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DRIVER EYE FIXATIONS UNDER IFFERENT OPERATING CONDITIONS

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16. Abstract

The eye fixations of six individuals were measured while driving on straight and curved sections of road, night and day, and with and without a car in front of them. Eye fixations on straight sections were distributed uniformly over the road, while on curves they tended in the direction the vehicle would be turning. At night fixations were concentrated relatively near the vehicle, in the area illuminated by its headlamps. Fixations averaged longer duration at night as well. When a lead vehicle was present, it dominated the attention of the drivers, especially at night and on straight sections of road.

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INTRODUCTION

There can be no question that the visual sense is of primary importance in acquiring the information necessary for the control of a motor vehicle. For this reason there has been interest in recording eye fixations as a means of studying the process by which drivers acquire visual information.

The term "eye fixations" refers to where the subject is looking with central (foveal) vision. When concentrating on some object or condition, people generally shift their direction of gaze so that its image falls on the foveal portion of the retina. Hence, when something is being attended to, a foveal fixation is to be expected. Unfortunately, when interpreting eye fixation data, one cannot turn this logic around and be confident that something is being attended to based on an apparent foveal fixation. In addition, certain information is routinely acquired peripherally. As an example, experienced drivers seem to rely on peripheral vision for maintaining lane position (Bhise and Rockwell, 1971), at least on straight sections. Thus, there are limitations to the inferences that can be drawn from eye fixation data. Most investigators have been content to report general trends in eye fixations as a function of the variables of interest. This is the approach that will be used in this study.

BACKGROUND

Driver eye fixations have been studied as a function of a number of variables. A good review of this work has been provided by Cohen (1978). The following is a brief discussion of research that has dealt with variables of interest to the current investigation.

Curved vs. straight roads. One variable that has been of interest to investigators is road geometry. Straight road driving provides a powerful directional cue in the focus of expansion; i.e., the apparent outward flow of the forward field from a point toward which the car is traveling. Research suggests that drivers' eye fixations on straight sections tend to cluster near the focus of expansion (Mourant and Rockwell, 1972). This cue is of no assistance when the road is curving, so there has been an interest in comparing fixations on straight and curved sections as a means for determining where the driver obtains necessary visual information while negotiating curves.

Several studies have been reported that compared eye fixations on straight and curved road sections (e.g., Cohen and Studach, 1977; Mortimer and Jorgeson, 1972; Shinar, McDowell and Rockwell, 1977). All of these agree in finding considerable differences in eye scanning behavior comparing straight and curved sections of highway. In general, fixations on curves were of shorter duration than those on straight sections. Eye fixations on right curves tended to be toward the right edge of the lane, while those on left curves were more distributed across the road surface.

Night vs. day. Typically, while driving at night, far less visual information is available to the driver. Presumably, this would have an effect on eye fixations. Relatively few studies of nighttime driver eye fixations have been conducted. One example is that of Zwahlen (1982), who found that eye fixations at night tend to be of longer duration, are more concentrated on the roadway ahead, and evidence shorter preview distances than during the day.

Car following. When following another vehicle the driver is confronted with something that is at once a cue to where the road is going (which may be particularly valuable at night), and a potential obstacle that must be monitored at least to some degree. Hence, it would be expected that the presence of a lead car would alter eye fixation patterns significantly. Only one study has been reported on this subject (Mourant and Rockwell, 1970). Their results show that the spatial distribution of eye fixations is significantly narrowed under car-following conditions, with the lead car becoming the focus of much of them.

METHOD

The purpose of the study described in this report was to record driver eye fixations under controlled conditions as a function of the three variables discussed above.

Independent Variables. Three independent variables were investigated in this study. These were:

a. Roadway configuration: Three levels, straight, right and left curves. The test road was run in both directions, yielding two straight sections, three right curves, and three left curves.

b. Ambient illumination: Two levels, day and night.

c. Car following: Two levels, following or not following another vehicle.

Each subject in the study was run under all combinations of the variables listed.

Dependent Variables. The dependent variables in the analysis were the number and duration of fixations on specified features or areas of the forward field and the percent of time spent fixating each. For purposes of this study, a "fixation" will be defined as a look to a specified area of the visual field, as listed below.

The following features of the visual field were noted in the analysis:

a. Left edge of road
b. Center of road
c. Right edge of road
d. Lead car
e. Far field
f. Signs
g. Inside the car
h. Other

Fixations in categories a, b, and c were relatively close to the car, generally 100-300 feet ahead. "Far field" fixations (category e) were much farther up the road.

Equipment. A NAC Eye Mark Recorder, Model 4 was used. This instrument uses the corneal reflection method. Field of view and eye position information are combined in that portion of the device that is mounted on the subject's head and conveyed to the recording device by a coherent fiber optics bundle.

The data were recorded on videotape. A monitor was provided within the car so that the experimenter could calibrate the instrument and observe performance continuously. For nighttime operation it was found that the scene as viewed through the eye mark optics did not provide sufficient detail to allow the vehicle's position on the road or the location of significant details in the roadway environment to be determined. To solve this problem a second, low light level camera was used, aimed through the windshield of the car. This showed the forward field with great clarity. The image from this camera was combined on a split screen with that from the eye mark recorder by use of a special effects generator.

Vehicles. Two full-size station wagons were used in the test. One of these was driven by the subject while data were being taken, the other was driven by one of the experimenters and served as the lead vehicle in the car-following trials. All the test equipment was installed in the first vehicle.

In addition, at night, the vehicle being operated by the subject was equipped with a set of marker lights across the front of the hood. These lights were red in color, and about 0.5 inch (1.3 cm) in diameter. Two lights, about one inch (2.54 cm) apart marked the center of the hood, a single light marked the right and left edges of the hood. These lights provided a frame of reference when determining the position of the subject's eye mark during data reduction. An obvious concern was whether these reference lights would distract the subjects or alter their fixation patterns. While there can be no certainty that this did not occur, no fixations on the lights themselves were noted during the study.

Facility. The test was run on a lightly-traveled road in a rural area. The section utilized was about one mile (1.6 km) long, and was paved with asphalt, in very good condition. It consisted of a straight section about one-quarter mile (400 m) long at one end, and a series of three approximately 90 degree curves. The curve radii were such that a maximum comfortable speed was about 40-45 mph (64-72 km/h). The road had a centerline (which had been repainted within a week of the start of the test), but no edge lines.

Procedure. Six subjects were used in this test. All were male; they ranged in age from 20 to 34 years of age. None wore eyeglasses (the eye mark recorder will not fit over glasses). People who were recruited for the test came in first for a fitting. In this session the eye mark instrument was fitted to their head and an effort made to find and calibrate the eye spot. This was necessary for two reasons. First, an eye spot cannot be found on all individuals. In addition, on some persons the spot can be found, but will not track accurately. The screening identified these individuals so they could be eliminated from the test. Second, by going through the procedure once in the office, the subject became familiar with it and the experimenter could note settings on the instrument associated with proper calibration. This made it easier to set up the instrument under test conditions, while working in the dark, and in the confinement of a car.

It was thought important that the subjects not realize that eye movements were being monitored. Therefore, they were told that the purpose of the study was to measure pupil size as it might be affected by different conditions while driving. To explain this they were told that previous research had established that pupil size was a good indicator of such things as stress and workload. This subterfuge seemed to work well. Questions and comments from the subjects indicated that they believed the story through the period of data collection.

When the subject appeared for a recording session he was placed in the passenger seat of the test vehicle and driven to the far end of the test road (i.e., the start of the straight section). At this point he moved to the driver's seat, positioned himself comfortably and adjusted the mirrors properly. The eye mark instrument was fitted to his head and adjustments made until the spot had been located, focussed, and calibrated. This took from five to fifteen minutes. The subject then made one round trip on the test road to become accustomed to driving with the camera on his head. This was also a period when the instrument was likely to move out of calibration, so it was closely monitored by the experimenter and recalibrated as necessary. Typically, after this first trip, the recorder stayed in calibration, although it was checked after each run.

At the conclusion of the first round trip the calibration was checked and altered if necessary. The subject was then told to drive to the other end of the road. At this point the experimenter turned around in his seat, looked out the rear window and said "ok, you can start out after this car passes." The other station wagon drove slowly past at this point and the subject pulled out behind it. No specific instructions were given to follow the other car, instead the driver of the lead car made an effort to adjust his speed so that the subject stayed about 200-300 feet behind. This was judged far enough away so that the lead car would not dominate the forward field of view, but close enough to be continuously visible even while rounding curves. The two vehicles moved to the far end of the road and turned around in separate driveways. The calibration was rechecked, and the process repeated on the way back. When the cars returned to the start point the calibration was checked once again and the subject was instructed to move off. This run was made without the lead car. At the conclusion of this round trip the equipment was removed from the subject's head, and he was driven back to the Institute. On another occasion as soon as possible afterwards the second session (daytime or nighttime) was scheduled, where additional data were taken using the exact same procedure.

Data Reduction. The data were reduced using special equipment that has been developed for that purpose. The equipment consists of a series of counters and timers and a ten-button keypad. The experimenter runs the videotape at slow speed (about one-tenth normal) and presses a button each time the eye spot moves to a point in the environment of interest. When the button is pressed a counter is advanced and a timer begins to run. It continues to run as long as the button is depressed. At the conclusion of each section of each run the experimenter has a compilation of the number of fixations on each feature of interest and data that can be converted into percent time spent fixating each feature. Correcting for the slow motion while reducing data, it is possible to calculate fixation durations as well.

Each single-direction run by each subject lasted about two minutes. All told, each subject's data totaled about eight minutes. A total of 4,343 eye fixations were recorded in the entire study.

RESULTS

Figure 1 shows the results in terms of percent time spent fixating the cataloged areas of the forward field. The format of this figure is the same as will be used for other figures to follow. There are three parts to the figure, one each for straight, right- and left-curve sections of the test road. The features of interest (e.g., left edge, center, etc.) are listed along the horizontal axis of each graph. The four bars above each feature represent the four test conditions (day-night, lead car, no lead car).

Starting with the top (straight road) portion of Figure 1, the most obvious result is the degree to which a lead car dominated in terms of eye fixations. Subjects spent 80% of their time looking at the lead car in the night session, and over 50% in the day session. In the absence of a lead car at night, the subjects spent 80% of the time looking toward the center of the road. This may be because the only delineation was a center line. During the day, absent a lead car, the subjects' eye fixations were widely distributed, with 40% in the "far field." Many of these were searches around the curve as it was approached. The bulk of the rest of the fixations were on the road closer to the car, with most of these being in the center. Again, the presence of a well-defined center line and the absence of any other delineation may have been a factor in the distribution of eye fixations.

The second portion of Figure 1 shows percent time spent fixating various areas while in the right curves. The distribution of fixations is quite different than while on the straight sections. Under all conditions tested, the area most fixated was the right edge of the road. When there was a lead car present, this was the second most fixated item, although the percent time dropped by about 50%, compared with the straight sections. In the absence of a lead car, the second most fixated area was the center of the road. In the day, absent a lead car, the subjects spent about 20% of their time looking into the far field. These were searches around the curve, apparently seeking lead information.

The third portion of Figure 1 shows percent time spent fixating various areas while in left curves. There is a clear shift in fixations to the left, as would be expected, but the pattern seems more dependent on the experimental conditions than in the case of right curves. For example, at night, with no lead car, virtually all fixations were on the center and left edge of the road. With the lead car present, about half of the fixations were on it, and looks to the center and left edge were reduced greatly. During the day, with no lead car, most fixations were on the left edge of the road, with looks to the far field being next most frequent. With a lead car present, that again dominated the subject's attention, with looks to the left edge and far field being correspondingly reduced.

Figure 2 shows the frequency of fixations to various areas of the forward field. These data have been converted to percent of total to make the figure more readable. Comparing Figure 2 with Figure 1 shows generally the same pattern.

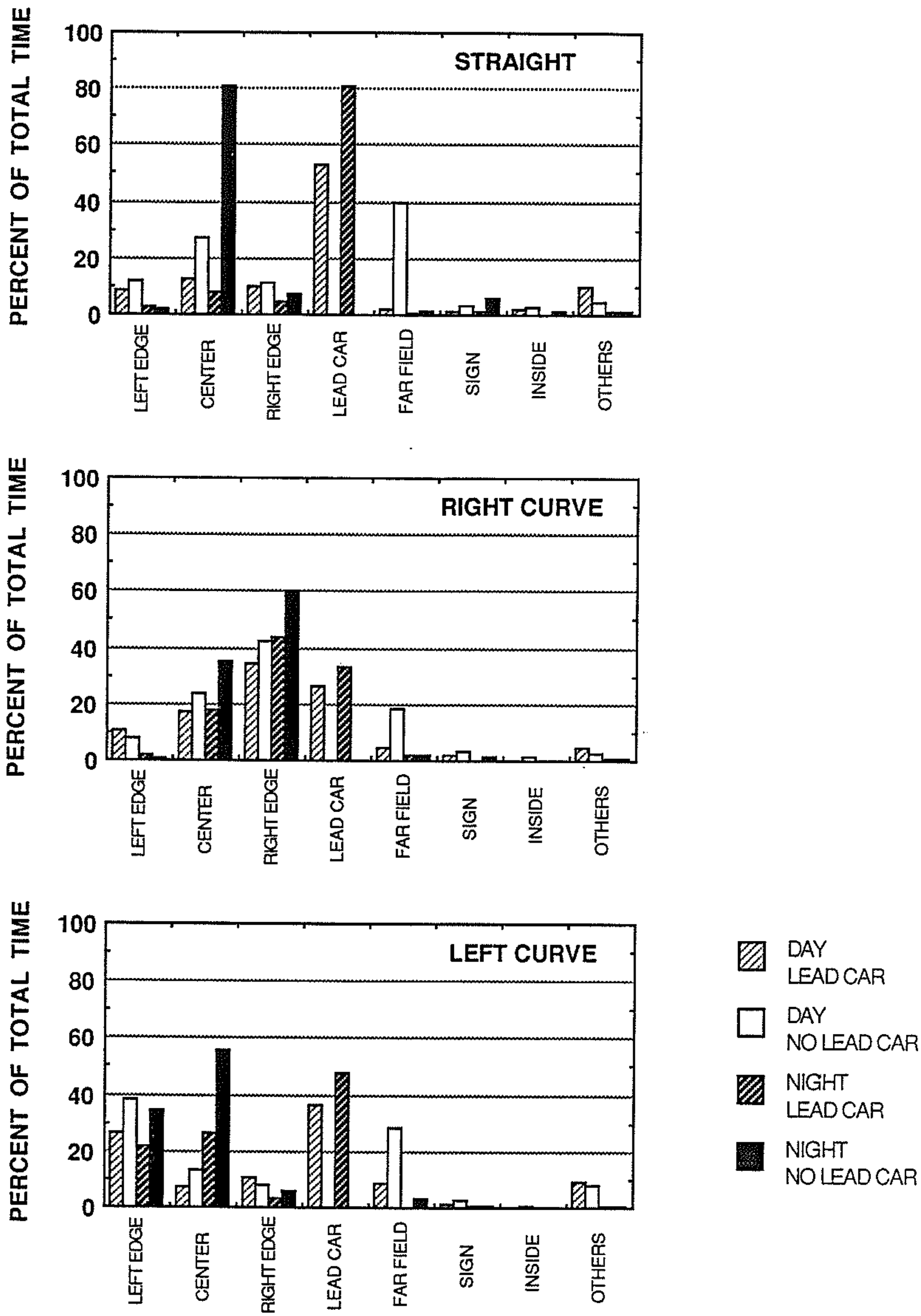

FIGURE. 1 Mean percent time toward various areas as a function of road geometry.

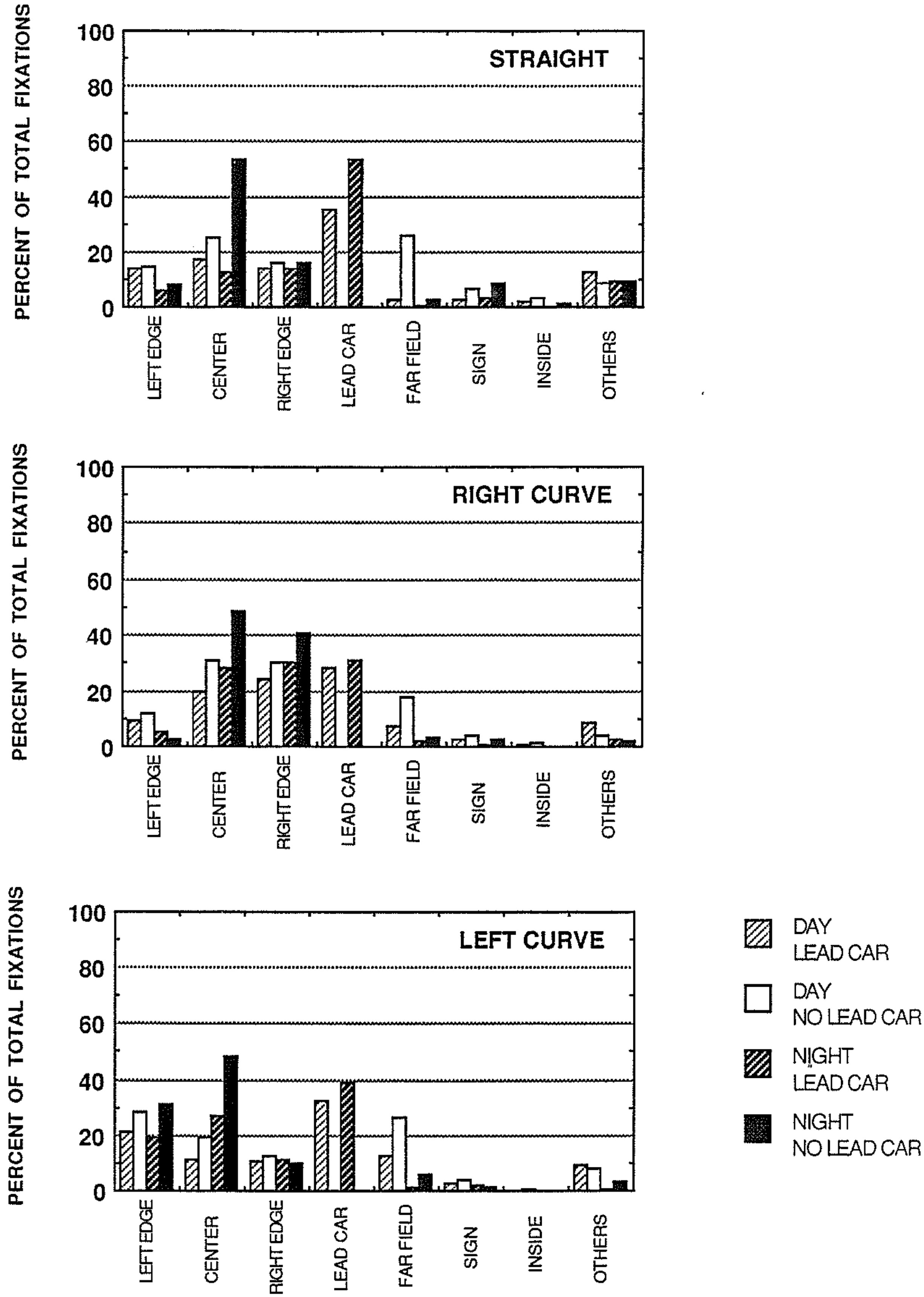

FIGURE 2 Mean percent of total fixations in various areas as a function of road geometory.

Figure 3 shows the mean time per fixation. Most areas listed in the figure drew fixations that averaged 0.30 to 0.60 second. But, a few areas tended to draw relatively long fixations, depending on the test conditions. By and large, these long average fixations are associated with areas of the forward field that commanded the most attention as shown in Figure 1.

Figure 3 also suggests that average fixation times were longer under the nighttime conditions. Those fixation times that average one second or more all occurred at night. During the day most fixation durations averaged 0.60 second and less.

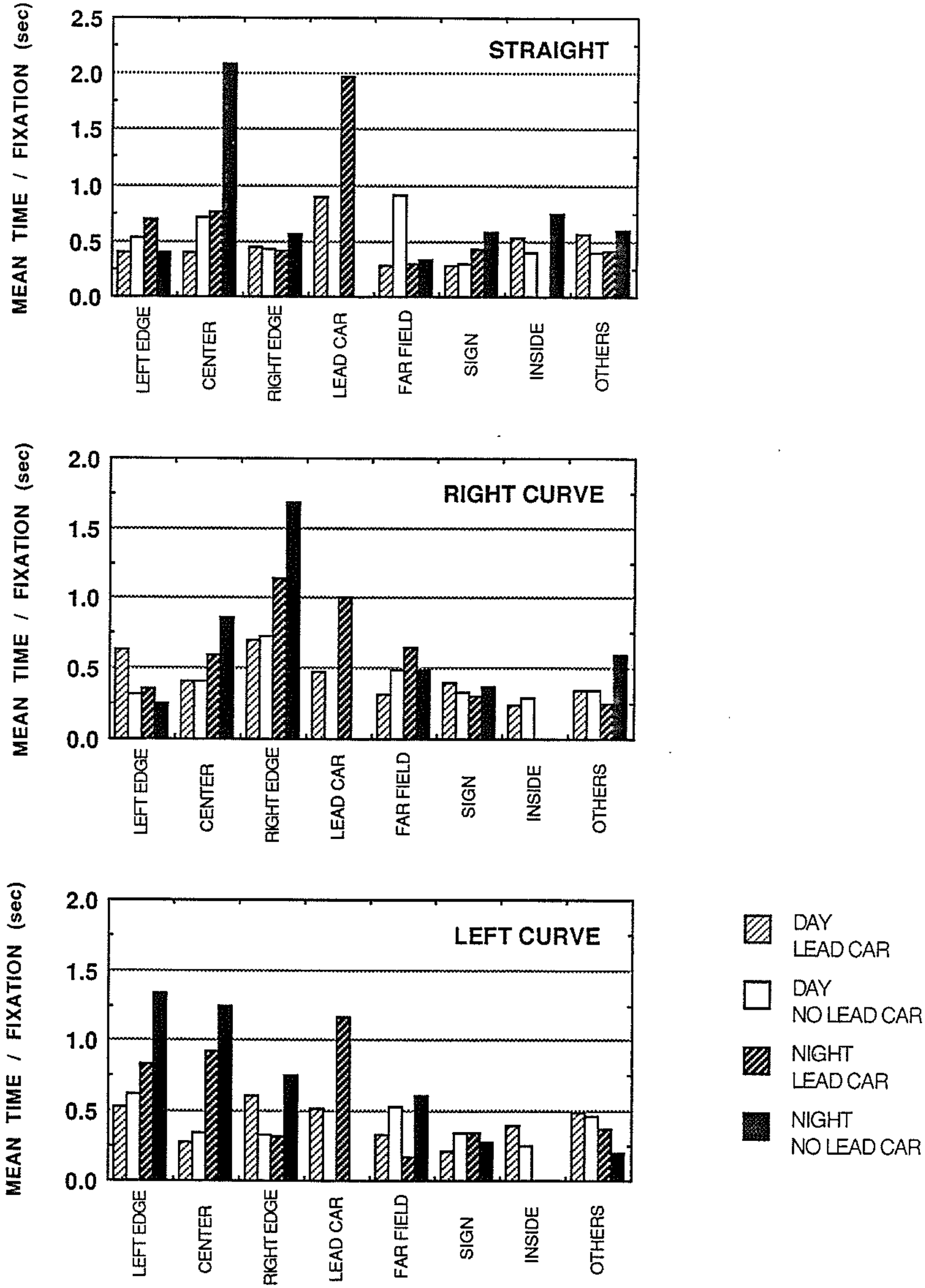

FIGURE 3 Mean time per fixation to various areas as a function of road geometory.

DISCUSSION

Straight vs. curved sections. The results for straight and curved sections generally correspond to that reported by other investigators. On straight sections drivers tend to scan the road uniformly, with an emphasis on the center, which would be near the focus of expansion. On curved sections the bulk of fixations were in the direction of the curve. These general trends varied as a function of the other variables investigated.

Day vs. night. Ambient illumination affected where the subjects looked as well as the duration of fixations. At night the fixations were more concentrated in the area immediately ahead of the car, particularly in the vicinity of the centerline. Of course, excepting the area illuminated by the car's headlamps, there was little else to see on the test road. This may account for much of the changed scanning pattern. The loss of information from the far field, often accessed during the day sessions, may have made the nighttime driving task more difficult, resulting in a greater need for such information as could be obtained from those areas closer to the car. In addition, the lack of edge delineation may have caused the subjects to rely on the center line for directional and lane position information to a degree greater than would otherwise have been the case. The duration of fixations in areas of the road in front of the car were generally longer at night than during the day, which suggests a more intense search for information and/or greater difficulty in extracting information.

The lack of edge delineation may also account for a difference in day/night fixations on the center and left edge of the road while making left turns. During the day more time was spent fixating the left edge than the center of the road, a situation that reverses at night. On right turns the pattern is the same night and day. This may have come about due to the distributional characteristics of low-beam headlamps, which causes far less light to be directed to the left side of the car, combined with the fact that the left edge is farther away. As a result, the left edge of a road in a left curve would be much less visible than the right edge in a right curve at night.

Car following. The presence of a lead car had a major effect on eye fixation patterns, particularly at night. On straight sections it was clearly the dominant stimulus. On curves the lead car still attracted a great deal of attention from the subjects, taking away from looks to the center and edges of the road. This was particularly true on left curves, where the lead car was still the object most fixated.

CONCLUSIONS

The results of this study generally confirm data reported by other investigators, as described in the introductory portion of this report. What is different about the present study is the examination of multiple variables and their interactions. It is clear that the general statements that one can make about factors such as road geometry, ambient illumination, and the presence of a lead vehicle must be modified somewhat when such variables exist in combination.

It should also be clear that the data from an investigation such as this depend on matters that are situation specific. For example, the lack of edge delineation, combined with the freshly-painted center line on the test road, may have affected the distribution of eye fixations in this study, particularly at night. Fixations to a lead car probably depend on the separation distance, a factor that would be particularly sensitive on curves. While the general trends noted here are interesting and suggestive, it is essential that the reader keep in mind the limitations that apply.

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