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16. Abstract

The objectives of this laboratory experiment were to investigate how reaction time to center high-mounted stop lamps (CHMSL) is affected by context (the presence or absence of conventional low-mounted stop lamps), aspect ratio (the ratio of height to width), intensity, and ambient illumination. Recent trends in auto body styling have led to the use of long, narrow CHMSLs. These developments have increased the importance of understanding the efficacy of stop lamps with effective luminous areas that are long and narrow.

Participants performed a reaction-time task by responding to the onset of CHMSLs with varying characteristics. The results of this experiment indicate that context, CHMSL aspect ratio and CHMSL intensity significantly affect reaction time. Specifically, participants' reaction times to the onset of simulated CHMSLs were longest when stimulus intensity was low, aspect ratio was large, and the CHMSL was shown without low-mounted stop lamps.

These results, which are similar to those of a previous investigation (Sayer, Flannagan, and Sivak, 1995), suggest that intensity should be emphasized in the design of all stop lamps, and that combinations of large aspect ratio and low intensity should in particular be avoided.

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INTRODUCTION

Background

This experiment investigated how reaction time to center high-mounted stop lamps (CHMSL) is affected by context (the presence or absence of low-mounted stop lamps), aspect ratio (the ratio of height to width), intensity, and ambient illumination. Currently, neither federal regulations (49 CFR, 1994) nor SAE standards (SAE, 1995) specify limitations on aspect ratio for either stop lamps or center high-mounted stop lamps. Recent trends in automotive body styling, achievable in part by technical advances in automotive lighting, have resulted in questions related to the efficacy of stop lamps whose effective luminous areas are long and narrow. A previous laboratory study by Sayer, Flannagan, and Sivak (1995) reported that the aspect ratio and intensity of stop lamps, as well as the interaction of these variables, affected participant reaction times. Specifically, Sayer et al. found that reaction times to the onset of simulated stop lamps were longer when low stimulus intensity was combined with a large aspect ratio. However, the earlier investigation did not examine the effects of either context (showing a stop lamp with or without additional lamps from a rear signaling system) or ambient illumination.

Current U.S. regulations concerning the minimum effective luminous area for stop lamps (non-CHMSL) on motor vehicles less than 203.2 cm (80 in) in width require an area not less than 50 cm^2 (49 CFR, 1994). This requirement is independent of the number of compartments included in the stop lamp. However, individual compartments can be no less than 22 cm^2. Intensity requirements for non-CHMSL stop lamps permit a range of 80 to 420 cd on the H-V axis, dependent upon the total number of lamp compartments.

U.S. regulations for CHMSLs require a minimum effective projected luminous area of not less than 29 cm^2 (4.5 in^2) for motor vehicles under 203.2 cm (80 in) in width (49 CFR, 1994). A combination of two high-mounted stop lamps can be used in certain circumstances, but each lamp is required to be no less than 14.5 cm^2 (2.25 in^2). Intensity requirements for CHMSLs permit a range of 25 to 160 cd on the H-V axis.

Investigating Stop Lamps in Context

Conditions exist in which only a single stop lamp from an entire rear signaling system is visible. Specific scenarios include:

- viewing a CHMSL on the second vehicle ahead through the windshield and rear window of a preceding vehicle

- viewing one low-mounted stop lamp on the second vehicle ahead when a lateral offset exists between preceding vehicles
- under conditions in which a preceding vehicle is poorly maintained (i.e., two of three stop lamps are not operational)

Because these conditions can exist, it is important to examine whether design characteristics of a single stop lamp affect the reaction time of a following driver. Stop lamp attributes such as aspect ratio, intensity, shape, and area cannot be considered only in the context of an intact rear signaling system. The combined effect of all lamps may override any effect that one lamp may otherwise produce were it to be viewed in isolation.

METHOD

Tasks

In a laboratory setting, participants were asked to respond as quickly as possible to the onset (illumination) of simulated stop lamps. Participants responded to either the illumination of a center high-mounted stop lamp (CHMSL) or the simultaneous illumination of a CHMSL and two standard (low-mounted) stop lamps. Participants responded to any stop lamp illumination by pressing a hand-held button (see Appendices A and B for participant instructions).

Participants

Twenty-four licensed drivers, balanced by age and gender, participated in the experiment. The younger group ranged in age from 21 to 30 with a mean age of 27.1 years. The older group ranged in age from 62 to 70 with a mean age of 66.8 years. Participants received $40 for completing two sessions, on different days, totaling 3.5 hours. All participants wore the same eyewear, if any, that they would normally wear when driving, with the exception of sunglasses.

Apparatus

Figures 1 and 2 show diagrams of the experimental setup. Participants sat at a table 5.7 m from the stimuli. Chin and forehead rests ensured a constant viewing distance for all participants, and a dimly illuminated fixation point located between the stop lamps helped control eye fixation. Each participant held the response button with his/her dominant hand.

The CHMSL and two low-mounted stop lamps had separate sources of illumination, housings, and power supplies. The light source for the CHMSL consisted of three tungsten halogen headlamps (2A1), powered by a DC power supply and a voltage regulator. Two lenticular-array lenses, placed in parallel, distributed light from the three lamps and reduced the occurrence of hot spots. The simulated low-mounted stop lamps and tail lamps used a set of auxiliary stop lamps outfitted with independently controlled 1157 bulbs. The low-mounted stop lamps were also powered by an independent DC power supply and a voltage regulator. The low-mounted stop lamps and tail lamps shared the same housing, but had separate power supplies. The tail lamps remained illuminated for the duration of simulated nighttime sessions. Calibration of both the CHMSL and low-mounted stop lamp sources ensured identical rise times (320 ms to reach 90% of their maximum intensity). A Macintosh computer and custom software collected reaction time data and controlled the illumination of stop lamps via a microcontroller.

The experimenter used sets of interchangeable filters and masks to vary CHMSL aspect ratio and CHMSL intensity. Three levels of neutral density filters and five aspect ratio masks, in combination, produced the appropriate intensity-by-aspect ratio combinations for each trial. These filters and masks were quickly changed by the experimenter between trials.

Existing overhead fluorescent lamps and two 500W incandescent photographic flood lamps produced the ambient illumination for the simulated daytime condition. The average luminance of the surrounding surface for the daytime condition was 654 cd/m^2. The surrounding surface was indirectly illuminated to 0.12 cd/m^2 in the simulated nighttime condition.

Low-mounted stop lamp size (area), horizontal separation, and vertical separation from the CHMSL were determined by an informal survey of rear signaling configurations found on 24 late-model sedans. The levels of CHMSL aspect ratio to be examined were also chosen on the basis of the survey. The horizontal separation (center-to-center) between low-mounted stop lamps was set at 4° of visual angle, and the vertical separation (center-to-center) between the CHMSL and low-mounted stop lamps was 1.25° of visual angle.

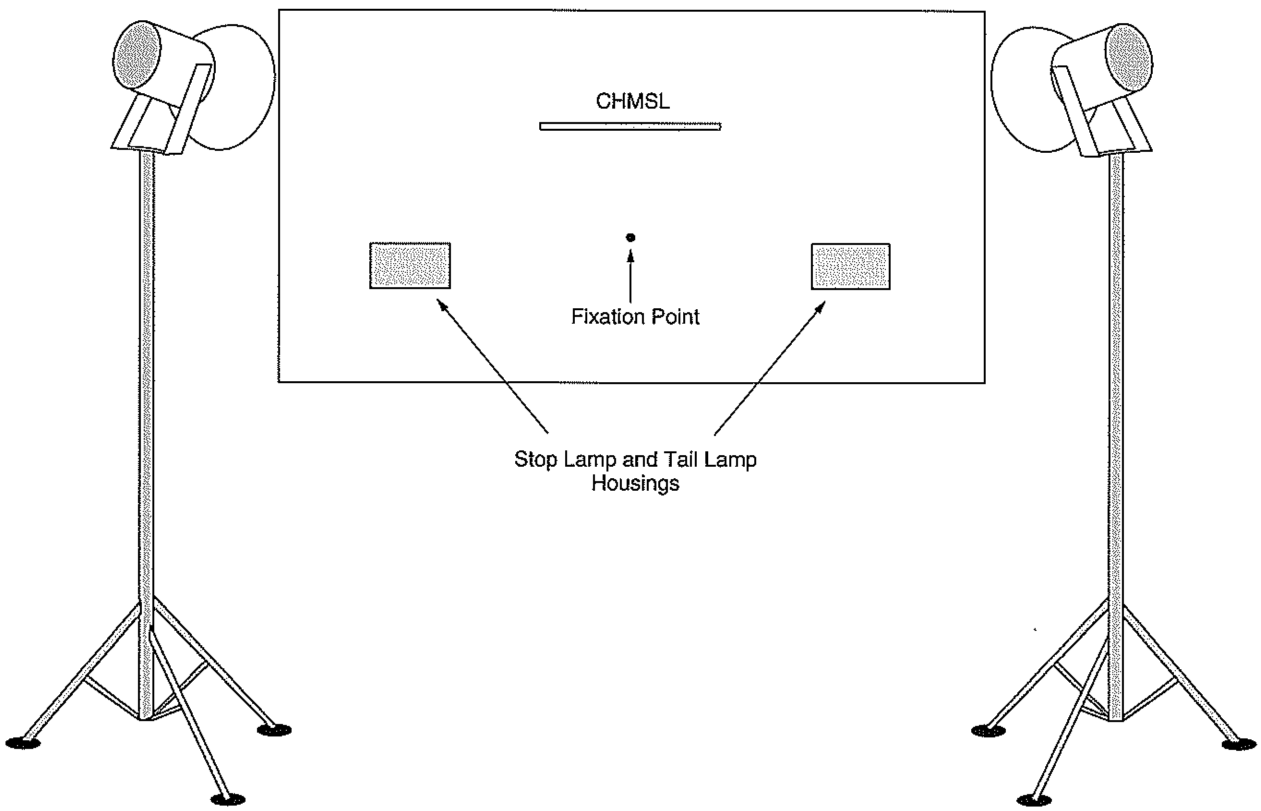

Figure 1. A diagram of the stimulus arrangement as seen by participants.

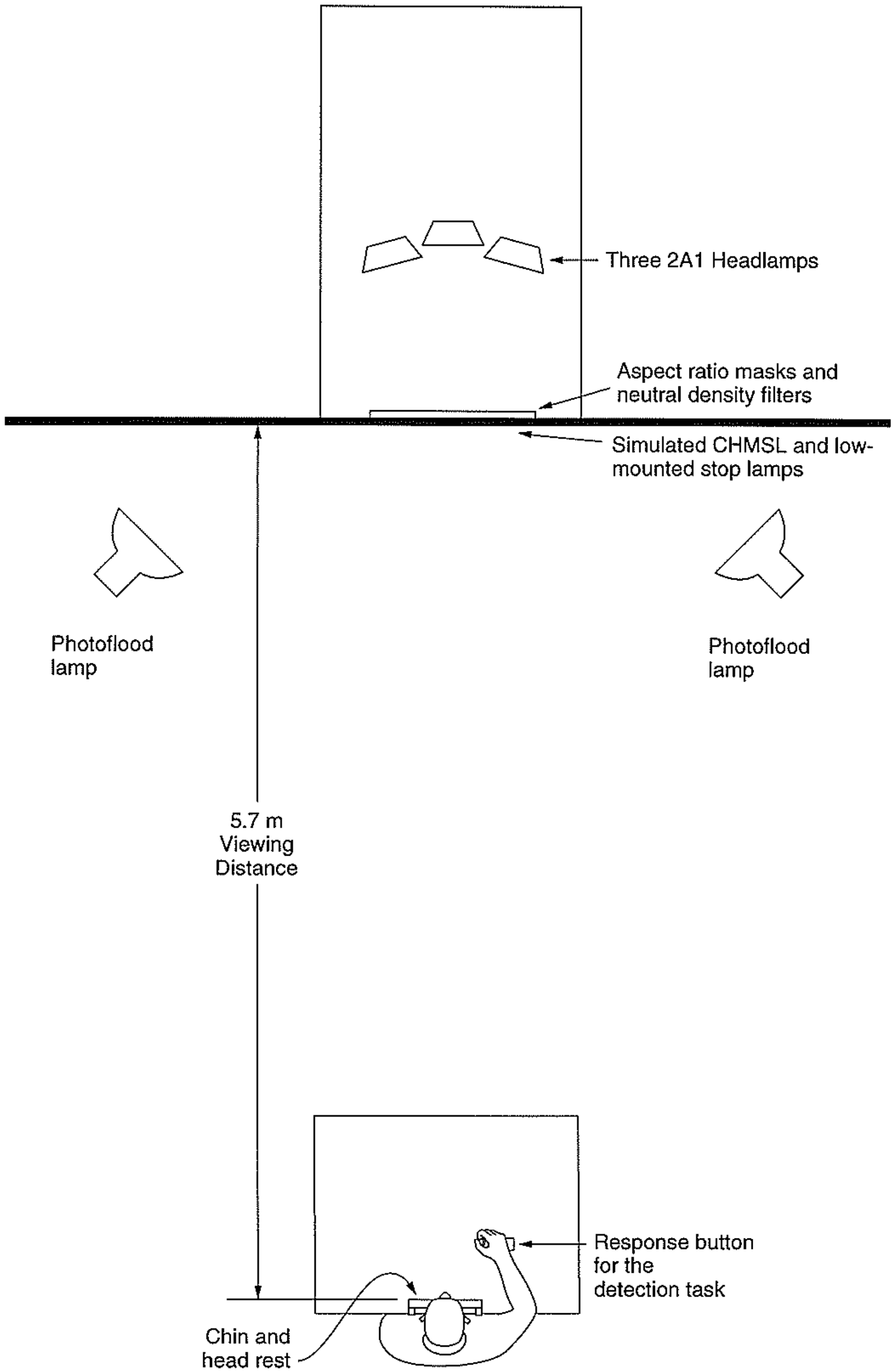

Figure 2. Overhead diagram of the experimental setup.

Stimuli

The laboratory stimuli simulated a complete rear-signaling system on a vehicle viewed from 13.4 m (44 ft). This distance is approximately equal to 1-second of headway when traveling at 48.3 km/h (30 m/h). The actual viewing distance in the laboratory was 5.7 m (18.7 ft). Stimulus size and intensity were scaled appropriately to account for differences in the simulated distance and the actual viewing distance in the laboratory.

Aspect ratio. Five levels of CHMSL aspect ratio (the ratio of height to width) were investigated: 1:1, 1:6, 1:19, 1:39, and 1:67. The largest aspect ratio, 1:67, was selected based on the realistic maximum CHMSL width, considering vehicle width, and minimum CHMSL area. The CHMSL aspect ratios of most vehicles surveyed were between the 1:1 and 1:6. Table 1 provides the dimensions of the stimuli, in subtended visual angle.

Table 1. Subtended visual angles of the stimuli.

Aspect Ratio	Height	Width
1:1	0.33°	0.33°
1:6	0.13°	0.80°
1:19	0.06°	1.68°
1:39	0.05°	2.20°
1:67	0.04°	2.67°

Intensity. Three levels of CHMSL intensity were examined. They were intended to be approximately 25, 75, and 150 cd. These levels were achieved through the use of neutral density filters for the 25- and 75-cd levels. No filtering was required for the 150-cd level. Table 2 provides the actual intensities, relative to the targeted values, observed in the experiment. The 25-cd level of intensity is representative of the lower end of the permissible luminous intensity range, the 75-cd level is believed to be consistent with typical CHMSL intensity, and the 150-cd level approaches the maximum allowable CHMSL intensity. Both CHMSL and stop lamp stimuli had CIE 1931 chromaticity coordinates of x = 0.685 and y = 0.316.

Table 2. Intensity values of the stimuli (cd).

Stop Lamp	Left	82	
	Right	81	
CHMSL	Target Value 150 cd	Target Value 75 cd	Target Value 25 cd
1:1	153	76	27
1:6	157	79	28
1:19	159	79	28
1:39	151	76	26
1:67	153	76	27
Tail Lamp	Left	2.5	
	Right	2.5	

Experimental Design

The independent variables in this experiment were stop lamp context (2 levels), CHMSL aspect ratio (5 levels), CHMSL intensity (3 levels), ambient illumination (2 levels), and participant age (2 levels).

Each of the sixty combinations of stop lamp context, CHMSL aspect ratio, CHMSL intensity, and ambient illumination were presented six times per participant. These six trials were blocked by context, CHMSL aspect ratio, and CHMSL intensity. All trials were further divided into sessions by ambient illumination, with the order of the sessions balanced across participants. The order of blocks within a session was random. The dependent measure was reaction time to the onset of any simulated stop lamp, measured from the time at which the lamps were energized. The interstimulus interval was random, with an approximately uniform distribution from 15 s to 25 s.

Procedure

The experimenter read instructions to the participants (see Appendix A). Participants responded to the onset of stop lamps by pressing a hand-held response button. Participants practiced the task for several minutes, and for the nighttime condition they were allowed to dark adapt for 15 minutes. Breaks between blocks of trials allowed participants to rest and permitted the experimenter to change stimuli. The experimental sessions, two per participant, lasted approximately one hour and forty minutes each.

RESULTS

Mean Reaction Time

Because of errors associated with the presentation apparatus, all participants received fewer than six trials in at least one block and three participants received only three trials in several blocks. Therefore the results examine only three of the six possible trials per block. Specifically, participant reaction times to the first three valid stimulus presentations per block were averaged to determine a mean reaction time per block for each participant.

Analysis of Variance

A mixed-factor repeated measures analysis of variance was performed on the mean reaction times. The variables included were stop lamp context, CHMSL aspect ratio, CHMSL intensity, ambient illumination, and participant age. The Greenhouse-Geisser correction factor was applied to independent variables with more than two levels, and the reported p values for these variables are based upon this correction. A significance level of $p = 0.05$ was adopted for the purpose of determining statistical significance in these analyses.

The main effect of context was statistically significant, $F(1, 22) = 406.2$, $p \leq 0.0001$. Mean reaction time was longer for the CHMSL-only condition (540 ms) than for the CHMSL-and-stop-lamp condition (476 ms). The main effect of CHMSL aspect ratio was also statistically significant, $F(4, 88) = 3.8$, $p = 0.0067$. The shortest mean reaction time was observed for the 1:1 condition, and the trend (see Figure 3) appears to suggest increasing reaction times associated with increasing levels of CHMSL aspect ratio. Post hoc analyses using the Newman-Keuls test for differences between means found the 1:39 level to be significantly different from both the 1:1 and 1:19 levels of CHMSL aspect ratio.

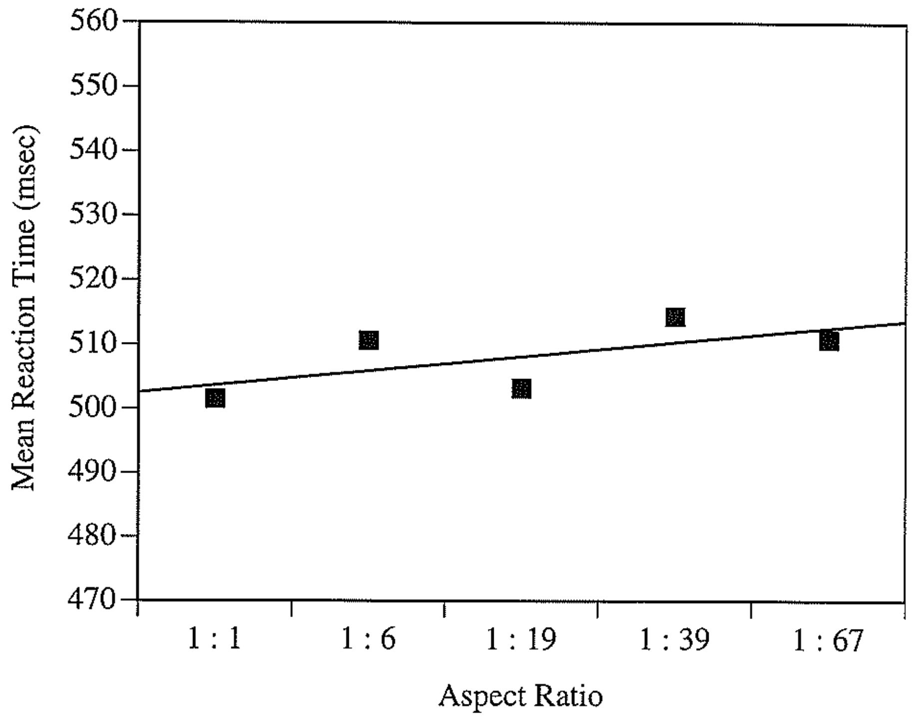

Figure 3. Mean reaction time by aspect ratio.

The main effect of CHMSL intensity was also statistically significant, $F(2, 44) = 7.6$, $p = 0.0016$. The longest mean reaction time was observed for the 25-cd level (514 ms), and the shortest mean reaction time was observed for the 150-cd level (502 ms). The remaining level of CHMSL intensity, 75-cd, resulted in a mean reaction time of 507 ms (Figure 4). Post hoc analyses using the Newman-Keuls test for differences between means found reaction times to the 25-cd level to be significantly longer than both the 75- and 150-cd levels. The main effects of ambient illumination and participant age were not statistically significant.

Two second-order interactions were statistically significant. The first was between context and CHMSL intensity, $F(2, 44) = 10.0, p = 0.0003$. Figure 5 shows that reaction time was increased with decreasing CHMSL intensity for the CHMSL-only condition, but was not affected by CHMSL intensity when low-mounted stop lamps were present.

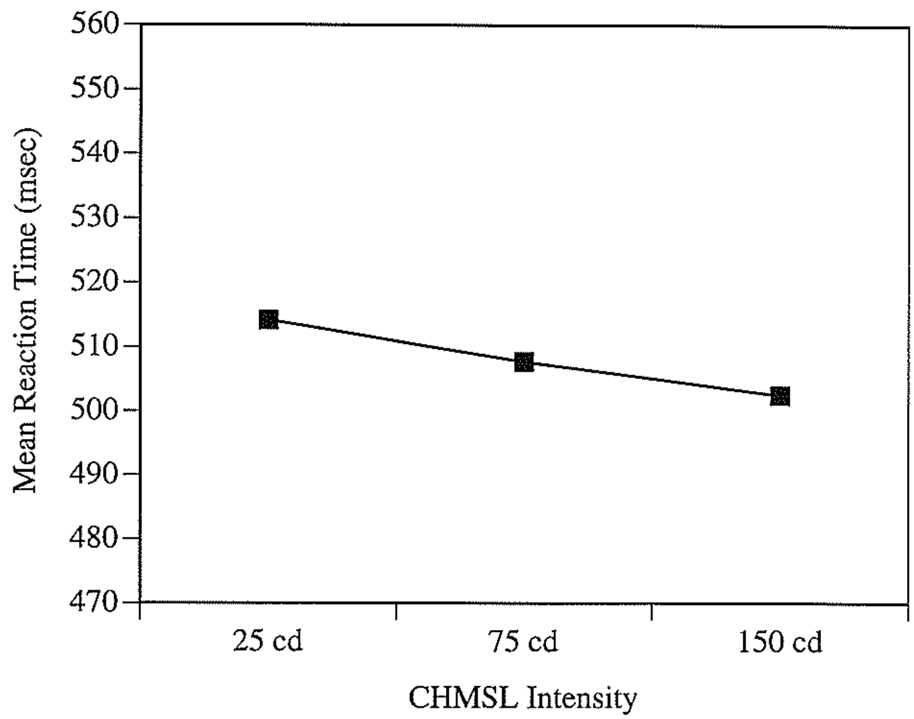

Figure 4. Mean reaction time by targeted CHMSL intensity.

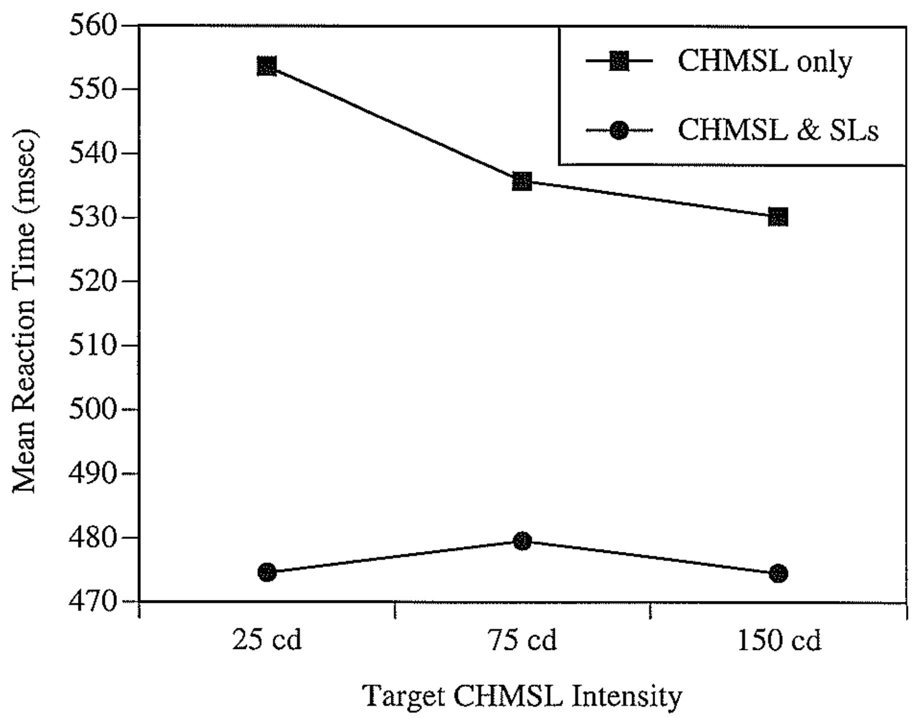

Figure 5. Mean reaction time by context and targeted CHMSL intensity.

Figure 6 illustrates the statistically significant interaction between context and ambient illumination, $F(2, 44) = 10.0, p = 0.0003$. The reaction time was longer with the daytime level of ambient illumination for the CHMSL-only condition, but reaction time was not affected by the level of ambient illumination when low-mounted stop lamps were present.

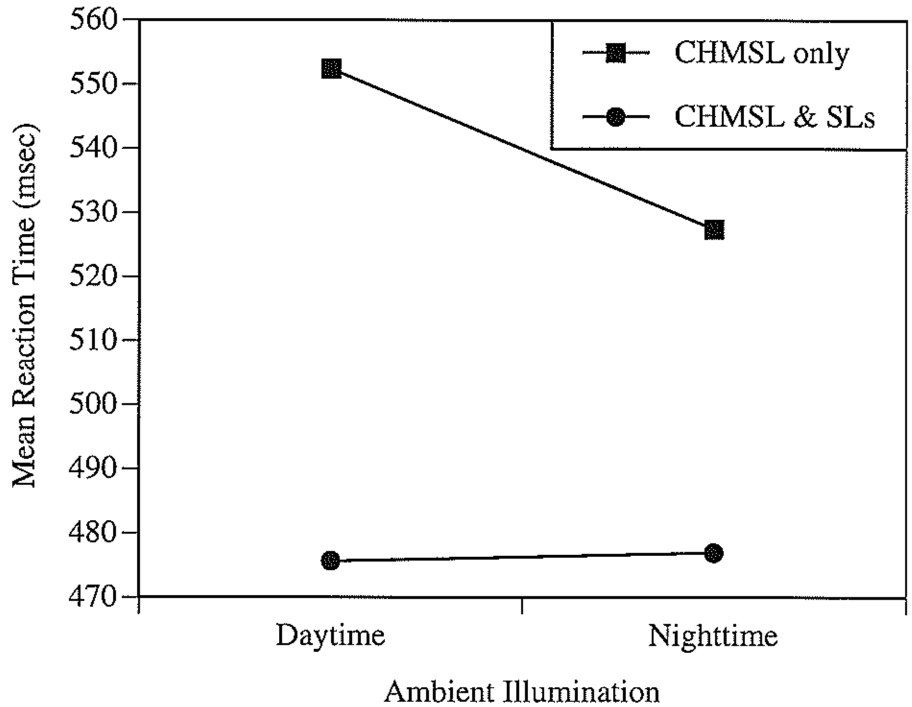

Figure 6. Mean reaction time by context and ambient illumination.

Comparison with Previous Research

In a previous investigation, Sayer, Flannagan, and Sivak (1995) examined the effects of intensity, area, and aspect ratio on reaction time to stop lamps. Although the nature of the task differed slightly from the present experiment, there exist similarities in the results of the two studies. Figure 7 indicates that, in both studies, lamp intensity and lamp aspect ratio significantly affected mean reaction times under daytime viewing conditions. Specifically, in both studies the lowest aspect ratio (1:1 in both studies) was associated with the fastest reaction times. In addition, the highest level of lamp intensity (approximately 150 cd in both studies) was associated with the fastest reaction times. However, the differences in reaction time associated with lamp aspect ratio in the previous study were larger than those observed in the present study.

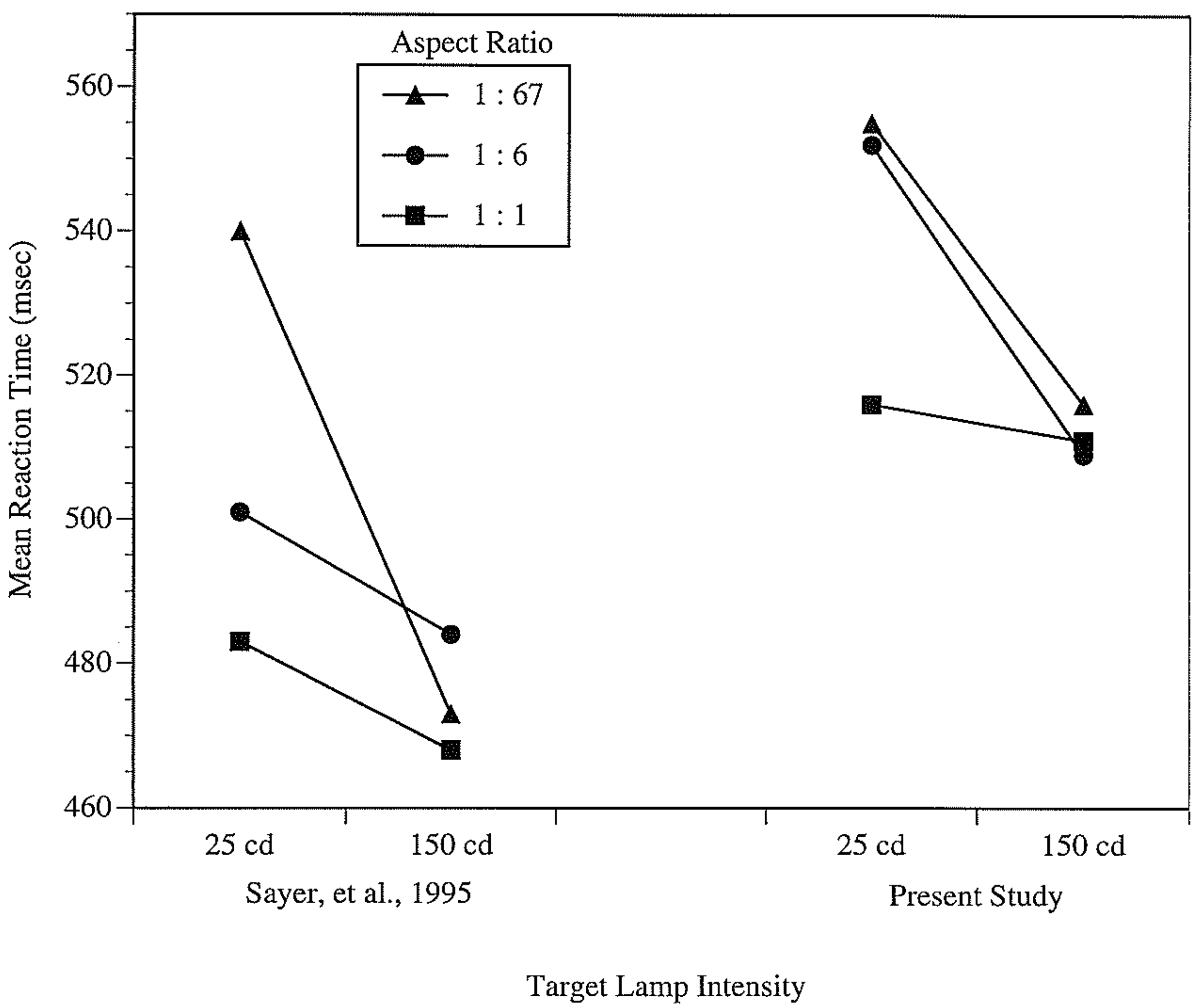

Figure 7. A comparison of a subset of the results from the present study and a previous investigation. The results shown in this figure from the present study are only for the conditions similar to those used in the previous investigation (i.e., when no low-mounted stop lamps were present and viewing was performed under daytime conditions).

DISCUSSION AND CONCLUSIONS

The results of this study indicate that context (the presence of other stop lamps), CHMSL aspect ratio, CHMSL intensity, and the interactions of context with both CHMSL intensity and ambient illumination are significant factors in driver reaction time to CHMSLs. These results are largely consistent with previous research (Sayer, et al., 1995) suggesting that large aspect ratios and low intensity detrimentally affect reaction time to the onset of CHMSLs when viewed without the context of the remaining rear-signaling system (low-mounted stop lamps). While the present study did not identify a definitive relationship between aspect ratio and reaction time, the trend appears to suggest increasing reaction times associated with increasing CHMSL aspect ratio. The lowest mean reaction times in response to a CHMSL in isolation were again observed when stimuli were of the highest intensity (150 cd) and the smallest aspect ratio (1:1).

Whenever possible, motor vehicle designers should emphasize high lamp intensity as well as small aspect ratios because of the possibilities that CHMSLs will be viewed in isolation. Similarly, lamp intensity should also be emphasized in the design of low-mounted stop lamps. While the optimal level of intensity required for an isolated CHMSL to result in the same level of reaction time observed for an entire rear-signaling system has yet to be determined, the results of this study suggest that it would be an intensity greater than 150 cd. Furthermore, neither this study nor the previous one took into consideration the effect that window/windshield transmittance of preceding vehicles (and subsequent reductions in stop lamp illuminance reaching the observer's eyes) can have on the reaction time to stop lamps.

When viewed in conjunction with the low-mounted stop lamps variations in CHMSL aspect ratio, CHMSL intensity, and ambient illumination did not significantly affect reaction time to stop lamp onset. This result emphasizes the influence that stop lamp context has on reaction time, and furthermore suggests that regulations and standards for stop lamps warrant re-examination to consider the effects of stop lamp context.

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APPENDIX A: SUBJECT INSTRUCTIONS

Thank you for agreeing to participate in this laboratory experiment investigating drivers' response times to various stop lamps. The lamps that you see on the white board in front of you simulate the stop lamps of an actual vehicle. Notice that there are the left and right low-mounted stop lamps, as well as one center high mounted stop lamp (CHMSL), which are present on most cars in the world today. *(point these out)* Also, notice this small red light. I will tell you more about this light a little bit later.

Your task involves pressing this *(show it)* response button as soon as you see the stop lamps come on. In some cases, all three stop lamps will come on at the same time. In other cases, only the center high mounted stop lamp will come on. Your job is to press the response button whenever either event occurs; that is, you will press the response button whenever you see **any** of the stop lamps come on. We are measuring reaction times in this experiment, so it's important that you respond as quickly as you possibly can at the onset of the lamps. Furthermore, the stop lamps will turn off after you press the response button, indicating that your response was recorded. Finally, it is also important that you do not push the response button between trials. However, we would like you to keep your forefinger on top of the response button throughout the study, so that you are ready to respond when you see the stop lamps come on.

Before we begin, I will ask you to position yourself comfortably with your chin in the chin rest. Feel free to adjust the height of the chair *(show them the lever on the side of the chair)* so that you will be comfortable throughout the entire experiment. During the blocks of trials, please keep your chin in place in the chin rest with your forehead pressed against the headrest. Please also keep your eyes focused on the small red light that I mentioned earlier *(point out the light again)*. It is very important that you keep your eyes focused on this red light throughout the study. It may be tempting to let your eyes wander, but it is important that you keep fixated on the small red light.

You will be given two short breaks throughout the experiment. During the breaks, you will be able to relax, stand up, and walk around should you want to. I will be changing various components of the experiment's setup throughout the study, but in the interest of time, we would like you to keep your chin in the chin rest and eyes focused on the red light even when I'm changing some the experimental setup. However, if you need longer or more frequent breaks, let me know and I'll be happy to provide them.

The experiment will last about an hour and a half. You will be given 6 practice trials before we begin the actual study to get you comfortable with the task. Remember to respond as quickly as you possibly can whenever you see any of the stop lamps come on. Also remember that in some instances, you will see all three stop lamps come on, and in others, only the high mounted stop lamp will come on. Finally, please keep you finger resting on top of the response button throughout the study.

Do you have any questions?