, "zeroes" were substituted for those subjects initially looking forward, and in the second analysis, subjects looking forward were deleted. Results demonstrated a substantial eye-glance drawing effect. In other words, the enhanced lighting caused the drivers to return their glances to the forward view more quickly, which largely explains how improvements seen in the earlier analyses in brake response times and stopping times were achieved.

The general impression of the results is that the enhanced lighting conditions improved driver responses by 0.25 to 0.35 seconds, corresponding to about 15 to 30 feet (4.6 to 9.1 m) of additional stopping distance, depending on speed and other aspects of the specific situation. The TCL generally produced slightly better mean values than the IAP, but the differences were small and never reached statistical significance.

The questionnaire data demonstrated that drivers "liked" the enhanced lighting and felt they could use it as an effective warning of heavy braking on the part of the lead vehicle. The responses were significantly different from responses that could be expected to occur at random (that is, having a uniform distribution). Drivers did not feel that the discomfort glare was too great. There was surprising agreement among drivers filling out the questionnaire, something rarely seen in behavioral and driver research. Those drivers receiving the TCL condition had responses very similar to those receiving the IAP condition.

Conclusions and Recommendations

This report contains a number of conclusions and recommendations. Foremost among the conclusions is that improvements in driver response times are possible with the enhanced lighting and that work in this area should continue, eventually resulting in fleet testing. For a typical situation, an analytical model shows that the enhanced lighting should result in 20 percent fewer rear-end crashes and that the remaining 80 percent should occur with lower severity (owing to the lower kinetic energy dissipation at the time of impact). The recommendations, briefly stated, are as follows:

- Design and develop a TCL kick circuit to improve initial startup.
- Develop generic specifications for the TCL.
- Review LED technology with the objective of converting the IAP to the use of LED arrays.
- Revise the open-loop activation/deactivation criteria to account for uphill/downhill situations, and increase timeout slightly.
- Raise the positions of the TCL and IAP in future studies and deployment so that these displays are near the "standard" CHMSL (center high-mounted stop lamp) position.
- Develop a dimming system for the enhanced lighting so it can be used at night while maintaining effectiveness.
- Begin planning for fleet deployment. Consider a follow-on project that piggybacks on other fleet studies currently in progress.
- Make a decision regarding open-loop deployment versus closed-loop deployment. If closed-loop deployment is pursued, develop a prototype vehicle that can be used to test algorithms.
- Consider the development of a supplementary auditory alarm system for the following vehicle. Such a system would be used as an adjunct to help re-alert drivers preoccupied with an in-vehicle task or other distraction.

Finally, the recommendation is made that further testing of the type completed under the Task 3 main experiment should not be pursued because of its great complexity. Rather, the testing should involve developmental refinements and should then be deployed in test-vehicle fleets.

INTRODUCTION TO THE TASK 3 EXPERIMENTS

Purpose

Task 3 was intended to determine whether imminent-warning rear-lighting signals improve the performance of inattentive drivers in car-following tasks, when the lead vehicle decelerates at a high rate. Two different imminent-warning signals were tested. Emphasis was placed on uninformed drivers: that is, drivers who had not seen or been exposed to an imminent-warning signal previously. Additional data were taken on a second (informed) exposure for purposes of comparison. The fundamental concept was to develop a realistic experimental scenario in which a distracted driver would be required to brake and to determine if the imminent-warning signals would redirect the driver's attention toward the lead vehicle more quickly. If so, it could be concluded that imminent-warning signals show promise in reducing the number and severity of rear-end crashes caused by the following-driver's inattention.

Background

Available crash data and law enforcement officer focus groups indicate that the majority of rear-end crashes are a result of inattentive drivers. Drivers may be looking away during the critical period just prior to the crash, or they may be looking but not seeing. Evidently, they do not perceive that the lead vehicle is decelerating or stopped. An imminent-warning signal is intended to provide a stimulus to the inattentive driver that heavy braking is probably required. Essentially, this signal is used to redirect the driver's attention to the lead vehicle. This Task 3 test was aimed at determining if such signals do, in fact, redirect the driver's attention and induce timelier braking.

The Task 3 test described in this report is the third experimental study in a series funded under NHTSA Contract DTNH 22-99-C-07235. Final reports for Tasks 1 and 2 are available (Lee, Wierwille, and Klauer, 2002; Wierwille, Lee, and DeHart, 2003) and should be read to obtain a full understanding of the justification and reasons for the Task 3 experiment. However, results of Task 1 and Task 2 are briefly summarized here for completeness.

Task 1 Brief Review

Task 1 had multiple objectives directed toward the eventual improvement of rear lighting and signaling of passenger vehicles, with the goal of reducing the number and severity of rear-end crashes. The task included an information-gathering phase and a development phase in which enhanced rear-lighting candidates were evolved. The information-gathering phase of the project included an extensive literature review, including patent and concept disclosure documents, crash statistic summary documents, and law enforcement officer focus groups. The information-gathering portion resulted in the following conclusions:

- Rear-end crashes are the most frequently occurring type of crash, representing approximately one-fourth of all crashes.

- Lead-vehicle-stopped crashes are the most common type of rear-end crashes.
- The majority of rear-end crashes occur in daylight under good weather conditions.
- Inattention, distraction, and following too closely are the most commonly cited causes of rear-end crashes.
- There are a multitude of ideas for enhanced rear-lighting systems.
- Many of the ideas are similar, contain overlapping features, and often do not address what is known about rear-end crashes.
- Human factors methods for capturing attention in a visual warning signal include the use of flashing, apparent motion, size, color contrast, and luminance contrast.

After the information-gathering phase, a trade study was performed using an expert group. The group included automotive lighting and vision experts from vehicle manufacturers, lighting equipment manufacturers, and academia. Using e-mail questionnaires, they first selected from among criteria on which rear lighting candidates should be judged. They also submitted suggestions for candidate lighting configurations. In addition, the research team developed candidates for the expert group to judge, since most of the ideas submitted were not well developed.

The research team developed five closed-loop candidates and three open-loop candidates. Closed-loop here refers to the use of radar, laser, or other technology to obtain measures of range and, possibly, range rate and angle between vehicles. This information is then used along with "own vehicle" sensor measurements to activate the rear-lighting display in a timely manner, thereby warning the following driver of an impending collision. Open-loop refers to the use of "own-vehicle" parameters only, such as braking, deceleration, or standing.

The experts rated the eight configurations using a Kepner-Tregoe trade study technique. The top three configurations were then recommended for experimental study in Task 2. These configurations included the following:

- *Closed-loop, radar-activated horizontal array of lights*. This design used eight lamps in a horizontal row across the back of the vehicle that would be illuminated sequentially from center outward to each side.
- *Open-loop, horizontal array of lights*. This design used the same lighting configuration as the closed-loop, radar-activated horizontal array of lights but triggered it based on lead-vehicle parameters only.
- *Closed-loop, high-intensity strobe lights*. This concept used a set of four strobe lamps: two on each side of the rear end of the vehicle. The two inner strobes would flash, followed by the two outer strobes.

In all the above cases, the configurations would repeat their outputs until impending crash conditions were no longer present.

The revised final report included statements indicating that experimental studies should include those configurations listed above, as well as simpler configurations. Several reviewers suggested that the three recommended configurations would meet with resistance on the basis of complexity alone, and therefore, simpler configurations should also be included in any testing.

Task 2 Brief Review

In this task, researchers at the Virginia Tech Transportation Institute conducted two experiments in an effort to develop systems that are potentially more attention-getting in the forward field of view and that can be seen further into the peripheral field of view, with an acceptable amount of discomfort glare. Both experiments used the same four dependent measures: Attention-Getting Rating, Discomfort-Glare Rating, Horizontal Peripheral Detection Angle, and Diagonal Peripheral Detection Angle.

Experiment 1 of Task 2 compared 17 different rear-lighting configurations using a mixed-factors design. There were three independent variables: gender and age group (between-subjects), each with two levels, and configuration (within-subject), with 17 levels. There were participants: 6 younger (21 to 28) and 6 older (59 to 70), with each age group balanced for gender. These two age groups were expected to represent the extremes of expected reaction time (based on previous research). If these groups could be accommodated by the enhanced rear signaling, it was expected that the middle-age group would similarly be accommodated. The 17 configurations covered the gamut from simple to complex, including several devices believed by the research team to be highly attention-getting. The 17 configurations were variants of the recommendations from Task 1 of the project (horizontal array, strobes, and additional simpler systems) as well as baseline systems (constant on, flashing, and single/dual devices). This initial experiment was conducted using white lights and clear lenses to provide a consistent comparison across all configurations.

The Experiment 1 results showed that the so-called Traffic Clearing Lamp (TCL), a lamp with a motorized reflector that moves in an "M-sweep" pattern (Figures 1 and 2), was the top candidate for an imminent-warning signal (e.g., for imminent crash warning), while a pair of centrally located alternating halogen lamps would be optimal for a stopped/slowly-moving vehicle signal. These conclusions were based on an analysis of all available data, including comparisons within configuration classes (e.g., all strobe lamps compared to one another) and comparisons of system complexity.

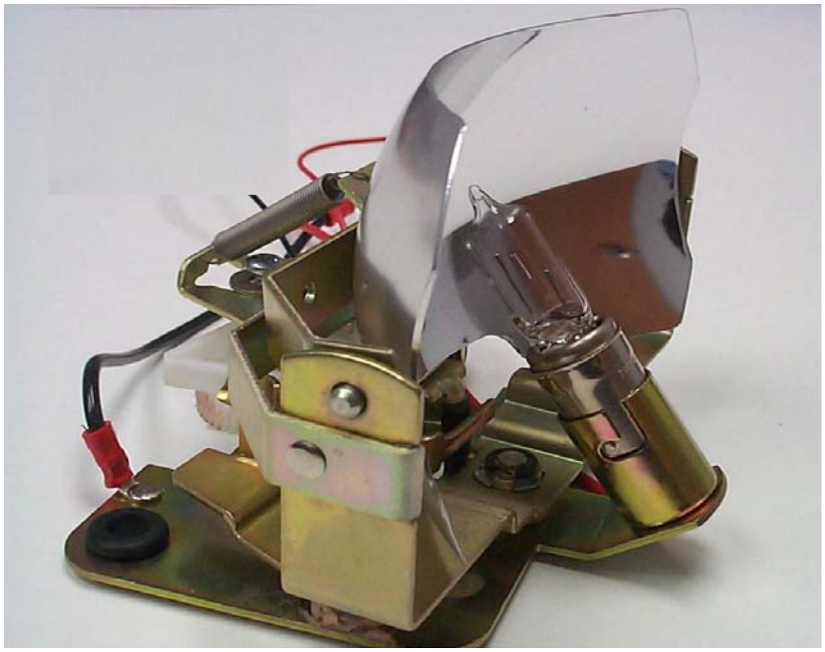

Figure 1. The TCL unit showing its bulb, reflector, and part of the reflector movement mechanism. The unit is 4.7 in. (11.9 cm) wide, 3.7 in. (8.8 cm) high, and 3.8 in. (9.6 cm) deep.

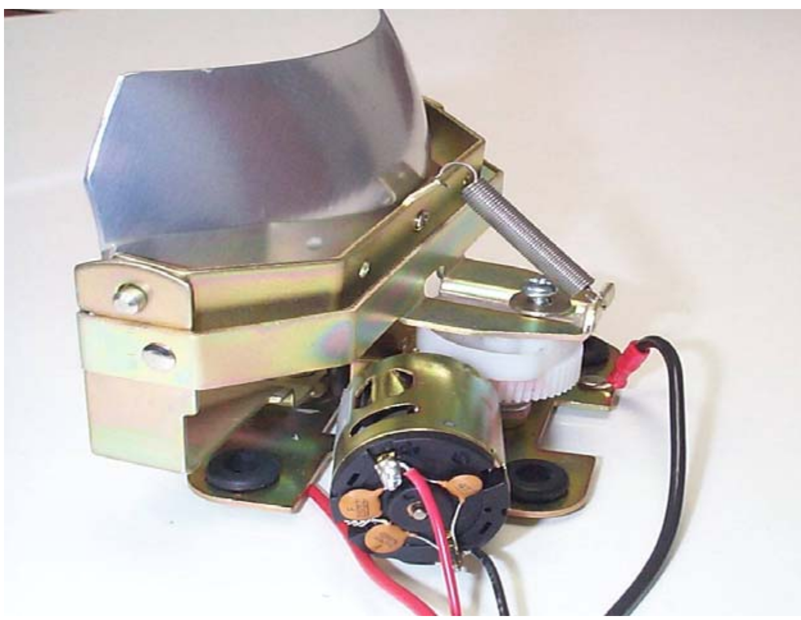

Figure 2. The TCL unit showing its drive motor, part of the reflector movement mechanism, and back of the reflector.

Experiment 2 of Task 2 also used a mixed-factors design. There were four independent variables: gender and age group (between-subjects), each with two levels; configuration (within-subject), with 4 levels; and lens tint (within-subject), with three levels. There were 12 participants: 6 younger (ages 20 to 28) and 6 older (ages 53 to 63), with each age group balanced for gender. The configurations tested included the TCL with a non-dispersive lens, a medium-output halogen alternating lamp pair with dispersive lenses, a medium-output halogen alternating lamp pair with non-dispersive lenses, and a high-output halogen alternating pair with dispersive lenses. Each of the four configurations was tested with lenses in three different tints: clear, amber, and red.

The Experiment 2 results showed that the TCL is superior to the alternating pair configurations in attention-getting and peripheral detection; however, it possesses somewhat higher levels of discomfort glare, a shortcoming that can be offset to some degree by the use of tinted lenses in either red or amber. The results also suggested that the high-output halogen alternating pair with dispersive lenses represented the best available configuration for the stopped/slowly-moving vehicle signal. Once again, either amber or red appears satisfactory for use in a modified rear-lighting system.

The final system recommendation as provided in the Task 2 report is for an additional (to the rear-lighting system as it currently exists) three-lamp bar to be mounted somewhere below the CHMSL (either directly below in the trunk lid, or midway between the bumper and the CHMSL). The center lamp would be the imminent-warning signal and would consist of the TCL. The outside signal pair would be the stopped/slowly-moving vehicle signal and would consist of the high-output halogen alternating pair. The TCL would use a non-dispersive lens in red (red was chosen mainly for the sake of consistency in the need for heavy braking). The alternating pair would use dispersive lenses in amber (the overriding consideration for the selection of amber is that the signal is cautionary).

The Task 2 report also contained a lengthy appendix presenting the algorithms to be used for the activation of each signal type. The combination of these two elements offered a complete specification for a promising rear-signaling system, developing it to the point of readiness for further system development and field or fleet testing.

Ramifications of the Task 1 and Task 2 results for Task 3

Reviewers of the Task 2 document were in agreement that the results for the TCL clearly indicated it should be the leading candidate for the imminent-warning (braking) signal. It had superior characteristics and ratings. However, they expressed concern that the device might meet with resistance on the part of some stakeholders because, even though it is quite simple, it uses an electromechanical drive system to move the mirror in an M-sweep pattern.

There was also a question concerning whether a stopped/slowly-moving vehicle signal was really necessary. For example, wouldn't the imminent-warning signal catch the most serious situations? If so, then efforts in Task 3 would best be directed at further testing of imminent-warning signal candidates only. The suggestion was made that there should be a second candidate for the imminent-warning signal so that "all the eggs were not in one basket." Furthermore, the second candidate should be one with no electromechanical components that remains relatively simple to implement.

After some discussion, it was agreed that the alternating pair, which had formerly been viewed as a stopped/slowly-moving vehicle signal, should be considered as a viable alternative for the imminent-warning signal. The device has the advantage of being composed of two lamps, spaced perhaps 15 to 20 cm apart. The lamps are conventional, but they are high-output and could be combined in a three-lamp set, in which the center lamp is the present-day CHMSL. Such a configuration would likely meet with little resistance from manufacturers and other stakeholders, provided a safety benefit could be demonstrated. In addition, the alternating pair might be implemented in the future using LED arrays. (At the time that Task 2 was undertaken, LEDs did not have the necessary luminance output to compete with the high-output halogen alternating pair.)

However, if implemented as an imminent-warning braking signal, the alternating pair would require some modifications. First, since the imminent-warning signal is viewed primarily as a braking signal, it should use red lenses. Furthermore, the attention-getting capability of the alternating pair would need to be improved since earlier tests showed it was not as effective as the TCL. Thus, in Task 3, some effort would need to be devoted to enhancements of the alternating pair prior to main experiment testing. Proposed enhancements were examined in a preliminary experiment that is described in this report.

Test Procedure Concepts for Task 3

Task 3 involved two important experimental aspects, as per previous discussions:

- The development of potential improvements in the alternating-pair imminent-warning rear-lighting signal and the testing of these potential improvements in a preliminary experiment. The main purpose of the preliminary experiment was to identify the alternating-pair configuration with the greatest potential for success as an imminent-warning rear-lighting signal.

- The examination of the TCL and the improved alternating pair (IAP) in a realistic experimental scenario in which drivers were distracted while a lead vehicle began heavy braking. The goal of the main experiment was to determine if the imminent-warning lighting signals showed promise in redirecting the following driver's attention to the lead vehicle. If so, the signal(s) could be considered a viable means of reducing the number and severity of rear-end crashes. Of course, further field or fleet testing would be required to fully demonstrate effectiveness.

This report first describes the preliminary experiment and its results. Thereafter, it describes the main experiment and its results. Conclusions and recommendations are then provided.

DESCRIPTION OF THE PRELIMINARY EXPERIMENT

As explained in the introduction, the two imminent-warning signals tested in the main experiment for Task 3 were the TCL (traffic clearing lamp) and the IAP (improved alternating pair). The alternating pair was added because there was concern among experts that the TCL relied on the mechanical movement of the parabolic mirror. The concern was that such a device might incur resistance from various stakeholders, even though the device was shown to be superior to all other configurations tested in the Task 2 experiment and was also relatively simple.

The alternating pair was selected because it had a reasonable "footprint"; it could be driven electronically, and it provided a relatively unique pattern. If red lenses are used, the only known competing similar signal is the stationary railroad-crossing signal. This signal, because of its placement and surroundings, would not likely be confused with an alternating pair at the back of a vehicle. (Some emergency vehicles also use an alternating pair, but they generally use blue, amber, or clear lenses. There may be a few cases in which red lenses are used, but other characteristics, such as the use of sirens, spacing, and vehicle size, generally make this case easily distinguishable from the back of an automobile.)

The alternating pair was recommended in Task 2 as a stopped/slowly-moving vehicle signal—not as an imminent-warning braking signal. It was selected in Task 2 for the stopped/slowly-moving vehicle signal because of its simplicity and because it possessed the appropriate combination of attention getting, discomfort glare, diagonal peripheral detection, and horizontal peripheral detection for a stopped/slowly-moving signal application. Because the alternating pair was now to be used as an imminent-warning signal, it was deemed desirable to re-optimize it prior to use in the Task 3 main experiment. The goal was to increase the attention-getting aspects of the signal at the possible expense of increased discomfort glare. Since the signal would be used sparingly in its new application, attention getting was considered to be of primary importance. Reasons for this are discussed in the Task 2 report.

The alternating pair recommended at the end of Task 2 used dispersive lenses and high-output halogen lamps. The alternating frequency was 2 Hz, and the lenses were spaced approximately 16 cm (6.29 in.) apart (measured inner edge to inner edge of lenses). Table 14 of the Task 2 final report contains the specifications for this alternating pair. Note, however, that lens tint was changed to red for an imminent-warning braking signal. The characteristics of the imminent-warning red dispersive lens are shown in Appendix A of this report (taken from Appendix E of the Task 2 report).

Proposed modifications for use as an imminent-warning signal

Four modifications were proposed for the alternating pair to increase the attention-getting characteristics. One was deemed appropriate simply by design, and the other three were tested in a preliminary experiment. The four modifications are described below:

1. *Increased voltage to the lamp*. In all of the Task 1 and Task 2 experiments, all lamps were driven at 13.7 to 13.8 volts. Great care was exercised to ensure that these voltages were used in all of the tests so that fair comparisons could be made across configurations and so that the tests could be replicated. Because lamp output increases with excitation voltage, a small increase in voltage can provide a modest increase in lamp output. Thus, the decision was made to increase the excitation voltage to the alternating pair in an attempt to achieve greater output. Such a voltage should be attainable by using heavier electrical leads or a small boost circuit, if necessary. Bulb life might be shortened slightly, but not by much, because of the 50-percent duty cycle of each lamp. The decision to use the higher voltage was made without experimental study because earlier tests on the lamps verified the increased output.

2. *Optimized alternating frequency*. The tests that were performed on alternating pairs during both Task 1 and Task 2 were performed at an alternating frequency of 2.0 Hz, as previously mentioned. While 2.0 Hz may have been an appropriate frequency, there was the possibility that another frequency might provide improved attention-getting capabilities. Thus, it was considered to be important to determine the "best" frequency in terms of attention getting. Based on the human factors literature, it appeared that the frequency should be made adjustable from 1.0 to 10 Hz and that this range should be tested.

3. *Kick (turn-on) circuit*. Incandescent lamps have filaments that require time to reach a "white-hot," steady-state temperature. There is a short interval after voltage is applied before the bulb reaches steady-state light output. One way to greatly shorten this turn-on interval is to use a boost, or kick, circuit that supplies a higher initial voltage to the bulb and then reduces the voltage to the usual level when the filament reaches the correct temperature. A special circuit was designed to provide this boost. At the beginning of each turn-on interval, the circuit initially applied 26 volts to the filament and then quickly tapered the voltage down to 14.8 volts (that is, the new voltage described in the first modification discussed above). The effect was to reduce lamp turn-on time to about one-third of its original value. Visually, the effect is that of a much sharper or crisper turn-on. Some late-model high-end vehicles use LEDs (light-emitting diodes) for stop lamps. Such lamps turn on virtually instantaneously. However, the brightness (at the time the experiment was planned) was not as great as some of the incandescent lamps tested in Task 2. Eventually, LED arrays should have sufficient brightness to replace the high-output incandescent lamps. The kick circuit was designed to take advantage of any increased attention-getting capability that rapid turn-on might provide.

4. *Startup filament pre-heat circuit*. Incandescent lamps have highly nonlinear resistance as a function of steady-state applied voltage. In the case of the high-output lamps used in the Task 3 experiment, bulb resistance was measured in steady-state conditions and was found to vary from 0.25 ohm when cold to 3.25 ohms when at full voltage. This nonlinearity places stress on all power-supply components when the bulb is initially switched on, usually resulting in an instantaneous reduction in voltage applied to the lamp. For the alternating pair, cold filaments are only a problem on the "first pulse" for each lamp. After that the lamp filaments remain sufficiently heated so that power

supplies can deliver full, applied voltage. Therefore, a circuit was designed that would warm the filaments at a low voltage: one that produced no visible light but would heat the lamps into the infrared output region. The circuit was only active in standby and was switched out when the alternating pair began flashing. The effect was to make the first output flash of each lamp in the pair a full-intensity flash: that is, the same as all following flashes.

Questions to be answered by the preliminary testing

Since the first modification involved increasing the lamp output and was known to produce additional "brightness," it did not need to be tested. In regard to the second modification involving frequency adjustment, it was not known if a better frequency than 2.0 Hz. existed. Similarly, the effectiveness of the third and fourth modifications was unknown. Since these modifications increased the complexity of the alternating pair, it was considered important to include them in the main experiment only if they appeared promising in increasing attention-getting capability. Thus, there were three questions to be answered by the preliminary testing, as follows:

- What is the best frequency for the alternating pair?
- Is the kick circuit an effective addition to the alternating pair?
- Is the startup preheat circuit an effective addition to the alternating pair?

In answering these questions, the possibility of an interaction had to be taken into account. In this case, interaction refers to the potential for the answer to one question to influence the answer of another. For example, preheat might only be effective when using the kick circuit. The preliminary experiment accounted for interactions by testing all combinations of kick/no kick and preheat/no preheat.

Design of the preliminary experiment

The preliminary experiment was set up to obtain answers rapidly, since its purpose was to set conditions for the main experiment. Thus, procedures were somewhat less formal than usual, and experts were used to make judgments. Nevertheless, care was taken to avoid bias in the data to the greatest extent possible.

The experts used in this experiment were professionals practicing in the human factors discipline who earned master's degrees or higher. All were currently working in transportation research at VTTI. These individuals observed the alternating pair (and the TCL) as implemented in a surrogate vehicle (to be described) and provided opinions/comparisons of conditions as they were presented. Tests were performed in a static, outdoor situation under bright daylight conditions. The test conditions were explained to the experts so that they would know what to expect. They could then judge whether or not the change made an appreciable enhancement to the capability of the alternating pair. The idea was that if experts did not feel that the modification produced an appreciable enhancement (when explained to them), then ordinary drivers would also not find an appreciable enhancement. In that case, the modification would not be implemented in the main experiment.

Eight experts participated. They were divided into two groups of four. Each expert in the first group began with an initial alternating frequency of 2.0 Hz. The expert then compared the alternating pair with and without the kick circuit in use. Thereafter, the expert compared the alternating pair with and without startup preheat. After these two comparisons, the expert compared the alternating pair with and without the combination of kick circuit and startup preheat. Conditions were then repeated for any comparisons the expert requested until the expert felt comfortable in making comparison judgments. Usually, this procedure involved several more presentations of the various configurations. The characteristics of the various combinations of preheat, kick, and baseline were explained to the subjects using Figures 3 through 6.

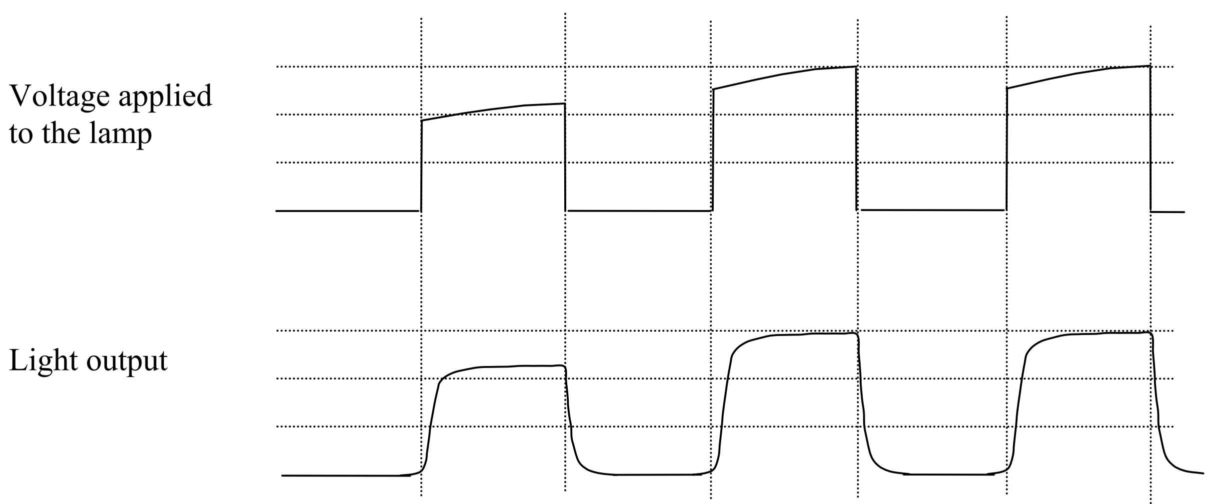

Figure 3. Waveforms of <u>Baseline</u> Alternating Pair.

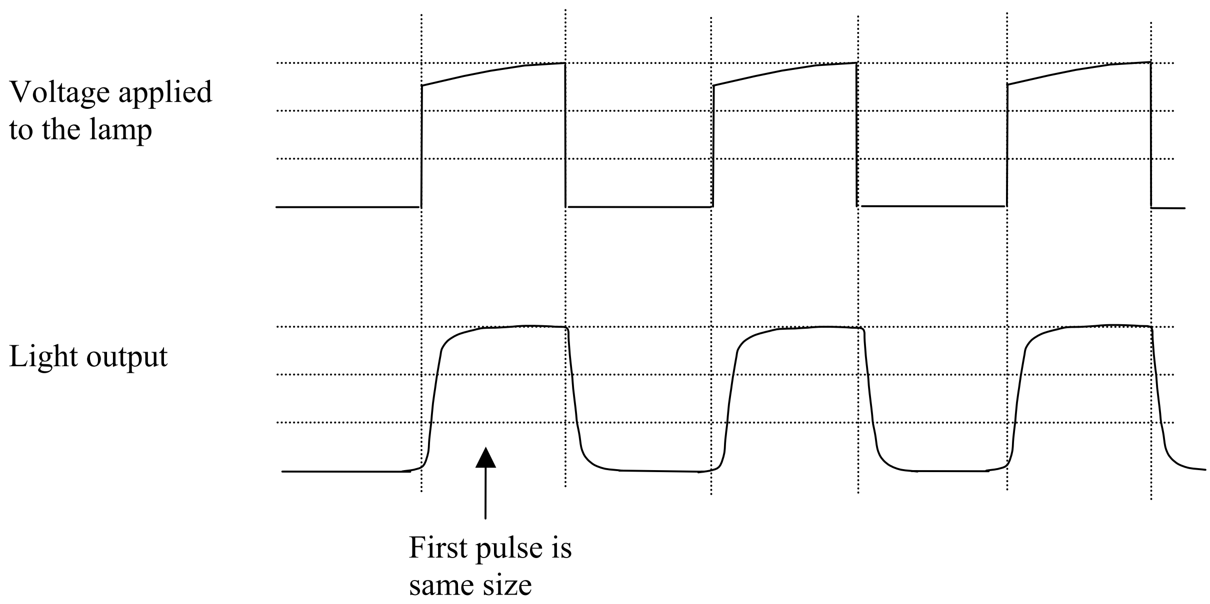

Figure 4. Waveforms of Preheat Alternating Pair.

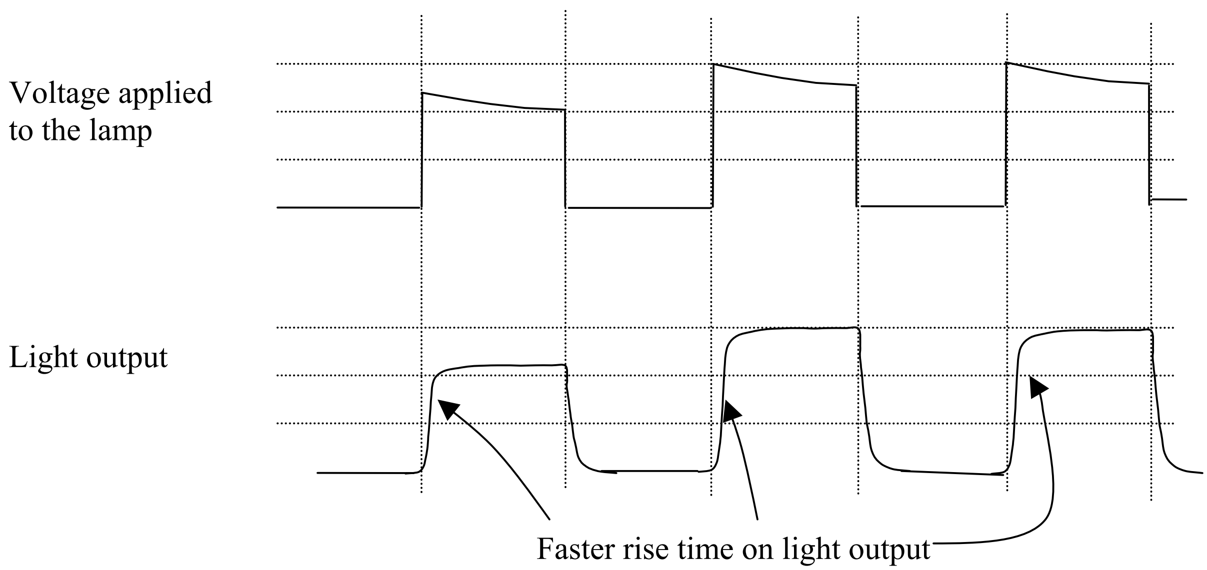

Figure 5. Waveforms with Kick Circuit.

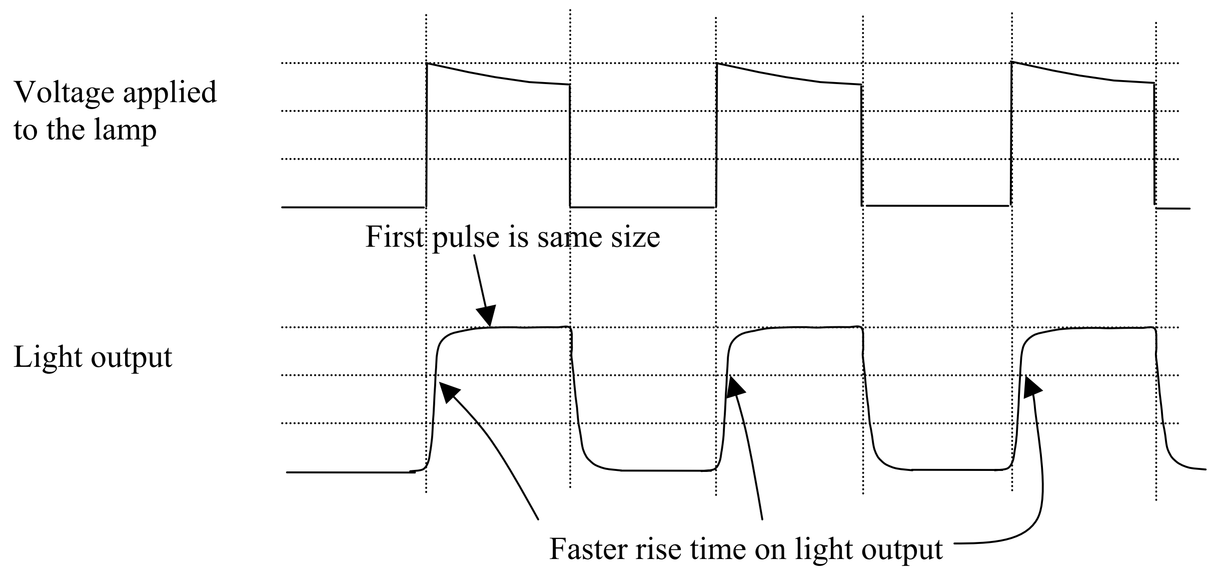

Figure 6. Waveforms with <u>Preheat</u> and <u>Kick</u> Circuit.

Each expert rank-ordered the four possible combinations of kick/no kick and startup preheat/no startup preheat. Ties were permitted. After rank ordering, each expert judged the "distance" between the *untied* ranks by one of the following descriptors: miniscule, slight, modest, or substantial.

After each expert had ranked the configurations, the top-ranked configuration was further tested in regard to best frequency. If the top ranking involved a tie, the simpler/simplest configuration was selected. Alternating ascending and descending trials were then used in this part of the testing. Two of the four experts began at 10 Hz and gave instructions to experimenters to adjust the frequency until they were satisfied that the best frequency had been found. They then repeated the test, starting at 1 Hz. If the results agreed within 1.0 Hz, then the average of the results for the two trials was used. Otherwise, the tests were repeated. The other two experts in the group of four began at 1 Hz in ascending trials, followed by 10 Hz in descending trials.

The second group of four experts followed exactly the same procedure, except that the initial frequency of the alternating pair was 5 Hz. They performed all their comparisons (involving kick circuit and startup preheat) at this frequency. Thereafter, they provided opinions on the "best" frequency, using the same ascending/descending trial procedure: that is, beginning at 1 and 10 Hz, respectively.

In the final phase of testing, each expert determined both the horizontal and diagonal peripheral detection limits of the expert's own final alternating-pair configuration as well as those of the TCL. The order of presentation was counterbalanced with odd-numbered experts receiving the alternating pair first, while even-numbered experts received the TCL first. Horizontal detection was always tested first. Detection limits were determined using procedures similar to those used in Task 2. The experts also provided a final attention-getting rating for their alternating pair configurations and for the TCL. Order of presentation was the same as for the peripheral detection tests, but repeats were permitted when requested by the expert.

Test Conditions

To the extent possible, test conditions mimicked those used during Tasks 1 and 2. As mentioned, testing was performed on days with bright or hazy sun and distinct shadows. Each expert sat in a vehicle and observed the rear of the surrogate vehicle at an eye distance of 150 feet (45.7 m). (The surrogate vehicle will be described in detail in the later sections that discuss the main experiment. For explanatory purposes here, the surrogate was a shell resembling the rear of a Ford Taurus containing both the TCL and the alternating pair. The lighting parameters for the alternating pair were adjustable.)

The sun angle was such that the sun was to the right, and the shadow was cast to the left of the research vehicle. Tests were run from 10 a.m. to 3:30 p.m. in November. Sun angles ranged from 35° (from the longitudinal axis of the observation vehicle) to 115°. These angles are the *projected* angles. If one adds 180° to these values, one has the shadow projection angle of a vertical rod. Again, these conditions were very similar to those used during the earlier testing. Testing was usually completed in about 45 minutes.

RESULTS OF THE PRELIMINARY EXPERIMENT

Ranking of Alternating Pair Configurations

The main purpose in ranking the four possible configurations was to determine which modifications improved rated attention getting, and by approximately how much. Two types of analyses were carried out: the first was intended to provide general information on how the configurations compared. It was based on assigned numerical values. The second was intended to determine the statistical reliability of any differences found. The two analyses were carried out separately.

General comparison

For this comparison, a re-ranking technique was used that placed numerical values on the difference descriptors the experts provided between ranks. Table 1 shows the rankings of the eight experts, along with the descriptors used between rankings. For example, expert 1 gave the kick and preheat-plus-kick tied first-place rankings. Preheat alone was given a second-place ranking, and baseline was given a third-place ranking. This expert also ranked the difference between the first- and second-place ranks as miniscule and between the second and third-place ranks as modest. In performing the re-ranking, first place was given a zero. The second place ranking was given a value based on numerical values assigned to the descriptors. Miniscule was given a value of 1, slight a value of 2, modest a value of 3, and substantial a value of 4. For the first expert, the second rank was thus set at a value of 1. Similarly, since the difference between second and third rank was considered modest, the value of 3 was added to 1 to get a value of 4 for this rank. Thus, new ranks were developed that took into account the experts' ranking of differences. Table 1 shows these re-ranked scores for each expert.

Each of the four configurations was then tallied for the total number of points it accrued across the eight experts. The results appear at the bottom of Table 1. As can be seen, kick-plus-preheat received the best ranking since it was always ranked at the top or tied for the top position. It was closely followed by kick alone. Preheat alone and baseline were ranked much lower. Therefore, the results suggest that either the kick-plus-preheat or the kick-alone configurations are highly ranked among the experts and that neither the preheat alone nor the baseline is as good in the experts' collective opinion.

Table 1. Rankings by the experts and assigned re-rankings.

Expert	System	Rank	Ties/Differences	Re-rank
1	Kick	1	Tie	0
	Preheat & Kick	1	Miniscule	0
	Preheat	2	Modest	1
	Baseline	3		4
2	Preheat & Kick	1	Minuscule	0
	Kick	2	Substantial	1
	Preheat	3	Tie	5
	Baseline	3		5
3	Baseline	1	Tie	0
	Preheat	1	Tie	0
	Kick	1	Tie	0
	Preheat & Kick	1		0
4	Preheat & Kick	1	Slight	0
	Kick	2	Modest	2
	Preheat	3	Substantial	5
	Baseline	4		9
5	Preheat & Kick	1	Slight	0
	Kick	2	Modest	2
	Preheat	3	Modest	5
	Baseline	4		8
6	Preheat & Kick	1	Tie	0
	Kick	1	Modest	0
	Preheat	2	Tie	3
	Baseline	2		3
7	Preheat & Kick	1	Tie	0
	Kick	1	Slight	0
	Preheat	2	Slight	2
	Baseline	3		4
8	Preheat & Kick	1	Tie	0
	Kick	1	Modest	0
	Preheat	2	Tie	3
	Baseline	2		3

Key for re-rank differences:

miniscule → 1
slight → 2
modest → 3
substantial → 4

Re-rank totals:

Preheat & kick	0
Kick	5
Preheat	24
Baseline	36

Statistical comparison

For this comparison, the data were again re-ranked, this time in a form suitable for a Friedman two-way analysis of variance (a nonparametric test). Table 2 shows the re-ranking for the test. Specifically, ties were given the average value of the ranks they would otherwise hold. For example, if two conditions were tied for first place, they would each receive a value of 1.5 (the average of first and second place.) The results of the Friedman test demonstrated that there was a statistically significant difference in the rankings for the four alternating-pair configurations ($\chi^2 = 19.4625$, $p < 0.001$).

Table 2. Expert rankings prepared for Friedman two-way analysis of variance.

	Condition			
Expert	**Baseline**	**Preheat**	**Kick**	**Kick & Preheat**
1	4.0	3.0	1.5	1.5
2	3.5	3.5	2.0	1.0
3	2.5	2.5	2.5	2.5
4	4.0	3.0	2.0	1.0
5	4.0	3.0	2.0	1.0
6	3.5	3.5	1.5	1.5
7	4.0	3.0	1.5	1.5
8	3.5	3.5	1.5	1.5

Sign tests were then used to determine where reliable differences existed among the conditions. There was no reliable difference between kick and kick-plus-preheat ($p > 0.05$). However, there were reliable differences between kick and preheat ($p < 0.008$) and between kick and baseline ($p < 0.008$). Additional sign tests are possible but do not add to the conclusions: namely, that the kick and kick-plus-preheat conditions are superior to the preheat and baseline conditions.

The results of the general and statistical tests are in agreement, demonstrating that either the kick or kick-plus-preheat conditions represent the best configurations. Considering that a statistically reliable improvement does not exist for the kick-plus-preheat condition (over the kick alone) and that adding preheat is a complication, it would seem that the kick (alone) condition provides the most cost-effective solution for improving the alternating pair.

Determination of the Alternating Pair Frequency

Table 3 shows the final frequency selected by each expert during the frequency optimization tests. Experts were permitted to select integral values or midpoints between integral values. The results show that there is a relatively tight clustering and that the median value is 4.0 Hz. The mean and median are in close agreement, also suggesting that the best frequency for the alternating pair is 4.0 Hz.

Table 3. Chosen frequency of the alternating pair by each expert.

Expert	Selected Final Frequency (Hz)
1	4.0
2	4.0
3	3.0
4	2.5
5	4.0
6	5.5
7	4.5
8	4.0
Mean:	**3.9**
Median:	**4.0**

Peripheral Detection Capabilities

The maximum peripheral detection angles are shown in Table 4 for both the alternating pair and the TCL. In this table, it is important to understand that the alternating-pair results are for the individual expert's optimized configuration and frequency. Thus, there could be small changes in the results if each expert who did not choose 4.0 Hz were to be retested with the "group-optimized" 4.0 Hz configuration.

Table 4. Results of the peripheral detection and attention-getting ratings tests.

	Alternating Pair			TCL		
Expert	Horiz (deg)	Diag (deg)	Att.-Getting Rating	Horiz (deg)	Diag (deg)	Att.-Getting Rating
1	50	30	5.5	90	40	6.0
2	90	30	5.0	90	70	8.0
3	60	20	7.0	90	45	8.0
4	50	20	6.0	90	45	7.5
5	55	30	6.0	80	50	7.0
6	85	55	5.0	90	70	6.0
7	85	45	6.0	90	50	6.5
8	30	10	6.0	90	45	7.0
Mean:	**63.1**	**30.0**	**5.8**	**88.8**	**51.9**	**7.0**

The results show that the peripheral detection capabilities of the alternating pair still lag behind those of the TCL. For horizontal peripheral detection, a paired T-test revealed a significant result (t =3.43, $p = 0.011$). Similarly, for diagonal detection, a T-test revealed a significant result (t = 5.18, $p = 0.0013$). As the table shows, the TCL has better than a 25° advantage in horizontal peripheral detection and better than a 21° advantage in diagonal detection. These results suggest that the TCL should be able to recapture the driver's attention more often than even the optimized alternating pair. Nevertheless, the alternating pair does have substantial peripheral detection capability during daytime conditions: probably much greater than ordinary vehicle rear stop lights.

Attention-Getting Ratings

The attention-getting ratings of the experts also appear in Table 4 for both the individual expert-optimized alternating pair and for the TCL. A paired T-test run on the ratings demonstrated a significant effect (t = 4.20, $p = 0.004$). Here again, the TCL demonstrates an advantage in attention getting, with a mean rating that is 1.2 rating points higher.

Comparison of Results with Similar Task 2 Results

Testing during Task 2 included configurations that were similar to those used in this Task 3 preliminary experiment. By comparing, one can get an indication of whether or not the optimized alternating pair offers any improvement. In addition, the TCL was driven by a higher voltage in the Task 3 experiment, so it is possible to see if this has any effect. Of course, several circumstances were different, including the use of experts in Task 3, the use of a different vehicle by the experts, and the use of the surrogate vehicle as opposed to the lighting board used for Task 2. Still, the comparison seems desirable.

Table 5 summarizes the comparable results for the two experiments. The Task 2 data are taken from Figures 55, 61, and 64 of the Task 2 final report. Note that the "High, Dispersive" condition in these figures corresponds to the alternating pair at 2 Hz with 13.8 volts applied to high-output halogen lamps. The data are compared for red lenses.

Table 5. Comparison of Task 3 results with earlier Task 2 results (red lenses).

Task	Source of data	Alternating Pair	TCL	Ratio
Horizontal peripheral detection	Task 3, Prelim. Experiment	63°	88°	0.72
	Task 2, Experiment 2	66°	89°	0.74
Diagonal peripheral detection	Task 3, Prelim. Experiment	30°	52°	0.60
	Task 2, Experiment 2	51°	70°	0.73
Attention-getting rating	Task 3, Prelim. Experiment	5.8	7.0	0.83
	Task 2, Experiment 2	5.3	6.2	0.85

In regard to mean attention-getting ratings, the table shows increases for the Task 3 configurations. These increases seem to be in line with the changes made to the configurations in Task 3. Thus, from the standpoint of attention getting, the enhancements to the hardware that were implemented in Task 3 seem to have been successful. In regard to peripheral detection, mean horizontal peripheral detection shows a similarity between the Task 2 and Task 3 results. Apparently, the greater attention-getting capability did not provide increases in detection angles, as was determined by the expert group. Diagonal peripheral detection shows a decrease from Task 2 to Task 3, which can only be explained by subject and procedure differences. Apparently, the experts set or needed higher standards for peripheral detection. Finally, the ratios of alternating-pair values to TCL values show a good deal of consistency between experiments, suggesting at least that the capabilities of the alternating pair relative to the TCL did not change much. Clearly, the TCL operating at a higher voltage remains the "champion," but the alternating pair with its enhancements also works well.

Discussion and Recommendations Associated with the Preliminary Experiment

The preliminary experiment provided information on which to base decisions about the alternating pair to be tested in the main experiment. The two main specifications of the Improved Alternating Pair (IAP) are:

- The IAP should include the kick circuit, which initially applies a higher voltage to each lamp. This circuit produces luminance rise times that are substantially shorter. The final value should also be a higher voltage, that is, 14.7 to 14.8 volts for the equipment used. (Appendix A shows this waveform.)

- The IAP frequency should be 4.0 Hz.

These two specifications provide answers to two of the three questions that the preliminary experiment was designed to answer. The third question concerned the startup preheat effectiveness. The results of the experiment do not justify its use because there was no statistically reliable improvement in the experts' rankings when it was used, and the improvement is, at best, very small. Considering that preheat requires constant standby power and increases complexity, it does not appear to be a worthwhile enhancement.

In addition to these specifications, there are indications that the attention-getting capability of the IAP is somewhat higher than the alternating pair tested in Task 2. Similarly, because of the higher drive voltage, the TCL appears to have a greater attention-getting capability than the same device that was used in Task 2. There is, then, one additional recommendation derived from the preliminary experiment, namely:

- The TCL should be driven by a higher voltage, that is, approximately 14.7 to 14.8 volts, for the bulb and equipment used.

In regard to attention-getting capability, the preliminary experiment appears to have met its objective. However, the results associated with peripheral detection are not as positive; the expert group seems to have placed more stringent conditions on peripheral detection. Finally, as stated above, based on all available information, the TCL (with higher drive voltage) would be expected to provide field-test performance results superior to the IAP. Nevertheless, the IAP would be expected to provide substantial improvement over ordinary stop lamps. Final specifications for the TCL and IAP appear in Appendix A.

DESCRIPTION OF THE MAIN EXPERIMENT

The main experiment consisted of a car-following experiment that was carried out on the Virginia Smart Road in Blacksburg, Virginia. The lead vehicle was composed of a towing vehicle pulling a surrogate vehicle. Figure 7 shows the towing/surrogate-vehicle combination, along with the following vehicle. (The following vehicle in the figure is closer than during the actual experiment.) Figure 8 shows the drive electronics in the trunk of the towing vehicle. These electronics drove the IAP, the TCL, and the snap-down panels (to be described) in the surrogate vehicle. Figures 9, 10, 11, and 12 show details of the surrogate vehicle. As can be seen, the surrogate vehicle was a lightweight trailer with a fiberglass shell resembling the rear portion of a Ford Taurus automobile. The trailer included a 40-foot (12.2-meter) collapsible boom. The fundamental concept of the surrogate vehicle was that if a rear-end crash occurred, it would cause little or no damage to the following vehicle. Thus, it provided a means of carrying out car-following experiments in relative safety. The surrogate-vehicle concept was initially developed and tested under the CAMP (Crash Avoidance Metrics Partnership) program (Kiefer, LeBlanc, Palmer, Salinger, Deering, and Shulman, 1999). The surrogate vehicle used in the current experiments was developed independently of CAMP, but it used many of the same concepts.

Figure 7. Towing/surrogate vehicle combination shown with the following vehicle. Note that the following vehicle is closer than during the actual experiment.

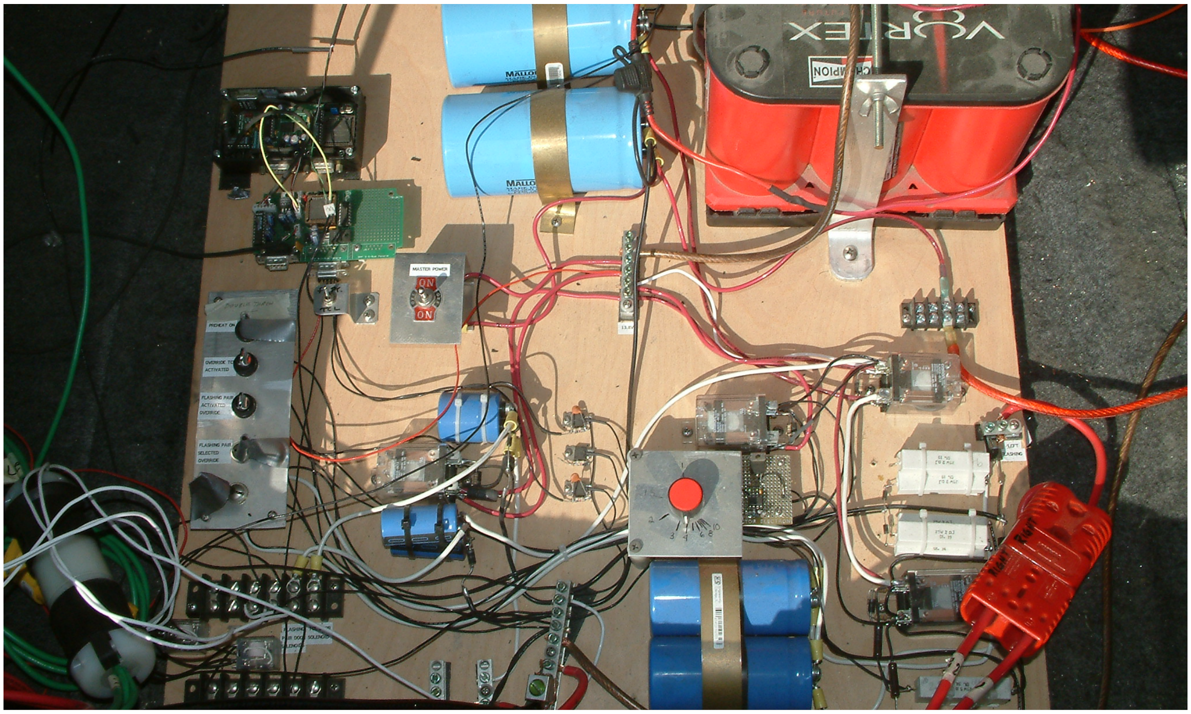

Figure 8. Imminent-warning lighting drive electronics in the trunk of the towing vehicle.

Figure 9. Rear of the surrogate vehicle with the imminent-warning lighting panels closed.

Figure 10. The TCL imminent-warning lighting signal with its snap-down panel open. (Lamp output was subjectively "redder" than it appears in this figure.)

Figure 11. The IAP imminent-warning lighting signal with its snap-down panels open. (Lamp output was subjectively "redder" than it appears in this figure.)

Figure 12. The interior of the surrogate vehicle shell. Note that the front curtains (fairings) have been temporarily removed for this photo.

The surrogate vehicle used in the Task 3 experiment had conventional brake lighting as well as the two proposed imminent-warning lighting signals: namely, the TCL (traffic clearing lamp) and the IAP (improved alternating pair), as shown in Figures 9, 10, 11, and 12. The two imminent-warning lighting signals were under computer control and could be activated and de-activated by the driver of the towing vehicle. Conventional lighting in the surrogate vehicle was accomplished by using the actual taillight/stoplight and CHMSL (center high-mounted stop lamp) components of a Ford Taurus. The towing vehicle was driven by a confederate.

The following vehicle (Figure 7) was a conventional, but instrumented, automobile driven by the driver/subject. The experimenter sat in the right front seat and had an auxiliary brake pedal as a safety precaution.

The subject was instructed ahead of time to follow at a specified distance of 120 ft (36.6 m) while carrying out instructed in-vehicle tasks. There were fixed markers on the Smart Road that permitted accurate spacing. The subject re-adjusted to the correct distance at the beginning of each loop on the road. The nominal speed of the lead vehicle was 30 mph (48.3 km/h).

Each driver/subject drove three loops around the Smart Road (each loop consisting of a total distance of 4.2 miles or 6.8 km.) The first loop allowed the driver/subject to become familiar with the vehicle and to practice in-vehicle tasks and separate braking tasks. The second loop was a data-taking loop in which a surprise condition (simultaneous task and imminent-warning braking) occurred. The third loop was also a data-taking loop in which another simultaneous task and heavy-braking condition occurred during a different in-vehicle task and at a different point on the road. Prior to beginning the third loop, the driver/subject was told the purpose of the imminent-warning signal, if he or she was in either the TCL or IAP use condition. For those driver subjects in the conventional rear-lighting condition, a parallel description was used so that any instructional bias effect could be minimized. Appendix B contains the experimenter's script and includes the descriptions read to the driver/subjects prior to the third loop.

In the way of further detail, during the second and third loops, the lead vehicle would occasionally brake at a level of deceleration below 0.35 g, and similarly, in-vehicle tasks would occasionally be carried out; however, they did not occur simultaneously. After the subject was acclimated to the situation, and unbeknownst to the subject, an in-vehicle task and a braking maneuver occurred simultaneously. This braking maneuver was at a level above 0.35g. When the driver looked away to perform the in-vehicle task, the experimenter in the following vehicle secretly signaled the confederate in the lead vehicle by radio to decelerate at a level well above 0.35g. Thus, the driver/subject was purposely distracted as a test scenario for the rear-lighting.

During the third loop, as indicated above, a second simultaneous task with high deceleration was used so that data for previously exposed drivers could be obtained. In this case, the driver/subject was made fully aware ahead of time that the purpose of the imminent-warning signal (if it was used) was to alert the driver to heavy braking by the lead vehicle.

Experimental Design

Subjects were in three separate driver/subject groups:

- Those in which the surrogate vehicle included conventional rear lighting only,
- Those in which the surrogate vehicle included both conventional rear lighting and the TCL, and
- Those in which the surrogate vehicle included both conventional rear lighting and the IAP.

As previously indicated, the experiment was intended to study the effects of the *addition* of the candidate imminent-warning lighting systems (as compared with conventional lighting alone.) The experimental design was as shown in Table 6.

Table 6. Experimental Design

Subjects	Condition	Exposure	
Subjects 1, 4, 7, . . ., n-2	Conventional rear lighting (CNV)	First (no prior exposure or knowledge)	Second (with one prior exposure and knowledge)
Subjects 2, 5, 8, . . ., n-1	Conventional + First imminent-warning rear lighting (TCL)	First (no prior exposure or knowledge)	Second (with one prior exposure and knowledge)
Subjects 3, 6, 9, . . ., n	Conventional + Second imminent-warning rear lighting (IAP)	First (no prior exposure or knowledge)	Second (with one prior exposure and knowledge)

Data Analysis / Independent Variables

This experiment was a mixed-factors design with Lighting as a between-subjects factor with three levels: conventional (termed CNV), conventional-plus-TCL (termed TCL), and conventional-plus-IAP (termed IAP). Exposure was a within-subject factor with two levels: First exposure (uninformed) and Second exposure (informed). There were 24 subjects in each lighting condition, resulting in a total of 72 subjects. A between-subjects design was considered to be necessary by both the sponsor and the research team in order to obtain an initial surprise exposure for each participant. Knowing that there would be a large amount of variance in a study such as this (measuring reaction time under close to real-world conditions with subjects of varying age and experience), a larger than usual number of subjects was chosen for each cell.

Dependent variables used to assess differences are presented in a later section of this chapter.

Controlled Variables

<u>Ambient Lighting Conditions</u>

This experiment was carried out in daylight conditions. Crash-data analyses show that most rear-end crashes occur during daylight hours under good weather conditions. These are the conditions under which conventional rear lighting has the lowest contrast with the surroundings. One hypothesis was that drivers in these crashes were distracted or inattentive and that their vision may not have been redirected by the rear lighting because of low contrast. It was believed that by using an imminent-warning signal, the driver's attention could be redirected to the forward view, thereby avoiding or reducing the severity of a rear-end crash.

Therefore, testing was carried out during daylight hours. However, wider latitude in the lighting level was allowed in comparison to all previous experimentation. The reason for this was that lighting could only be controlled in general, not specifically, at the instant that the simultaneous in-vehicle task and heavy braking occurred. Since this simultaneous task and heavy braking occurred as part of a scenario, there was no way to predict exactly what the lighting conditions would be at the instant the simultaneous stimuli occurred. Generally, however, testing was limited to days with bright or hazy sun or light cloud cover. Tests took place in February, March, April, and May of 2003. Weather during this time interval was particularly severe and prolonged the data-gathering phase of the project.

As discussed in the earlier reports (Task 1 and Task 2), brighter daylight conditions require maximum lamp output for high contrast. Lamp design must be such that it can provide the necessary light output for these conditions. Under lower ambient-lighting conditions (and assuming success of the bright-condition experiments), it would be expected that the imminent-warning signal would be attenuated to avoid unacceptable discomfort glare. This could be done while still maintaining high contrast.

Equipment Details

Towing Vehicle/Surrogate Vehicle

The surrogate vehicle was equipped with conventional brake lighting, including the CHMSL, and was also equipped with both the TCL and the IAP, as shown in Figures 9 through 12. The conventional lighting nacelles were from a 1995 Ford Taurus. Great care was taken to ensure that there was no appreciable voltage drop along the electrical lines leading from the trunk of the towing (lead) vehicle to the surrogate vehicle. This was accomplished by using very heavy (low-gauge) conductors. For conventional data runs, the TCL and IAP were not used. For the first set of enhanced lighting data runs, the TCL was activated whenever the lead vehicle reached 0.35 g of deceleration. Once activated, it remained activated until deceleration decreased to 0.15 g. Thereafter, 4.0 seconds of timeout were added.[*] These parameter values are the ones recommended for the open-loop configuration developed in Task 2. For the second set of enhanced lighting runs, the IAP was similarly activated whenever the lead vehicle reached 0.35 g of deceleration. It was also deactivated in the same way as the first imminent-warning signal (the TCL): that is, when deceleration fell below 0.15 g and 4.0 seconds of timeout had passed. Figure 13 provides a block diagram of the towing/surrogate vehicle equipment modifications.

A further note of explanation is required in regard to the triggering deceleration. Because some braking maneuvers (alone, that is, without a concurrent task) occurred on downhill sections, and the combined braking maneuvers for which the main data were gathered were on uphill sections, the stopping distances and decelerations differed (owing to the different angle of the gravitation force vector). Thus, on the downhill sections, the TCL and IAP were made inoperative so that if the 0.35 g criterion was inadvertently met, the systems would not be activated.

To avoid the possibility of occasional glimpses of the *towing* vehicle's rear lights, they were disconnected for this experiment. Thus, the rear-lighting wiring from the towing vehicle was routed to the surrogate vehicle. As mentioned, heavy conductors were used for all interconnections so that there would be no appreciable voltage drop to the lamps at the rear of the surrogate vehicle.

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[*] Although testing in this experiment used the open-loop concept (as described in the Task 2 report), the results obtained would also be applicable to the closed-loop concept. The reason for this is that the tests were directed at determining any reductions in response time and incursion (reduction in spacing between vehicles). It could be assumed that whether operating in the open- or closed-loop mode, there would be little or no change in the driver's response to the imminent-warning signal.

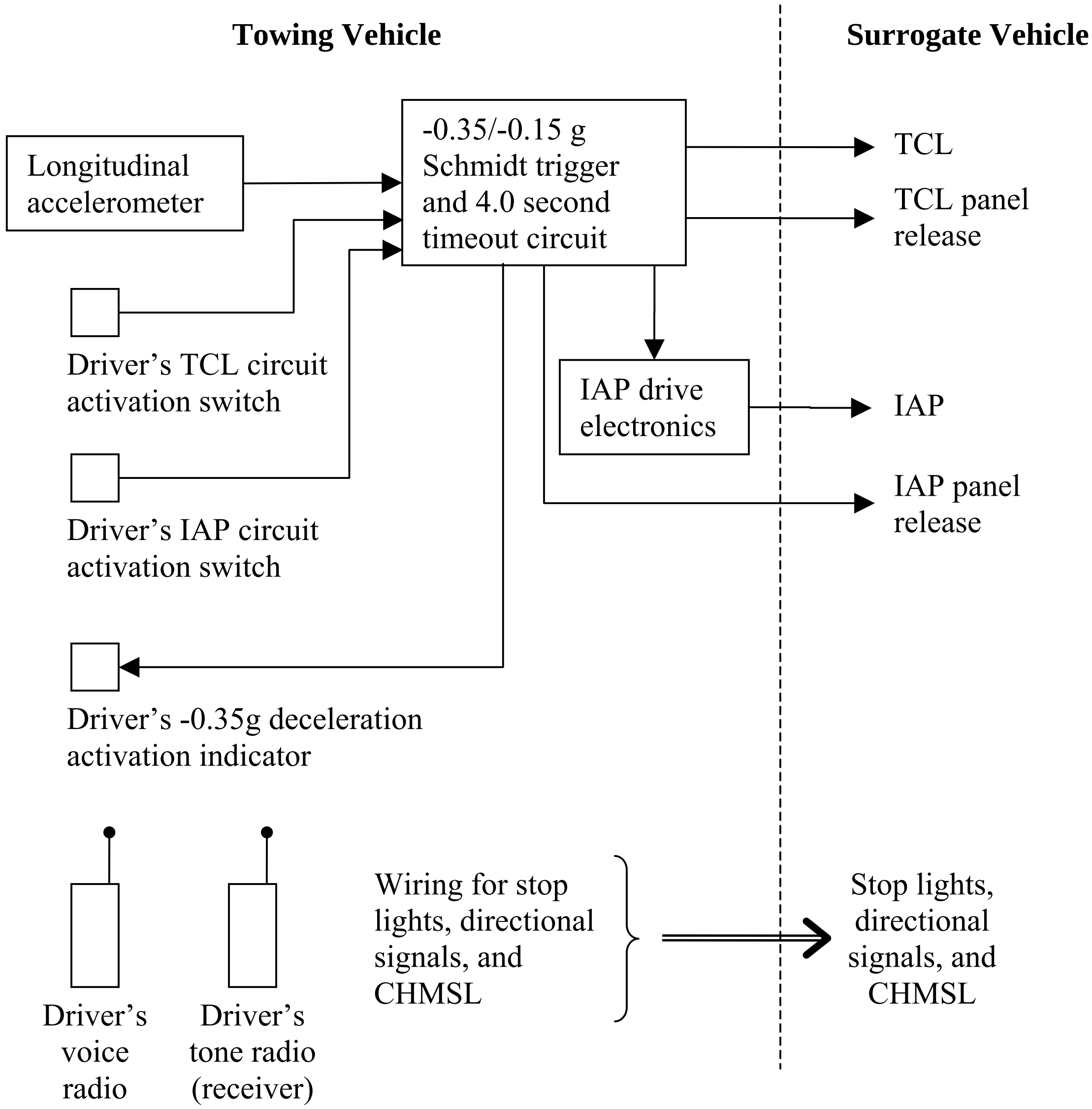


Figure 13. Lead Vehicle Equipment Modifications

The experimenter and the confederate driving the towing vehicle were connected by a voice radio link. In addition, the experimenter was able to secretly signal the confederate (via a second radio) to indicate when to hit the brakes for the deceleration tasks. A tone (that could not be heard in the following vehicle) was used for this purpose. For the simultaneous in-vehicle task/heavy braking, the second radio was used to time the braking maneuvers so that they occurred when the experimenter saw the driver/subject look away from the forward view to carry out an instructed in-vehicle task.

The towing vehicle was equipped with a light indicator to inform the confederate that 0.35 g of deceleration had been achieved. This ensured that conditions were satisfied that would activate the rear lighting. It also ensured that for the conventional condition, the same level of braking would occur.

Hiding the Imminent-Warning Signals

If the imminent-warning signal lamps were visible to the driver subject (when not in operation), they might have created a curiosity that could have affected the results obtained. Thus, it was considered desirable to keep the lamps hidden from the driver subject until the lamps were to be used for the first time. The method for hiding the lamps was to embed them in the shell of the surrogate vehicle so that the contour of the surrogate vehicle was not changed. An unobtrusive rectangular panel section was cut and hinged for each of the three imminent-warning lights (one for the TCL and two for the IAP). When any of the imminent-warning lamps were to be activated for the first time, the cover panel(s) would snap open to reveal the lamp(s). At the same time, the appropriate lamp(s) would illuminate in accordance with specifications. Each cover panel was released by a solenoid, and then a spring forced the panel to open quickly. This approach had the advantage that the panel could be made unobtrusive by using the same color and same shape as the contour of the surrogate vehicle. In fact, the sections cut from the surrogate vehicle were used as the panels. The TCL used a single centered cover panel, and the IAP used a pair of cover panels, as shown in Figures 9, 10, and 11.

After the first exposure, the panel(s) was (were) *not* re-closed, and the experiment continued. Since the driver/subject knew of the existence of the additional lighting after the first exposure and was instructed on the use of the additional lighting, there seemed little point in hiding it for the second exposure. In addition, if used in production vehicles, the lighting would not be hidden. Thus, different rationales were used for hiding the lamps on the first exposure and for revealing them on the second exposure.

Following Vehicle

The following vehicle was equipped with a forward-looking radar system, an accelerometer, a speed sensor, pedal sensors, and a video system, as shown in Figure 14. An on-board computer stored the digital data, while a VCR recorded the video data. These systems made it possible to determine the driver's reactions to the lighting conditions.

The video configuration for this experiment was composed of a four-camera quad-split system. The first camera was directed forward and picked up the surrogate vehicle and its rear lighting. This image was used to determine when the normal brake lighting was activated as well as when the imminent-warning lighting was activated. The second camera was directed toward the driver's face and picked up the driver's eye position. This camera helped to discern where the driver was looking when the surrogate vehicle's rear-lighting was activated. The third camera was directed downward toward the feet of the driver subject. This camera helped to determine the driver's foot movements at the time of the lead vehicle's deceleration.

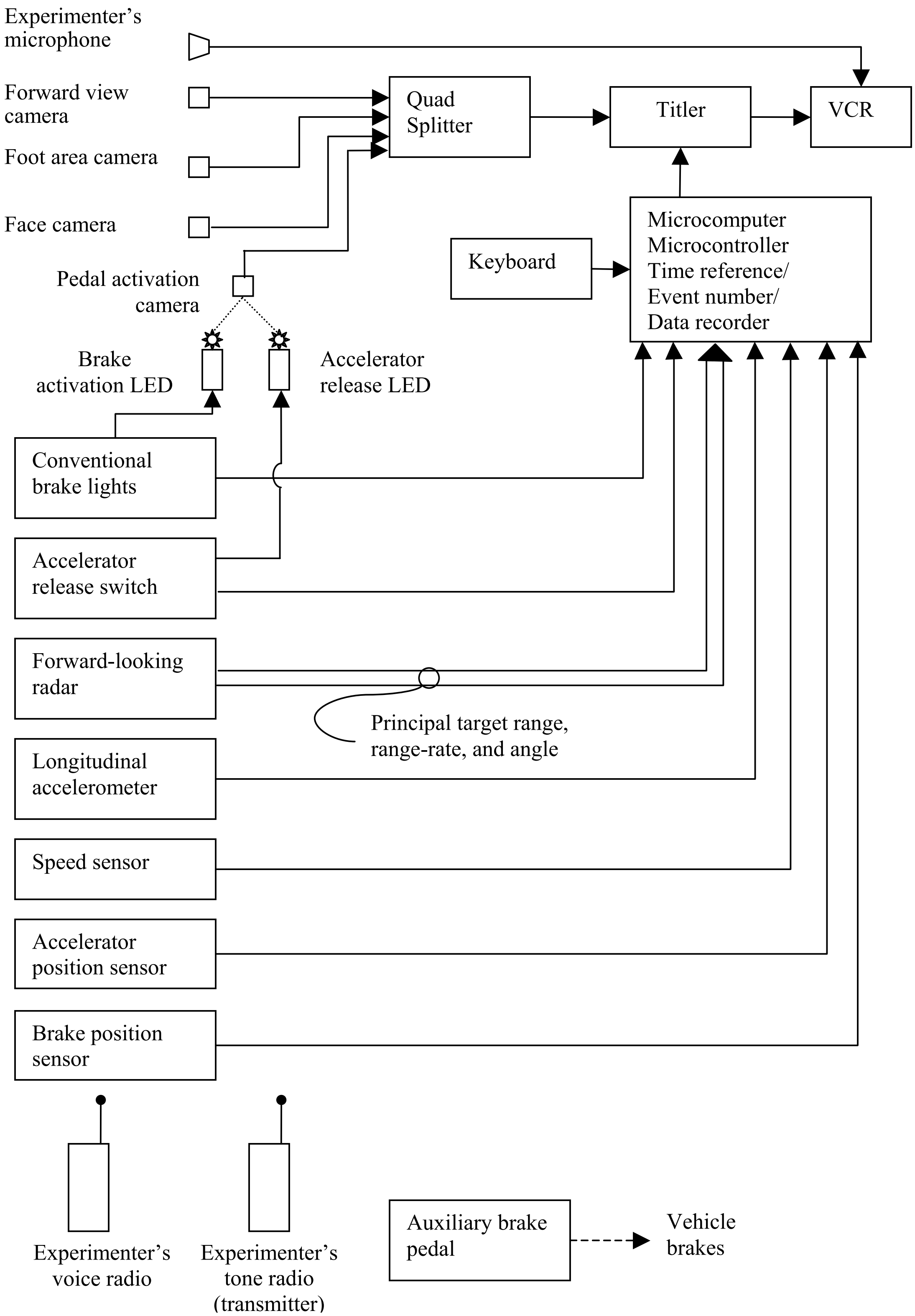


Figure 14. Following vehicle equipment modifications.

The fourth camera was used in an unusual way. It was directed at two LEDs instrumented in the back seat of the following vehicle. The first LED illuminated whenever the driver/subject depressed the brake pedal. This LED was intended to provide precise measurement of the driver/subject's brake activation. The second LED illuminated whenever the driver released the accelerator. It was intended to capture those situations in which the driver detects a problem ahead and releases the accelerator but does not immediately depress the brake pedal. The two LEDs were fitted into a small metal box (approx. 10 in. or 25.4 cm long) with a Complementary Metal-Oxide Semiconductor (CMOS) camera and lens at the other end. This box provided a light-tight enclosure so that LED illumination could be easily detected on the video image.

The video system also had a titler and running-time indicator for synchronization of digital data and video information.

The following digital variables were stored in memory for later analysis:

- Event number
- Running time indicator
- Distance between surrogate and following vehicle
- Closing rate between surrogate and following vehicle
- Following vehicle brake application
- Following vehicle brake pedal position
- Following vehicle accelerator release
- Following vehicle accelerator position
- Following vehicle deceleration
- Following vehicle velocity

All of the above variables (except event number) were recorded as a function of time.

Dependent Measures

An initial set of dependent measures was selected to assess such aspects as response time to rear signals and incursions (i.e., reductions) in the following distance. The purpose of using these measures was to assess the effects of each imminent-warning signal on the driver/subject's ability to respond quickly and to maintain a uniform following distance. These measures were intended to provide an indication of the potential benefits, if any, of each imminent-warning signal. Measures initially selected were as follows:

- Peak closing rate (for first 4.0 seconds following brake-light stimulus of surrogate vehicle);
- Peak incursion (for first 4.0 seconds following brake-light stimulus of surrogate vehicle; incursion is defined as initial separation minus minimum separation);
- Response time (from brake-light stimulus of surrogate vehicle to applied brakes of following vehicle; maximum permitted value was 4.0 seconds);
- Response time (from brake-light stimulus of surrogate vehicle to accelerator release of following vehicle; maximum permitted value was 4.0 seconds);
- Peak deceleration of following vehicle (for first 4.0 seconds following brake-light stimulus of surrogate vehicle);
- Peak brake pedal depression of following vehicle (for first 4.0 seconds following brake-light stimulus of surrogate vehicle);
- Average incursion over the first 4.0 seconds following brake-light stimulus of surrogate vehicle;
- Time to a full stop, measured from initiation of brake-light stimulus.

In the above measures (except the last measure), the valid interval of driver/subject response was limited to 4.0 seconds. If the driver had not responded until late in this time interval, the experimenter then found it necessary to use the auxiliary brake pedal to stop the following vehicle. Such cases were handled in the data analysis.

As the analysis progressed, five additional dependent measures were defined. These measures were intended to evaluate additional research hypotheses that could be tested using the data set. These measures are defined along with their corresponding analyses in later portions of the results section of this report.

Subject Instructions

Each driver/subject was instructed ahead of time to maintain a distance of 120 ft (behind the surrogate vehicle). While maintaining the specified distance, the driver/subject was to carry out various in-vehicle tasks as instructed by the experimenter (Appendix B). Typical (although not identical) in-vehicle tasks were used to train the driver/subject ahead of time, while the vehicle was standing and during the first loop of the Smart Road. Subjects were instructed not to wear sunglasses during the experiment.

Subjects were initially unaware that braking and an in-vehicle task would occur simultaneously. Subjects in the TCL and IAP conditions were also not aware that activation of the imminent-warning signals indicated a high level of deceleration for the lead vehicle. In fact they had no previous exposure to the imminent-warning signals. Thus, their first exposure was during the simultaneous task with high deceleration, which occurred during the second loop.

After the first high-deceleration task occurred, the experiment continued in order to obtain a repeat set of data (for which the driver had one previous exposure). This second exposure occurred after several other in-vehicle tasks had been presented, and it was presented at a different point on the Smart Road so that subjects would not be able to associate it with a given location. The second exposure occurred during the third loop. As previously mentioned, driver/subjects at this point had been made fully aware that the imminent-warning signal indicated heavy braking by the lead vehicle.

Scenario

The fundamental concept of the scenario was for the driver to carry out the in-vehicle tasks while maintaining a uniform distance to the surrogate vehicle. Once the driver was familiar with the routine, the simultaneous task with high deceleration was carried out. This particular task represented the first crucial data-gathering element for each subject, in that it was intended to indicate whether or not there was an improvement in response for the distracted driver when the imminent-warning signaling was used (under uninformed conditions).

As indicated, the scenario continued until a second exposure to a similar situation was presented. To avoid priming the subject, several other events were inserted between the first and second high-deceleration exposures.

Thus, the experimental scenario is depicted in outline form in Figure 15. As stated, events were carried out separately, except for two cases of simultaneous task and heavy braking. These events represented the critical data-gathering components of the experiment.

Two specific in-vehicle tasks were used during the critical data-gathering events. The first of these was called the Clock Task. The precise instruction was, “Adjust the clock to be 3 hours and 7 minutes ahead of its current setting.” The clock was located on the vehicle centerline, relatively high on the instrument panel. It was digital and was controlled by pushbuttons located nearby. The second in-vehicle task was called the Dot Task. In this case, the precise instruction was, “Point to the sticker with the number 8 and tell me what color it is.” In fact, there was no sticker with the number 8, so the driver/subject had to perform a search. There were several stickers in the vehicle, and they were all located near the vehicle centerline, relatively high on the instrument panel.

The horizontal, vertical, and diagonal angles to the centroid positions for the two tasks are presented in Table 7. The values shown are for a seated individual with a height of 5 feet, 6 inches (168 cm). These angles provide approximate information on how far away in angle (from the central forward view) the driver had to scan to perform the in-vehicle task.

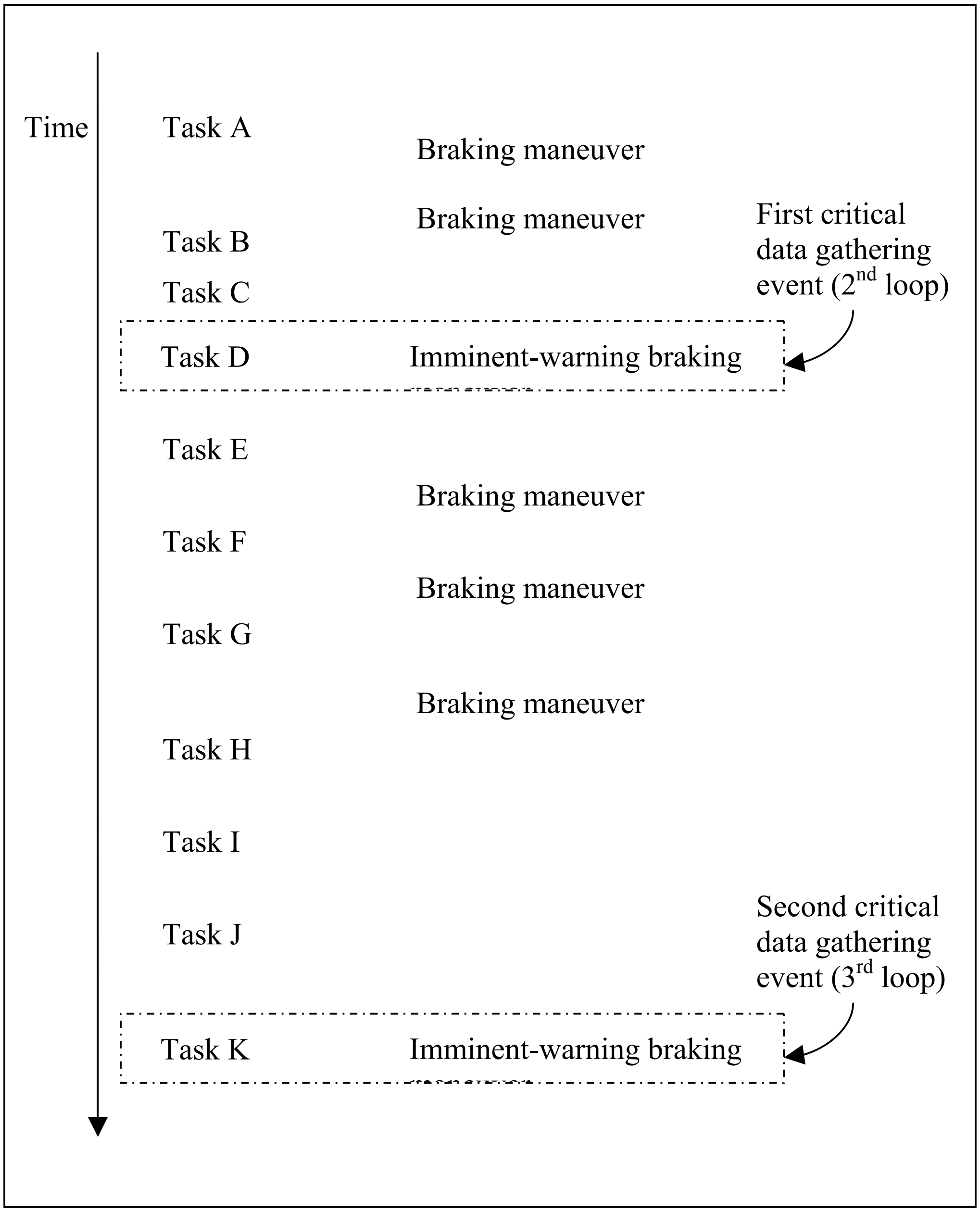


Figure 15. Depiction of the experimental scenario (time is increasing from top to bottom). The critical data-gathering portions are shown by dotted outlines.

Table 7. Visual angles to the centroid positions of the two in-vehicle tasks for an individual of approximately average height. (Measured from the straight-ahead seated viewing position.)

In-Vehicle Task	Horizontal Angle (deg)	Vertical Angle (deg)	Diagonal Angle (deg)
Clock	30	20	36
Dot	31	19	36

Half the driver/subjects in each of the three lighting conditions received the clock task on first exposure to heavy braking and the dot task on second exposure to heavy braking. The other half of the driver/subjects received the dot task on first exposure to heavy braking, and the clock task on second exposure. This resulted in counterbalancing of the in-vehicle tasks across first and second exposures to heavy braking, making it possible to directly compare the effects of being uninformed (first exposure) vs. being informed (second exposure). A complete listing of all in-vehicle tasks performed by the driver subjects, along with experimenter notes and instructions, appears in Appendix B.

Subject Characteristics and Procedures

Ordinary driver/subjects 18 to 78 years of age were used in this experiment. An attempt was made to obtain a representative sample of ages for each of the three lighting conditions. The purpose was to ensure that the sample would be reflective of the general motoring public so that the results of the study would be generalizable. As shown in Table 8, the final distribution resulted in age groupings that were somewhat older for the enhanced rear-lighting conditions than for the conventional conditions, thus biasing the results slightly against the enhance conditions, given the numerous studies that have shown measurably slower reaction times for older drivers.

Table 8. Age distribution of participants by lighting condition.

Lighting	**Mean**	**Min**	**Max**	**St. dev.**
CNV	39.2	18	69	16.023
IAP	42.3	20	76	17.194
TCL	46.0	18	78	20.578
Grand Mean	**42.5**			**18.124**

Subjects were required to show a valid driver's license. They also had to certify that they were free of medical conditions and drug/alcohol usage that would impair their driving ability. Subjects were volunteers who were solicited using VTTI's subject database and, in a few cases, through flyer responses (Appendix C). Prior to entering the Smart Road for experimentation, subjects were briefed and then signed an informed consent form (Appendix D). (All material supplied to the driver/subjects and all procedures used had been previously approved by the Virginia Tech Institutional Review Board.)

Immediately after completion of the first exposure to the simultaneous in-vehicle and heavy braking task (occurring during the second loop), the experiment was suspended for a moment. At this time, the driver/subject was given an additional form to sign that indicated the true nature of the experiment being conducted (Appendix E). This form was considered to be necessary because, up until this time, the driver subject had not been given precise information on the true purpose of the experiment. The experiment then continued with completion of the second loop and then the third loop, as previously described.

Once the experiment had been completed, the driver/subject was returned to the main building at VTTI. Those driver/subjects in the imminent-warning lighting conditions filled out a final questionnaire providing their opinions of the imminent-warning lighting (Appendix F.) Any remaining questions were then answered for the subject; the subject was then paid, thanked, and dismissed.

RESULTS OF THE MAIN EXPERIMENT

Initial Data Reduction

Shortly after each subject's data were gathered, the data were carefully stored and then extracted. Data were gathered continuously during the driving task. The main process of extraction involved selecting the interval during which the two simultaneous in-vehicle/heavy braking tasks were carried out. Both digital data and video data were extracted. These two important intervals of data were then used for analyses. Questionnaire data, obtained after the experimental runs, were analyzed separately by extracting and tabulating driver/subject responses.

In the way of review, there were three lighting conditions for the experimental runs (between subjects): CNV, TCL, and IAP. There were also two exposures (within subject): First (Uninformed), and Second (Informed). These independent variables were the ones used for the initial statistical analyses.

Measures were computed from both the extracted digital data and slow-motion analysis of the videotape images. Videotape images were first digitized into MPEG files so that they could be easily studied frame-by-frame. Measures were entered into a spreadsheet for use in the statistical analyses. Once the data were in spreadsheets, they were carefully checked for correctness and reasonableness. Any suspect data were examined carefully, the source of the problem was determined, and then the data were corrected if necessary. Once the data were fully verified as correct, the measures were computed.

It is important to note in the following analyses that the enhanced lighting (the IAP and TCL lamps) *did not* illuminate at the instant that the ordinary brake lighting illuminated. Rather, the enhanced lighting illuminated when the criterion for activation was met: namely, at 0.35 g of deceleration. Therefore, when the lead-vehicle driver braked heavily, the ordinary brake lights, including the CHMSL, would illuminate first. Then, when deceleration reached 0.35 g, the additional lighting would illuminate. The rear lighting would remain illuminated until deceleration decreased to 0.15 g and an additional 4.0 seconds of timeout had passed. This procedure was explained earlier in Section IV under the title "Towing Vehicle/Surrogate Vehicle." The information is repeated here because all measurements were made from *brake light* activation, regardless of Lighting condition.

General statistical procedures were developed for handling the data. These procedures were adhered to throughout the analyses. Generally, for tests of significance, alpha was set at 0.05, in accordance with accepted convention. However, it was found that variability of the data was substantial (as expected) and so an additional definition was developed. A "trend" was said to exist for cases in which the statistical test resulted in $0.05 < p < 0.110$. The purpose of presenting trend results was to avoid losing results with a high likelihood of repeatability and significance for larger sample sizes. The inclusion of trends also reduced the tendency to assume that a lack of significant differences implies there are no differences. The experiment performed here was close to real-world and, as such, had substantial variability. In the authors' opinions, the use of trends appears appropriate and justified.

Post hoc Student Newman-Keuls (SNK) tests were performed on all significant main effects (associated with Lighting) using an alpha level of 0.05. However, in some cases, although the main effect was significant ($p < 0.05$), the SNK test did not result in any significant difference among levels of the independent variable at alpha = 0.05. In such cases, the test was repeated with increasing increments in the alpha level of 0.01, until one of the levels of the independent variable showed a significant difference. The results were then presented with the notation of the alpha value for which the difference was first obtained.

Group I Analyses (Driver Glance Direction Not Taken into Account)

Group I analyses were intended to determine if there was an overall effect in the data resulting from differences in the lighting conditions and exposures (that is, first or second). These analyses were performed without reference to where the driver was looking during the stimulus (i.e., brake lighting) presentation. As described previously, an attempt was made to begin the stimulus when the driver looked toward the in-vehicle task (and therefore, away from the forward view). However, drivers often looked back after initially taking their eyes off the forward view. In fact, a large variety of glance behavior was observed. Group I analyses were intended to determine whether there were reliable effects in the data without considering glance position.

The first data analysis was performed using the entire data set in an “equal N’s” analysis. A 3 (Lighting) by 2 (Exposure) mixed-factors analysis of variance was performed on each dependent measure. As previously described, Lighting was a between-subjects independent variable, and Exposure was a within-subject independent variable. Accordingly, there were 24 values in each of the six cells of the data matrix for each dependent measure.

In this initial analysis, cases in which the experimenter had to step on the auxiliary brake pedal were *not* deleted. There were 11 instances out of a possible 144 in which the experimenter had to use the brakes. These were distributed across the 6 cells of the data (3 lighting conditions by 2 exposures) as shown in Table 9 ($\chi^2(2, N=11) = 0.588, p = 0.75$). The reason for not deleting them in the initial analysis was that the results would be conservative because the experimenter responded before the driver/subject would have responded. (Later analyses in Group I and elsewhere deleted data in which the experimenter had to intervene.)

Table 9. Distribution of 11 experimenter braking incidents by lighting condition and exposure (shown for information purposes only—differences not significant using Chi Square analysis).

	Conventional	IAP	TCL
1st Exposure	1	4	2
2nd Exposure	1	1	2

The eight dependent measures defined in Section IV of this report were each subjected to an analysis of variance (ANOVA). The complete set of results for all eight dependent measures appears in Appendix G, Part 1, with a summary provided in this section in Table 10. A full set of descriptive statistics is provided along with the eight two-way ANOVA summaries. The main results of these analyses are as follows:

- When one examines mean values of the performance measures, the use of the IAP and TCL additions appears to improve driver performance. However, there is large variance in the data.

- For the given data set, noteworthy trends and significance are as follows:

  For accelerator release time, Exposure (that is, first vs. second) demonstrates a trend $F(1,69) = 2.88$, $p = 0.0941$. The mean values for first and second exposure were 1.43 and 1.23 seconds respectively.

  For brake activation time, Lighting demonstrates a trend $F(2,69) = 0.236$, $p = 0.1025$. This trend is graphed in Figure 16.

  For peak brake pedal depression the interaction of Lighting and Exposure demonstrates a trend $F(2,69) = 2.49$, $p = 0.090$. This trend is graphed in Figure 17.

  For peak closing rate, Exposure demonstrates significance $F(1,69) = 7.70$, $p = 0.0071$. The mean values for first and second exposure were 22.0 and 19.7 mph, respectively.

  For peak incursion, Exposure similarly demonstrates significance $F(1,69) = 15.25$, $p = 0.0002$. The mean values for first and second exposure were 80.6 and 70.9 ft, respectively.

  For average incursion, Exposure similarly demonstrates significance $F(1,69) = 18.20$, $p < 0.0001$. The mean values for first and second exposure were 33.1 and 29.1 ft, respectively.

  For time to a full stop, Lighting is significant $F(2,69) = 6.26$, $p = 0.0032$, and the interaction of Lighting and Exposure demonstrates a trend $F(2,69) = 2.86$, $p = 0.0639$. These results are graphed in Figure 18. The combined means for each level of Lighting were subjected to SNK post hoc tests. The results indicated CNV differed significantly from IAP and TCL conditions (alpha = 0.05).

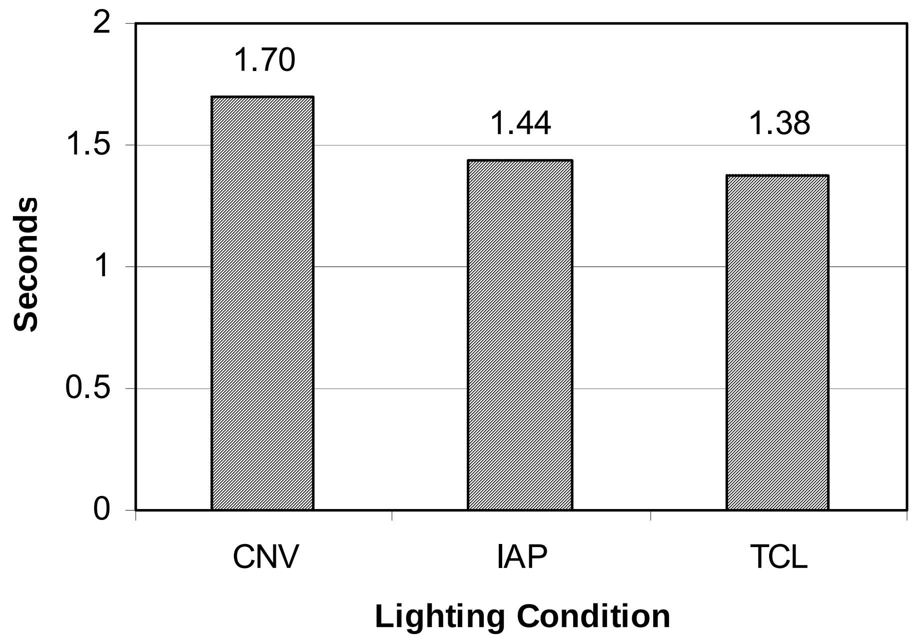


Figure 16. Trend effect of Lighting on brake response time. (Group I analysis, full data set.)

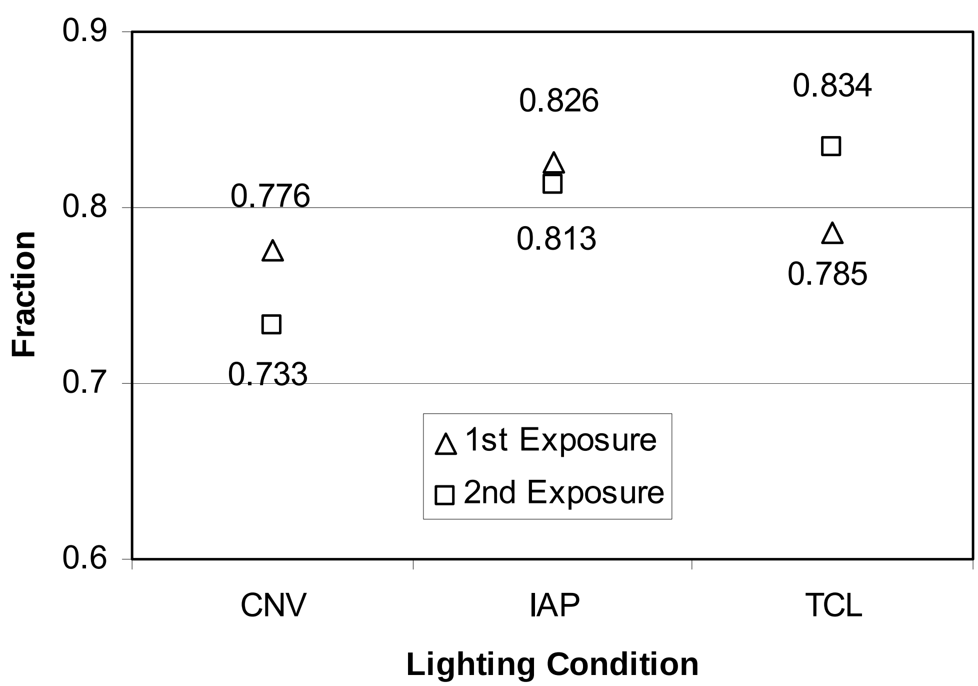


Figure 17. Interactive trend in peak brake depression. (Group I analysis, full data set.)

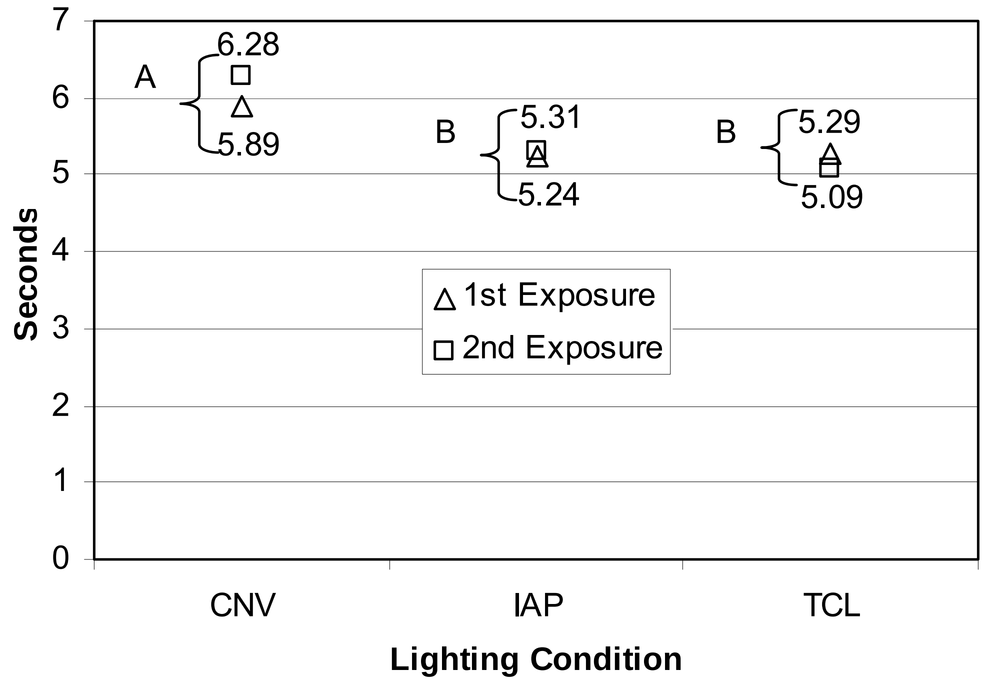


Figure 18. Graph of the significant main effect of Lighting and the trend in the interaction of Lighting and Exposure for Time to a Full Stop. (Group I analysis, full data set.) Means with a common letter do not differ significantly (alpha = 0.05).

Table 10. Summary of Group I results, all 144 data points included.

Dependent Variable	Lighting	Exposure	Ltg x Exp
Accelerator Release	NS	Trend	NS
Brake Activation	Trend	NS	NS
Peak Brake Depression	NS	NS	Trend
Peak Deceleration	NS	NS	NS
Peak Closing Rate	NS	Significant	NS
Peak Incursion	NS	Significant	NS
Average Incursion	NS	Significant	NS
Time to Full Stop	Significant	NS	Trend

Unequal N's Analyses

As mentioned, there were 11 cases in which the experimenter had to use the auxiliary brake pedal to avoid a collision with the surrogate vehicle. To account for these cases, two sets of unequal N's analyses were carried out. In the first set of unequal N's analyses, data for the 11 cases were deleted. This procedure unbalanced the experimental design, along both independent variables. Thus, a one-way analysis of variance was performed on the first exposure data with lighting as the independent variable, and a second one-way analysis was performed on the second exposure data. This procedure resulted in a total of 16 one-way ANOVAs: one for each dependent measure and each exposure.

As with the full data set previously described, the eight dependent measures defined in Section IV of this report were each subjected to analyses of variance. However, as indicated, two one-way analyses were used for each dependent measure, with Lighting condition as the independent variable. The complete set of results for all eight dependent measures appears in Appendix G, Part 2, with a summary of results provided in this section in Table 11. A full set of descriptive statistics is provided along with the 16 one-way ANOVA summaries. The main results of these analyses are as follows:

- In general, the descriptive statistics show improved performance for both the IAP and TCL conditions, as compared with the CNV condition. In addition, the TCL condition shows somewhat greater improvement than does the IAP. Once again, there is a good deal of variability in the data, which tends to reduce the likelihood of demonstrating significance (alpha = 0.05).

- For this data set, noteworthy trends and significance were as follows:

  Brake activation time for first exposure was significant $F(2,62) = 3.21$, $p = 0.0471$. This result is graphed in Figure 19. A post hoc SNK test showed that the CNV condition differed from the two enhanced lighting conditions (alpha = 0.07).

  Peak brake pedal depression for second exposure demonstrated a trend that was nearly significant $F(2,65) = 3.02$, $p = 0.0559$. This result is graphed in Figure 20.

  Peak deceleration for second exposure demonstrated a trend $F(2,65) = 2.31$, $p = 0.1075$. This result is graphed in Figure 21.

  Peak incursion for first exposure demonstrated a trend $F(2,62) = 2.55$, $p = 0.0864$. This result is graphed in Figure 22.

  Time to a full stop demonstrated significance for both first exposure $F(2,62) = 3.23$, $p = 0.0463$ and second exposure $F(2,65) = 7.49$, $p = 0.0012$. These results are plotted on the same axes in Figure 23. Two sets of post hoc SNK test results are also shown in the graph. The results indicate that CNV differs from IAP and TCL in both cases (alpha = 0.09, first exposure; alpha = 0.05, second exposure).

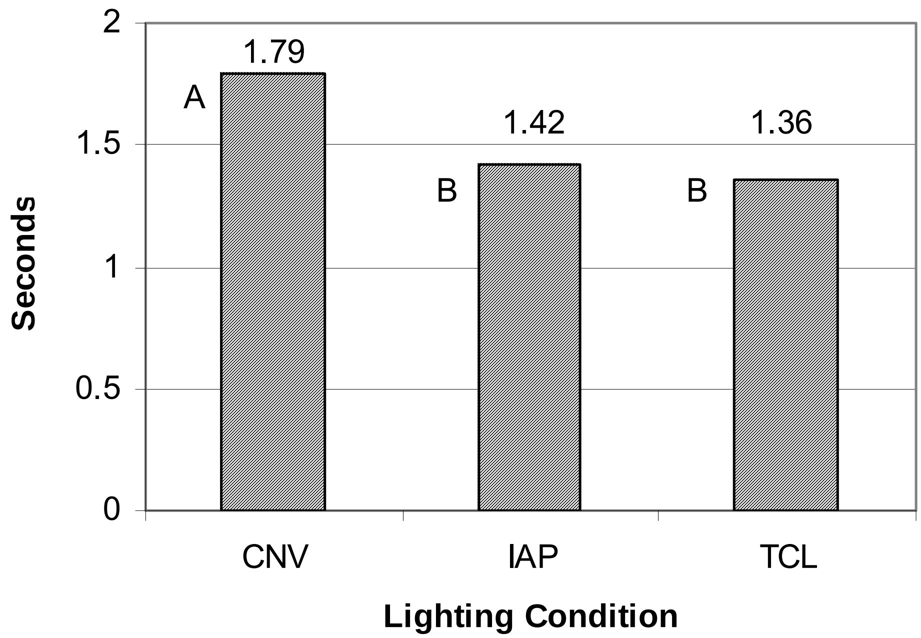


Figure 19. Significant main effect of Lighting on brake activation time, first exposure. (Group I analysis, 11 experimenter braking incidents deleted.) Means with a common letter do not differ significantly (alpha = 0.07).

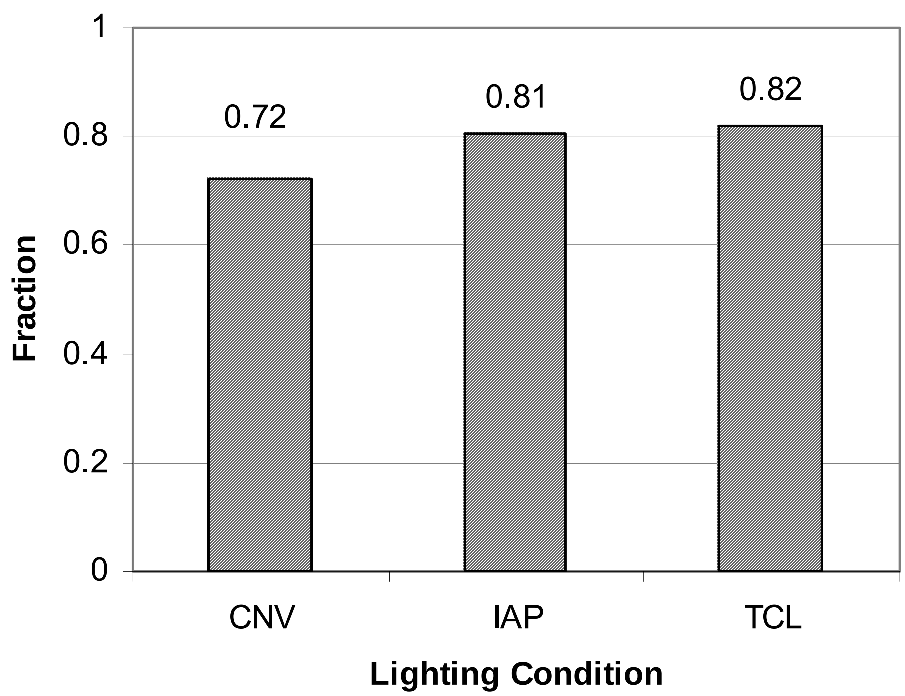


Figure 20. Trend effect of Lighting on peak brake pedal depression, second exposure. (Group I analysis, 11 experimenter braking incidents deleted.)

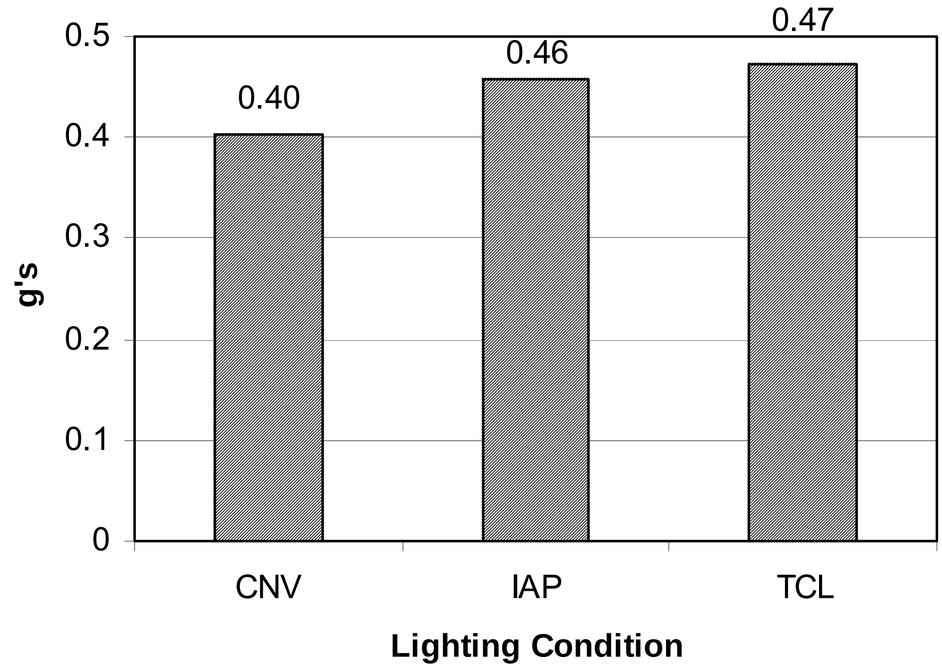


Figure 21. Trend effect of Lighting on peak deceleration, second exposure. (Group I analysis, 11 experimenter braking incidents deleted.)

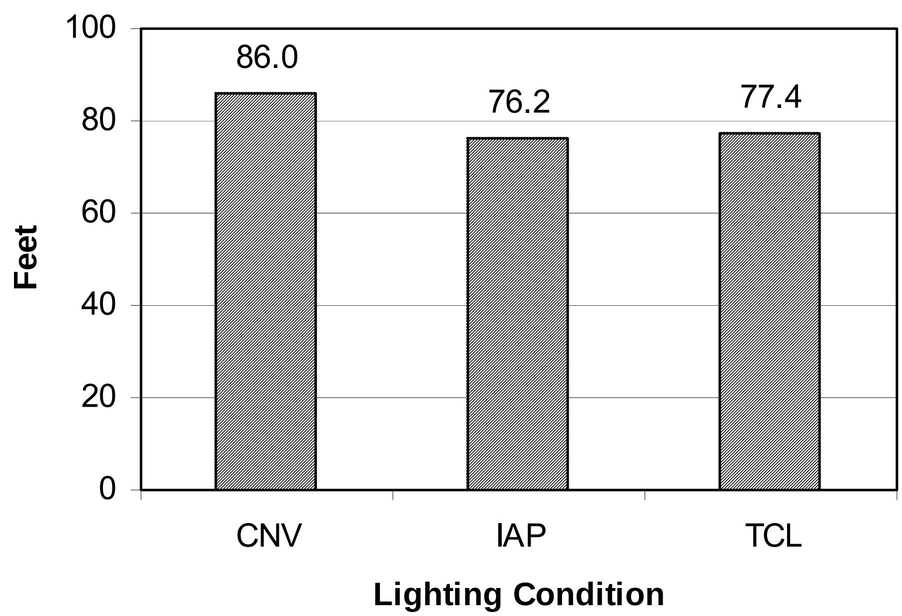


Figure 22. Trend effect of Lighting on peak incursion, first exposure. (Group I analysis, 11 experimenter braking incidents deleted.)

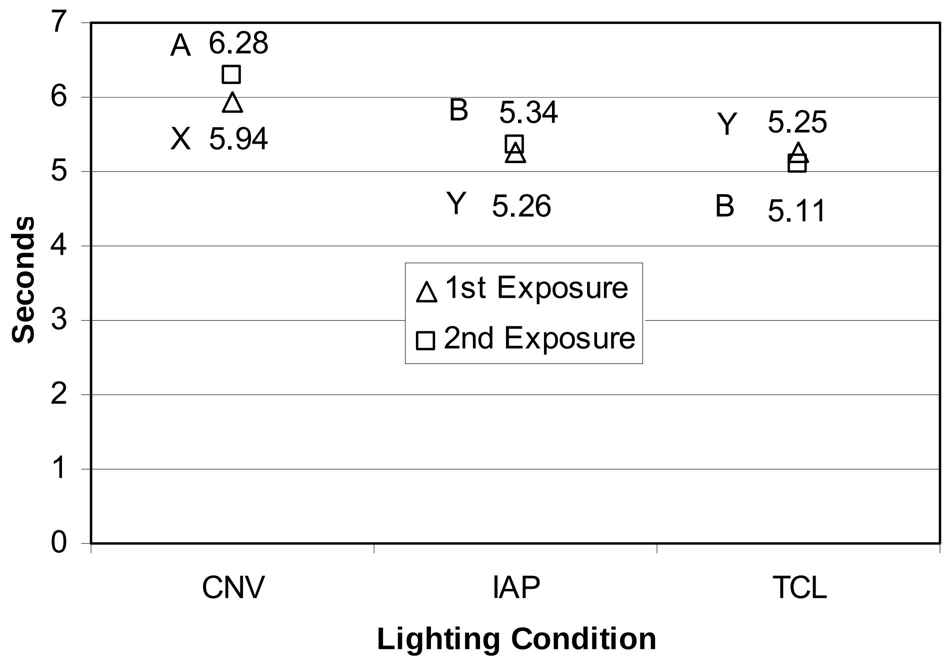


Figure 23. Two significant main effects of Lighting on time to a full stop. One main effect is for first exposure and the other is for second exposure. For each exposure, means with a common letter do not differ significantly (alpha = 0.09, first exposure; alpha = 0.05, second exposure). (Group I analysis, 11 experimenter braking incidents deleted.)

Table 11. Summary of Group I results, 11 experimenter braking incidents deleted (133 data points).

Dependent Variable	1st Exposure	2nd Exposure
Accelerator Release	NS	NS
Brake Activation	Significant	NS
Peak Brake Depression	NS	Trend
Peak Deceleration	NS	Trend
Peak Closing Rate	NS	NS
Peak Incursion	Trend	NS
Average Incursion	NS	NS
Time to Full Stop	Significant	Significant

The second set of unequal N's analyses deleted both exposures for those subjects for which the experimenter had to use the auxiliary brake on either exposure. The effect was to rebalance the design in terms of exposure, which could then be treated once again as a within-subject variable. In this case, 11 sets of data were deleted from the first exposure data, and correspondingly, 11 were deleted from the second exposure data. This resulted in unequal N's for Lighting but equal N's (within subject) for Exposure. Consequently, a two-way analysis of variance could be run.

This procedure resulted in a total of 8 two-way ANOVAs: one for each dependent measure. With the deletions, there remained 61 data sets, for a total of 122 data points per dependent measure. As summary of results for this analysis is provided in Table 12.

The main results of the analysis were as follows:

- The results generally track the earlier results but include main effects covering both the first and second exposures. Thus, once again, improvements were demonstrated for the IAP and TCL lighting conditions.

- For this data set, noteworthy trends and significant effects were as follows:

  For accelerator release time, Lighting demonstrated a trend $F(2,58) = 2.45$, $p = 0.0952$. This result is plotted in Figure 24.

  For brake activation time, Lighting demonstrated a significant main effect $F(2,58) = 3.57$, $p = 0.0346$. This result is plotted in Figure 25. SNK results demonstrated that the CNV condition differed significantly from the IAP and TCL conditions (alpha = 0.05).

  For peak brake pedal depression, there was a trend in the interaction of Lighting and Exposure that was nearly significant $F(2,58) = 2.85$, $p = 0.0663$. This result is plotted in Figure 26.

  For peak closing rate, there was a significant main effect of Exposure $F(1,58) = 8.19$, $p = 0.0059$. The mean value for first exposure was 21.8 mph and the mean value for second exposure was 19.4 mph.

  For peak incursion, there was a significant main effect of Exposure $F(1,58) = 14.81$, $p = 0.0003$. The mean values were 80.4 and 70.4 ft for first and second exposure, respectively.

  For average incursion, there was a significant main effect of Exposure $F(1,58) = 15.45$, $p = 0.0002$. The mean values were 33.2 and 29.0 ft for first and second exposure, respectively.

  For time to a full stop, there was a significant main effect of Lighting $F(2,58) = 5.47$, $p = 0.0067$. This result is plotted in Figure 27. SNK results revealed that the CNV condition differed significantly from the enhanced lighting conditions (alpha = 0.05)

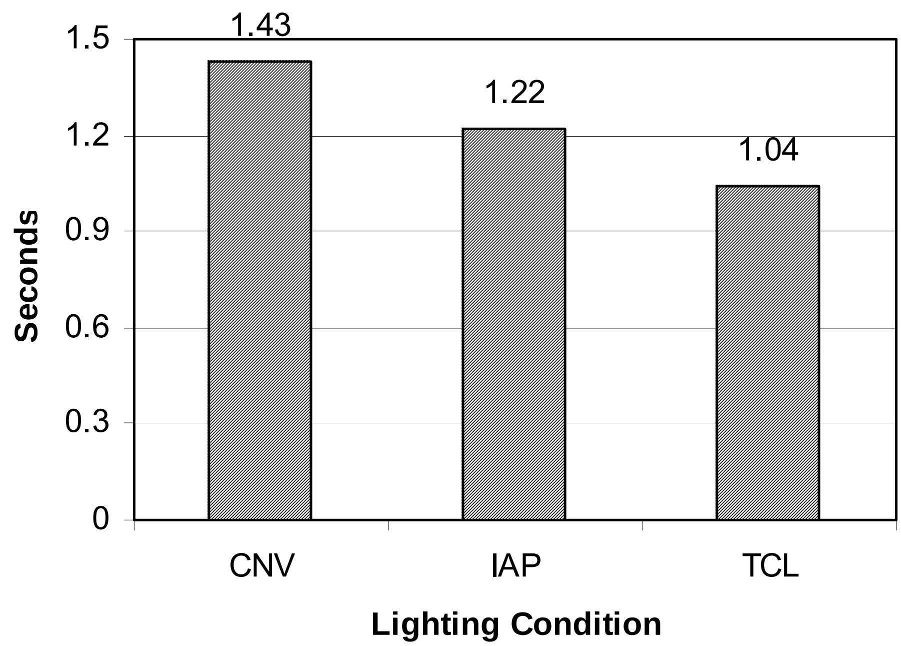


Figure 24. Trend effect of Lighting on accelerator release time. (Group I analysis, 11 subjects deleted owing to experimenter braking.)

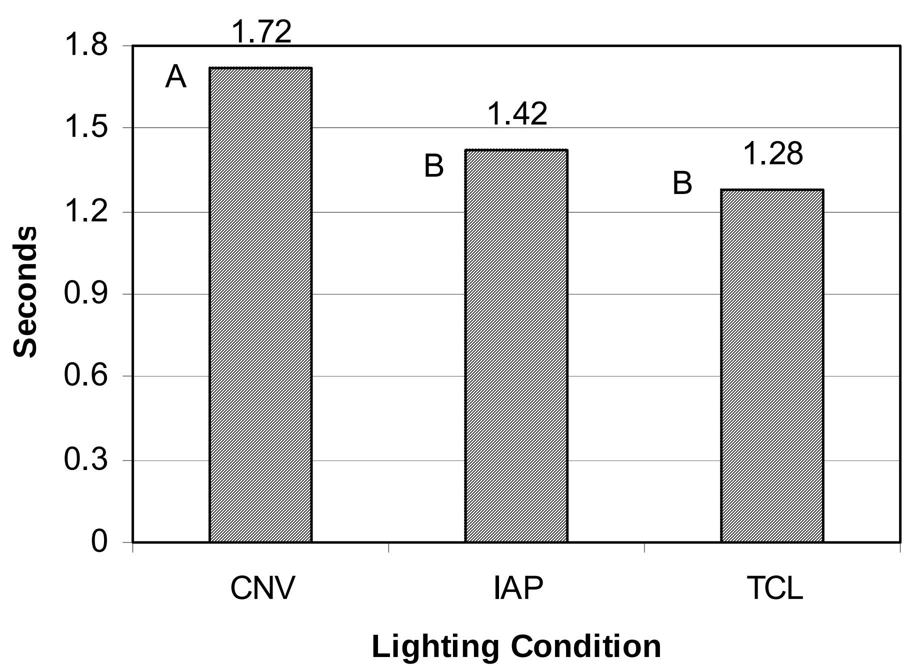


Figure 25. Significant main effect of Lighting on brake activation time. (Group I analysis, 11 subjects deleted owing to experimenter braking.) Means with a common letter do not differ significantly (alpha = 0.05).

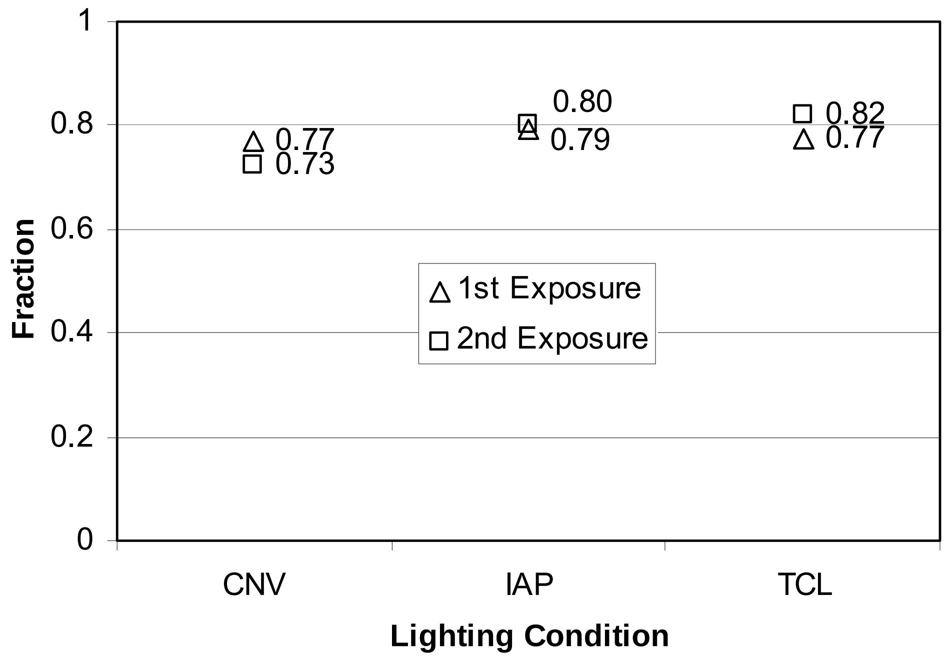


Figure 26. Interactive trend in peak brake pedal depression. (Group I analysis, 11 subjects deleted owing to experimenter braking.)

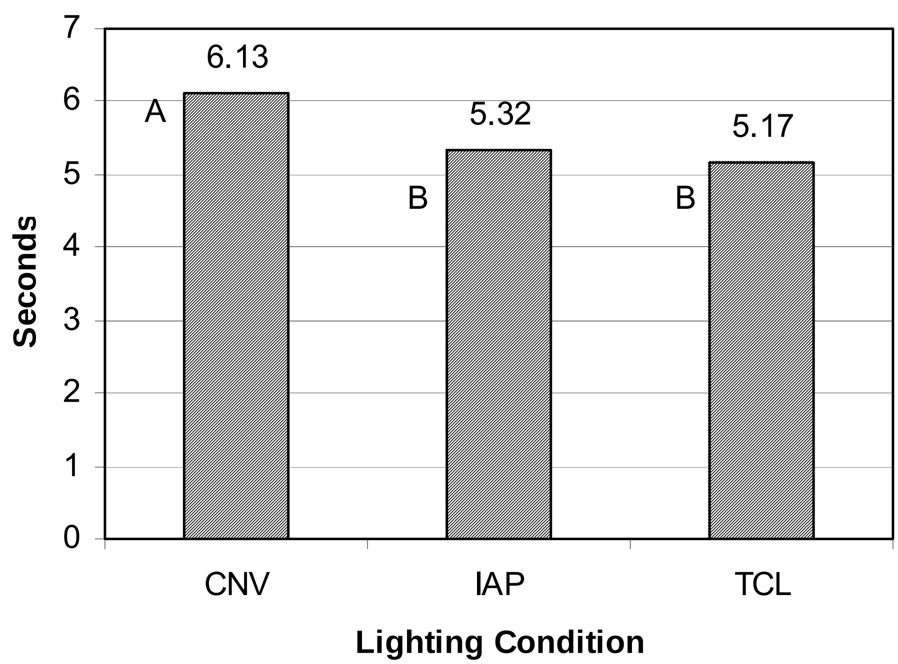


Figure 27. Significant main effect of Lighting on time to a full stop. (Group I analysis, 11 subjects deleted owing to experimenter braking.) Means with a common letter do not differ significantly (alpha = 0.05).

Table 12. Summary of Group I results, 11 subjects deleted due to experimenter braking (122 data points).

Dependent Variable	Lighting	Exposure	Ltg x Ex
Accelerator Release	Trend	NS	NS
Brake Activation	Significant	NS	NS
Peak Brake Depression	NS	NS	Trend
Peak Deceleration	NS	NS	NS
Peak Closing Rate	NS	Significant	NS
Peak Incursion	NS	Significant	NS
Average Incursion	NS	Significant	NS
Time to Full Stop	Significant	NS	NS

Group II Analyses (Includes Only Drivers Who Took an Early Glance to the Forward View)

The second group of analyses was directed toward assessing the performance of drivers when they had at least one glance to the forward view early in the lead vehicle's braking. Here, the idea was to assess whether the enhanced rear lighting would "draw" the drivers attention better and result in better braking performance. Specifically, if the driver *did* look near the lead vehicle during or shortly after brake-light illumination, was the driver's braking performance improved with the enhanced lighting?

The specific visual criterion for inclusion in the Group II analyses was the following:

> Immediately after the brake lights of the surrogate vehicle were illuminated, the driver had a glance to the forward view for 0.2 second or longer within the first 0.5 second.

In this visual criterion, the forward view was defined as a glance in the vicinity of the lead vehicle: that is, within plus or minus 5° horizontally. If the driver was looking forward when the lights illuminated and continued to look for 0.2 second or longer, the data were included.

Driver data that met the above stated criterion on first exposure were included in all first-exposure analyses, and driver data meeting the criterion on second exposure were included in all second exposure analyses. For first exposure, this procedure resulted in a total of 30 values for each dependent measure. For second exposure, the procedure resulted in a total of 38 values for each dependent measure.

It is important to note that the data that qualified based on the above criterion were mutually exclusive of data for which the experimenter had to use the auxiliary brake pedal. Thus, the question of whether or not to include data in cases of experimenter braking was moot, since no such cases existed in the data set.

Because of the unequal numbers of data in the various cells of the independent variables, two unequal N's one-way analyses of variance were run for each dependent measure: one for the first exposure and one for the second exposure. The descriptive statistics and analyses of variance for this Group II analyses are presented in Appendix H, with a summary in Table 13. Highlights of the results are as follows:

- The descriptive statistics indicate that there is a general improvement in braking performance with the enhanced lighting and that the TCL condition is usually (but not always) superior to the IAP condition. However, as in the previous analyses, there is much variability in the data, which limits the domain of statistical significance. Nevertheless, even with substantially reduced sample sizes, there is a moderate domain of trends and statistical significance.

- For this data set, noteworthy trends and instances of statistical significance are as follows:

  For brake activation time, Lighting demonstrated a trend on both first exposure $F(2,27) = 2.67$, $p = 0.0877$, and on second exposure $F(2,35) = 2.63$, $p = 0.0860$. These results are plotted on the same axes in Figure 28.

  For peak closing rate, Lighting demonstrated significance on second exposure $F(2,35) = 3.51$, $p = 0.0409$. These results are plotted in Figure 29. A post hoc SNK test demonstrated that the CNV differed from the IAP and TCL conditions (alpha = 0.06).

  For peak incursion, Lighting demonstrated a trend that was nearly significant on second exposure $F(2,27) = 3.18$, $p = 0.0539$. The results are plotted in Figure 30.

  Average incursion demonstrated a trend in Lighting on second exposure as well $F(2,35) = 2.48$, $p = 0.0987$. The results are plotted in Figure 31.

  For time to a full stop, Lighting demonstrated significance on second exposure $F(2,35) = 4.64$, $p = 0.0163$. The results are plotted in Figure 32. The SNK test in this case demonstrated once again that the CNV condition differed significantly from the two enhanced lighting conditions (alpha = 0.05).

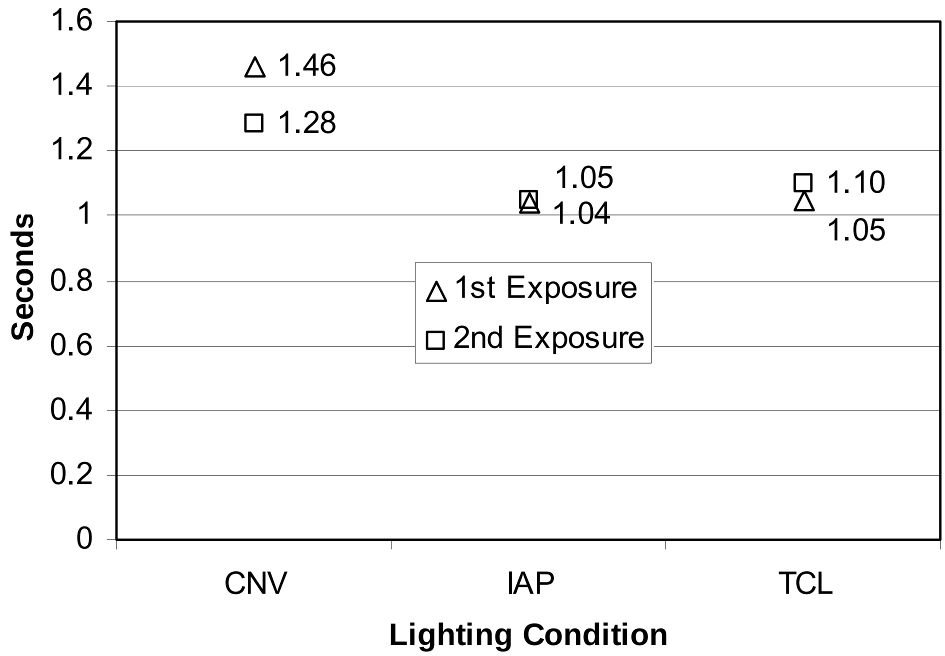


Figure 28. Trend effects of Lighting on brake activation times, for first and second exposures. (Group II analyses.)

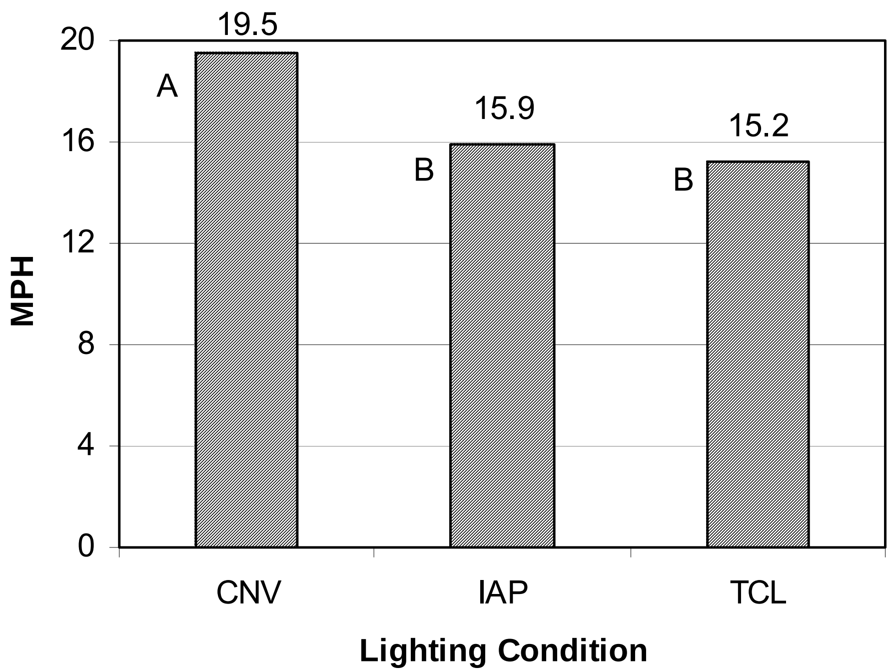


Figure 29. Significant effect of Lighting on peak closing rate for second exposure. Group II analyses.) Means with a common letter do not differ significantly (alpha = 0.06).

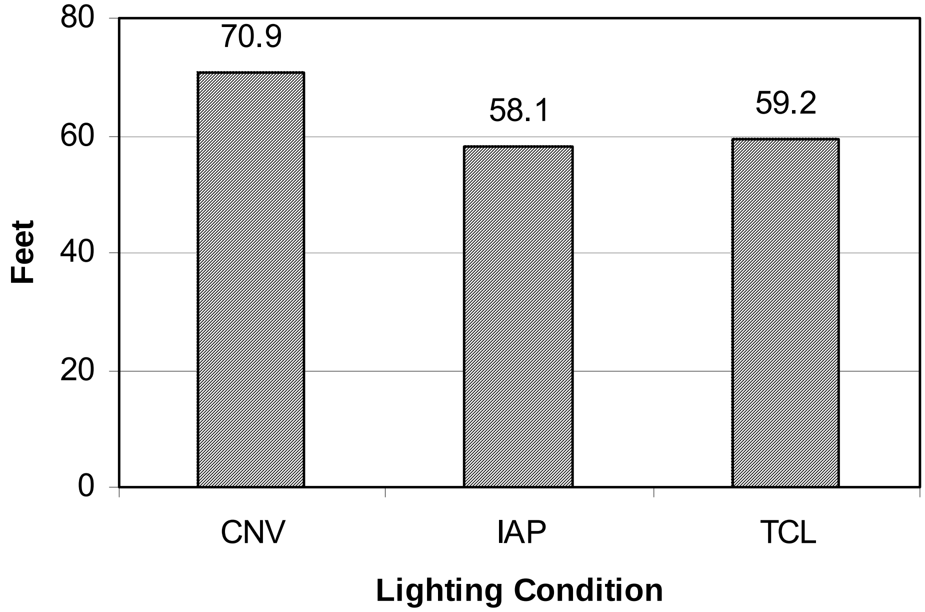


Figure 30. Trend effect of Lighting on peak incursion for second exposure. (Group II analyses.)

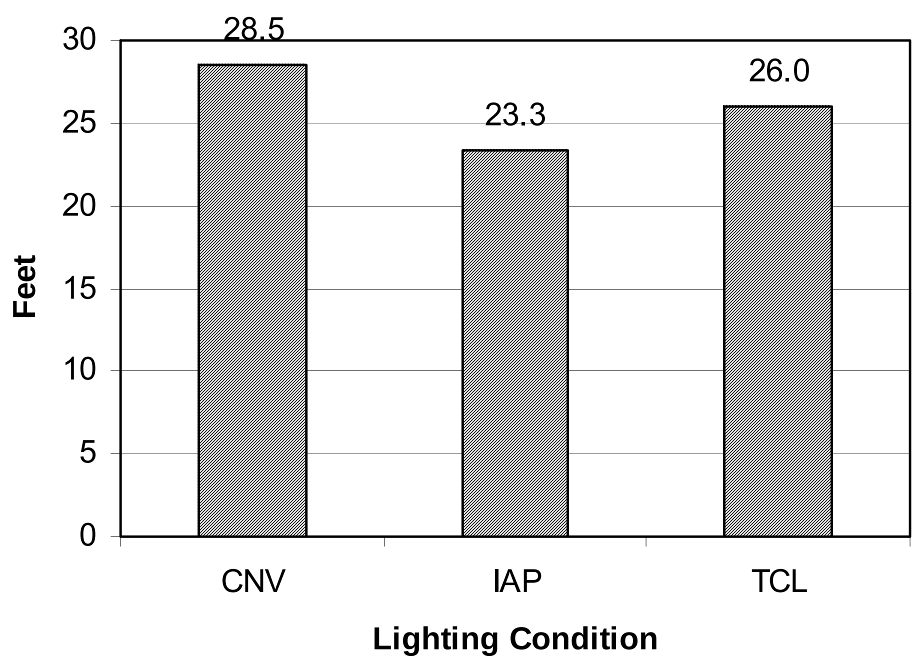


Figure 31. Trend effect of Lighting on average incursion for second exposure. (Group II analyses.)

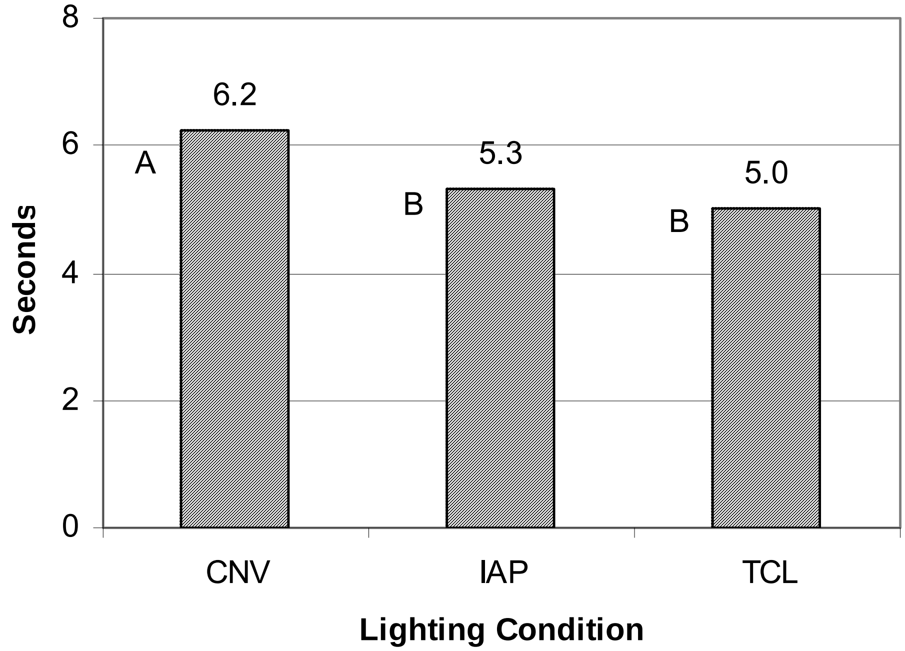


Figure 32. Significant effect of Lighting on time to a full stop, for second exposure. (Group II analyses.) Means with a common letter do not differ significantly (alpha = 0.05).

Table 13. Summary of Group II results (30 data points for first exposure and 38 data points for second exposure).

Dependent Variable	1st Exposure	2nd Exposure
Accelerator Release	NS	NS
Brake Activation	Trend	Trend
Peak Brake Depression	NS	NS
Peak Deceleration	NS	NS
Peak Closing Rate	NS	Significant
Peak Incursion	NS	Trend
Average Incursion	NS	Trend
Time to Full Stop	NS	Significant

Group III Analyses (Driver Performance Once the Driver Returned Glance to the Forward View)

The third group of analyses was intended to determine if there were any improvements in stopping performance once the driver returned his or her glance to the forward view after the surrogate vehicle's braking lamps had illuminated. For this case, all data were included in the analysis, except those cases in which the experimenter was forced to use the auxiliary brake pedal. These latter cases were not included because the driver never responded or responded late.

Since the measurement's starting point was changed in the Group III analyses, new measures had to be defined. These measures were intended to assess performance once the driver returned glance to the forward view. Four new dependent measures were thus defined as follows:

TVA: The time from first view of the brake lights to accelerator release.

TVB: The time from first view of the brake lights to brake activation.

TVPB: The time from first view of the brake lights to peak braking.

TVFS: The time from first view of the brake lights to a full stop.

In the first three measures above, the maximum allowable values were 4.0 sec. This was particularly important for peak braking, where the "true" peak might have occasionally occurred after 4.0 sec. The fourth measure above was not limited.

In the above definitions, first view is defined as follows:

> First view is the point in time at which the brake lights illuminate if the driver is looking forward at that time. First view is the first point in time that the driver returns his or her glance to the forward view if the driver is not looking forward at the time that the brake lights illuminate.

Two separate sets of unequal N's analyses were carried out for the new dependent measures. In the first set, the 11 data sets in which the experimenter used the auxiliary brake pedal were first deleted. Thereafter, the four dependent measures were subjected to two one-way analyses of variance with Lighting as the independent variable. (This type of procedure was identical to the one used in the first unequal N's analysis in Group I. Of course, the new measures were used instead.) One analysis was for first exposure, and the other was for second exposure. Thus, eight one-way ANOVAs were performed: one for each dependent measure and each exposure.

The results of these analyses along with all descriptive statistics are presented in Appendix I, Part 1, with a summary of results presented in Table 14. The main results of these analyses are as follows:

- There is evidence of improvement using the enhanced lighting: that is, the IAP and TCL. However, certain measures show reversed trends, which suggests a more complex reaction or strategy on the part of the driver subjects.

- For this given data set, noteworthy trends and significance are as follows:

  For TVB, there is a trend in Lighting for second exposure $F(2,65) = 2.37$, $p = 0.1016$. The results are plotted in Figure 33.

For TVPB, there is a significant effect of Lighting for first exposure $F(2,62) = 4.35$, $p = 0.0171$. The results are plotted in Figure 34. SNK results are also shown. In this case the CNV condition differed significantly from the IAP condition only (alpha = 0.05).

For TVFS, there is a trend that is nearly significant for second exposure $F(2,65) = 2.85$, $p = 0.0651$. The results are plotted in Figure 35.

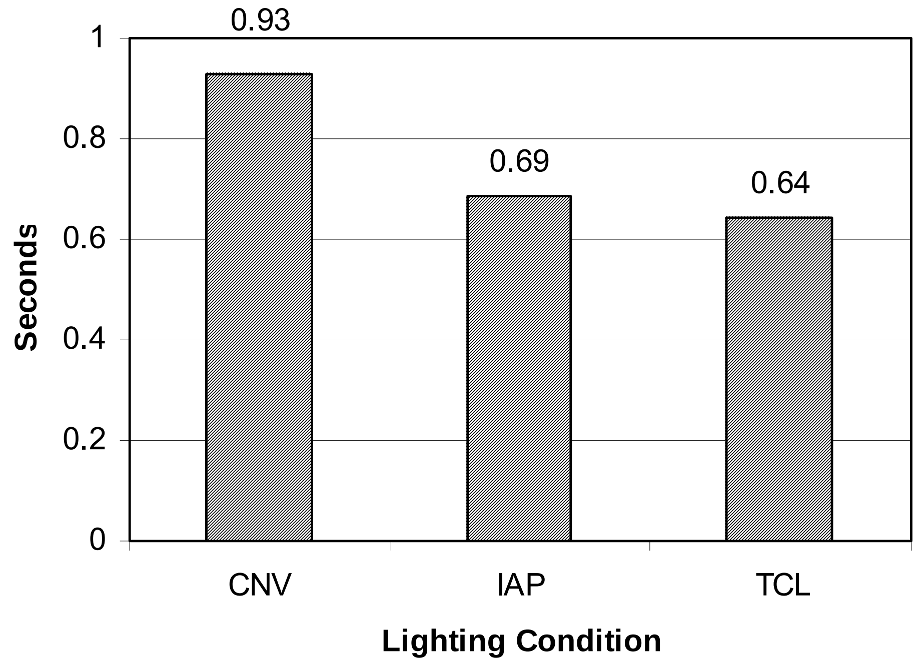


Figure 33. TVB trend effect of Lighting. (Group III results, second exposure, excluding experimenter braking incidents.)

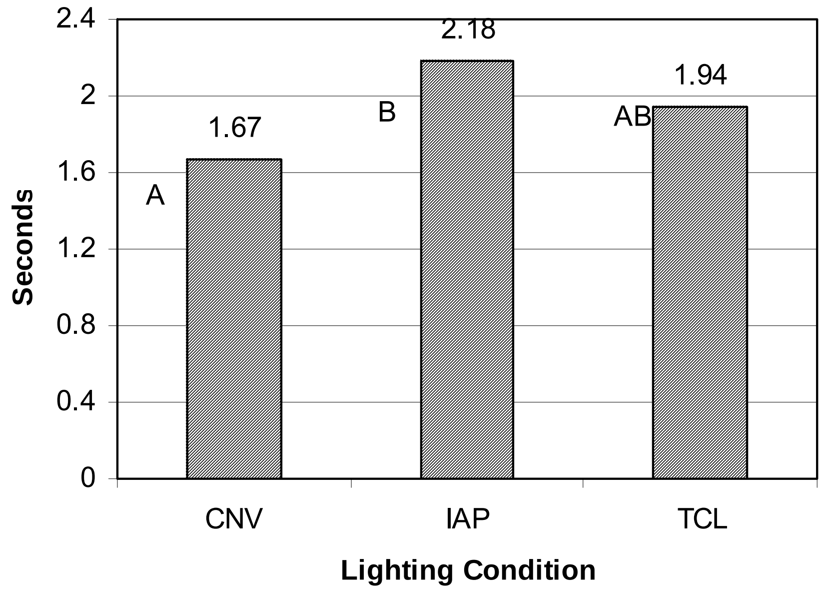


Figure 34. TVPB significant effect of Lighting. (Group III results, excluding experimenter braking incidents.) Means with a common letter do not differ significantly (alpha = 0.05).

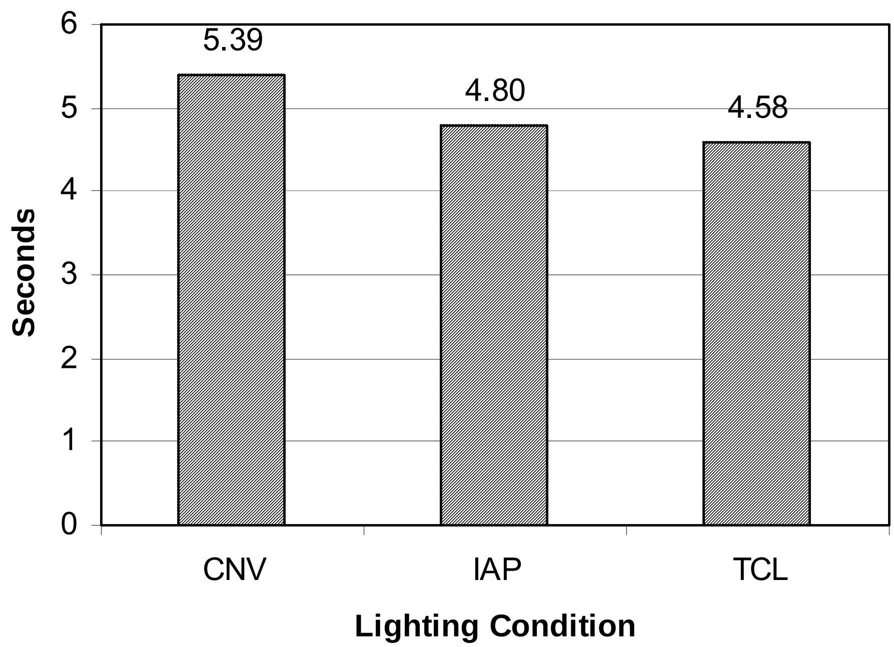


Figure 35. TVFS trend effect of Lighting. (Group III results, second exposure, excluding experimenter braking incidents.)

Table 14. Summary of Group III results with 11 experimenter braking incidents deleted (65 data points for first exposure and 68 data points for second exposure).

Dependent Variable	1st Exposure	2nd Exposure
Forward View to Accelerator Release (TVA)	NS	NS
Forward View to Brake Activation (TVB)	NS	Trend
Forward View to Peak Brake Depression (TVPB)	Significant	NS
Forward View to Full Stop (TVFS)	NS	Trend

The second set of analyses deleted *all data* for those subjects for whom the experimenter had to use the auxiliary brake pedal. This produced a data set with unequal N's in Lighting and equal N's in Exposure (a within subject variable). Accordingly, a mixed-factors two-way analysis of variance could be performed on each dependent variable (four such analyses in total). (This type of procedure was identical to that used in the second unequal N's analysis of Group I.)

The results of the analyses and the corresponding descriptive statistics are presented in Appendix I, Part 2, with a summary of results presented here in Table 15. The main results of these analyses are as follows:

- There is greater variability on first exposure than second.

- There is only one trend and one significant result in the analyses, as follows:

  For TVFS, there is a trend in the main effect of Lighting that approaches significance $F(2,58) = 2.97$, $p = 0.0593$. This result is plotted in Figure 36.

  Also, for TVFS, there is a significant main effect of Exposure $F(2,58) = 4.93$, $p = 0.0304$. The mean for first exposure was 4.5994 sec., and the mean for second exposure was 4.9761 sec.

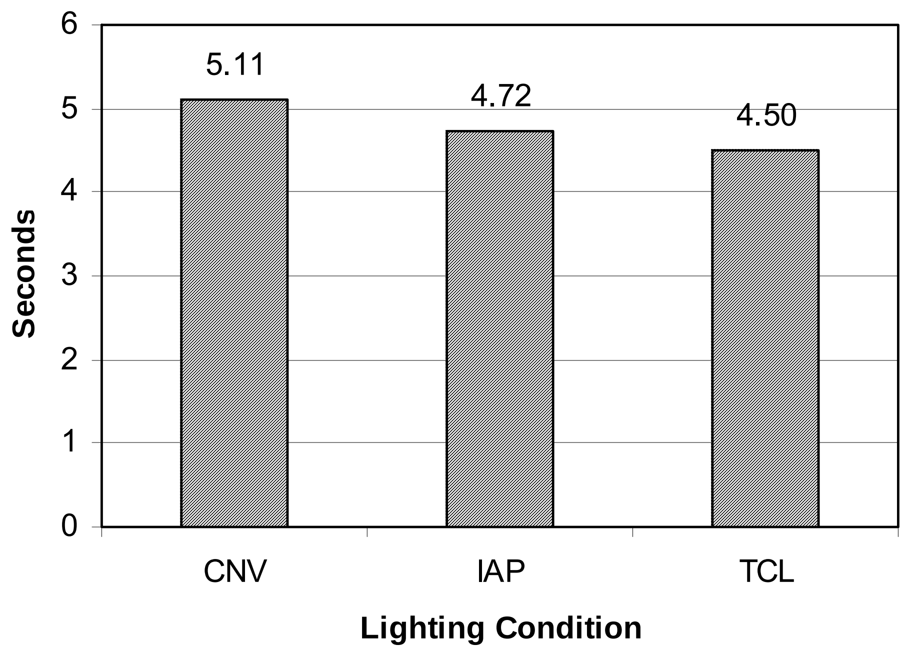


Figure 36. TVFS trend main effect of Lighting. (Group III results, completely eliminating subjects for whom the experimenter braked.)

Table 15. Summary of Group III results with 11 participants deleted due to experimenter braking (122 data points).

Dependent Variable	Lighting	Exposure	Ltg x Exp
Forward View to Accelerator Release (TVA)	NS	NS	NS
Forward View to Brake Activation (TVB)	NS	NS	NS
Forward View to Peak Brake Depression (TVPB)	NS	NS	NS
Forward View to Full Stop (TVFS)	Trend	Significant	NS

Group IV Analyses (Eye Glance Drawing Effect of Lighting)

One additional question that is important to answer is whether or not the enhanced rear lighting tended to draw the driver's eyes to the forward view. The original hypothesis was that the enhanced lighting, (that is, the IAP or TCL) should help to redirect the driver's attention to the deceleration of the lead vehicle. Group IV analyses were devised to test this redirection hypothesis to the extent that the data would allow. This group of analyses differs from earlier analyses in that the new single measure used is an eye-return measure, not a task performance measure. Specifically, the following new dependent measure was defined:

TFV: The time from brake-light illumination to the driver's first glance to the forward view.

Group IV analyses were carried out in two fundamentally different ways. In the first, those subjects who were looking forward at the time when the lights illuminated were included. Thus, the data set would include TFV = 0 values for them. In the second, those subjects who were looking forward at the time when the lights illuminated were excluded. This process resulted in smaller sample sizes, but the remaining data would then concentrate on the drawing effect, if any.

Since TFV was the only dependent measure in these analyses, the analyses are presented sequentially, with the necessary description preceding each. The complete analyses and corresponding descriptive statistics are presented in Appendix J.

The first analysis involved two one-way analyses of variance: one for first exposure and one for second exposure. Cases in which the subjects were looking forward at the time of brake-light illumination were included (TFV = 0 cases were included). Data for experimenter braking were excluded. The results showed no domain of trends or significance. Nevertheless, the sample mean values for return times were much shorter for the enhanced lighting situations. This last statement is included to avoid possible misinterpretation of the results.

The second analysis also involved two one-way analyses of variance: one for first exposure and one for second exposure. Cases in which the subjects were looking forward at the time of brake light illumination were excluded (TFV = 0 cases excluded). As before, data for experimenter braking were excluded. The results showed a trend for second exposure to Lighting, as shown in Figure 37. As can be seen, return of glance to the forward view was substantially shorter for the enhanced-lighting situations.

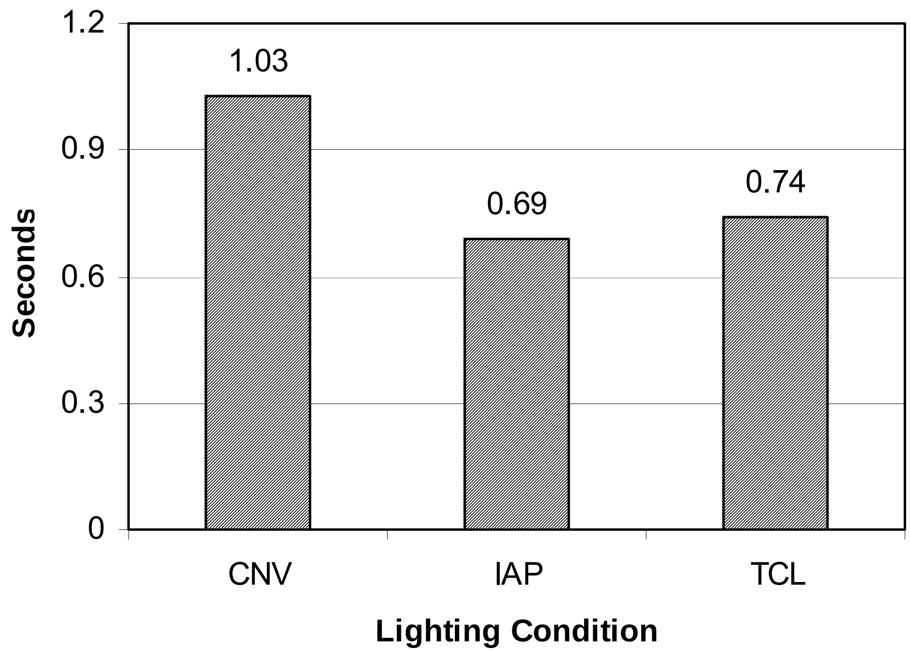


Figure 37. TFV trend effect of Lighting. (Group IV results, second exposure, excluding experimenter braking incidents.)

The third analysis was a single two-way analysis in which TFV = 0 cases were included. In this analysis, all data were excluded for any subject for whom the experimenter had to brake. These conditions permitted a two-way analysis in which Lighting was a between-subjects variable with unequal N's and Exposure was a within-subject variable (of course, with equal N's). The results exhibit a main-effect trend for Lighting (Figure 38). Once again, the IAP and TCL conditions show shorter response times than the CNV condition.

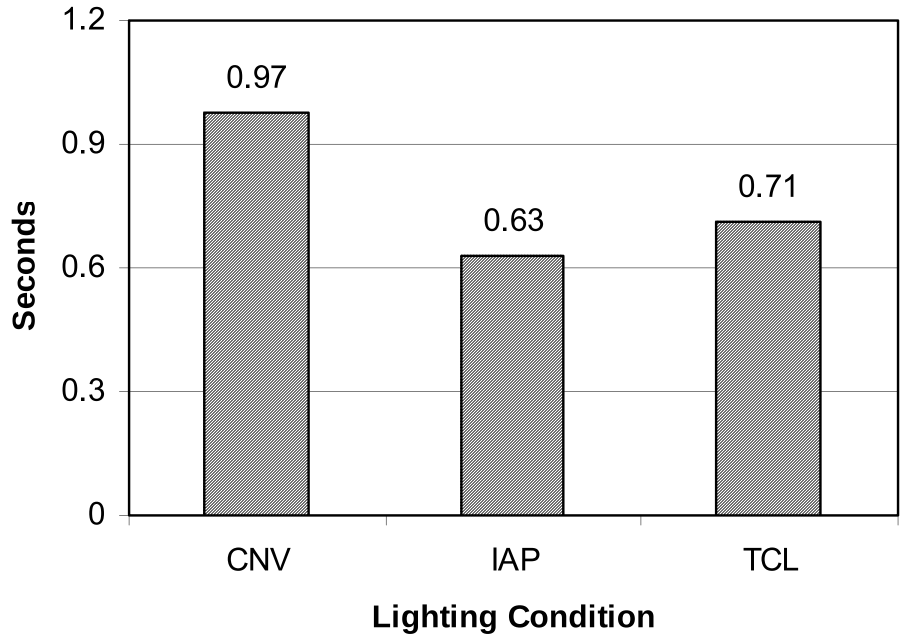


Figure 38. TFV trend main effect of Lighting. (Group IV results, completely excluding subjects for whom experimenter had to brake.)

In the fourth (and last analysis), a single two-way analysis of variance was used. In this case, any subject who had a TFV = 0 was completely eliminated (for both first and second exposure). In addition, any subject for whom the experimenter had to brake was also completely eliminated. This left only subjects who were looking away on both first and second exposures and for whom the experimenter never had to brake. As before, Lighting was a between-subjects independent variable with unequal N's and Exposure was a within-subject independent variable. The results exhibited main-effect trends in both Lighting and Exposure. The Lighting trend is plotted in Figure 39 and shows that the enhanced lighting resulted in reduced "drawing" times. The trend in Exposure had the following mean values: 1.107 seconds on first exposure and 0.875 second on second exposure. These results suggest that drivers learned to use the enhanced lighting to redirect their glances to the forward view.

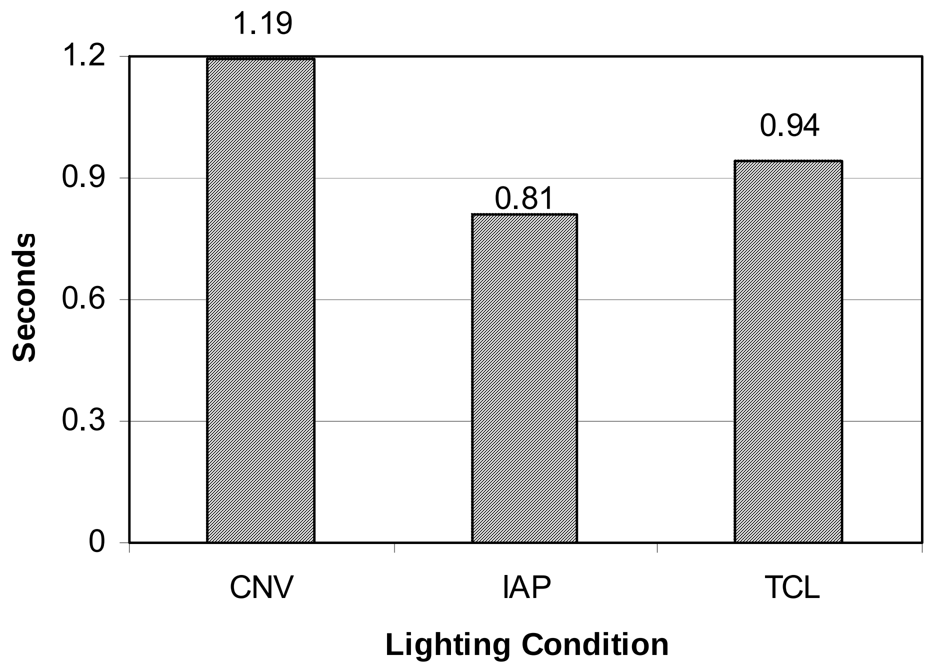


Figure 39. TFV main effect trend of Lighting. (Group IV results, subjects with TFV = 0 completely eliminated and subjects with experimenter braking completely eliminated.)

Questionnaire Data Analysis

Post-experiment questionnaires were filled out by driver/subjects in the two imminent-warning lighting conditions, that is, the TCL and IAP conditions. Questionnaires were not administered to several of the initial driver subjects, simply because opinion data did not initially appear to be necessary. However, after the first few driver/subjects were run, questions arose as to what the driver subjects *thought* of the additional lighting. Thus, a questionnaire was composed and administered. (The questionnaire appears in Appendix F.)

Figures 40 through 49 show the distributions of responses for each question on the questionnaire. The plots are separated according to imminent-warning lighting condition.

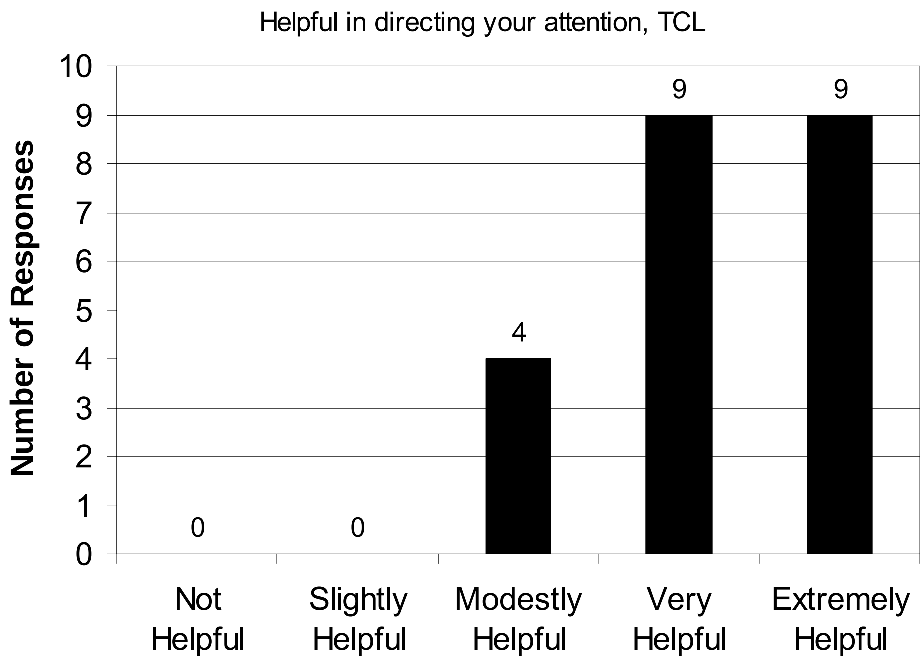


Figure 40. Distribution of responses for the question regarding helpfulness of the additional lighting, TCL condition.

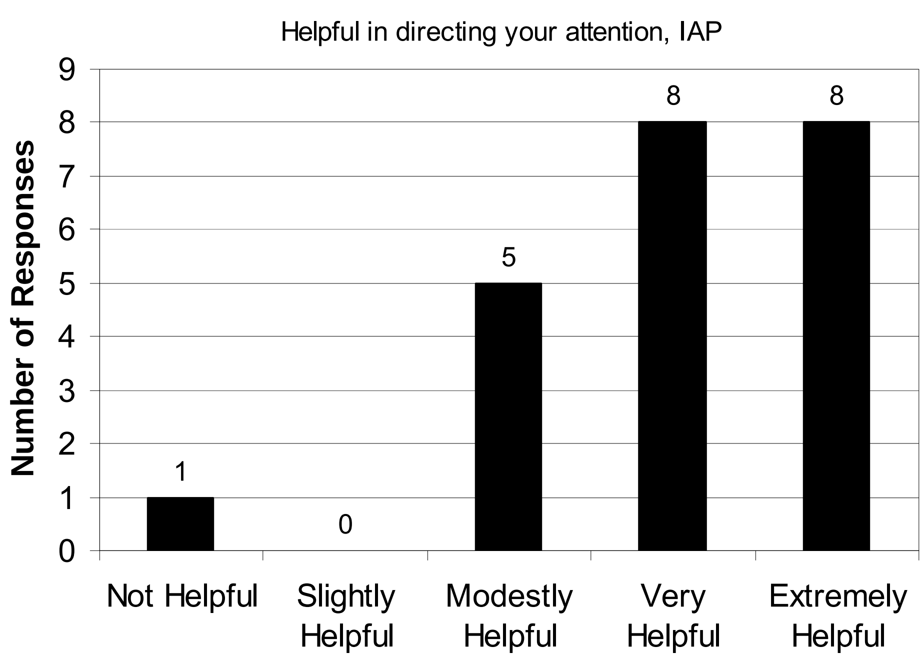


Figure 41. Distribution of responses for the question regarding helpfulness of the additional lighting, IAP condition.

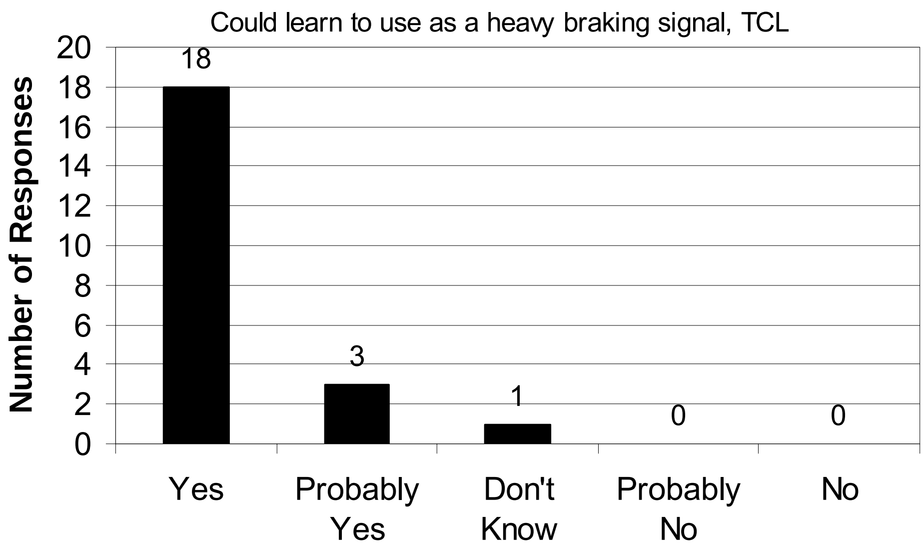


Figure 42. Distribution of responses for the question regarding usefulness as a hard braking signal, TCL condition.

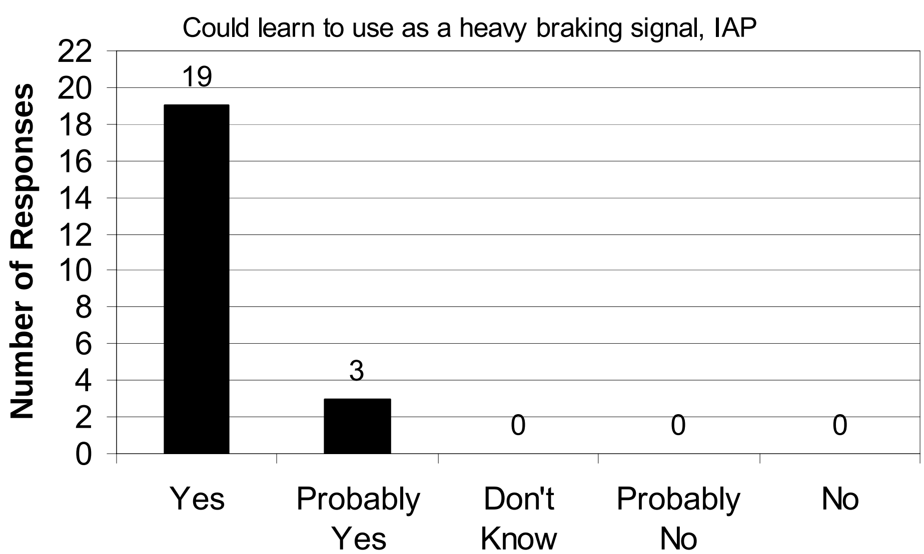


Figure 43. Distribution of responses for the question regarding usefulness as a hard braking signal, IAP condition.

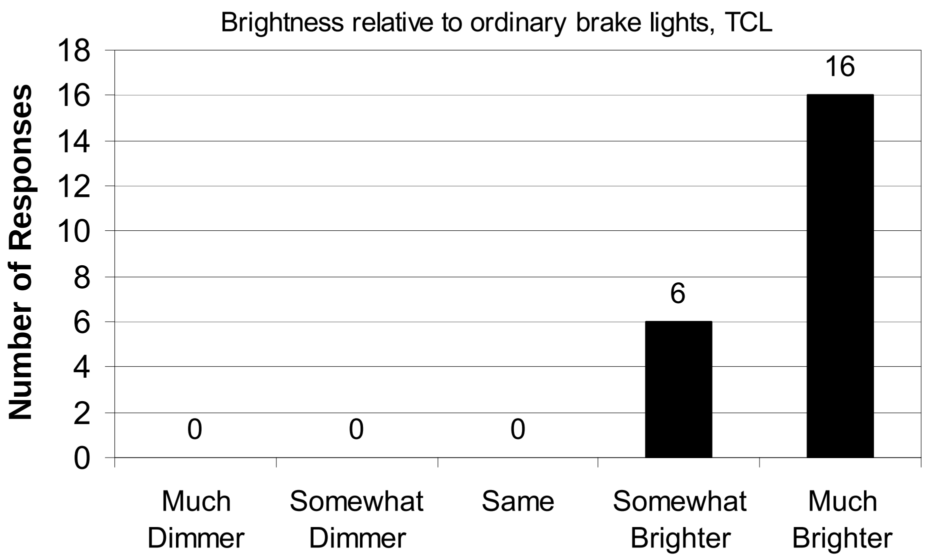


Figure 44. Distribution of responses for the question regarding brightness of the additional lighting relative to conventional lighting, TCL condition.

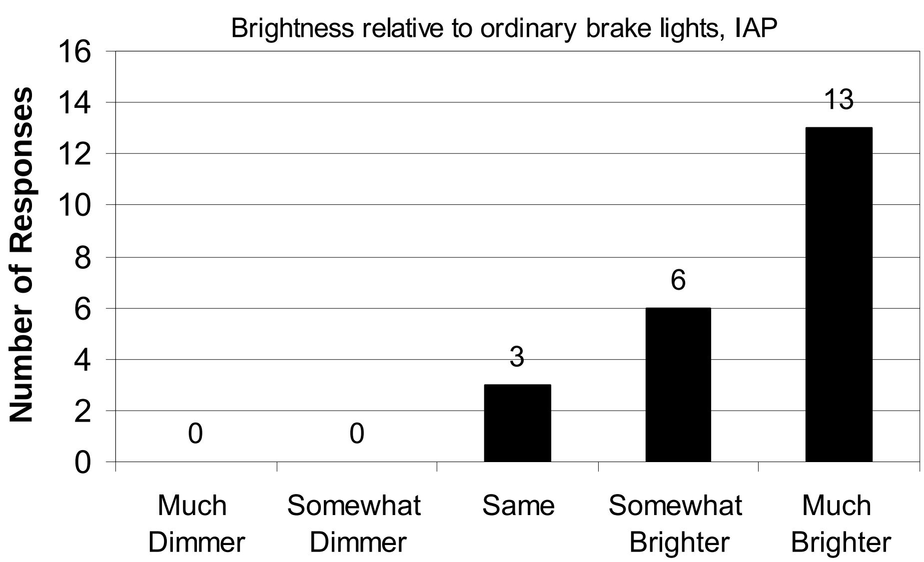


Figure 45. Distribution of responses for the question regarding brightness of the additional lighting relative to conventional lighting, IAP condition.

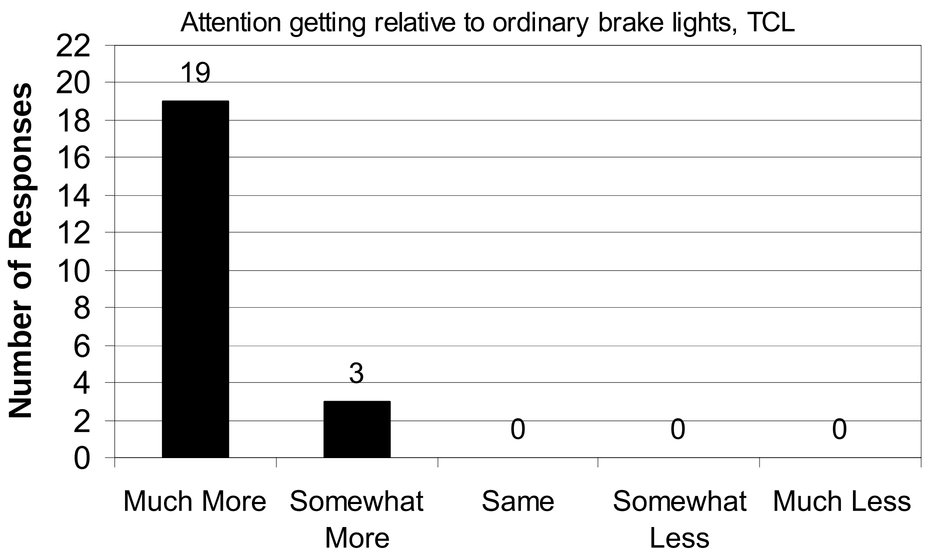


Figure 46. Distribution of responses for the question regarding attention-getting capability of the additional lighting, TCL condition.

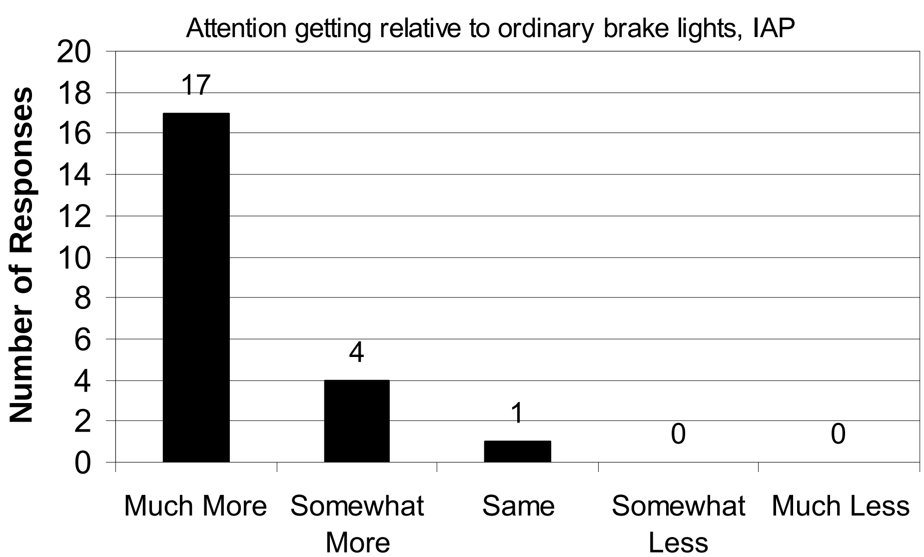


Figure 47. Distribution of responses for the question regarding attention-getting capability of the additional lighting, IAP condition.

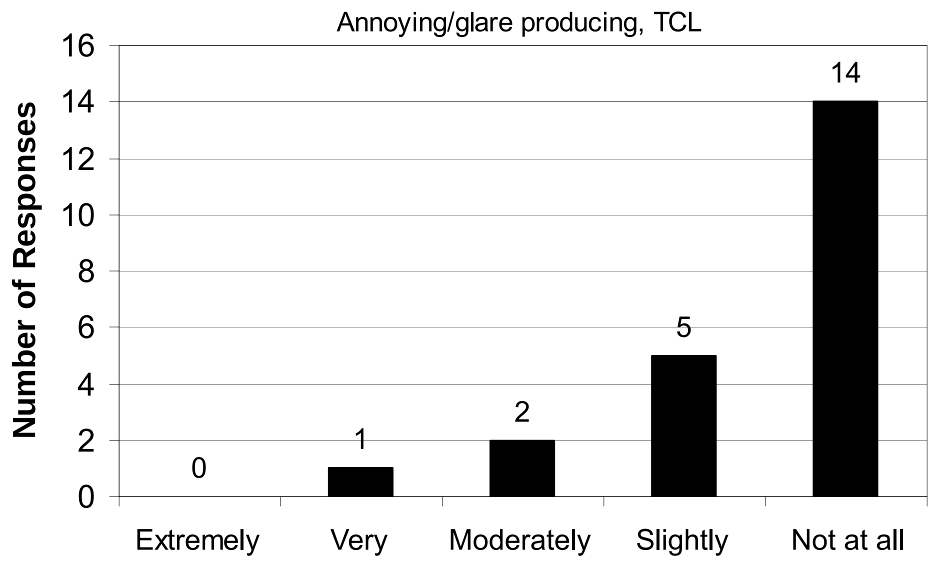


Figure 48. Distribution of responses for the question regarding annoyance and glare of the additional lighting, TCL condition.

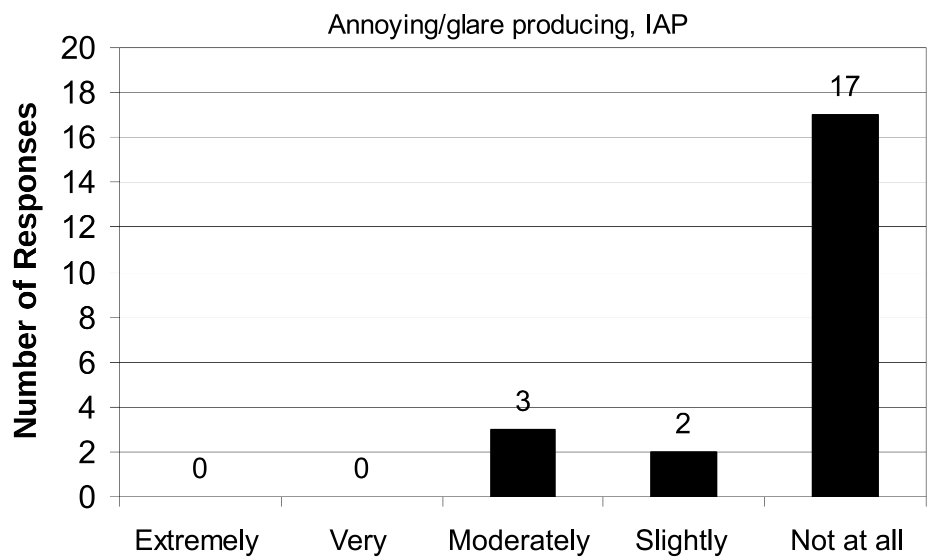


Figure 49. Distribution of responses for the question regarding annoyance and glare of the additional lighting, IAP condition.

These distributions show that the 22 driver/subjects in each condition (for whom the questionnaires were administered) felt the imminent-warning lighting was "valuable." To test whether or not the responses to each question were indeed reliably different from random responses, a set of Kolmogorov-Smirnov One-Sample tests were performed: one for each distribution. In these tests, the comparison distribution was considered to be uniform because each possible response was assumed to be equally likely. The results of the tests are shown in Table 16. As can be seen, all of the distributions depicted in Figures 40 through 49 are significantly different from a uniform distribution ($p < 0.01$). It can, therefore, be assumed that the responses shown in the distributions did not occur by chance.

To determine whether or not there were statistically reliable differences in opinion *between* the two imminent-warning lighting conditions, nonparametric Kolmogorov-Smirnov Two-Sample (two-tailed) tests were performed for each question on the questionnaire. The independent variable in each case was an imminent-warning lighting condition with two levels: TCL and IAP. This statistical test determines whether or not there are significant differences in the cumulative distributions of the driver/subject responses to the questionnaire questions, as a function of the lighting condition. As indicated, 22 driver/subjects completed the questionnaire for the TCL condition, and another 22 driver subjects completed the questionnaire for the IAP condition. The results of the statistical tests are summarized in Table 17. These results show that the responses did not differ significantly between the TCL respondents and the IAP respondents on any question ($p > 0.05$). In fact, the K_D values are far from significant, suggesting that there was no appreciable difference in the responses. This is equivalent to saying that even a much larger sample size would not likely have demonstrated significance.

Table 16. Summary of Kolmogorov-Smirnov One-Sample Tests Comparing Responses on Each Question to a Uniform Distribution.

Question	D_{TCL}	Significance: D_{TCL} (22, 0.01) = 0.342	D_{IAP}	Significance: D_{IAP} (22, 0.01) = 0.342
Helpful in directing your attention	0.4182	yes	0.3545	yes
Could learn to use as a heavy braking signal	0.6182	yes	0.6636	yes
Brightness relative to ordinary brake lights	0.6000	yes	0.4636	yes
Attention getting relative to ordinary brake lights	0.6636	yes	0.5727	yes
Annoying/glare producing	0.4636	yes	0.5727	yes

Table 17. Summary of Kolmogorov-Smirnov Two-Sample Tests on Questionnaire Data Comparing TCL and IAP.

Question	K_D	Significance: K_D (22, 0.05) = 9
Helpful in directing your attention	2	N.S.
Could learn to use as a heavy braking signal	1	N.S.
Brightness relative to ordinary brake lights	3	N.S.
Attention getting relative to ordinary brake lights	2	N.S.
Annoying/glare producing	3	N.S.

The additional handwritten comments provided by the driver/subjects are presented in Appendix K. Seven comments were made by those in the TCL group, and nine were made by those in the IAP group. One recurring comment is that the additional lighting should be located in a higher position on the rear of the vehicle. Other comments are generally positive.

DISCUSSION OF RESULTS OF MAIN EXPERIMENT

Overall Perspective

The results of the main experiment demonstrate that the experiment was a success, in the sense that there is a domain of statistical significance (alpha = 0.05) as well as an additional domain showing trends (defined as statistical results with $0.05 < p < 0.110$). The experiment was enormously complex, and it used ordinary drivers from diverse backgrounds. These drivers covered the full range of ages and educational levels, as well as both genders. Weather conditions varied, in that cloud cover occurred at random, and the sun angle changed.

Examination of the videotapes showed a full range of eye-scanning behavior by the subjects. There were those drivers who "glued" their visual glance to the in-vehicle task and those who used rapid sampling between the in-vehicle task and the forward view. In the former case, the experimenter often had to use the auxiliary brake to prevent a collision. Some drivers exhibited eye "mannerisms," including staring at a neutral point, nervous sideways glances of about 0.1 second, and closures of perhaps 0.3 second that were not suggestive of drowsiness. Such behaviors are not normally considered to be performed for visual information gathering, suggesting that they wasted a visual resource at a time when it should have been used to the maximum extent possible.

The data shown in Appendices G, H, I, and J contain a great deal of variability. In most cases, the magnitude of the standard deviation of data within a given treatment cell is 50 percent or more of the treatment means. Such results suggest great variability and a corresponding difficulty in obtaining significant results with ordinary sample sizes. However, substantial variability would be expected for the type of field experiment that was performed. Nevertheless, as mentioned, a domain of significance and trends was obtained.

Before going into a detailed discussion of the experimental results, it is important to mention that the treatment means indicated an improvement with the enhanced lighting. There were almost no cases in which reverse results were obtained regarding means. Thus, a lack of significance and a lack of trends should not be construed as "zero differences." It is quite clear that much larger samples would have resulted in a much larger domain of significance.

In regard to questionnaire data following the experiment, drivers were quite favorable to the enhanced lighting. In fact, they were in almost unanimous agreement that the enhanced lighting was useful. More will be said about this later, but there is no shortage of positive results in the opinion data.

Discussion of the Group I Analyses (Driver Glance Direction Not Taken into Account)

As indicated, these analyses included virtually all of the data, regardless of eye position at the time of stimulus presentation. Figure 17 shows a 0.24 second reduction in brake activation time when the IAP was used and a 0.32 second reduction when the TCL was used. Figures 18 and 19 show improvements in peak brake depression and total stopping time for both the IAP and TCL. The significant main effect of Lighting on time to a full stop represents time savings of nearly one second. Thus, the enhanced lighting can be said to shorten brake response time and peak braking; combined, these shorten a driver's time to a full stop.

It is also important to note that there are differences between the first and second exposures. Recall that first exposure was "uninformed" and that the second exposure was "informed." Substantial improvements occur between the first and second exposures in accelerator release time, peak closing rate, peak incursion, average incursion, and time to full stop. These results demonstrate a strong learning effect, as expected. Mean values appear in the appendix and also in the text under the Group I heading.

The later analyses in Group I deleted either the specific data for which the experimenter had to brake or all subject data for which the experimenter had to brake. The domain of significance and trends is increased by doing so. Figures 19 through 27 show the results of the various analyses. Perhaps the most important results are those shown in Figures 25 and 27.

Figure 25 shows the overall improvement in brake activation time as a function of Lighting. There is a 0.30-second improvement for the IAP and a 0.44-second improvement for TCL over conventional (CNV) rear lighting. This main effect is statistically significant and can, therefore, be considered reliable. The post hoc tests demonstrate a statistically significant difference between the conventional and enhanced lighting conditions; however, they do not show a significant difference between the IAP and the TCL. Nevertheless, there is reason to believe that the TCL would demonstrate significance if a larger sample had been used.

Similarly, Figure 27 shows a significant overall improvement for time to a full stop. There is a 0.81-second improvement for the IAP and a 0.96-second improvement for the TCL. Post hoc tests showed the same pattern as that for Figure 25, described above.

Generally, the results of Group I suggest there is an overall improvement in driver response using the enhanced lighting and that the TCL is perhaps slightly more effective than the IAP. However, the TCL and IAP are close in their levels of performance improvement. The results also demonstrate a learning effect between the first and second exposures, with braking performance improving with second exposure.

Discussion of the Group II Analyses (Includes Only Drivers Who Took an Early Glance to the Forward View)

In these analyses, drivers had to have an “early glance” to the forward view to be included in the analysis. The concept was to determine whether the enhanced lighting aided drivers who were attentive to the vehicle in front. To determine whether an early glance took place, the criterion of 0.2 second (or more) to the forward view within the first 0.5 second was developed. This criterion had to be met for the subject’s data to be included in the analysis.

There is another possible interpretation of the Group II analyses. Since the driver had to have a short glance forward to be included, it could be said that the driver was looking in the vicinity of the lead vehicle. In other words, the driver would have a small angle of view to the lead vehicle early in the illumination scenario. The peripheral angle to the lead vehicle would then be either small or zero. In this case, the concept would be to determine whether the enhanced lighting aided drivers with a small (or zero) peripheral angle of glance to the lead vehicle.

Not surprisingly, no subject for whom the experimenter had to use the auxiliary brake pedal qualified for this analysis. This result alone demonstrates that drivers who did not respond appropriately to the lead vehicle’s braking also did not do a good job of sampling the forward view.

The results of the Group II analyses suggest that qualifying drivers derived benefits from the enhanced lighting. Figures 28 through 32 demonstrate these results. In particular, brake activation times on the second exposure, as seen in Figure 28, show a 0.23 second improvement for the IAP condition and a 0.36 second improvement for the TCL condition. These results are quite similar to those of Group I (Figure 16), suggesting that results for drivers looking near the lead vehicle had performance improvements similar to those of the entire spectrum of drivers (Group I).

Similarly, Figure 29 shows significant improvements in peak closing rates. Note that peak closing rates may be highest for drivers who brake late; thus, reductions could demonstrate improvement. Also, Figure 31 shows the results for time to a full stop on the second exposure that are almost identical to those of the main effect shown in Figure 27. There is a 0.81 second improvement for the IAP condition and a 0.96 second improvement for the TCL condition. Other results, such as those in Figures 30 and 32, show corresponding improvements. Note in particular the similarity of results in Figure 32 and those of Figure 27 (Group I).

The results of the Group II analyses indicate that drivers with an “early” glance to the forward view derived essentially the same benefit as did *all* of the drivers tested (Group I analyses). It could be said that the *improvements* in braking performance are essentially the same whether or not the driver has an early glance.

Discussion of the Group III Analyses (Driver Performance Once the Driver Returned Glance to the Forward View)

In these analyses, four new dependent measures were defined. These measures were intended to reflect driver responses and performance once the driver returned glance to the forward view. The domain of significance and trends is a bit smaller. Figures 33 through 36 show the results. In regard to braking, Figure 33 shows a trend of improvements for the IAP and TCL conditions, with IAP showing a 0.21-second improvement and TCL showing a 0.28-second improvement. Figure 34 shows a significant change in time to peak braking for the enhanced lighting on first exposure. However, this result is difficult to interpret since whether early or late peak braking is better is dependent on other measures.

Figures 35 and 36 show mean times to a full stop. In both cases the enhanced lighting has the effect of reducing this time, with the TCL condition doing a slightly better job than the IAP condition.

The results of the Group III analyses suggest that the dependent measures selected for analysis are not as explanatory (of the results) as the earlier measures, but they do account for a portion of the overall improvements in performance found in the Group I and II analyses. Specifically, when the driver returns his or her glance to the forward view, some measures of braking performance are improved when the start point is taken as the point of first view.

Discussion of the Group IV Analyses (Eye Glance Drawing Effect of Lighting)

This group of analyses was directed at determining whether the enhanced lighting had an overall "drawing" effect on the drivers' glance patterns. Specifically, did the enhanced lighting induce the drivers to return their glances to the forward view more quickly? If so, such a drawing effect would help to explain how the improvements in braking performance seen in the earlier analyses were achieved. For these analyses, a single new measure was defined, TFV, which was the time from stimulus onset (brakelight illumination) to the first forward eye glance. Those subjects who were looking forward at the time of stimulus onset were handled in two different ways to get a complete picture of the drawing effect: they were given TFV values of zero in some analyses and they were completely eliminated in other analyses.

The results are depicted in Figures 37 through 39. Figures 37 and 38 show the results for cases in which TFV = 0 values were used for subjects looking forward at the time of stimulus onset. The results show a trend of improvement for the second exposure and for a main effect, with the unusual result that the IAP afforded slightly greater improvement than the TCL. However, the difference is not statistically significant since the main effect did not reach significance. Figure 39 shows the result for the situation in which those subjects looking forward at the time of stimulus onset were eliminated. Note that the entire data set is shifted to higher values, as expected, but the same trend exists.

The results of the Group IV analyses suggest that there is indeed a mild drawing effect for the enhanced-lighting conditions. This drawing effect is in the range of 0.36 second for the IAP condition and 0.27 second for the TCL condition. Assuming that these findings are reliable, what would explain this reverse trend between the IAP and TCL conditions? One possible explanation could be that the IAP included a kick circuit that reduced any delays in lamp startup, whereas the TCL did not have a kick circuit. Consequently, there may have been a slower startup for the TCL, which might explain the difference. Neither the drive motor, nor the bulb of the TCL was subjected to a kick voltage. Therefore, if both had been included, slightly improved drawing effects might have been observed.

If the slight delay in the TCL resulted in the reduced drawing effect, why do all other results show the TCL to be slightly better that the IAP? The answer may be that the TCL was more effective once it was fully activated. In other words, it started later but caught up by being brighter and more attention-getting. Of course these are speculations, but they do provide a plausible explanation for the results seen in this experiment.

In general, the drawing effect of the enhanced lighting on drivers' vision helps to explain the braking-performance improvements that were observed in the analyses associated with Groups I and II. If a drawing effect of perhaps 0.30 second is assumed, the results closely track the reductions in brake activation times seen in Groups I and II, which had an average reduction of almost exactly the same duration.

Questionnaire Results

The opinion results show that drivers nearly universally understood and favored the use of the IAP and TCL. Since the two groups tested were between subjects, it is not surprising that a comparison of the two groups did not show appreciable differences. Their only frame of reference would have been ordinary brake lights. In all cases, drivers' responses were significantly different from a uniform distribution ($p < 0.01$), as shown in Table 8, and were not significantly different from one another for the same response ($p > 0.05$), as shown in Table 9. In fact, the criterion values for significance in Table 9 were quite distant, suggesting that even an extremely large sample would not have demonstrated a significant difference between the IAP and TCL conditions.

What do the questionnaire results suggest? Insofar as the subjects are concerned, they "liked" the enhanced lighting and felt that they could benefit from it. Responses suggest that drivers found the enhanced lighting to be attention-getting, and at the same time, they found it to have a tolerable level of discomfort glare. The general impression is that they would be receptive to such additional lighting.

An important comment written on several questionnaires was that the enhanced lighting should be higher. Apparently, subjects wanted the additional lamps to be closer to the CHMSL.

General Perspective on the Results

The overall impression that the results of the experiment provide is that both the IAP and TCL conditions afford an improvement (reduction) in brake reaction times and stopping times. This improvement seems to occur by "drawing" the driver's eye glance to the forward view. The TCL appears to have a slight *performance* advantage over the IAP, even though the IAP has a slightly better eye glance-drawing capability. As mentioned above, this better capability could be attributed to the kick circuit used with the IAP. Therefore, a kick circuit should also be used with the TCL in any future experimentation.

A very important finding that has not been discussed previously concerns the first exposure to the enhanced lighting. In general, the results are more variable for the first exposure when compared to the second exposure. In addition, braking performance is better on the second exposure, in which subjects were informed on the intended use of the enhanced lighting. Nevertheless, first exposure results for the enhanced lighting are generally superior to conventional lighting. Moreover, there was no case in which the enhanced lighting created worse braking behavior. This result is important because it suggests that driver-braking performance would not be harmed if the driver encountered the enhanced lighting without any knowledge of its intended use. On the contrary, there would likely be some improvement.

What type of general improvement could be expected in terms of response time and reductions in crash rates with the use of enhanced lighting? If it is assumed that a typical following-vehicle speed might be 45 mph (66 ft/sec), and if the enhanced lighting can be assumed to reduce response times by between 0.25 and 0.35 seconds (values that are consistent with the results of the experiment), then there would be stopping-distance savings of 16.5 to 23.1 feet (5.03 to 7.04 m). The selected values assume that all other aspects of the scenario are the same. These distances would definitely reduce either the likelihood or severity of an impending rear-end crash. Unfortunately, there appears to be no way to tie these potential improvements to crash or severity reductions based on accident databases because initial separations for vehicles ending in collision scenarios are unknown.

As an alternative, it is probably worthwhile to try to determine the effect of these findings on a typical collision. Again, assume a following vehicle is traveling at 45 mph while the lead vehicle is standing still. How does the faster response time affect the likelihood and severity of the collision? If it is assumed that the following vehicle has a braking deceleration of 0.7 g, then an analysis can be carried out using straightforward kinematic equations. Figure 50 and Table 18 show the results of such an analysis.

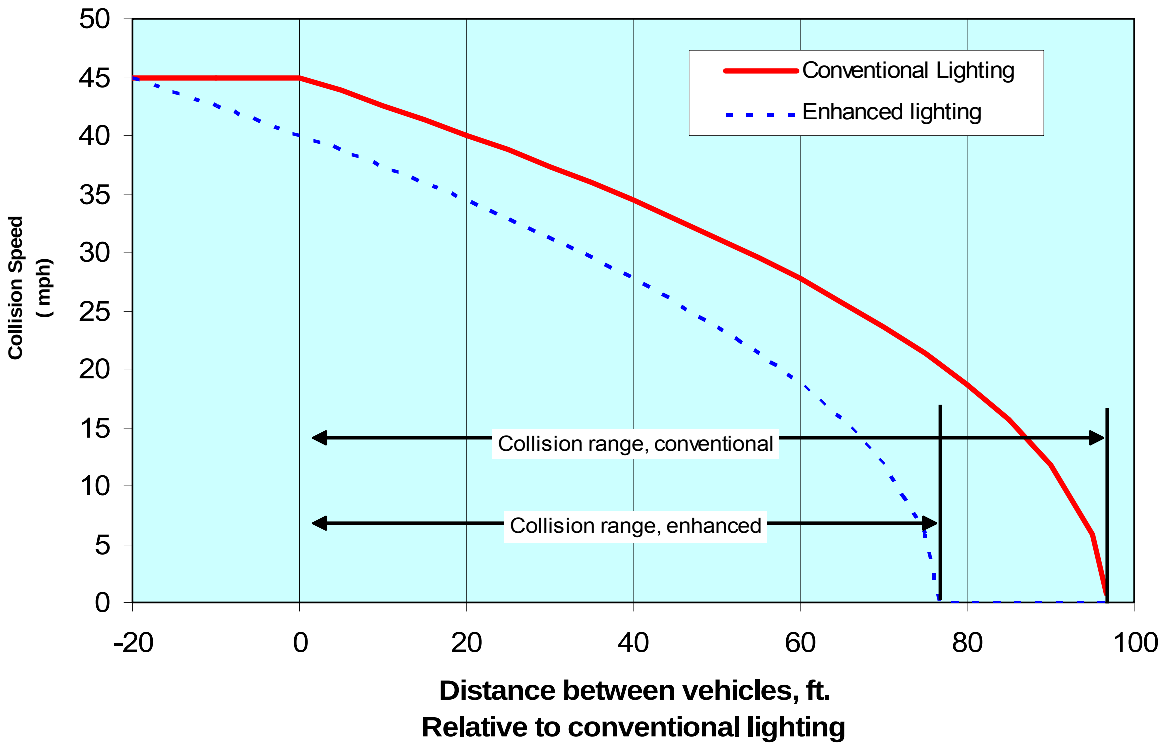


Figure 50. Analytically derived estimate of collision speeds and collision ranges for CNV and enhanced lighting conditions. (Initial speed of following vehicle is 45 mph, 66 ft/sec; lead vehicle is stopped; deceleration of following vehicle is 0.7 g.)

Table 18. Kinetic energy reduction factor at collision for enhanced lighting, referenced to conventional lighting distance and speeds.

CNV Distance at Brake Onset, ft	CNV Collision Speed, mph	Corresponding Enhanced Collision Speed, mph	Kinetic Energy Reduction Factor
0	45.0	40.1	0.79
10	42.6	37.4	0.77
20	40.1	34.4	0.74
30	37.4	31.3	0.70
40	34.4	27.7	0.65
50	31.3	23.6	0.57
60	27.7	18.7	0.45
70	23.6	11.8	0.25
80	18.7	0.0	0.0
90	11.8	0.0	0.0
95	5.8	0.0	0.0

As Figure 50 illustrates, for a collision to occur with conventional rear lighting and for the conditions stated above, braking had to begin somewhere in a following distance range of 0 to 96.6 feet (29.4 m) behind the standing lead vehicle. If not, no collision would occur. These results can be seen by using the upper curve in the figure that shows collision speed as a function of initial range. At 45 mph (66 ft/sec), a vehicle travels 19.7 feet (6.0 m) in 0.30 seconds. For simplicity, this distance will be rounded to 20 feet (6.1 m). Translating the curve by 20 feet on the abscissa then produces the enhanced lighting relative collision speed as a function of conventional lighting range. The enhanced-lighting curve shows that the less severe crashes for conventional lighting would no longer occur (those at ranges of 76.6 to 96.6 feet). In addition, all remaining crashes would be less severe because of lower collision speeds. Table 10 shows the effects of the reduced response time on impact speed and on kinetic energy reduction at impact. The latter is obtained by taking the ratio of collision speeds with and without enhanced lighting and then squaring the result.

These analytical results suggest that if crash ranges are uniformly distributed across the distance range, there would be an approximate 20-percent reduction in number of rear-end crashes, eliminating the least severe crashes. For the 80 percent that are more severe, the kinetic energy dissipated at impact would be reduced according to the factors shown in Table 18.

It should also be recognized that with greater lead time, the following driver may have a better response selection. The experimentation and results presented in this report concentrate on braking and similar aspects. However, if there is greater lead time, there is also a possibility that evasive action could be taken in avoiding a rear-end crash. Conceivably, a small additional reduction in number of rear-end crashes might occur with the enhanced rear lighting, owing to responses other than braking.

The discussion assumes that the enhanced rear lighting is activated on the lead vehicle. In practice, the enhanced lighting would be activated if the lead vehicle's driver braked hard to a stop and the time-out limit was not yet reached. In the closed-loop case, it would be activated at any time that a collision was imminent, whether the lead vehicle was stopped or not. So the graph is applicable to most, but not all, cases in which the lead vehicle was standing (the major exception would be in the open-loop case in which the lead vehicle had been standing on the pavement for a substantial length of time).

Peripheral Detection Aspects

A final observation during the experiment concerned drivers' performance of the critical in-vehicle tasks. These tasks were placed high on the instrument panel along the centerline of the vehicle. The diagonal angle for visual glance to each of the two tasks was approximately 36°, as shown in Table 7. This angle represents the peripheral angle to the enhanced lighting when the driver is attending to the in-vehicle task. The surprising aspect is that 36° is within the peripheral detection angle for the TCL and near the edge of detection for the IAP as determined in the preliminary experiment (Table 5). The diagonal detection angles shown in Table 5 are for diagonal angles with much greater vertical components. In addition, Table 5 summarizes the results for diagonal detection in Task 2. In this case, the diagonal angles to the in-vehicle tasks are well within those for which detection should be possible. Thus, it would seem that drivers should *not* have had trouble detecting the enhanced lighting with peripheral vision.

Video-image analysis showed that some drivers detected the enhanced lighting quickly, others did not detect the enhanced lighting quickly, and still other drivers never detected it. The Group IV results do show a "drawing" effect on vision, but the effect is not as large as might have been expected. What would cause late (or total lack of) detection? It appears that peripheral cue suppression may be responsible. The cognitive load associated with the in-vehicle tasks, which could be considered moderate, combined with the visual load, gives every impression of having interfered with peripheral detection. Certain drivers concentrated on the in-vehicle task, heavily blocking cues associated with the lead vehicle.

Earlier work by Summala, Lamble, and Laakso (1998) also showed suppressed detection of ordinary brake lights when drivers attended to simple in-vehicle tasks. The results of the Task 3 main experiment reported in the current document do not show as large of a suppression effect, owing mainly to the "brighter" and more attention-getting enhanced rear lighting. Clearly, the enhanced lighting "breaks through" for some drivers, but not for all. This result suggests that imminent-warning lighting does indeed create improvement but that some drivers still do not benefit.

The ramifications of peripheral suppression are serious. Some drivers were using their resources to attend to the in-vehicle task and were not detecting what was going on in the forward view. It could be said that, at these times, the vehicle was essentially on "autopilot." Any emergency that did not include an auditory component would likely have been missed. Drivers should be taught to sample often and appropriately. Otherwise, attending to *any* cognitively-loading in-vehicle task becomes very dangerous.

Peripheral cue suppression suggests that to obtain even larger improvements in braking responses than were obtained in the present experiment, the imminent-warning lighting should be supplemented by an in-vehicle (following vehicle) auditory cue: that is, an alarm. This auditory cue must warn the driver in no uncertain terms to look forward immediately. Relatively simple technologies could be used. For example, a small directional microwave transmitter at the back of the lead vehicle could transmit a tone when the imminent-warning lighting is initiated. This signal would be detected by the following vehicle and presented to the driver. Such an arrangement would provide both the auditory and visual stimuli necessary to obtain greater reductions in braking response time. The transmitter/receiver pair could be relatively simple and inexpensive. Design of such a system should take advantage of the CAMP work previously done on crash-warning design (Kiefer et al, 1999). However, complexity should not be made greater than is absolutely necessary to achieve the design goal.

For closed-loop systems (systems in which the lead vehicle contains a radar at the rear), the emergency auditory alarm could be transmitted by some type of modulation on the radar emission. The closed-loop concept would then be as follows: the vehicle equipped with the enhanced rear lighting computes whether or not a rear-end collision is imminent. If a collision is imminent, it activates the imminent-warning rear lighting and transmits the emergency signal to the following vehicle. That vehicle receives the signal with a simple receiver and converts it to an appropriate, urgent, auditory warning.

For open-loop systems (systems without a radar at the rear), when the lead vehicle detects appropriate heavy-braking conditions, it activates the rear lighting and transmits a directional signal to the rear using a simple transmitter.

Why would such a system be preferred to one in which both auditory and visual warnings are presented within the following vehicle? A good case can be made for putting the visual display where the driver should be looking and at the appropriate accommodation distance. Drivers are not likely to be confused by the visual display at the rear of the lead vehicle once they have been informed of its purpose. However, if the visual display is inside the following vehicle, it might be confused with other displays. In any case, the only competing visual display that might be used in the following vehicle would be one that is head-up, with an appropriate virtual image distance.

What type of improvement might be expected if the auditory warning is introduced in the following vehicle? It would seem that that if the enhanced rear lighting alone produces, say, a 0.30-second average improvement in brake response time, the addition of an appropriate auditory alarm should produce approximately 0.50 seconds of average total improvement. Of course, the latter value is an estimate, and the currently reported experiments do not verify it. However, the number does seem realistic, based on experimenter observations of driver behavior in the current experiment.

CONCLUSIONS AND RECOMMENDATIONS

This section of the report is divided into two related subsections. In the first, conclusions deriving from the experimentation carried out in Task 3 are briefly presented. Thereafter, the ramifications of these conclusions are presented in the form of recommendations for future work.

Conclusions

The most important conclusion that can be drawn from Task 3 is that appropriate enhanced lighting, as embodied in the main experiment, demonstrated improvements in brake response times and other related performance measures. These improvements were obtained under realistic experimental conditions in which drivers were, to some extent, preoccupied with in-vehicle tasks. A quantitative overall estimate of improvement for the configurations tested (in terms of brake response times) is 0.25 to 0.35 seconds. This time interval would correspond to about 15 to 30 feet of additional distance in which to stop the vehicle (depending on relative speed and conditions).

The data from the experiment also exhibit great variability, making it difficult to achieve statistical significance with reasonable sample sizes. Standard deviations for many cells were of a size that was 50 percent or more of the sample means. Nevertheless, there was a domain of significance in the experiment sufficient to draw the general conclusion of improvement, with magnitudes as stated above. Trend analyses further support the conclusion.

Virtually all descriptive statistics (namely, sample mean values) favored the enhanced-lighting conditions in terms of performance. Considering that there were hundreds of these values, as shown in the appendices, it would be difficult to draw any other conclusion.

In regard to the comparison of the IAP and the TCL conditions, the TCL seems to have a slight edge in regard to descriptive statistics. However, this edge was not so large as to result in statistical significance in any measure.

There is an improved eye-glance-drawing effect that occurs for the enhanced-lighting conditions. This effect causes the driver to return his or her glance to the forward view more quickly than does conventional rear lighting. It is believed that the drawing effect is the primary reason for reduced braking times and improvements in other performance measures. Nevertheless, there were some drivers who were not drawn to the forward view by the lighting. These drivers appeared to have poor sampling behavior.

While the results for enhanced lighting do show improvement, it is believed that peripheral cue suppression under visual and cognitive load occurred. In particular, when drivers divert their eyes to an in-vehicle task with a moderate cognitive load, they suppress visual detection associated with the forward view. In other words, the forward (driving) scene becomes peripheral and is suppressed to a degree. (The preliminary tests carried out in Task 3, as well as those carried out in Task 2, demonstrate that drivers could detect the imminent-warning lighting with peripheral vision when there was no other task load.)

Because of this result, one of the recommendations made later is for the enhanced lighting to be supplemented eventually by a following-vehicle (in-vehicle) auditory alert.

Driver performance in the first exposure (uninformed) situation showed improvements for the enhanced lighting, but there was greater variability than in the second exposure. Driver performance results improved in the second exposure (informed). It is very important to note that there were *no* observed detrimental effects of uninformed exposure to the enhanced lighting. In fact, as stated, the first exposure resulted in some improvement. The implications of this finding are that the enhanced lighting can be used on public roadways without ensuring that all drivers who might observe it are informed about the reasons for its use and what to do if they observe it.

Drivers "liked" the enhanced lighting, and they definitely felt that they could benefit from it. In fact, the research team has never seen opinion data on questionnaires as uniformly positive as that seen in the questionnaires administered after the Task 3 main experiment. Drivers seemed to understand that the lighting had to be "bright" to get their attention. Nevertheless, they did not find the lighting unacceptable from the standpoint of discomfort glare. Several drivers added the comment that they wanted the enhanced lighting to be at a higher physical location (presumably at, say, CHMSL height). This suggestion has resulted in a recommendation of raising the location of the enhanced lighting. There was no significant difference between the IAP and TCL groups of drivers in any question. In fact, based on distributions, there was no effect at all. Drivers in the two groups had very similar responses.

The open-loop activation criteria used in the Task 3 main experiment appeared to operate reasonably well. In the way of review, the criteria included: activation at 0.35 g of deceleration, and deactivation at 0.15 g of deceleration, but after 4.0 seconds of timeout. However, uphill and downhill situations do create problems. On downhill roadways, the gravity vector biases the values toward overly sensitive activation, and on uphill roadways the gravity vector biases the activation toward somewhat insensitive activation. Furthermore, timeout seems a bit short in some circumstances. Thus, recommendations are made later for changes.

In some instances (namely Group IV results), the IAP condition showed an eye-glance-drawing effect that was greater than that for the TCL (based on descriptive statistics only and not on significance). Nevertheless, stopping distance is shorter for the TCL. It is hypothesized that the kick circuit used with the IAP created this improvement. The TCL did not use a kick circuit, and thus had a slightly slower initial startup. Consequently, a recommendation is made that a kick circuit be used with the TCL in any future experimentation.

The improvement in brake response times was used to develop a theoretical model of estimated reductions in the severity and number of rear-end crashes. This model is analytical and does not use crash databases because such databases do not contain brake activation times. In this theoretical model, the following vehicle must be within a specific range at the time that braking begins for a rear-end collision to occur. Otherwise there would be no collision. If one assumes a uniform distribution over that vehicle range, then the following results accrue for the use of enhanced lighting:

- Approximately 20 percent of rear-end crashes would not occur; these would be the least severe crashes for conventional lighting.

- The severity of the remaining 80 percent would be reduced because of reduced kinetic energy dissipation at impact. Reduction factors are presented in Table 18.

These results are for a stopped lead vehicle and for a following vehicle initially traveling at 45 mph (66 ft/sec). Such conditions are typical for rear-end crashes.

The final conclusion of this report is that the Task 3 experiments successfully met the objectives of refining and field testing two viable candidates for enhanced rear lighting and that these candidates show considerable promise in reducing the number and severity of rear-end crashes.

Recommendations

The results of the research carried out in Task 3 provide sufficient information to define the future path of enhanced-rear-lighting research and development. In this subsection, recommendations are made for that future path. Clearly, since the experiments demonstrated improvement in driver response, work should continue, with particular emphasis on final equipment development and field or fleet testing. Considering that, conservatively, 25 percent of all crashes are rear-end crashes, there is huge potential for reducing the number and severity of crashes.

The TCL has once again shown the most positive results. Specifically, brake response times are reduced, and it appears to be modestly better than the IAP. However, the IAP showed a greater eye-glance-drawing effect in descriptive statistics. The experimenters believe this better drawing effect is a result of the kick circuit that was used. The TCL did not have such a circuit and, thus, had a slightly slower startup. It is believed that use of a kick circuit on both the drive motor and the bulb would improve the eye-glance-drawing capability of the TCL, possibly reducing brake response times further. The kick circuit would bring the motor speed and bulb illumination up to full output more quickly.

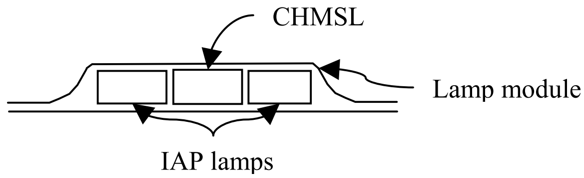
The kick waveform used could be similar to that of the IAP but, of course, would go from an initial high-peak voltage to a steady-state voltage. The initial portion of the waveform should be as shown in Appendix A for the IAP: that is, starting at 26 volts and tapering to 14.8 volts, with a time constant of about 40 milliseconds.

The TCL relies on the use of a high-output parallel beam that is not dispersed by the lens. (The lens simply changes the color of the beam.) The beam is "steered about" by the motorized reflector. It is unlikely that LED devices could perform this operation as well as a high-output halogen lamp, so future efforts should probably remain on the halogen lamp version of the TCL. One such effort should be an attempt to specify the device in non-commercial terms so that its performance could be duplicated by other simple mechanical drive systems.

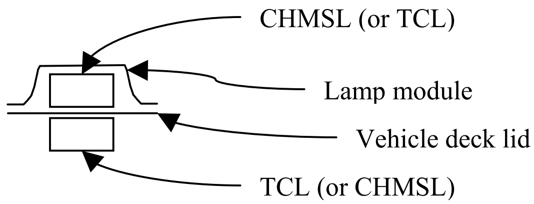
The IAP should also be further pursued with the intent of refinement. The IAP has the advantage that it has no mechanical or electromechanical components. In mass production, electronic drive circuits may be easier and less expensive to fabricate than motorized mechanisms. Specifically, the latest high-output LED arrays should be studied to determine if they can compete (from a light-output standpoint) with the IAP as developed for the current study. (Appendix A contains the specifications for the IAP, including on-axis light output.) If LED arrays can compete in terms of light output, they should be used. Doing so would make the kick circuit unnecessary because such arrays illuminate and extinguish nearly instantaneously. They are also less power consuming, and they are probably more reliable.

In regard to open-loop activation/deactivation criteria, these should be modified slightly. The experimenters observed that downhill activation sensitivity was too high, and uphill sensitivity was too low. This difference is a result of the gravity vector component blending into the accelerometer. There appear to be two possible approaches for correction. The first is to use an appropriately designed high-pass filter on the output of the accelerometer. Doing so would remove the gravity component, which is low in frequency. This may be the simplest approach. Alternatively, brake-line pressure or brake-pedal force could be used. One of these measures could be calibrated to correspond to 0.35 g of deceleration on a flat surface at a specified speed, say, 45 mph (66 ft/sec). Once this threshold is exceeded, the enhanced rear lighting would be activated. In both approaches, deactivation, which was originally specified as deceleration below 0.15 g plus 4.0 seconds of timeout, would have to be modified. The lower deceleration threshold might need to be re-specified, based on analytical study. In any case, the timeout should be increased to 5.0 seconds. In the present experiment, there seemed to be a few circumstances in which 4.0 seconds seemed a bit short.

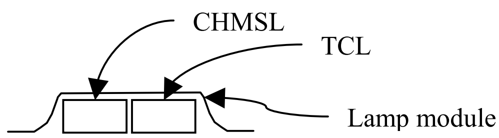
Whether using the TCL or the IAP, the positions of the lamps should be raised. Several drivers stated that they wanted the lamps higher on the lead vehicle. These drivers may be relying on the current CHMSL and may want to see the enhanced lighting in that area. Figures 10 and 11 show the positions used in the Task 3 main experiment. Indeed, the lamps are relatively low: that is, they are somewhat below the standard stoplights and well below the CHMSL. The recommendation, therefore, is to put the TCL or the IAP near the CHMSL, as shown in Figure 51. Figure 51a shows a convenient arrangement in which the IAP pair straddles the current CHMSL. This arrangement results in a compact design that requires very little vehicle modification. The arrangement also forces a CHMSL to have a reasonable form factor (ratio of height to width). Figures 51b and 51c show how the TCL might be integrated vertically and horizontally, respectively. The vertical arrangement requires the use of trunk space for one of the lamps, and the horizontal arrangement requires a slight off-center design for each module. It is unlikely that the off-center approach would cause any problems because the angular shift at the following driver's eyes is so small. Furthermore, any other effects due to misalignment should be negligible.



a. IAP Addition



b. TCL Vertical Addition



c. TCL Horizontal Addition

Figure 51. Presentation of the Imminent-warning Signal along with the CHMSL.

The most important recommendation is that, once the above elements are incorporated, plans for fleet testing should begin. There is obviously no substitute for a fleet test. Such tests might begin on a small scale and then, if successful, be expanded. VTTI is currently involved in a study referred to loosely as the “Hundred-Car Study.” This study has the dual objectives of gathering naturalistic driver behavior data as well as examining more carefully the precise circumstances and behavior just prior to and during crashes. This study is funded by NHTSA (Contract no. DTNH 22 00-C-07007, Task order no. 6). The possibility exists to eventually equip vehicles with the enhanced rear lighting. This could be done as the current hundred-car study data-gathering phase comes to a close. Vehicles could be modified at that time and redeployed.

As future efforts advance toward fleet deployment, decisions should be made regarding whether the first deployment should be open-loop or closed-loop, or possibly both. Closed-loop work thus far has been analytical, but would certainly make use of the display concepts proven in Task 3. If the decision is made to use closed-loop designs, one vehicle should be designed and fabricated as a prototype. Algorithms for activation will need to be verified and possibly modified or simplified. These algorithms were presented in the Task 2 report. Once an appropriate design is fully developed, it could then be duplicated for use in test fleet vehicles.

As mentioned in the conclusions subsection, some effort should be devoted to the use of a supplementary following-car auditory alert. This alert, if properly implemented, should provide even greater benefits than the enhanced lighting alone. The reason for using the additional auditory alert is that some drivers "glue" their vision to in-vehicle tasks. They are, therefore, oblivious to events that are taking place in the forward (driving) scene. (As indicated earlier, they suppress events taking place in their peripheral vision.) If such drivers are redirected to the forward view, they might benefit greatly. It is possible that such drivers are, at the present time, a major factor in the rear-end crash statistics.

Finally, lamp dimming systems should be developed. Clearly, fleet deployment would include the use of vehicles at night. If so, then lamp-dimming systems must be used in the enhanced lighting. Care must be taken to maintain the attention-getting characteristics of the TCL and IAP without creating excessive discomfort-glare for the following driver. Particular attention must be directed toward maintaining rapid illumination rise-times, even though lamp output is not as great as for daytime use.

In summary, the following steps should be included in any follow-on effort:

- Design and develop a TCL kick circuit to improve initial startup.
- Develop generic specifications for the TCL so that equivalent mechanisms can be developed.
- Review LED technology with the objective of converting the IAP to use LED arrays in place of the halogen lamps, if feasible.
- Revise the open-loop activation/deactivation criteria to account for uphill/downhill situations, and increase timeout slightly.
- Raise the positions of the TCL and IAP in future studies and deployment so that these displays are near the "standard" CHMSL position.
- Develop a dimming system for the enhanced lighting so that it can be used at night while maintaining effectiveness (but without excessive discomfort glare).
- Begin planning for fleet deployment. Consider a follow-on project that piggybacks on the Hundred-Car Study, or some other study.
- Make a decision regarding open-loop deployment versus closed-loop deployment. If closed-loop deployment is to be included, develop a prototype vehicle that can be used to test algorithms; modify or simplify them in accordance with tests.
- Consider the development of a following-car supplementary auditory-alarm system. Such a system would be used to re-alert drivers preoccupied with an in-vehicle task or other distraction.

In closing, it should be mentioned that the tests performed under Task 3 were extremely complex and time consuming. It is therefore recommended that future testing should be of two types: developmental testing and fleet testing. The Task 3 results are sufficient to conclude that effective rear-lighting improvements are possible and likely. Specifically, it is *not* recommended that the tests be repeated with refinements. Instead, efforts should be directed toward proving the effectiveness of the lighting in fleet tests.

REFERENCES

Lee, S. E., Wierwille, W. W., and Klauer, S. G. (2002). Enhanced Rear Lighting and Signaling Systems: Literature Review and Analyses of Alternative System Concepts. Washington, DC, National Highway Traffic Safety Administration, Report Number DOT HS 809 425, Task 1 Final Report, Contract DTNH-22-99-C-07235, (March).

Kiefer, R., LeBlanc, D., Palmer, M., Salinger, J., Deering, R., and Shulman, M. (1999). Development and Validation of Functional Definitions and Evaluation Procedures for Collision Warning/Avoidance Systems. Washington, DC, National Highway Traffic Safety Administration, Report Number DOT HS 808 964.

Summala, H., Lamble, D., and Laakso, M. (1998) Driving Experience and Perception of the Lead Car's Braking When Looking at In-Car Targets. *Accident Analysis and Prevention*, *30* (4), 401-407.

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APPENDIX A: FINAL SPECIFICATION OF THE IMMINENT-WARNING BRAKING SIGNALS AND DRIVE WAVEFORMS[1]

Final specifications for the TCL imminent-warning signal

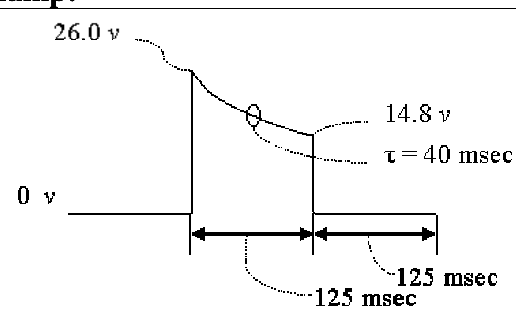
Oscillating (M-sweep) parabolic mirror assembly with lamp socket:
F.S. #TCLF2
Dimensions overall: 11.9cm W x 8.8cm H x 9.6cm D
Frequency of oscillation (full sweeps per second): 3.0
Drive motor for above assembly:
F.S.#Z8572233
Bulb for above assembly:
Sylvania No. 795X-12V, Vertical Filament, Halogen, 50 watts nominal at 12 volts
Base: Bayonet
F.S.#Z8107141A
Bare bulb measured characteristics for applied voltage of 14.8V:
Current: 4.45a
Power: 65.9w
Light output: 180 equivalent cd (measured at a distance of 2 m.)
Lens: Non-dispersive, red tint:[2]
Effective dimensions: 10.7cm W x 7.0 cm H
Overall dimensions: 10.9 cm W x 7.9 cm H x 2.3 cm D
F.S.#Z8575030-A-02
Transmissivity:
0.148
CIE Color coordinates:
x y
0.639 0.354

[1] In these specifications the use of the code "F.S.#" indicates that the unit was obtained from Federal Signal Corporation.

[2] Measurements for lens characteristics are described at the end of this appendix.

Drive voltage for the drive motor:
14.8 volts (constant)
Drive voltage for the bulb:
14.8 volts (constant)
Light-tight compartment housing the components, with lens at front aperture:
Custom-made metal enclosure (excluding lens):
12.7 cm W x 9.5 cm H x 10 cm D
System on-axis light output in equivalent candelas (measured at 8m with 14.8v at lamp):
Max: 3660 cd (drive motor disconnected, turned manually to max output)
Min: 152 cd (drive motor disconnected, turned manually to min output)
Average: 864 cd (drive motor running)

Final specifications for the IAP imminent-warning signal

Stationary parabolic mirror assembly with lamp socket (note that a rotating mirror assembly was modified by fixing the rotation assembly with a screw and nut):	(2 required)
F.S.#Z8583142A	
Dimensions overall[3]: 11.0 cm W x 8.0 cm H x 5.3 cm D	
Bulb (same bulb as the TCL):	(2 required)
Lens: Dispersive, red tint	(2 required)
Effective dimensions: 10.5 cm W x 5.0 cm H	
Overall dimensions: 11.8 cm W x 5.7 cm H x 4.5 cm D	
F.S.#Z8573001A-01	
Transmissivity:	
0.144	
CIE Color coordinates:	
x y	
0.638 0.359	
Light-tight compartment housing the components, with lens at front aperture:	(2 required)
Custom-made metal enclosure (excluding lens): 12.5 cm W x 9.0 cm H x 6.5 cm D	
Lens separation (inner edge to inner edge):	
15.7 cm (6.2 in)	
Frequency of flashing in full-cycles per second: 4.0	
Drive waveform for each lamp:	
	
System on-axis output in equivalent candelas (measured at 8m):	
Average for operating alternating pair: 1376 cd	

[3] The base of the rotating assembly was cut to produce a more compact design. The dimensions given are after the modification.

LENS PARAMETER MEASUREMENTS

Samples of each type of lens were measured to obtain color coordinates. The purpose of the measurements was to provide information on specifications of the lenses for possible future use in any field studies.

To accomplish these measurements, a white surface was illuminated by a white light at a 45° angle (from the perpendicular). Then a Minolta CS 100 Chromometer was aimed at the surface from the opposite 45° angle. The light source was shaded in such a way that its light output could not directly enter the lens of the meter. The chromometer and the light source were each approximately 30 cm from the white surface.

Readings were then made for the white surface and for each type of lens inserted in the optical path of the meter. The focus was not changed when the lens was inserted. The lens was placed approximately 6 cm from the meter, and again, care was taken to ensure that the light source did not directly illuminate the lens. In other words, all light measured was a result of reflection from the white surface.

Table A1 shows the results of the tests. In the table, the first column is the measured luminance. The second and third columns represent the x and y color coordinates using the 1931 CIE standard. Note that ratios of luminance were used to determine the transmissivity of each lens, as specified earlier in this appendix.

As a point of clarification, a non-dispersive lens is one that does not appreciably bend light rays as they pass through the lens, such as a flat pane of glass. A dispersive lens is one that does bend the light rays, similar to the taillight lens of a vehicle. The word dispersive is used to indicate that the light is purposely spread over a specified angle.

Description	Tint	Luminance cd/m²	x	y
White surface (no lens)	NA	2660	0.385	0.399
TCL, non-dispersive	Red	394	0.639	0.354
IAP, dispersive	Red	382	0.638	0.359

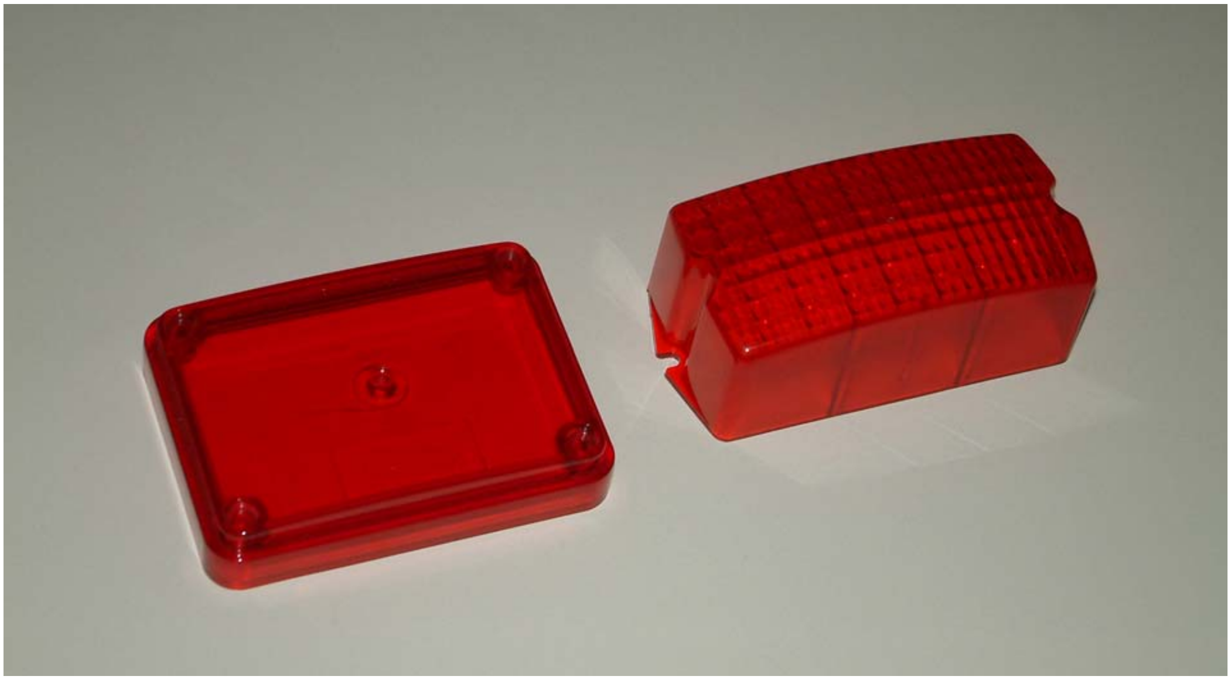


Figure A. 1. Lenses used in the Task 3 experiments: TCL on the left; IAP on the right.

APPENDIX B: EXPERIMENTER'S SCRIPT AND NOTES

Script for Car Following/In-Vehicle Task (RL Task 3) Experiment

1. The surrogate vehicle is 120 feet in front of you right now. Your job will be to maintain that same distance from the surrogate vehicle, regardless of the speed; if the car in front of you speeds up, you speed up to maintain the distance, and if the car in front of you applies the brakes to slow down, you slow down to maintain the distance. Do you understand? You don't need to watch your own speed at all, but the lead vehicle will probably maintain around 30 miles an hour. To maintain this speed without having to worry about applying the brakes very often, you will be driving in second gear at all times. I will remind you to put the car in second gear every time we are stopped here.

2. I will ask you to perform tasks while you drive, so I'm going to point out some of the controls you'll be using to follow my instructions.

   a. This area controls the radio. Press this button to turn it ON and OFF, and turn it to adjust the volume. These buttons are for AM and FM, and this button tunes the exact frequency. This is the treble and this is the base. These are the preset station buttons. Any questions?

   b. This area is for the heating, ventilation, and air conditioning systems, which I'm going to refer to as the ventilation system. To turn it on you press this button right here that says "auto" on it. The first number you see is what the system is set on; to adjust it up and down you press these buttons here with the red and the blue. This button controls how hard the fan is blowing. You're probably familiar with these symbols – they control defrost and which vents the system is using.

   c. Find the windshield wipers low setting (lowest continuous) and turn them on. We'll be using this setting during the experiment. Also note the location of the odometer, trip odometer, and the clock – you may be asked to do tasks related to these displays. Finally, you will notice a lot of colored stickers on the dashboard. I may ask you to find a sticker with a certain number and point to it or tell me what color it is.

   d. When I am about to present a task, I will say OK. Then I will give you a short list of instructions, followed by the word "Begin." Do not begin the task until I say "Begin." For example, I may say "Turn on the radio by pressing the ON button, adjust the volume to a comfortable level, then turn the radio off. Begin." Do you have any questions about the tasks or instructions?

   e. In order that you can focus your full attention to the car-following task, I will not be able to speak to you during the periods between tasks. I just wanted to tell you this so that you won't think I'm being unfriendly. Feel free to ask me any questions relating to the experiment at any time, however.

3. We're going to take a practice loop first so you can practice following that car as well as performing the types of tasks you'll be doing. Then we'll collect data during the following loops. Remember that the purpose of the experiment is to investigate how well drivers can maintain a set following distance while performing various types of in-vehicle tasks.

4. As soon as I tell the lead vehicle we're ready, they'll pull onto the road going about 30 mph. We'll go a total of three loops around the road, and we'll stop right here to recalibrate after every loop. While I go into the back seat and turn on the data collection system, take a minute to study the lead vehicle and determine how far ahead of you it is. Your main job during the experiment will be to maintain that distance while performing tasks. If you don't have any questions and are ready to being, I'll let them know we're ready.

Loop 1, Downhill

1. GREEN SIGN. Signal a moderate LV braking by pressing the ring button on the radio.

2. MIDDLE OF FIRST BRIDGE. Turn on the radio by pressing the ON button. Adjust the volume to a comfortable level, then turn the radio off. Begin.

3. END OF MOBILE SNOW TOWERS. Signal a moderate LV braking by pressing the ring button on the radio.

4. TWO BIG BLOCKS ON RIGHT SIDE OF ROAD. Turn on the ventilation system by pressing the button that says "auto." Tell me what the temperature setting is, then turn the ventilation system off. Begin.

5. RIGHT AFTER LAST FOG-ENABLE GUARD RAIL. Find the sticker with the number 14 and tell me what color it is. Begin.

Loop 1, Uphill

1. MIDDLE OF WIDE SECTION OF ROAD AFTER BRIDGE. Turn on the windshield wipers to the lowest continuous setting. Leave them on for 5 cycles, then turn them back off. Begin.

2. SIGN TRANSOM ACROSS ROAD. Turn on the radio by pressing the ON button. Change it to AM, and then turn the radio off. Begin.

3. BLACK WIND GUAGE ON RIGHT. Turn on the ventilation system by pressing the button that says "auto." Adjust the inside temperature to 75 °, then turn the fan to its lowest level. Turn the ventilation system off. Begin.

Recalibrate

We're going to recalibrate the distance now. Follow the surrogate vehicle around the curve. Drive up until your head is in line with the second speed bump. When you are ready to continue, make sure the car is in second gear and let me know so I can tell the lead vehicle driver.

Loop 2, Downhill

1. END OF FIRST BRIDGE. Read the odometer, and then tell me the reading. Read the trip odometer and tell me the reading. Begin.

2. END OF FIRST TURNAROUND. Signal a moderate LV braking by pressing the ring button on the radio.

3. BEGINNING OF GUARDRAIL. Signal a moderate LV braking by pressing the ring button on the radio.

4. AS SOON AS SPEED REACHES 30 MPH AFTER BRAKING FOR #3. Turn on the ventilation system by pressing the button that says "auto." Check the outside temperature, tell me what it is, then turn the ventilation system off. Begin.

5. AS SOON AS DONE WITH #4. Turn on the radio by pressing the ON button. Change it to FM, press preset 3, then turn the radio off. Begin.

Loop 2, Uphill

1. AT THE VERY END OF THE CONCRETE OF THE SECOND BRIDGE. Adjust the clock to be 3 hours and 7 minutes ahead of its current setting. Begin.

2. DEBRIEF while stopped, using debriefing form.

3. AT CHANGE OF CONCRETE FROM LIGHT GRAY TO BEIGE WITH CONTROL TOWER IN SIGHT. Turn on the radio by pressing the ON button. Change it to AM, then tune it to 1260 AM using the Tuning button (not the Seek button). Turn the radio off. Begin.

4. AFTER TOP BRIDGE JUST BEFORE VERTICAL LINES IN ROAD (| | | | |). Signal a moderate LV braking by pressing the ring button on the radio.

Recalibrate

We're going to recalibrate the distance now. Follow the surrogate vehicle around the curve. Drive up until your head is in line with the second speed bump. When you are ready to continue, make sure the car is in second gear and let me know so I can tell the lead vehicle driver.

Read Additional Statement Explaining Braking Signals (next page)

Statement for Subjects Receiving an imminent-warning Lighting Configuration

In the remainder of your drive, please remember that In-Vehicle Tasks and Braking may occur either separately or at the same time. You are to maintain the 120-foot distance at all times. The braking may be at a low level in which only the ordinary brake lights of the lead vehicle will come on. The braking may also be at a high level, in which case both the ordinary brake lights and the Additional Imminent-warning Lighting will come on. So, remember, if you see only the ordinary brake lights come on, you will need to brake somewhat to maintain the 120-foot distance. If, on the other hand, you see the imminent-warning lighting come on, it is an indication that the lead vehicle is braking relatively hard and <u>YOU</u> will need to brake relatively hard to maintain the desired 120-foot distance.

Do you have any questions?

Statement for Subjects Receiving the Ordinary Brake Light Configuration

In the remainder of your drive, please remember that In-Vehicle Tasks and Braking may occur either separately or at the same time. You are to maintain the 120-foot distance at all times. The braking may be at a low level or at a high level. In both cases the brake lights will come on. So, remember, if the brake lights come on, you should be prepared to brake at an appropriate level to maintain the desired distance of 120 feet.

Do you have any questions?

Loop 3, Downhill

1. BEGINNING OF BRIDGE. Turn on the ventilation system by pressing the button that says "auto." Turn on the front defrost, then turn the fan up to its highest level. Next, turn the ventilation system off. Begin.

2. AT FIRST MOBILE SNOW TOWER. Signal a moderate LV braking by pressing the ring button on the radio.

3. AS SOON AS POSSIBLE AFTER BRAKING IN #2. Report your current speed. If one loop of the Smart road is four miles long, approximately how many loops could you make in an hour? Begin.

4. AT END OF FOG-ENABLED GUARDRAIL. Signal a moderate LV braking by pressing the ring button on the radio.

5. AS SOON AS POSSIBLE AFTER BRAKING IN #4. Turn on the radio by pressing the ON button. Turn the treble all the way up. Turn the radio off. Begin.

Loop 3, Uphill

1. AT END OF RAIL AFTER SECOND BRIDGE. Turn on the ventilation system by pressing the button that says "auto." Tell me what the temperature setting is, then lower it by four degrees. Turn the system off. Begin.

2. AT SIGN TRANSOM ABOVE ROAD. Turn the radio on and tune it to your favorite station using the seek button, then turn the radio off. Begin.

3. AT FIRST MOBILE SNOW TOWER. Point to the sticker with the number 8 and tell me what color it is. Begin.

4. DEBRIEF again if needed.

RETURN TO VTTI MAIN BUILDING, PAY SUBJECT, AND GET SUBJECT QUESTIONNAIRE FILLED OUT FOR SUBJECTS IN THE IMMINENT-WARNING CONDITIONS.

APPENDIX C: RECRUITMENT FLYER

Participants Needed for Smart Road Study

Earn $20 per hour
(study will last about one hour)

Do you have a valid driver’s license?
and
Are you in good health?

If yes to both of these questions, please call

XXXXX XXXX @ 231-XXXX or
email XXXX@vtti.vt.edu

APPENDIX D: INFORMED CONSENT FORM

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Virginia Tech Transportation Institute

Informed Consent for Participants of Investigative Projects

Title of Project:	Evaluation of Car-Following Performance while Performing Secondary Tasks
Principal Investigators:	Dr. Walt Wierwille, Senior Transportation Research Fellow and Associate Director of the Virginia Tech Transportation Institute Dr. Suzie Lee, Research Scientist, Virginia Tech Transportation Institute

I. The Purpose of the Research/Project

You are invited to participate in a study designed to evaluate driver performance while following a vehicle at a set distance and performing various in-vehicle tasks. The experiment will take place at the Smart Road (a controlled, closed driving environment) at the Virginia Tech Transportation Institute. There will be a total of approximately 72 participants of various ages taking part in this study.

II. Procedures

You will be driving, with an experimenter beside you, on a closed, controlled road for approximately one hour. While you are driving, you will be asked to maintain a certain distance from the vehicle in front while performing a variety of in-vehicle tasks such as adjusting the air conditioning or estimating mileage. Please maintain a speed as close as possible to 30 miles per hour while continuing to follow the vehicle in the front. Throughout the course, the lead vehicle may brake every so often, and when this happens you will be expected to maintain a constant following distance of 120 feet by braking as well. The session is expected to last approximately one hour. You will then be paid for your participation.

This vehicle contains sensors and data processing equipment that will capture aspects of your driving behavior. Small video cameras are also mounted in the vehicle. One of these cameras will be directed toward your face while you are driving. The equipment has been installed in such a way that you will hardly be able to notice its presence. It will not interfere with your driving, and there is nothing special that you will need to do in regard to the equipment.

This experiment will consist of five experimental stages:

1. Introductory stage
This stage consists of preliminaries. You will be asked to read the informed consent form. Once you have signed this form, we will also ask to see your driver's license. Once you have completed this stage we will go on to stage 2.

2. Familiarization with the test vehicle
While the instrumented vehicle is parked you will be shown how to operate the vehicle (for example, lights, mirror adjustments, windshield wipers, etc.) as this may be different from your personal vehicle. You will then be asked to set each control to optimize your comfort and driving performance. The experimenter will explain the procedure and lead you through examples of in-vehicle tasks similar to the ones you will be performing. This stage should take approximately 15 minutes.

3. Familiarization with experimental conditions
You will be asked to drive around the test track once or twice and to perform simple tasks while following the lead vehicle so that you get used to maintaining a headway distance as the vehicle in front brakes occasionally. Only when you are comfortable with the conditions of the experiment will the experiment begin.

4. Driving the test track
As you follow the vehicle in front maintaining the instructed speed and the required headway distance, you will be asked to perform a variety of simple tasks. Also expect the vehicle you are following to brake every now and then.

5. Debriefing and Payment
After completing the experiment, you will be asked your opinion about the difficulty of maintaining a headway distance to the lead vehicle while performing secondary tasks. You will then be paid for your participation. It is expected that the complete session will last approximately 1 hour.

III. Risks

The tests described here are believed to pose no more than minimal risk to your health or well-being. In order to minimize any risks associated with driving around the test track, you will be required to maintain a low speed throughout the session. If at any point in the session the experimenter believes that continuing the session would endanger you or the equipment, she will stop the testing.

Participants who have had previous eye injuries and/or surgeries are at an increased risk of further eye injury by participating in this study where risks, although minimal, include the possibility of collision and airbag deployment.

IV. Benefits of the Project

Your participation in this study will provide useful information about car-following behavior and comfort. While there are no direct benefits of participating in this study (apart from payment), you may find the experiment interesting. No guarantee of benefits has been made to encourage you to participate. However, to avoid biasing other potential participants, you are requested not to discuss this study with anyone for at least 8 months after participation.

V. Extent of Anonymity and Confidentiality

The results obtained from this study will be kept completely anonymous. Your name will not appear on data derived from your session. Only a number will differentiate your data from others who take part in the study. This number, and not your name, will also be used in subsequent data analyses and reports.

As indicated, video will be recorded while you are driving. The video includes an image of your face, so that we can determine where you are normally looking. The video will be treated with confidentiality and kept secure. It will be shared only with other qualified researchers, and not published except as noted in the following paragraph.

If at a later time we wish to use the video information for other than research purposes, say, for public education, or if we wish to publish (for research or for other purposes) your likeness or other information from the study that identifies you either directly or indirectly, we will only do so after we have obtained your permission.

VI. Compensation

You will be paid $20 per hour to compensate for the time that you spend participating in this study.

VII. Freedom to Withdraw

You are free to withdraw at any time without penalty. If you choose to withdraw from this study you will be compensated for your time up until that point.

VIII. Medical Treatment and Insurance

If you should become injured in an accident, the medical treatment available to you would be that provided to any driver or passenger by emergency medical services in the vicinity where the accident occurs. The vehicle you will be driving is insured for automobile liability and collision/comprehensive through Virginia Tech and the Commonwealth of Virginia. There is medical coverage for you under this policy. The total policy amount per occurrence is $2,000,000. This coverage would apply in case of an accident, except as noted below.

Under certain circumstances, you may be deemed to be driving in the course of your employment, and your employer's worker's compensation provisions may apply in lieu of the Virginia Tech and Commonwealth of Virginia insurance provisions, in case of an accident. The particular circumstances under which worker's compensation would apply are specified in Virginia law. If worker's compensation provisions do not apply in a particular situation, the Virginia Tech and Commonwealth of Virginia insurance provisions will provide coverage.

Briefly, worker's compensation would apply if your driving for this research can be considered as part of the duties you perform in your regular job. If it is not considered as part of your regular job, then the insurance policy would apply.

IX. Approval of Research

This research project has been approved by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University.

X. Participant's Responsibilities

I voluntarily agree to participate in this study. I have the following responsibilities:

1) I should not participate in this study if I do not have a valid driver's license or if I am not in good health.

2) I should notify the experimenter if at any time I do not want to continue my participation.

3) I should operate the instrumented vehicle in a safe and responsible manner.

4) I should answer all questions truthfully.

XI. Participant's Permission

Check one of the following:

____ I have **not** had an eye injury/eye surgery (including, but not limited to, LASIK, Radial Keratotomy, and cataract surgery.

____ I **have** had eye injury/eye surgery and I have been informed of the possible risks to participants who have had eye surgery. I choose to accept this possible risk to participate in this study.

I have read and understand the Informed Consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

____

Signature **Date**

Should I have any questions about this research project or its conduct, I may contact:

Maryanne DeHart, Research Assistant
Dr. Suzanne E. Lee, Co-Principal Investigator
David Moore, Chair of the Virginia Tech Institutional Review Board

Subjects must be given a complete copy (or duplicate original) of the signed Informed Consent.

APPENDIX E: SUPPLEMENTARY INFORMED CONSENT

DEBRIEFING AND NEW INFORMED CONSENT

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY:
Virginia Tech Transportation Institute

Debriefing and Informed Consent for Participants of Investigative Projects

Title of the Project:	NHTSA Enhanced Rear Signaling, Task 3: Imminent-Warning Signal Evaluation Experiment
Investigators:	Dr. W. W. Wierwille, Dr. S. E. Lee, Maryanne DeHart

The Purpose of this Research

The true purpose of this research is to evaluate novel rear-lighting systems. To do this, we needed to create a situation where you had to brake suddenly while looking away from the vehicle in front of you. If you had been looking directly at the lead vehicle when it decelerated, the data would not have been as indicative of the efficacy of the lighting systems being tested. There was no “correct” or “incorrect” information in the data that you provided. We needed to compare your response to others who (were/were not) presented with a novel rear-lighting system. All known precautions were taken to ensure your complete safety throughout this session and during the presentation of the scenario. We would like to thank you for your participation in this study, as the results may contribute to future improvements of rear signaling and collision avoidance systems. We would also like to ask that you do not talk about the details of this study to others for at least 8 months after your participation as this may invalidate future data that may be collected.

We again assure you that all data will be treated with complete anonymity. Shortly after participating, your name will be separated from the data. A coding scheme will be employed to identify the data by subject number only (for example, Subject No. 3).

I hereby acknowledge the above and give my voluntary consent for my data to be used in this project.

____

Participant's Signature Date

APPENDIX F: POST-EXPERIMENT QUESTIONNAIRE GIVEN TO SUBJECTS IN THE IMMINENT-WARNING LIGHTING CONDITIONS

Questionnaire about the Lighting You Experienced in the Experiment Today

In the experiment today we were testing some new, additional rear lighting, to determine if it was helpful in directing your attention to the vehicle in front of you as it began hard braking. We have your responses recorded, but we would now like to get your *opinion* on this additional lighting. You can help us by answering the questions below honestly. Please circle one response to each question below.

---

1. Do you think that the added lighting was helpful in directing your attention to the vehicle in front of you while the lead driver was braking to a stop?

Not Helpful	Slightly Helpful	Moderately Helpful	Very Helpful	Extremely Helpful

---

2. Assuming the added lighting only occurred when the vehicle ahead was braking hard, do you think you could *eventually* learn to use the lighting to help you detect hard braking by the vehicle ahead? In other words, do you think the added lighting would serve well as a hard braking signal?

Yes	Probably Yes	Don't Know	Probably No	No

---

3. The added lighting was:

Much Dimmer	Somewhat Dimmer	Same	Somewhat Brighter	Much Brighter

than the ordinary brake lights on the lead vehicle. (Note that the ordinary brake lights were also lit whenever the added lighting was lit.)

---

4. The added lighting was:

Much More	Somewhat More	Same	Somewhat Less	Much Less

"attention-getting" than the ordinary brake lights on the lead vehicle.

---

5. Did you find the added lighting to be annoying and/or glare producing?

Extremely	Very	Moderately	Slightly	Not at All

Please add any additional comments that you feel might be helpful to the research team. Feel free to write on the back of this page if you need more space.

Thank you very much for your help.

APPENDIX G

GROUP I RESULTS (driver glance direction not taken into account)

Part 1. Equal n's analysis, all data points; descriptive statistics presented first, followed by ANOVA summary table.

1) Accelerator release time (seconds)

```
------------------------------------- Exposure=1stExposure ------------------------------------
                                       The MEANS Procedure
                                     Analysis Variable : ART

                                   N
                     Lighting    Obs       N            Mean         Std Dev
                     ------------------------------------------------------
                     CNV          24      24          1.5160          0.7706
                     IAP          24      24          1.5321          1.0783
                     TCL          24      24          1.2402          0.7432
                     ------------------------------------------------------

------------------------------------- Exposure=2ndExposure ------------------------------------
                                   N
                     Lighting    Obs       N            Mean         Std Dev
                     ------------------------------------------------------
                     CNV          24      24          1.3685          1.0293
                     IAP          24      24          1.1731          0.4933
                     TCL          24      24          1.1388          0.5933
                     ------------------------------------------------------

------------------------------------- Collapsed across exposure---------------------------------
                                   N
                     Lighting    Obs       N            Mean         Std Dev
                     ------------------------------------------------------
                     CNV          48      48          1.4422          0.9026
                     IAP          48      48          1.3526          0.8491
                     TCL          48      48          1.1895          0.6672
                     ------------------------------------------------------

------------------------------------- Collapsed across lighting --------------------------------
                                     N
                   Exposure        Obs       N            Mean         Std Dev
                   --------------------------------------------------------
                   1stExposure      72      72          1.4294          0.8753
                   2ndExposure      72      72          1.2268          0.7392
                   --------------------------------------------------------
```

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	1.5764	0.7882	0.97	0.3824
SubjNo(Lighting)	69	55.7845	0.8085		
Exposure ‡	1	1.4774	1.4774	2.88	0.0941
Exposure *Lighting	2	0.4531	0.2266	0.44	0.6447
Exposur*SubjNo(Lighting)	69	35.3819	0.5128		
Model	143	94.6734	0.6621		

‡ In this and subsequent ANOVA summary tables, gray shading represents main effects or interactions with p-values < 0.11.

2) Brake activation time (brake reaction time; seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                              The MEANS Procedure
                            Analysis Variable : BRT

                     N
  Lighting         Obs        N            Mean          Std Dev
  ---------------------------------------------------------------
  CNV               24       24          1.7764           0.6919
  IAP               24       24          1.5262           0.5835
  TCL               24       24          1.4415           0.6226
  ---------------------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                     N
  Lighting         Obs        N            Mean          Std Dev
  ---------------------------------------------------------------
  CNV               24       24          1.6286           0.9748
  IAP               24       24          1.3542           0.4741
  TCL               24       24          1.3236           0.5583
  ---------------------------------------------------------------

------------------------------------ Collapsed across exposure---------------------------------
                     N
  Lighting         Obs        N            Mean          Std Dev
  ---------------------------------------------------------------
  CNV               48       48          1.7025           0.8395
  IAP               48       48          1.4402           0.5331
  TCL               48       48          1.3826           0.5880
  ---------------------------------------------------------------

------------------------------------ Collapsed across lighting ---------------------------------
                       N
  Exposure           Obs        N            Mean          Std Dev
  -----------------------------------------------------------------
  1stExposure         72       72          1.5814           0.6414
  2ndExposure         72       72          1.4355           0.7076
  -----------------------------------------------------------------
```

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	2.7919	1.3960	2.36	0.1025
SubjNo(Lighting)	69	40.9006	0.5928		
Exposure	1	0.7664	0.7664	2.51	0.1176
Exposure *Lighting	2	0.0177	0.0088	0.03	0.9715
Exposur*SubjNo(Lighting)	69	21.0506	0.3051		
Model	143	65.5271	0.4582		

3) Peak brake pedal depression for first 4.0 seconds (fraction depression)

```
------------------------------------- Exposure=1stExposure -------------------------------------
                                       The MEANS Procedure
                               Analysis Variable : PeakBrake4sec

                           N
            Lighting     Obs      N            Mean         Std Dev
            -------------------------------------------------------
            CNV           24     24          0.7762          0.1942
            IAP           24     24          0.8258          0.1250
            TCL           24     24          0.7854          0.0969
            -------------------------------------------------------


------------------------------------- Exposure=2ndExposure -------------------------------------
                           N
            Lighting     Obs      N            Mean         Std Dev
            -------------------------------------------------------
            CNV           24     24          0.7329          0.2017
            IAP           24     24          0.8125          0.1125
            TCL           24     24          0.8338          0.1152
            -------------------------------------------------------

------------------------------------- Collapsed across exposure---------------------------------
                           N
            Lighting     Obs      N            Mean         Std Dev
            -------------------------------------------------------
            CNV           48     48          0.7546          0.1971
            IAP           48     48          0.8192          0.1179
            TCL           48     48          0.8096          0.1081
            -------------------------------------------------------

------------------------------------- Collapsed across lighting --------------------------------

                              N
          Exposure          Obs      N            Mean         Std Dev
          ---------------------------------------------------------
          1stExposure        72     72          0.7958          0.1442
          2ndExposure        72     72          0.7931          0.1533
          ---------------------------------------------------------
```

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	0.1127	0.0563	1.70	0.1911
SubjNo(Lighting)	69	2.2924	0.0332		
Exposure	1	0.0002	0.0002	0.02	0.9015
Exposure *Lighting	2	0.0504	0.0252	2.49	0.0903
Exposur*SubjNo(Lighting)	69	0.6986	0.0101		
Model	143	3.1542	0.0221		

4) Peak deceleration for first 4.0 seconds (g's)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                     The MEANS Procedure
                              Analysis Variable : PeakDecel4sec

                              N
              Lighting      Obs      N          Mean         Std Dev
              -----------------------------------------------------
              CNV            24     24       -0.4413          0.1254
              IAP            24     24       -0.4771          0.1172
              TCL            24     24       -0.4438          0.0803
              -----------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------
                              N
              Lighting      Obs      N          Mean         Std Dev
              -----------------------------------------------------
              CNV            24     24       -0.4142          0.1426
              IAP            24     24       -0.4638          0.1141
              TCL            24     24       -0.4904          0.1101
              -----------------------------------------------------

------------------------------------ Collapsed across exposure---------------------------------
                              N
              Lighting      Obs      N          Mean         Std Dev
              -----------------------------------------------------
              CNV            48     48       -0.4277          0.1335
              IAP            48     48       -0.4704          0.1146
              TCL            48     48       -0.4671          0.0982
              -----------------------------------------------------

------------------------------------ Collapsed across lighting --------------------------------

                               N
            Exposure          Obs      N          Mean         Std Dev
            -----------------------------------------------------
            1stExposure        72     72       -0.4540          0.1091
            2ndExposure        72     72       -0.4561          0.1255
            -----------------------------------------------------
```

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	0.0494	0.0247	1.25	0.2921
SubjNo(Lighting)	69	1.3591	0.0197		
Exposure	1	0.0004	0.0004	0.05	0.8206
Exposure *Lighting	2	0.0344	0.0172	2.23	0.1154
Exposur*SubjNo(Lighting)	69	0.5325	0.0077		
Model	143	1.9757	0.0138		

5) Peak closing rate for first 4.0 seconds (mph)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                              The MEANS Procedure
                       Analysis Variable : PkClosRate4sec

                         N
        Lighting       Obs      N           Mean         Std Dev
        -----------------------------------------------------
        CNV             24     24       -22.9549          5.7358
        IAP             24     24       -22.0777          6.7759
        TCL             24     24       -21.1083          4.0217
        -----------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------
                         N
        Lighting       Obs      N           Mean         Std Dev
        -----------------------------------------------------
        CNV             24     24       -20.9981          5.5856
        IAP             24     24       -18.6415          4.9403
        TCL             24     24       -19.5955          6.0373
        -----------------------------------------------------

------------------------------------ Collapsed across exposure---------------------------------
                         N
        Lighting       Obs      N           Mean         Std Dev
        -----------------------------------------------------
        CNV             48     48       -21.9765          5.6873
        IAP             48     48       -20.3596          6.1177
        TCL             48     48       -20.3519          5.1319
        -----------------------------------------------------

------------------------------------ Collapsed across lighting --------------------------------
                          N
      Exposure           Obs      N           Mean         Std Dev
      --------------------------------------------------------
      1stExposure         72     72       -22.0470          5.5989
      2ndExposure         72     72       -19.7450          5.5471
      --------------------------------------------------------
```

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	84.0637	42.0319	1.15	0.3217
SubjNo(Lighting)	69	2515.0457	36.4499		
Exposure	1	190.7642	190.7642	7.37	0.0084
Exposure *Lighting	2	24.3386	12.1693	0.47	0.6270
Exposur*SubjNo(Lighting)	69	1786.9192	25.8974		
Model	143	4601.1314	32.1757		

6) Peak incursion for first 4.0 seconds (feet)

```
------------------------------------- Exposure=1stExposure ------------------------------------
                                    The MEANS Procedure
                            Analysis Variable : PeakIncurs4sec

                               N
                  Lighting    Obs      N            Mean         Std Dev
                  -------------------------------------------------------
                  CNV          24     24         85.2792         14.9565
                  IAP          24     24         78.6736         18.9347
                  TCL          24     24         77.9563         13.7596
                  -------------------------------------------------------

------------------------------------- Exposure=2ndExposure ------------------------------------
                               N
                  Lighting    Obs      N            Mean         Std Dev
                  -------------------------------------------------------
                  CNV          24     24         74.5042         17.8521
                  IAP          24     24         66.1236         17.3927
                  TCL          24     24         72.1625         17.4785
                  -------------------------------------------------------
------------------------------------- Collapsed across exposure---------------------------------
                               N
                  Lighting    Obs      N            Mean         Std Dev
                  -------------------------------------------------------
                  CNV          48     48         79.8917         17.1776
                  IAP          48     48         72.3986         19.0708
                  TCL          48     48         75.0594         15.8341
                  -------------------------------------------------------

------------------------------------- Collapsed across lighting --------------------------------
                                N
                Exposure       Obs      N            Mean          Std Dev
                ---------------------------------------------------------
                1stExposure     72     72         80.6363          16.1541
                2ndExposure     72     72         70.9301          17.6873
                ---------------------------------------------------------
```

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	1385.2254	692.6127	1.94	0.1513
SubjNo(Lighting)	69	24621.9397	356.8397		
Exposure	1	3391.6064	3391.6064	16.21	0.0001
Exposure *Lighting	2	294.4416	147.2208	0.70	0.4983
Exposur*SubjNo(Lighting)	69	14437.6677	209.2416		
Model	143	44130.8808	308.6076		

7) Average incursion for first 4.0 seconds (feet)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                     The MEANS Procedure
                              Analysis Variable : AvgIncurs4sec

                                    N
                     Lighting     Obs       N            Mean         Std Dev
                     ------------------------------------------------------
                     CNV           24      24         34.4713          6.7557
                     IAP           24      24         32.1198          6.1090
                     TCL           24      24         32.6251          5.9368
                     ------------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                                    N
                     Lighting     Obs       N            Mean         Std Dev
                     ------------------------------------------------------
                     CNV           24      24         29.6802          7.6996
                     IAP           24      24         26.9950          7.0109
                     TCL           24      24         30.4804          7.3507
                     ------------------------------------------------------
------------------------------------ Collapsed across exposure---------------------------------

                                    N
                     Lighting     Obs       N            Mean         Std Dev
                     ------------------------------------------------------
                     CNV           48      48         32.0758          7.5635
                     IAP           48      48         29.5574          7.0016
                     TCL           48      48         31.5527          6.6981
                     ------------------------------------------------------

------------------------------------ Collapsed across lighting --------------------------------

                                     N
                   Exposure        Obs       N            Mean         Std Dev
                   --------------------------------------------------------
                   1stExposure      72      72         33.0721          6.2712
                   2ndExposure      72      72         29.0519          7.4084
                   --------------------------------------------------------
```

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	169.5550	84.7775	1.36	0.2630
SubjNo(Lighting)	69	4295.6242	62.2554		
Exposure	1	581.8454	581.8454	18.59	<.0001
Exposure *Lighting	2	63.9819	31.9910	1.02	0.3653
Exposur*SubjNo(Lighting)	69	2159.9083	31.3030		
Model	143	7270.9149	50.8456		

8) Time to full stop (seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                   The MEANS Procedure
                                Analysis Variable : TTFS

                                N
                    Lighting    Obs      N            Mean         Std Dev
                    ----------------------------------------------------------
                    CNV          24     24          5.8912          1.4787
                    IAP          24     24          5.2437          0.6749
                    TCL          24     24          5.2892          0.5568
                    ----------------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                                N
                    Lighting    Obs      N            Mean         Std Dev
                    ----------------------------------------------------------
                    CNV          24     24          6.2458          1.5848
                    IAP          24     24          5.3053          0.7171
                    TCL          24     24          5.0923          0.6123
                    ----------------------------------------------------------
------------------------------------ Collapsed across exposure---------------------------------

                                N
                    Lighting    Obs      N            Mean         Std Dev
                    ----------------------------------------------------------
                    CNV          48     48          6.0685          1.5268
                    IAP          48     48          5.2745          0.6896
                    TCL          48     48          5.1907          0.5874
                    ----------------------------------------------------------
------------------------------------ Collapsed across lighting --------------------------------

                                 N
                  Exposure       Obs      N            Mean         Std Dev
                  ----------------------------------------------------------
                  1stExposure     72     72          5.4747          1.0221
                  2ndExposure     72     72          5.5478          1.1646
                  ----------------------------------------------------------
```

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	22.5274	11.2637	6.26	0.0032
SubjNo(Lighting)	69	124.0957	1.7985		
Exposure	1	0.1923	0.1923	0.60	0.4403
Exposure *Lighting	2	1.8276	0.9138	2.86	0.0639
Exposur*SubjNo(Lighting)	69	22.0192	0.3191		
Model	143	170.6621	1.1934		

GROUP I RESULTS (Continued)

Part 2. Unequal n's analysis.

A. Unequal n's analysis, deleting data points where experimenter hit the aux. brake first; descriptive statistics presented first, followed by ANOVA summary table.

1) Accelerator release time (seconds)

```
----------------------------------  Exposure    =1stExposure ----------------------------------

                                   The MEANS Procedure

                                 Analysis Variable : ART

                                 N
                    Lighting    Obs            Mean         Std Dev       N
                    -------------------------------------------------------
                    CNV          23          1.5006          0.7841      23

                    IAP          20          1.2117          0.5533      20

                    TCL          22          1.1014          0.5917      22
                    -------------------------------------------------------

----------------------------------  Exposure    =2ndExposure ----------------------------------

                                 Analysis Variable : ART

                                 N
                    Lighting    Obs            Mean         Std Dev       N
                    -------------------------------------------------------
                    CNV          23          1.3264          1.0311      23

                    IAP          23          1.1689          0.5040      23

                    TCL          22          1.0454          0.5251      22
                    -------------------------------------------------------
```

1st exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	1.9132	0.9566	2.22	0.1170
Lighting*SubjNo	62	26.6950	0.4306		
Model	64	28.6081	0.4470		

2nd exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	0.8942	0.4471	0.84	0.4381
Lighting*SubjNo	65	34.7684	0.5349		
Model	67	35.6626	0.5323		

2) Brake activation time (brake reaction time; seconds)

```
----------------------------------- Exposure    =1stExposure -----------------------------------

                                     The MEANS Procedure

                                 Analysis Variable : BRT

                          N
       Lighting         Obs            Mean         Std Dev        N
       ------------------------------------------------------------
       CNV               23          1.7867          0.7056       23

       IAP               20          1.4180          0.5160       20

       TCL               22          1.3635          0.5745       22
       ------------------------------------------------------------

----------------------------------- Exposure    =2ndExposure -----------------------------------

                                 Analysis Variable : BRT

                          N
       Lighting         Obs            Mean         Std Dev        N
       ------------------------------------------------------------
       CNV               23          1.6051          0.9897       23

       IAP               23          1.3683          0.4796       23

       TCL               22          1.2502          0.5230       22
         ------------------------------------------------------------
```

1st exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	2.3766	1.1883	3.21	0.0471
Lighting*SubjNo	62	22.9424	0.3700		
Model	64	25.3191	0.3956		

2nd exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	1.4773	0.7386	1.48	0.2343
Lighting*SubjNo	65	32.3533	0.4977		
Model	67	33.8306	0.5049		

3) Peak brake pedal depression for first 4.0 seconds (fraction depression)

```
---------------------------------- Exposure    =1stExposure ----------------------------------
                                   The MEANS Procedure

                            Analysis Variable : PeakBrake4sec

                           N
                Lighting    Obs            Mean          Std Dev       N
                -----------------------------------------------------------
                CNV          23          0.7713          0.1971      23

                IAP          20          0.7925          0.1083      20

                TCL          22          0.7727          0.0879      22
                -----------------------------------------------------------

---------------------------------- Exposure    =2ndExposure ----------------------------------

                            Analysis Variable : PeakBrake4sec

                           N
                Lighting    Obs            Mean          Std Dev       N
                -----------------------------------------------------------
                CNV          23          0.7213          0.1979      23

                IAP          23          0.8061          0.1105      23

                TCL          22          0.8186          0.1080      22
                -----------------------------------------------------------
```

1st exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	0.0058	0.0029	0.15	0.8643
Lighting*SubjNo	62	1.2393	0.0200		
Model	64	1.2451	0.0195		

2nd exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	0.1276	0.0638	3.02	0.0559
Lighting*SubjNo	65	1.3751	0.0212		
Model	67	1.5027	0.0224		

4) Peak deceleration for first 4.0 seconds (g's)

```
----------------------------------  Exposure    =1stExposure ----------------------------------
                                     The MEANS Procedure

                              Analysis Variable : PeakDecel4sec

                                 N
                    Lighting    Obs            Mean         Std Dev      N
                    -----------------------------------------------------
                    CNV          23         -0.4374          0.1268     23

                    IAP          20         -0.4525          0.1049     20

                    TCL          22         -0.4377          0.0812     22
                    -----------------------------------------------------

----------------------------------  Exposure    =2ndExposure ----------------------------------

                              Analysis Variable : PeakDecel4sec

                                 N
                    Lighting    Obs            Mean         Std Dev      N
                    -----------------------------------------------------
                    CNV          23         -0.4030          0.1347     23

                    IAP          23         -0.4565          0.1109     23

                    TCL          22         -0.4732          0.0945     22
                    -----------------------------------------------------
```

1st exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	0.0031	0.0015	0.14	0.8724
Lighting*SubjNo	62	0.7010	0.0113		
Model	64	0.7041	0.0110		

2nd exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	0.0609	0.0305	2.31	0.1075
Lighting*SubjNo	65	0.8577	0.0132		
Model	67	0.9186	0.0137		

5) Peak closing rate for first 4.0 seconds (mph)

```
------------------------------------- Exposure=1stExposure ------------------------------------
                                        The MEANS Procedure

                              Analysis Variable : PkClosRate4sec

                                    N
                     Lighting    Obs       N            Mean         Std Dev
                     ------------------------------------------------------
                     CNV          23      23        -23.0992          5.8200

                     IAP          20      20        -20.8711          6.0224

                     TCL          22      22        -20.7277          3.9459
                     ------------------------------------------------------

------------------------------------- Exposure=2ndExposure ------------------------------------

                              Analysis Variable : PkClosRate4sec

                                    N
                     Lighting    Obs       N            Mean         Std Dev
                     ------------------------------------------------------
                     CNV          23      23        -20.4111          4.8960

                     IAP          23      23        -18.7613          5.0156

                     TCL          22      22        -18.4202          4.7102
                     ------------------------------------------------------
```

1st exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	79.0530	39.5265	1.39	0.2564
Lighting*SubjNo	62	1761.3020	28.4081		
Model	64	1840.3550	28.7555		

2nd exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	51.5318	25.76589973	1.08	0.3447
Lighting*SubjNo	65	1546.6876	23.79519		
Model	67	1598.2193	23.8540		

6) Peak incursion for first 4.0 seconds (feet)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                    The MEANS Procedure

                            Analysis Variable : PeakIncurs4sec

                              N
                 Lighting    Obs       N            Mean         Std Dev
                 -----------------------------------------------------
                 CNV          23      23         86.0391         14.8113

                 IAP          20      20         76.1683         18.4801

                 TCL          22      22         77.4159         14.2210
                 -----------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                            Analysis Variable : PeakIncurs4sec

                              N
                 Lighting    Obs       N            Mean         Std Dev
                 -----------------------------------------------------
                 CNV          23      23         72.9652         16.5456

                 IAP          23      23         66.6072         17.6178

                 TCL          22      22         69.9136         16.1087
                 -----------------------------------------------------
```

1st exposure

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	1278.9228	639.4614	2.55	0.0864
Lighting*SubjNo	62	15561.9928	250.9999		
Model	64	16840.9156	263.1393		

2nd exposure

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	465.1152	232.5576	0.83	0.4423
Lighting*SubjNo	65	18300.4780	281.5458		
Model	67	18765.5932	280.0835		

7) Average incursion for first 4.0 seconds (feet)

```
------------------------------------ Exposure=1stExposure ------------------------------------

                                     The MEANS Procedure

                              Analysis Variable : AvgIncurs4sec

                                N
                  Lighting    Obs       N            Mean         Std Dev
                  ------------------------------------------------------
                  CNV          23      23         34.6803          6.8278

                  IAP          20      20         31.7222          6.4968

                  TCL          22      22         32.8969          5.4187
                  ------------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                              Analysis Variable : AvgIncurs4sec

                                N
                  Lighting    Obs       N            Mean         Std Dev
                  ------------------------------------------------------
                  CNV          23      23         29.2892          7.6250

                  IAP          23      23         26.8572          7.1351

                  TCL          22      22         30.0669          7.5127
                  ------------------------------------------------------
```

1st exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	96.0244	48.0122	1.22	0.3028
Lighting*SubjNo	62	2444.1719	39.4221		
Model	64	2540.1963	39.6906		

2nd exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	127.1745	63.5872	1.15	0.3220
Lighting*SubjNo	65	3584.3743	55.1442		
Model	67	3711.5488	55.3963		

8) Time to full stop (seconds)

```
----------------------------------  Exposure    =1stExposure ----------------------------------

                              The MEANS Procedure

                           Analysis Variable : TTFS

                        N
          Lighting    Obs             Mean         Std Dev       N
          -------------------------------------------------------
          CNV          23           5.9356          1.4955      23

          IAP          20           5.2604          0.7295      20

          TCL          22           5.2504          0.5661      22
          -------------------------------------------------------

----------------------------------  Exposure    =2ndExposure ----------------------------------

                           Analysis Variable : TTFS

                        N
          Lighting    Obs             Mean         Std Dev       N
          -------------------------------------------------------
          CNV          23           6.2839          1.6092      23

          IAP          23           5.3403          0.7120      23

          TCL          22           5.1067          0.6320      22
          -------------------------------------------------------
```

1st exposure

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	6.8824	3.4412	3.23	0.0463
Lighting*SubjNo	62	66.0440	1.0652		
Model	64	72.9265	1.1395		

2nd exposure

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	17.6431	8.8215	7.49	0.0012
Lighting*SubjNo	65	76.5064	1.1770		
Model	67	94.1494	1.4052		

GROUP I RESULTS (Continued)

<u>Part 2. Unequal n's analysis (continued)</u>

B. Unequal n's analysis, completely eliminating those subjects for whom the aux brake was activated on either the first or second exposure; descriptive statistics presented first, followed by ANOVA summary table.

1) Accelerator release time (seconds)

```
----------------------------------  Exposure    =1stExposure ----------------------------------
                                     The MEANS Procedure
                                   Analysis Variable : ART
                                  N
                     Lighting    Obs             Mean         Std Dev      N
                     ------------------------------------------------------
                     CNV          22           1.5051          0.8022     22
                     IAP          19           1.2334          0.5596     19
                     TCL          20           1.1081          0.6157     20
                     ------------------------------------------------------

----------------------------------  Exposure    =2ndExposure ----------------------------------
                                  N
                     Lighting    Obs             Mean         Std Dev      N
                     ------------------------------------------------------
                     CNV          22           1.3610          1.0417     22
                     IAP          19           1.1991          0.5047     19
                     TCL          20           0.9733          0.4800     20
                     ------------------------------------------------------

------------------------------ Collapsed across exposures ----------------------
                                  N
                     Lighting    Obs             Mean         Std Dev      N
                     ------------------------------------------------------
                     CNV          44           1.4330          0.9217     44
                     IAP          38           1.2162          0.5259     38
                     TCL          40           1.0407          0.5492     40
                     ------------------------------------------------------

------------------------------ Collapsed across lighting ----------------------------
                                    N
                    Exposure        Obs             Mean         Std Dev      N
                   ---------------------------------------------------------
                   1stExposure      61           1.2903          0.6843     61
                   2ndExposure      61           1.1834          0.7453     61
                   ---------------------------------------------------------
```

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	3.2492	1.6246	2.45	0.0952
SubjNo(Lighting)	58	38.4727	0.6633		
Exposure	1	0.3322	0.3322	0.98	0.3260
Exposure *Lighting	2	0.0731	0.0365	0.11	0.8978
Exposur*SubjNo(Lighting)	58	19.6332	0.3385		
Model	121	61.7766	0.5106		

2) Brake activation time (brake reaction time; seconds)

```
-----------------------------------  Exposure    =1stExposure ----------------------------------
                                      The MEANS Procedure
                                    Analysis Variable : BRT

                                   N
                     Lighting    Obs            Mean         Std Dev      N
                     ------------------------------------------------------
                     CNV          22          1.7967          0.7205     22
                     IAP          19          1.4453          0.5151     19
                     TCL          20          1.3681          0.5985     20
                     ------------------------------------------------------

-----------------------------------  Exposure    =2ndExposure ----------------------------------

                                   N
                     Lighting    Obs            Mean         Std Dev      N
                     ------------------------------------------------------
                     CNV          22          1.6417          0.9969     22
                     IAP          19          1.3985          0.4736     19
                     TCL          20          1.1852          0.4766     20
                                  ------------------------------------------------------

------------------------------- Collapsed across exposures ----------------------

                                   N
                     Lighting    Obs            Mean         Std Dev      N
                     ------------------------------------------------------
                     CNV          44          1.7192          0.8632     44
                     IAP          38          1.4219          0.4886     38
                     TCL          40          1.2767          0.5420     40
                       ------------------------------------------------------
------------------------------- Collapsed across lighting ----------------------------

                                      N
                    Exposure         Obs            Mean         Std Dev      N
                   ----------------------------------------------------------
                   1stExposure       61          1.5467          0.6415     61
                   2ndExposure       61          1.4163          0.7236     61
                     ----------------------------------------------------------
```

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	4.2988	2.1494	3.57	0.0346
SubjNo(Lighting)	58	34.9648	0.6028		
Exposure	1	0.5007	0.5007	1.73	0.1930
Exposure *Lighting	2	0.1008	0.0504	0.17	0.8403
Exposur*SubjNo(Lighting)	58	16.7418	0.2887		
Model	121	56.6252	0.4680		

3) Peak brake pedal depression for first 4.0 seconds (fraction depression)

```
---------------------------------  Exposure    =1stExposure -----------------------------------
                                     The MEANS Procedure
                               Analysis Variable : PeakBrake4sec

                    N
   Lighting    Obs             Mean         Std Dev      N
   -------------------------------------------------------
   CNV          22           0.7695          0.2015     22
   IAP          19           0.7932          0.1112     19
   TCL          20           0.7715          0.0911     20
   -------------------------------------------------------

-----------------------------------  Exposure    =2ndExposure -----------------------------------

                    N
   Lighting    Obs             Mean         Std Dev      N
   -------------------------------------------------------
   CNV          22           0.7245          0.2019     22
   IAP          19           0.8037          0.1104     19
   TCL          20           0.8220          0.1115     20
   -------------------------------------------------------

------------------------------- Collapsed across exposures ---------------------

                    N
   Lighting    Obs             Mean         Std Dev      N
   -------------------------------------------------------
   CNV          44           0.7470          0.2007     44
   IAP          38           0.7984          0.1094     38
   TCL          40           0.7968          0.1037     40
   -------------------------------------------------------
------------------------------- Collapsed across lighting ----------------------------

                          N
   Exposure         Obs             Mean         Std Dev      N
   -----------------------------------------------------------
   1stExposure      61           0.7775          0.1438     61
   2ndExposure      61           0.7811          0.1541     61
   -----------------------------------------------------------
```

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	0.0718	0.0359	1.02	0.3685
SubjNo(Lighting)	58	2.0516	0.0354		
Exposure	1	0.0008	0.0008	0.10	0.7542
Exposure *Lighting	2	0.0484	0.0242	2.85	0.0663
Exposur*SubjNo(Lighting)	58	0.4937	0.0085		
Model	121	2.6659	0.0220		

4) Peak deceleration for first 4.0 seconds (g's)

```
-----------------------------------  Exposure    =1stExposure -----------------------------------
                                      The MEANS Procedure
                               Analysis Variable : PeakDecel4sec

                           N
                Lighting    Obs            Mean         Std Dev      N
                ------------------------------------------------------
                CNV          22         -0.4368          0.1297     22
                IAP          19         -0.4511          0.1076     19
                TCL          20         -0.4350          0.0847     20
                ------------------------------------------------------

-----------------------------------  Exposure    =2ndExposure -----------------------------------

                           N
                Lighting    Obs            Mean         Std Dev      N
                ------------------------------------------------------
                CNV          22         -0.4064          0.1369     22
                IAP          19         -0.4558          0.1161     19
                TCL          20         -0.4785          0.0975     20
                ------------------------------------------------------

------------------------------- Collapsed across exposures ----------------------

                           N
                Lighting    Obs            Mean         Std Dev      N
                ------------------------------------------------------
                CNV          44         -0.4216          0.1327     44
                IAP          38         -0.4534          0.1104     38
                TCL          40         -0.4567          0.0928     40
                ------------------------------------------------------

------------------------------- Collapsed across lighting ----------------------------

                              N
               Exposure         Obs            Mean         Std Dev      N
              ----------------------------------------------------------
              1stExposure      61         -0.4407          0.1081     61
              2ndExposure      61         -0.4454          0.1207     61
              ----------------------------------------------------------
```

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	0.0319	0.0159	0.82	0.4476
SubjNo(Lighting)	58	1.1333	0.0195		
Exposure	1	0.0010	0.0010	0.16	0.6911
Exposure *Lighting	2	0.0286	0.0143	2.18	0.1226
Exposur*SubjNo(Lighting)	58	0.3817	0.0066		
Model	121	1.5762	0.0130		

5) Peak closing rate for first 4.0 seconds (mph)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                       The MEANS Procedure
                               Analysis Variable : PkClosRate4sec

                           N
           Lighting    Obs       N             Mean         Std Dev
           -----------------------------------------------------
           CNV          22      22         -23.0118          5.9415
           IAP          19      19         -21.2222          5.9735
           TCL          20      20         -20.8675          4.0960
           -----------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                           N
           Lighting    Obs       N             Mean         Std Dev
           -----------------------------------------------------
           CNV          22      22         -20.8120          4.6086
           IAP          19      19         -19.0184          4.9686
           TCL          20      20         -18.2407          4.8931
           -----------------------------------------------------

   ------------------------------ Collapsed across exposures ----------------------

                           N
           Lighting    Obs       N             Mean         Std Dev
           -----------------------------------------------------
           CNV          44      44         -21.9119          5.3713
           IAP          38      38         -20.1203          5.5332
           TCL          40      40         -19.5541          4.6484
           -----------------------------------------------------

------------------------------ Collapsed across lighting ----------------------------

                            N
         Exposure         Obs       N             Mean         Std Dev
         --------------------------------------------------------
         1stExposure       61      61         -21.7513          5.4134
         2ndExposure       61      61         -19.4103          4.8628
         --------------------------------------------------------
```

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	128.1804	64.0902	1.99	0.1455
SubjNo(Lighting)	58	1864.9704	32.1547		
Exposure	1	166.9286	166.9286	8.19	0.0059
Exposure *Lighting	2	1.2150	0.6075	0.03	0.9707
Exposur*SubjNo(Lighting)	58	1182.7006	20.3914		
Model	121	3344.2232	27.6382		

6) Peak incursion for first 4.0 seconds (feet)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                      The MEANS Procedure
                              Analysis Variable : PeakIncurs4sec

                                N
                    Lighting    Obs      N           Mean         Std Dev
                    ------------------------------------------------------
                    CNV          22     22        85.2318         14.6327
                    IAP          19     19        77.1982         18.3874
                    TCL          20     20        77.9825         14.8029
                    ------------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                                N
                    Lighting    Obs      N           Mean         Std Dev
                    ------------------------------------------------------
                    CNV          22     22        74.0545         16.0687
                    IAP          19     19        66.8719         17.8684
                    TCL          20     20        69.6750         16.4145
                    ------------------------------------------------------
------------------------------ Collapsed across exposures ----------------------

                                N
                    Lighting    Obs      N           Mean         Std Dev
                    ------------------------------------------------------
                    CNV          44     44        79.6432         16.2057
                    IAP          38     38        72.0351         18.6328
                    TCL          40     40        73.8288         15.9910
                    ------------------------------------------------------

------------------------------ Collapsed across lighting ----------------------------

                                 N
                  Exposure       Obs      N           Mean         Std Dev
                  --------------------------------------------------------
                  1stExposure     61     61        80.3527         16.1093
                  2ndExposure     61     61        70.3814         16.7478
                  --------------------------------------------------------
```

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	1321.0830	660.5415	1.99	0.1462
SubjNo(Lighting)	58	19274.3871	332.3170		
Exposure	1	3002.5074	3002.5074	14.81	0.0003
Exposure *Lighting	2	44.8777	22.4389	0.11	0.8954
Exposur*SubjNo(Lighting)	58	11759.6429	202.7525		
Model	121	35432.5158	292.8307		

7) Average incursion for first 4.0 seconds (feet)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                     The MEANS Procedure
                              Analysis Variable : AvgIncurs4sec

                            N
          Lighting        Obs       N            Mean         Std Dev
          -----------------------------------------------------------
          CNV              22      22         34.2820          6.7094
          IAP              19      19         32.0176          6.5354
          TCL              20      20         33.0347          5.6772
          -----------------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                            N
          Lighting        Obs       N            Mean         Std Dev
          -----------------------------------------------------------
          CNV              22      22         29.5837          7.6694
          IAP              19      19         26.9416          7.4146
          TCL              20      20         30.2441          7.1114
          -----------------------------------------------------------

------------------------------ Collapsed across exposures ----------------------

                            N
          Lighting        Obs       N            Mean         Std Dev
          -----------------------------------------------------------
          CNV              44      44         31.9328          7.5072
          IAP              38      38         29.4796          7.3579
          TCL              40      40         31.6394          6.5066
          -----------------------------------------------------------

------------------------------ Collapsed across lighting ----------------------------

                             N
        Exposure           Obs       N            Mean         Std Dev
        ---------------------------------------------------------------
        1stExposure         61      61         33.1678          6.2972
        2ndExposure         61      61         28.9773          7.4213
        ---------------------------------------------------------------
```

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	141.8394	70.9197	1.17	0.3170
SubjNo(Lighting)	58	3510.3581	60.5234		
Exposure	1	533.2452	533.2452	15.45	0.0002
Exposure *Lighting	2	29.8820	14.9410	0.43	0.6507
Exposur*SubjNo(Lighting)	58	2001.8129	34.5140		
Model	121	6219.4851	51.4007		

8) Time to full stop (seconds)

```
----------------------------------  Exposure    =1stExposure ----------------------------------
                                     The MEANS Procedure
                                  Analysis Variable : TTFS

                                N
                    Lighting    Obs            Mean          Std Dev      N
                    -----------------------------------------------------
                    CNV          22          5.9554           1.5276     22
                    IAP          19          5.2899           0.7371     19
                    TCL          20          5.2603           0.5872     20
                    -----------------------------------------------------

----------------------------------  Exposure    =2ndExposure ----------------------------------

                                N
                    Lighting    Obs            Mean          Std Dev      N
                    -----------------------------------------------------
                    CNV          22          6.2968           1.6458     22
                    IAP          19          5.3504           0.7194     19
                    TCL          20          5.0708           0.6516     20
                    -----------------------------------------------------

------------------------------ Collapsed across exposures ----------------------

                                N
                    Lighting    Obs            Mean          Std Dev      N
                    -----------------------------------------------------
                    CNV          44          6.1261           1.5787     44
                    IAP          38          5.3202           0.7191     38
                    TCL          40          5.1655           0.6197     40
                    -----------------------------------------------------

------------------------------ Collapsed across lighting ----------------------------

                                  N
                   Exposure       Obs            Mean          Std Dev      N
                  ---------------------------------------------------------
                  1stExposure      61          5.5202           1.0944     61
                  2ndExposure      61          5.6000           1.2365     61
                  ---------------------------------------------------------
```

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	22.5113	11.2557	5.47	0.0067
SubjNo(Lighting)	58	119.4453	2.0594		
Exposure	1	0.1541	0.1541	0.44	0.5081
Exposure *Lighting	2	1.4813	0.7407	2.13	0.1279
Exposur*SubjNo(Lighting)	58	20.1559	0.3475		
Model	121	163.7883	1.3536		

APPENDIX H

GROUP II RESULTS (includes only drivers who took an early glance to the forward view).

A. <u>Unequal n's analysis, deleting data points where subject did not have at least 200 msec of glance time to forward view within first 500 msec; descriptive statistics presented first, followed by ANOVA summary table.</u>

1) Accelerator release time (seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------

                                    The MEANS Procedure

                                  Analysis Variable : ART

                                N
                Lighting      Obs       N            Mean         Std Dev
                -----------------------------------------------------------
                CNV             9       9          1.0841          0.6187

                IAP             9       9          0.8000          0.1796

                TCL            12      12          0.8556          0.5119
                -----------------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                                  Analysis Variable : ART

                                N
                Lighting      Obs       N            Mean         Std Dev
                -----------------------------------------------------------
                CNV            15      15          0.9689          0.5688

                IAP            13      13          0.8137          0.2779

                TCL            10      10          0.6900          0.2739
                -----------------------------------------------------------
```

<u>1st exposure</u>

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	0.4171	0.2085	0.91	0.4154
Lighting*SubjNo	27	6.2028	0.2297		
Model	29	6.6199	0.2283		

<u>2nd exposure</u>

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	0.4831	0.2416	1.38	0.2652
Lighting*SubjNo	35	6.1317	0.1752		
Model	37	6.6149	0.1788		

2) Brake activation time (brake reaction time; seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                    The MEANS Procedure

                                  Analysis Variable : BRT

                                N
                   Lighting    Obs       N            Mean          Std Dev
                   -----------------------------------------------------
                   CNV           9       9          1.4623           0.5178

                   IAP           9       9          1.0363           0.1769

                   TCL          12      12          1.0969           0.4847
                   -----------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                                  Analysis Variable : BRT

                                N
                   Lighting    Obs       N            Mean          Std Dev
                   -----------------------------------------------------
                   CNV          15      15          1.2806           0.5407

                   IAP          13      13          1.0481           0.2902

                   TCL          10      10          0.9174           0.2557
                     -----------------------------------------------------
```

1st exposure

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	0.9839	0.4920	2.67	0.0877
Lighting*SubjNo	27	4.9797	0.1844		
Model	29	5.9636	0.2056		

2nd exposure

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	0.8566	0.4283	2.63	0.0860
Lighting*SubjNo	35	5.6927	0.1626		
Model	37	6.5493	0.1770		

3) Peak brake pedal depression for first 4.0 seconds (fraction depression)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                     The MEANS Procedure

                              Analysis Variable : PeakBrake4sec

                                 N
                    Lighting    Obs       N            Mean         Std Dev
                    -----------------------------------------------------
                    CNV           9       9          0.7822          0.1076

                    IAP           9       9          0.7289          0.0807

                    TCL          12      12          0.7433          0.0713
                    -----------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                              Analysis Variable : PeakBrake4sec

                                 N
                    Lighting    Obs       N            Mean         Std Dev
                    -----------------------------------------------------
                    CNV          15      15          0.7133          0.0923

                    IAP          13      13          0.7623          0.1078

                    TCL          10      10          0.7600          0.0971
                    -----------------------------------------------------
```

1st exposure

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	0.0139	0.0069	0.93	0.4052
Lighting*SubjNo	27	0.2005	0.0074		
Model	29	0.2144	0.0074		

2nd exposure

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	0.0209	0.0105	1.07	0.3554
Lighting*SubjNo	35	0.3436	0.0098		
Model	37	0.3645	0.0099		

4) Peak deceleration for first 4.0 seconds (g's)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                    The MEANS Procedure

                             Analysis Variable : PeakDecel4sec

                                N
                  Lighting    Obs       N            Mean         Std Dev
                  ------------------------------------------------------
                  CNV           9       9         -0.4411          0.0903

                  IAP           9       9         -0.3967          0.0800

                  TCL          12      12         -0.4158          0.0734
                  ------------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                             Analysis Variable : PeakDecel4sec

                                N
                  Lighting    Obs       N            Mean         Std Dev
                  ------------------------------------------------------
                  CNV          15      15         -0.3827          0.0746

                  IAP          13      13         -0.4169          0.0981

                  TCL          10      10         -0.4260          0.0864
                  ------------------------------------------------------
```

1st exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	0.0090	0.0045	0.69	0.5113
Lighting*SubjNo	27	0.1758	0.0065		
Model	29	0.1847	0.0064		

2nd exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	0.0137	0.0069	0.92	0.4075
Lighting*SubjNo	35	0.2606	0.0074		
Model	37	0.2743	0.0074		

5) Peak closing rate for first 4.0 seconds (mph)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                      The MEANS Procedure

                              Analysis Variable : PkClosRate4sec

                                     N
                      Lighting    Obs       N            Mean         Std Dev
                      -----------------------------------------------------
                      CNV           9       9        -22.6343          8.4813

                      IAP           9       9        -17.8177          3.4273

                      TCL          12      12        -19.3966          3.3791
                      -----------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                              Analysis Variable : PkClosRate4sec

                                     N
                      Lighting    Obs       N            Mean         Std Dev
                      -----------------------------------------------------
                      CNV          15      15        -19.4755          5.3208

                      IAP          13      13        -15.9486          4.1142

                      TCL          10      10        -15.2045          3.1266
                      -----------------------------------------------------
```

1st exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	109.3544	54.6772	1.86	0.1756
Lighting*SubjNo	27	795.0370	29.4458		
Model	29	904.3914	31.1859		

2nd exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	137.7267	68.8634	3.51	0.0409
Lighting*SubjNo	35	687.4507	19.6414		
Model	37	825.1774	22.3021		

6) Peak incursion for first 4.0 seconds (feet)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                 The MEANS Procedure

                         Analysis Variable : PeakIncurs4sec

                               N
                    Lighting    Obs       N            Mean         Std Dev
                    -----------------------------------------------------
                    CNV           9       9         77.4333         13.6540

                    IAP           9       9         65.9185         12.3928

                    TCL          12      12         73.8875         13.8183
                    -----------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                         Analysis Variable : PeakIncurs4sec

                               N
                    Lighting    Obs       N            Mean         Std Dev
                    -----------------------------------------------------
                    CNV          15      15         70.8667         15.7862

                    IAP          13      13         58.0821         14.2446

                    TCL          10      10         59.1700         13.7038
                    -----------------------------------------------------
```

1st exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	631.8750	315.9375	1.77	0.1896
Lighting*SubjNo	27	4820.5120	178.5375		
Model	29	5452.3869	188.0133		

2nd exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	1382.8347	691.4174	3.18	0.0539
Lighting*SubjNo	35	7613.8846	217.5396		
Model	37	8996.7193	243.1546		

7) Average incursion for first 4.0 seconds (feet)

```
------------------------------------ Exposure=1stExposure ------------------------------------

                                  The MEANS Procedure

                         Analysis Variable : AvgIncurs4sec

                              N
              Lighting      Obs       N            Mean         Std Dev
              -----------------------------------------------------------------
              CNV             9       9         31.3739          3.9772

              IAP             9       9         27.8822          4.1867

              TCL            12      12         32.2585          6.3410
              -----------------------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                         Analysis Variable : AvgIncurs4sec

                              N
              Lighting      Obs       N            Mean         Std Dev
              -----------------------------------------------------------------
              CNV            15      15         28.5457          6.1012

              IAP            13      13         23.2876          6.6335

              TCL            10      10         25.9843          5.8917
              -----------------------------------------------------------------
```

1st exposure

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	104.6860	52.3430	1.99	0.1558
Lighting*SubjNo	27	709.0626	26.2616		
Model	29	813.7486	28.0603		

2nd exposure

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	192.6526	96.3263	2.48	0.0987
Lighting*SubjNo	35	1361.5832	38.9024		
Model	37	1554.2358	42.0064		

8) Time to full stop (seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                    The MEANS Procedure

                                 Analysis Variable : TTFS

                               N
               Lighting      Obs        N             Mean          Std Dev
               ------------------------------------------------------------
               CNV             9        9           5.3814           0.7075

               IAP             9        9           5.2262           0.6220

               TCL            12       12           5.1116           0.5539
               ------------------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                                 Analysis Variable : TTFS

                               N
               Lighting      Obs        N             Mean          Std Dev
               ------------------------------------------------------------
               CNV            15       15           6.2346           1.4028

               IAP            13       13           5.3242           0.7779

               TCL            10       10           5.0039           0.7531
               ------------------------------------------------------------
```

1st exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	0.3745	0.1873	0.48	0.6223
Lighting*SubjNo	27	10.4739	0.3879		
Model	29	10.8485	0.3741		

2nd exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	10.5827	5.2914	4.64	0.0163
Lighting*SubjNo	35	39.9177	1.1405		
Model	37	50.5005	1.3649		

APPENDIX I

GROUP III RESULTS (driver performance once the driver returned the glance to the forward view).

Part 1. Unequal n's analysis, deleting data points where experimenter hit the aux brake first; descriptive statistics presented first, followed by ANOVA summary table.

1) Forward view to accelerator release time (seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------

                                      The MEANS Procedure

                                   Analysis Variable : TVA

                                   N
                    Lighting    Obs      N            Mean         Std Dev
                    -----------------------------------------------------
                    CNV          23     23          0.4665          0.2237
                    IAP          20     20          0.5393          0.3987
                    TCL          22     22          0.5544          0.8880
                    -----------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                                   Analysis Variable : TVA

                                   N
                    Lighting    Obs      N            Mean         Std Dev
                    -----------------------------------------------------
                    CNV          23     23          0.6897          0.7681
                    IAP          23     23          0.4843          0.1844
                    TCL          22     22          0.4074          0.1742
                    -----------------------------------------------------
```

1st exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	0.0992	0.0496	0.15	0.8622
Lighting*SubjNo	62	20.6816	0.3336		
Model	64	20.7808	0.3247		

2nd exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	0.9655	0.4828	2.18	0.1207
Lighting*SubjNo	65	14.3660	0.2210		
Model	67	15.3316	0.2288		

2) Forward view to brake activation time (seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                     The MEANS Procedure

                                   Analysis Variable : TVB

                                N
                   Lighting    Obs       N             Mean         Std Dev
                   -----------------------------------------------------
                   CNV          23      23           0.6450          0.3588

                   IAP          20      20           0.7928          0.4722

                   TCL          22      22           0.6287          0.5120
                   -----------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                                   Analysis Variable : TVB

                                N
                   Lighting    Obs       N             Mean         Std Dev
                   -----------------------------------------------------
                   CNV          23      23           0.9264          0.7717

                   IAP          23      23           0.6876          0.1710

                   TCL          22      22           0.6444          0.1756
                     -----------------------------------------------------
```

1st exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	0.3390	0.1695	0.84	0.4384
Lighting*SubjNo	62	12.5750	0.2028		
Model	64	12.9139	0.2018		

2nd exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	1.0491	0.5246	2.37	0.1016
Lighting*SubjNo	65	14.3927	0.2214		
Model	67	15.4418	0.2305		

3) Forward view to peak brake pedal depression for first 4.0 seconds (seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------

                              The MEANS Procedure

                           Analysis Variable : TVPB

                        N
    Lighting    Obs       N              Mean          Std Dev
    -----------------------------------------------------------------
    CNV          23      23            1.6705           0.5036

    IAP          20      20            2.1752           0.5754

    TCL          22      22            1.9397           0.6045
    -----------------------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                           Analysis Variable : TVPB

                        N
    Lighting    Obs       N              Mean          Std Dev
    -----------------------------------------------------------------
    CNV          23      23            2.1314           0.6881

    IAP          23      23            2.0263           0.6220

    TCL          22      22            1.9826           0.5880
    -----------------------------------------------------------------
```

1st exposure

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	2.7420	1.3710	4.35	0.0171
Lighting*SubjNo	62	19.5428	0.3152		
Model	64	22.2848	0.3482		

2nd exposure

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	0.2648	0.1324	0.33	0.7211
Lighting*SubjNo	65	26.1897	0.4029		
Model	67	26.4545	0.3948		

4) Forward view to full stop (seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------

                                      The MEANS Procedure

                                   Analysis Variable : TVFS

                                N
                    Lighting    Obs       N            Mean         Std Dev
                    -----------------------------------------------------
                    CNV          23      23          4.7749          1.0097

                    IAP          20      20          4.6252          0.6655

                    TCL          22      22          4.3806          0.6367
                    -----------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------

                                   Analysis Variable : TVFS

                                N
                    Lighting    Obs       N            Mean         Std Dev
                    -----------------------------------------------------
                    CNV          23      23          5.3923          1.7131

                    IAP          23      23          4.7958          0.7486

                    TCL          22      22          4.5781          0.8437
                    -----------------------------------------------------
```

1st exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	1.7733	0.8866	1.40	0.2551
Lighting*SubjNo	62	39.3545	0.6348		
Model	64	41.1278	0.6426		

2nd exposure

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	8.0527	4.0264	2.85	0.0651
Lighting*SubjNo	65	91.8426	1.4130		
Model	67	99.8953	1.4910		

GROUP III RESULTS (continued)

Part 2. Unequal n's analysis, completely eliminating those subjects for whom the aux brake was activated on either the first or second exposure; descriptive statistics presented first, followed by ANOVA summary table.

1) Forward view to accelerator release time (seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                     The MEANS Procedure
                                   Analysis Variable : TVA

                            N
           Lighting       Obs       N             Mean          Std Dev
           ------------------------------------------------------------
           CNV             22      22           0.4709           0.2279
           IAP             19      19           0.5396           0.4096
           TCL             20      20           0.5565           0.9326
           ------------------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------
                            N
           Lighting       Obs       N             Mean          Std Dev
           ------------------------------------------------------------
           CNV             22      22           0.7090           0.7805
           IAP             19      19           0.4846           0.2006
           TCL             20      20           0.3931           0.1758
           ------------------------------------------------------------

------------------------------ Collapsed across exposures ----------------------
                            N
           Lighting       Obs       N             Mean          Std Dev
           ------------------------------------------------------------
           CNV             44      44           0.5899           0.5809
           IAP             38      38           0.5121           0.3193
           TCL             40      40           0.4748           0.6675
           ------------------------------------------------------------

------------------------------ Collapsed across lighting ----------------------------
                             N
         Exposure           Obs       N             Mean          Std Dev
         --------------------------------------------------------------
         1stExposure         61      61           0.5204           0.5877
         2ndExposure         61      61           0.5355           0.5037
         --------------------------------------------------------------
```

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	0.2914	0.1457	0.47	0.6293
SubjNo(Lighting)	58	18.1053	0.3122		
Exposure	1	0.0015	0.0015	0.01	0.9432
Exposure *Lighting	2	0.9119	0.4559	1.59	0.2128
Exposur*SubjNo(Lighting)	58	16.6358	0.2868		
Model	121	35.9513	0.2971		

2) Forward view to brake activation time (brake reaction time; seconds)

```
------------------------------------- Exposure=1stExposure ------------------------------------
                                      The MEANS Procedure
                                    Analysis Variable : TVB

                                  N
                     Lighting    Obs      N            Mean         Std Dev
                     ------------------------------------------------------
                     CNV          22     22          0.6499          0.3665
                     IAP          19     19          0.8012          0.4836
                     TCL          20     20          0.6151          0.5353
                     ------------------------------------------------------

------------------------------------- Exposure=2ndExposure ------------------------------------

                                  N
                     Lighting    Obs      N            Mean         Std Dev
                     ------------------------------------------------------
                     CNV          22     22          0.9458          0.7841
                     IAP          19     19          0.6905          0.1855
                     TCL          20     20          0.6305          0.1783
                     ------------------------------------------------------

------------------------------- Collapsed across exposures ----------------------

                                  N
                     Lighting    Obs      N            Mean         Std Dev
                     ------------------------------------------------------
                     CNV          44     44          0.7978          0.6231
                     IAP          38     38          0.7458          0.3656
                     TCL          40     40          0.6228          0.3939
                     ------------------------------------------------------

------------------------------- Collapsed across lighting ----------------------------

                                   N
                   Exposure       Obs      N            Mean         Std Dev
                   ---------------------------------------------------------
                   1stExposure     61     61          0.6856          0.4629
                   2ndExposure     61     61          0.7629          0.5053
                   ---------------------------------------------------------
```

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	0.6675	0.3338	1.42	0.2499
SubjNo(Lighting)	58	13.6280	0.2350		
Exposure	1	0.1378	0.1378	0.62	0.4358
Exposure *Lighting	2	0.8999	0.4500	2.01	0.1432
Exposur*SubjNo(Lighting)	58	12.9817	0.2238		
Model	121	28.3593	0.2344		

3) Forward view to peak brake pedal depression for first 4.0 seconds (seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                       The MEANS Procedure
                                    Analysis Variable : TVPB

                                  N
                    Lighting    Obs      N            Mean         Std Dev
                    ------------------------------------------------------
                    CNV          22     22          1.6751          0.5149
                    IAP          19     19          2.1669          0.5899
                    TCL          20     20          1.8971          0.5940
                    ------------------------------------------------------


------------------------------------ Exposure=2ndExposure ------------------------------------

                                  N
                    Lighting    Obs      N            Mean         Std Dev
                    ------------------------------------------------------
                    CNV          22     22          2.1419          0.7024
                    IAP          19     19          2.0739          0.6273
                    TCL          20     20          1.9759          0.6175
                    ------------------------------------------------------

------------------------------ Collapsed across exposures ----------------------

                                  N
                    Lighting    Obs      N            Mean         Std Dev
                    ------------------------------------------------------
                    CNV          44     44          1.9085          0.6528
                    IAP          38     38          2.1204          0.6024
                    TCL          40     40          1.9365          0.5994
                    ------------------------------------------------------

------------------------------ Collapsed across lighting ----------------------------

                                   N
                  Exposure       Obs      N            Mean         Std Dev
                  --------------------------------------------------------
                  1stExposure     61     61          1.9010          0.5916
                  2ndExposure     61     61          2.0663          0.6452
                  --------------------------------------------------------
```

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	1.0484	0.5242	1.46	0.2396
SubjNo(Lighting)	58	20.7559	0.3579		
Exposure	1	0.6983	0.6983	1.80	0.1846
Exposure *Lighting	2	1.7084	0.8542	2.20	0.1194
Exposur*SubjNo(Lighting)	58	22.4700	0.3874		
Model	121	46.8156	0.3869		

4) Forward view to full stop (seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                     The MEANS Procedure
                                  Analysis Variable : TVFS

                                N
                  Lighting    Obs       N            Mean         Std Dev
                  -----------------------------------------------------
                  CNV          22      22          4.7887          1.0312
                  IAP          19      19          4.6353          0.6822
                  TCL          20      20          4.3571          0.6639
                  -----------------------------------------------------


------------------------------------ Exposure=2ndExposure ------------------------------------

                                N
                  Lighting    Obs       N            Mean         Std Dev
                  -----------------------------------------------------
                  CNV          22      22          5.4283          1.7445
                  IAP          19      19          4.8108          0.7332
                  TCL          20      20          4.6359          0.8595
                  -----------------------------------------------------

------------------------------ Collapsed across exposures ----------------------

                                N
                  Lighting    Obs       N            Mean         Std Dev
                  -----------------------------------------------------
                  CNV          44      44          5.1085          1.4526
                  IAP          38      38          4.7231          0.7041
                  TCL          40      40          4.4965          0.7711
                  -----------------------------------------------------

------------------------------ Collapsed across lighting ----------------------------

                                 N
                Exposure       Obs       N            Mean         Std Dev
                -------------------------------------------------------
                1stExposure     61      61          4.5994          0.8273
                2ndExposure     61      61          4.9761          1.2580
                -------------------------------------------------------
```

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	8.0794	4.0397	2.97	0.0593
SubjNo(Lighting)	58	78.9771	1.3617		
Exposure	1	4.0537	4.0537	4.93	0.0304
Exposure *Lighting	2	1.2404	0.6202	0.75	0.4752
Exposur*SubjNo(Lighting)	58	47.7247	0.8228		
Model	121	140.3505	1.1599		

APPENDIX J

GROUP IV RESULTS (eye glance drawing effect)

A. <u>Measure of lighting ability to draw the subject's view forward: Unequal n's analysis, deleting data points where experimenter hit the brakes first, but including those who were already looking forward upon exposure; descriptive statistics presented first, followed by ANOVA summary table.</u>

1) Exposure to forward view (seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                      The MEANS Procedure
                                   Analysis Variable : ExpFV

                                N
                    Lighting    Obs      N           Mean         Std Dev
                    ------------------------------------------------------
                    CNV          23     23         1.0616          0.8884
                    IAP          20     20         0.6684          0.5770
                    TCL          22     22         0.8050          0.8340
                    ------------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------
                                   Analysis Variable : ExpFV

                                N
                    Lighting    Obs      N           Mean         Std Dev
                    ------------------------------------------------------
                    CNV          23     23         0.8537          0.6645
                    IAP          23     23         0.5371          0.5229
                    TCL          22     22         0.6015          0.5259
                    ------------------------------------------------------
```

<u>1st exposure</u>

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	1.7326	0.8663	1.40	0.2537
Lighting*SubjNo	62	38.2961	0.6177		
Model	64	40.0287	0.6254		

<u>2nd exposure</u>

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	1.2841	0.6420	1.94	0.1523
Lighting*SubjNo	65	21.5363	0.3313		
Model	67	22.8204	0.3406		

GROUP IV RESULTS (continued)

B. <u>Measure of lighting ability to draw the subject's view forward: Unequal n's analysis, deleting data points where experimenter hit the brakes first, and also excluding those who were already looking forward upon exposure; descriptive statistics presented first, followed by ANOVA summary table.</u>

1) Exposure to forward view (seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                    The MEANS Procedure
                                 Analysis Variable : ExpFV

                                N
                    Lighting    Obs      N           Mean         Std Dev
                    -----------------------------------------------------
                    CNV          19     19         1.2851          0.8133
                    IAP          16     16         0.8355          0.5223
                    TCL          15     15         1.1807          0.7538
                    -----------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------
                                 Analysis Variable : ExpFV

                                N
                    Lighting    Obs      N           Mean         Std Dev
                    -----------------------------------------------------
                    CNV          19     19         1.0335          0.5862
                    IAP          18     18         0.6863          0.4954
                    TCL          18     18         0.7368          0.4847
                    -----------------------------------------------------
```

<u>1st exposure</u>

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	1.8629	0.9314	1.83	0.1720
Lighting*SubjNo	47	23.9519	0.5096		
Model	49	25.8147	0.5268		

<u>2nd exposure</u>

Source	**DF**	**Type III SS**	**Mean Square**	**F Value**	**Pr > F**
Lighting	2	1.3115	0.6558	2.38	0.1029
Lighting*SubjNo	52	14.3499	0.2760		
Model	54	15.6614	0.2900		

GROUP IV RESULTS (continued)

C. **Measure of lighting ability to draw the subject's view forward: Equal n's analysis, completely eliminating those subjects for whom the aux brake was activated on either the first or second exposure, but including those who were already looking forward upon exposure; descriptive statistics presented first, followed by ANOVA summary table.**

1) Exposure to forward view (seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                      The MEANS Procedure
                                   Analysis Variable : ExpFV
                                   N
                   Lighting    Obs       N            Mean         Std Dev
                   ----------------------------------------------------------
                   CNV          22      22          1.0630          0.9092
                   IAP          19      19          0.6895          0.5848
                   TCL          20      20          0.8405          0.8561
                   ----------------------------------------------------------

------------------------------------ Exposure=2ndExposure ------------------------------------
                                   N
                   Lighting    Obs       N            Mean         Std Dev
                   ----------------------------------------------------------
                   CNV          22      22          0.8848          0.6628
                   IAP          19      19          0.5730          0.5592
                   TCL          20      20          0.5815          0.4777
                   ----------------------------------------------------------

------------------------------ Collapsed across exposures ----------------------
                                   N
                   Lighting    Obs       N            Mean         Std Dev
                   ----------------------------------------------------------
                   CNV          44      44          0.9739          0.7915
                   IAP          38      38          0.6313          0.5674
                   TCL          40      40          0.7110          0.6968
                   ----------------------------------------------------------

------------------------------ Collapsed across lighting ----------------------------
                                   N
                 Exposure        Obs       N            Mean         Std Dev
                 ---------------------------------------------------------
                 1stExposure      61      61          0.8737          0.8052
                 2ndExposure      61      61          0.6882          0.5848
                 ---------------------------------------------------------
```

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	2.6853	1.3426	2.63	0.0803
SubjNo(Lighting)	58	29.5539	0.5096		
Exposure	1	1.0362	1.0362	2.22	0.1417
Exposure *Lighting	2	0.0999	0.0499	0.11	0.8987
Exposur*SubjNo(Lighting)	58	27.0786	0.4669		
Model	121	60.4670	0.4997		

GROUP IV RESULTS (continued)

D. **Measure of lighting ability to draw the subject's view forward: Equal n's analysis, completely eliminating those subjects for whom the aux brake was activated on either the first or second exposure, and also excluding those who were already looking forward upon exposure; descriptive statistics presented first, followed by ANOVA summary table.**

1) Exposure to forward view (seconds)

```
------------------------------------ Exposure=1stExposure ------------------------------------
                                     The MEANS Procedure
                                  Analysis Variable : ExpFV
                                  N
                    Lighting    Obs      N            Mean         Std Dev
                    -----------------------------------------------------
                    CNV          15     15          1.2549          0.7914
                    IAP          13     13          0.8616          0.5544
                    TCL          12     12          1.1870          0.8158
                    -----------------------------------------------------
------------------------------------ Exposure=2ndExposure ------------------------------------
                                  N
                    Lighting    Obs      N            Mean         Std Dev
                    -----------------------------------------------------
                    CNV          15     15          1.1266          0.6055
                    IAP          13     13          0.7523          0.5479
                    TCL          12     12          0.6939          0.4986
                    -----------------------------------------------------

------------------------------ Collapsed across exposures ----------------------
                                  N
                    Lighting    Obs      N            Mean         Std Dev
                    -----------------------------------------------------
                    CNV          30     30          1.1907          0.6955
                    IAP          26     26          0.8070          0.5429
                    TCL          24     24          0.9405          0.7075
                    -----------------------------------------------------

------------------------------ Collapsed across lighting ----------------------------
                                   N
                  Exposure        Obs      N            Mean         Std Dev
                  -------------------------------------------------------
                  1stExposure      40     40          1.1067          0.7332
                  2ndExposure      40     40          0.8752          0.5776
                  -------------------------------------------------------
```

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Lighting	2	2.1387	1.0694	2.58	0.0891
SubjNo(Lighting)	37	15.3204	0.4141		
Exposure	1	1.1693	1.1693	2.72	0.1078
Exposure *Lighting	2	0.5875	0.2938	0.68	0.5117
Exposur*SubjNo(Lighting)	37	15.9288	0.4305		
Model	79	35.0478	0.4436		

APPENDIX K

COMPLETE LISTING OF ADDITIONAL DRIVER/SUBJECT COMMENTS ON POST EXPERIMENT QUESTIONNAIRES

Note that wording in parentheses has been added to improve clarity of the driver/subjects' responses.

TCL Group

The additional light is very similar to emergency vehicle lights, and that helps get my attention since I'm already used to paying attention to emergency lights.

I almost didn't notice it when I first saw it (the additional lighting). But at the second instance when I was kind of expecting it, it was much more noticeable. Locating the light higher up on the vehicle may make it more noticeable.

Raise the light somewhat. Do not leave in the same row or lower than regular lights.

2. (In regard to question 2 about learning to use the additional lighting as a hard braking signal, I think it) would work best only at extreme rates of deceleration, i.e., slamming on brakes in highway driving. Using it at 30 mph is probably excessive.

5. (In regard to question 5 involving glare and discomfort) I found the added lighting to be alarming at first, but after it was explained, I found it very useful…Almost reassuring.

I found it (the additional lighting) extremely useful in knowing when to stop when my eyes were not on the road, completely. When just regular brake lights came on, I only felt like slowing down some, by applying slight pressure to the brakes.

I would be interested in knowing my response time to (the) additional lighting.

(Fifteen questionnaires had no additional comments.)

IAP Group

The added lighting was annoying, but if it wasn't annoying it would not be as noticeable. The added lighting was much more noticeable than the normal brake lights.

(The additional lighting was) Not annoying; Alarming, yes. So, they actually do what you mean them to do.

(This was my) Very first experiment. (I) Enjoyed it.

The new lighting caused me to feel much more urgency.

Maybe (the additional lighting should be) spaced closer to the outside lights.

The additional lighting made me think he (the lead vehicle driver) was going to come to a dead stop, and I did likewise.

Higher positioning (of the additional lighting on the rear of the vehicle) may lend itself to be more noticeable.

It (the additional lighting) didn’t call my attention while performing tasks, but when I looked back at the road, it told me that something was wrong, and that I had to be sure to stop.

It seemed like the new brake lights (the additional lighting) were not only brighter but were flashing in a different pattern from normal lights.

(Thirteen questionnaires had no additional comments.)

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