Perceptual and Field Factors Causing Lateral Displacement

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•WHEN an object is placed near the path of a driver, a lateral movement away from the object occurs as the driver approaches. The amount of this lateral displacement has been shown to be directly dependent on the distance of the object from the path of travel (2, 6). Thus, Taragin (6) has shown that there is a shift in position for objects located up to 6 ft to the right of the driver's path of travel. However, the process that the human operator must carry out in order to locate himself relative to fixed objects in his path has not been specified. The present research was an attempt to isolate the variables involved in this location process.

From a perceptual standpoint, the transverse location of an object in a driver's path may be considered a problem in trigonometry. The transverse distance, a, or an object may be derived from the simple trigonometric expression:

$$a = 1 \tan \theta$$

The conditions are shown in Figure 1.

Thus, at any point in space, the observer may determine the distance, a, by estimating both 1 and θ. For small angles, $\tan \theta = \theta$, and therefore, the equation becomes simply

$$a = 1\,\theta$$

However, a problem arises for the driver because of the interaction of distance and angle. At long distances, the angle θ is so small that errors in estimation preclude a solution of sufficient accuracy to determine whether the object is in the driver's path. Similarly, at short distances, θ increases so rapidly that solutions also become inaccurate. Therefore, there should be a range of distance for which judgment of the angle θ has maximum accuracy. On the basis of this angle estimation model, as the driver approaches the object, he eventually moves into an optimum range of discrimination. If the angle is smaller than some critical value he will displace from the object, the magnitude being directly related to the size of the angle at the distance at which the discrimination is made. According to this model, lateral displacement should begin at some fixed distance from the object independent of the absolute location of the object and independent of travel speed.

An alternative model exists, however. Because the driver is moving continuously toward the object, the angle as well as distance is changing continuously. If the driver tracks the object over a period of time and estimates the rate at which the angle is changing, he can also determine the lateral location of the object relative to his path of travel. This derivative is a nonlinear function of time and is, furthermore, dependent on the speed of travel. If the driver were to operate on this basis, he would be solving the equation:

$$\frac{d\theta}{dt} = \frac{av}{a^2 + 1^2}$$

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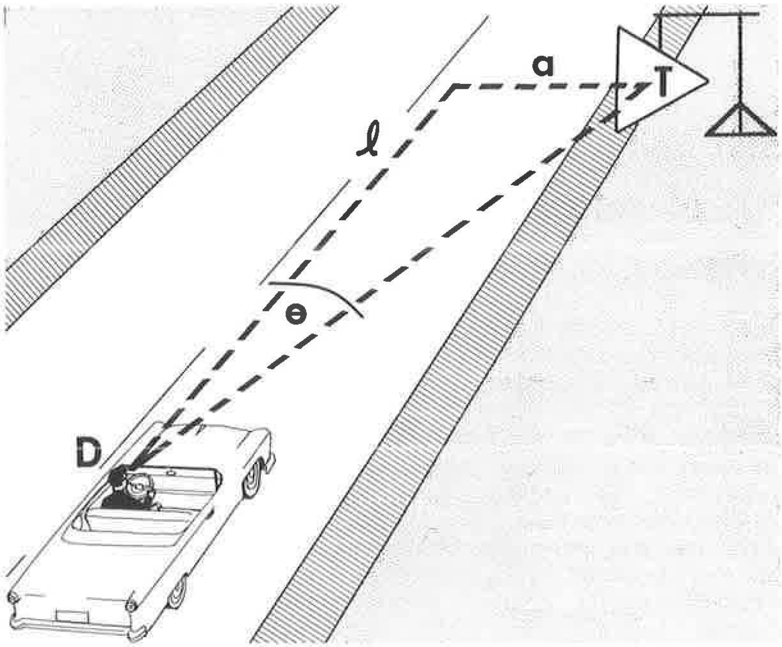

Figure 1. Geometry of object location problem.

Estimation of the rate of change of the angle between himself and the object in his path has several advantages for the driver. First, his judgment very quickly becomes a simple binary one. If the rate of change does not exceed a certain critical value, regardless of sight distance and object location, the driver can predict a collision course. Second, the driver has a physical anchor for speed judgment and one source of error may be minimized. Third, vehicle speed must be taken into account in any steering inputs imposed on the vehicle.

On the basis of the derivative model a set of hypotheses arises which is very different from the angle estimation model. The hypotheses may be stated as follows:

1. The magnitude of lateral displacement will be directly related to vehicle speed.
2. Lateral displacement will begin at a distance dependent on vehicle speed.
3. The derivative of the visual angle at the point where displacement begins will be independent of speed and object location so long as displacement occurs.

A final consideration that exists in the displacement effect concerns the spatial characteristics of the stimulus object. In the description of both models, it was implicitly assumed that the object was a point in space which served as a simple visual reference. Actually, all practically realized displacing objects have some extension. It would appear reasonable that the nature of the contours of the object would influence the driver's perception of the location of the object. The study of Case et al. (2) did find that the size of the object significantly affected displacement.

It might be expected that the angle would be taken to the contour of the object nearest the path of travel. If, however, the shape of the object is of limited extent and has one dominant contour, the driver might be expected to use that as a point of reference. An example is a triangular object with the base oriented perpendicular to the driver's regard. It may be expected that, when that base is farthest from the roadway (the apex being nearest the travel path), there should be less displacement than when the situation is reversed. Obviously, this is a limited case for there should be a limit to contour effectiveness if the farthermost border has too great an extent. Within these limits, it is reasonable to hypothesize that the dominant figure contours should influence the magnitude of displacement. In this study, an equilateral triangle was used to test this hypothesis.

In summary, this study was an attempt to isolate the perceptual variables that cause lateral displacement and to discriminate between two alternative models of that process.

APPARATUS AND PROCEDURE

To determine where and when lateral displacement began and the magnitude, it was necessary to devise a method for measuring lateral position continuously. An optical tracking system was developed by Melpar, Inc., for this purpose. It was a housing anchored on the rear bumper of a vehicle containing 37 individual photodetector units mounted to face downward. The detector is shown in Figure 2. Each unit contains a light source and lens system to focus the beam on the roadway, and a mirror system that focuses light reflected back from a specially prepared road onto a photoresistor. A schematic of the detector unit is shown in Figure 3. To get sufficient light reflected back to the photoresistor, a 2-in. retroreflective strip was placed on the pavement. With this material, a high proportion of the incident light from the lamp is reflected back into the mirror and hence to the photoresistor.

The photoresistor itself was connected directly to a transistor amplifier. If no light fell on the photocell, so that its resistance was high, the amplifier was biased below cut-off. When, however, the incident light was high and resistance dropped, sufficient current flowed to close a relay. Thus, whenever one of the detector units passed over the reflective line, it and only it, would fire. As the vehicles moved laterally, a different unit was activated. Because the units were on 2-in. centers, lateral position could be estimated to the nearest inch. With a total of 37 detector units, displacement could be measured over a range of 6 ft.

To record the diplacement data continuously, the digital output of the amplifier relays was used to switch an appropriate step in a 37-section potentiometer. This analog voltage was then recorded on a Brush recorder. With this complete system, it was possible to plot the path of a vehicle continuously as it traveled down the test track. By leaving 5-ft gaps in the reflective line every 100 ft, it was possible to determine lateral placement as a function of distance from the displacing object.

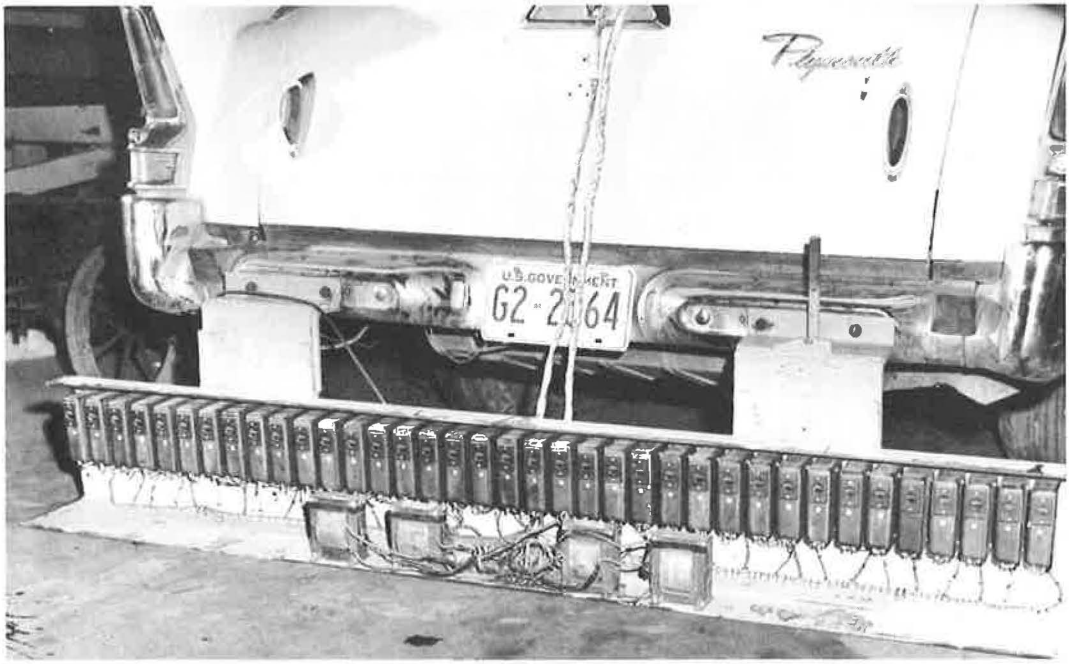

Figure 2. Lateral displacement detector.

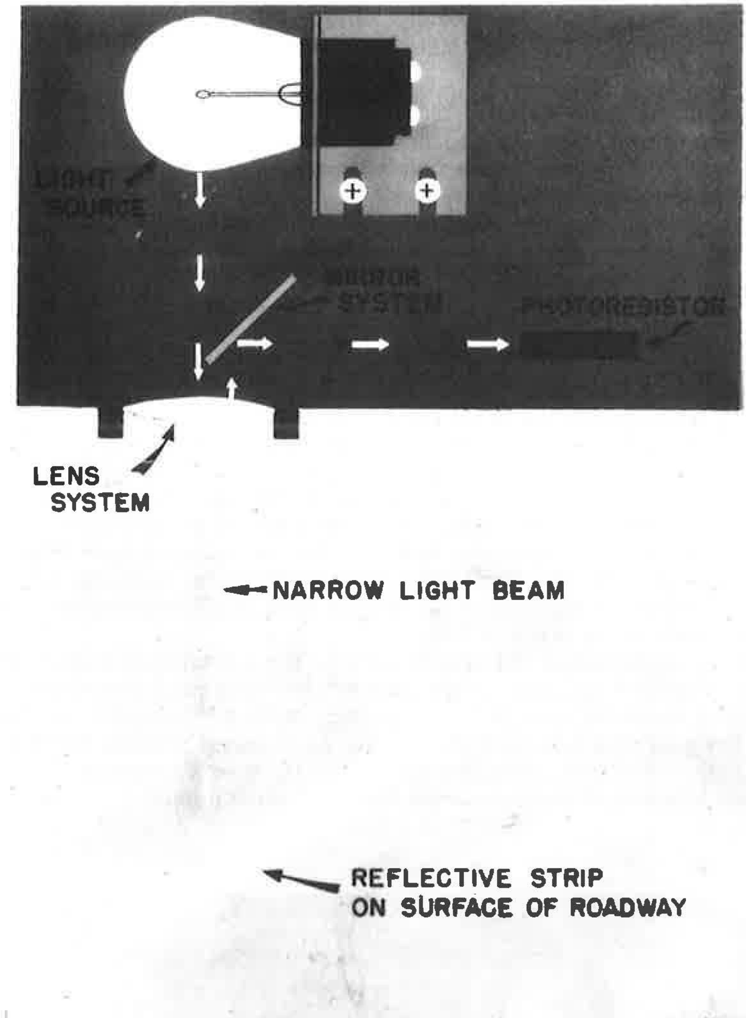

Figure 3. Photodectector unit.

The test track was a 1-mi section of a jet aircraft runway. The runway was of concrete, 100 ft in width plus an additional 25-ft wide asphalt shoulder on each side. The runway was made up of four 25- by 20-ft sections of concrete. The maximum vertical curvature of the section used was less than 0.1 percent. A single section nearest the edge of the runway was used. Thus, the travel path was effectively a lane 25 ft wide with its limits being demarcated by the asphalt shoulder on the driver's right and the longitudinal joint on his left.

The reflective strip was laid in the center of the lane. It was placed with an accuracy such that the deviation from the center was never more than 1 in. over the mile course. The reflective material was a metallic buff color that was clearly visible to the observer. No way was found to camouflage this line and still retain sufficient retroflectivity to insure reliable operation of the placement detector. The arrangement of the test situation is shown in Figure 4.

The displacing objects used were two identical equilateral triangles 6 ft on a side, mounted on a boom. This boom was 12 ft long, of sufficient length to minimize any effect that the mounting base might have on displacement. The boom could be moved in

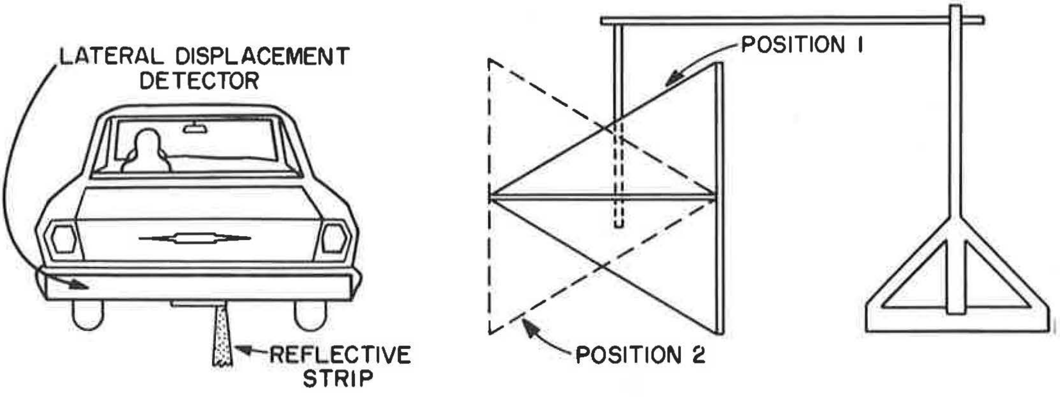

Figure 4. Test situation.

or out and the triangle could be rotated about its mounting point to have either the base or the apex nearest the path of travel. One object was placed 2,000 ft from the beginning of the course, and the other, 4,000 ft. Four lateral locations for each object were selected. From an analysis of the angle estimation model, the distance at which the tangent function begins to exhibit an obvious change in slope is about 200 ft. This model predicts a direct relation between lateral displacement and the size of the angle; hence, object location was chosen in units of angular separation at the distance of 200 ft. The closest location was chosen at this point to subtend an angle of 2°. Three other positions were chosen so that they subtended angles of 2¼°, 2½°, and 2¾°. In lineal distance from the driver the object was placed 7.0, 7.8, 8.9, and 9.6 ft.

In these experiments, each object was placed at random among the four locations. In addition, the orientation of the triangle was arranged randomly. The complete matrix of conditions was randomized using orthogonal latin squares so that any interaction effects between the two objects were counterbalanced.

Four vehicle speeds were used: 15, 30, 45, and 60 mph. Each subject was tested at each speed for all combinations of object location and orientation. In total, each subject went through a 4 by 4 by 2 factorial design. In addition, the design was replicated four times.

All the electronic equipment for measuring and recording lateral position was mounted in a station wagon and included a 1.5-kv generator on top. A driver subject and the experimenter were the only occupants of the vehicle. Four assistants adjusted the position and orientation of the displacing objects according to a prearranged schedule.

The subjects were five male drivers, ranging in age from 25 to 40 years. All were licensed drivers with five or more years of driving experience. None were told the purpose of the tests. Rather, they were told that the study was aimed at finding out how well they could maintain the vehicle at a constant assigned speed.

RESULTS

The maximum lateral displacement was determined for each condition and each subject. These data were subjected to an analysis of variance, and the summary is given in Table 1. As may be seen, differences among the main variables are significant at the 0.01 level. The analysis also shows a significant interaction among these variables.

Figure 5 is a plot of displacement as a function of object location for each of the four speeds. These curves include data for the base orientation only. The line shown is the mean displacement for the five subjects. The general form of the curve is the same as that for each individual subject. The straight-line relationship shown is similar to Taragin's (6) data, but the magnitude of lateral displacement is less.

The displacement at each object location increased markedly with speed as summarized in Figure 6. Again, these four curves are for the the base orientation only.

TABLE 1

ANALYSIS OF VARIANCE FOR LATERAL DISPLACEMENT UNDER 32 EXPERIMENTAL CONDITIONS

Source of Variation	Sum of Squares	d. f.	Mean Square	F
Vehicle speed (VS)	2,911.7	3	970.5	46.88[a]
Object distance (OD)	3,658.4	3	1,291.3	62.38[a]
Object orientation (OS)	252.5	1	252.5	12.20[a]
Driver (D)	9,610.8	4	2,402.7	116.07[a]
VS × OD	110.5	9	12.3	-
VS × OS	135.0	3	45.0	2.13
VS × D	2,015.9	12	168.0	8.12[a]
OD × OS	240.1	3	80.0	3.86[a]
OD × D	1,979.4	12	164.9	7.97[a]
OS × D	34.9	4	8.7	-
VS × OD × OS	226.2	9	25.1	1.21
VS × OD × D	1,007.2	36	279.8	13.52[a]
VS × OS × D	297.4	12	24.8	-
OD × OS × D	637.6	12	53.1	2.06
VS × OD × OS × D	796.4	36	22.1	-
Error: within treatments	9,917.8	480	20.7	-
Total	33,831.8	639		

[a]Significant with probability less than 0.01

The data demonstrate that lateral displacement is directly dependent on travel speed as well as object location.

In the rate of change of angle model it was hypothesized that lateral displacement would begin at a distance from the object that was directly dependent on vehicle speed. Figure 7 shows the relation between vehicle speed and the distance at which displacement began. The parameter is the lateral location of the displacing object. As may be seen the beginning point varied from approximately 50 ft at 15 mph to about 275 ft at 60 mph. The data are consistent in showing a significant increase in starting distance for all four object locations and, thus, the hypothesis is confirmed.

A third hypothesis that derived from the angular change model was that the rate of change of angle at which displacement began would be independent of both object location and vehicle speed. To test this hypothesis, it was necessary to determine from each run the point at which lateral displacement began. This determination was confounded by two factors. First, there was a certain variability in lateral position for all subjects. Thus, considerable error was possible in the judgment of the beginning of displacement because it was frequently uncertain whether the change was in response to the displacing object or just random changes in position. Second, not all conditions yielded a significant displacement, in which case no determination of starting distance was possible. In general, this occurred when the object was located farthest from the travel path and at the lowest speed (15 mph). In general, lateral displacement occurred reliably for the three highest speeds, and the three closest object locations. The distance at which displacement began could reliably be estimated for these cases. Further analysis was done only on these data.

For these combinations of speed and lateral location of the object, the rate of change of angle was determined for each speed and each driver subject, and an analysis of variance was done on these data. The summary is shown in Table 2; none of the differences are significant. It seems reasonable to conclude, therefore, that there is a constant rate of change of angle between the driver and the object at the point where displacement is begun.

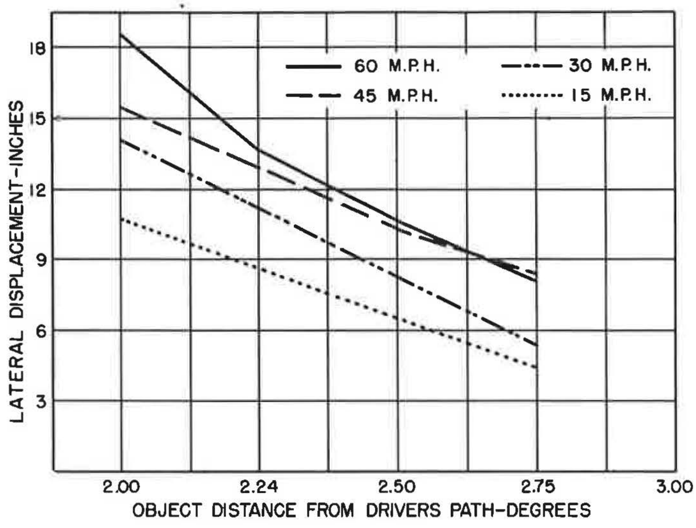

Figure 5. Lateral displacement as a function of object location at different speeds.

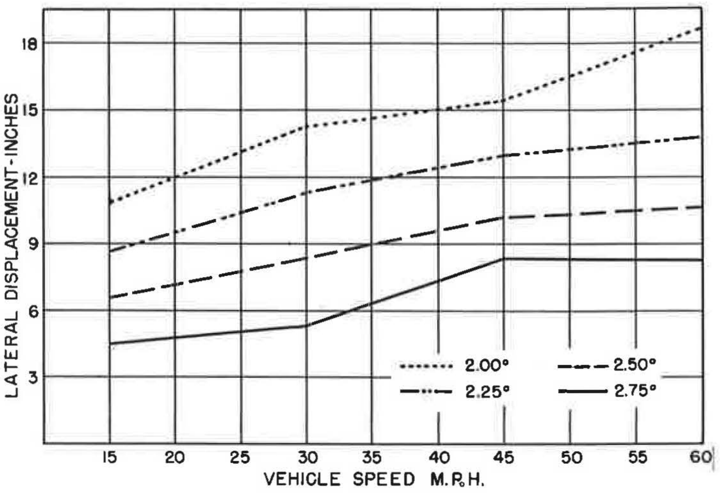

Figure 6. Lateral displacement as a function of vehicle speed for different object locations.

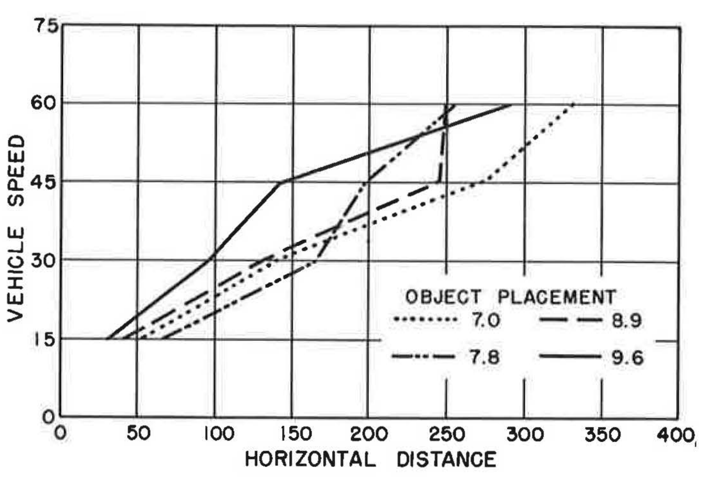

Figure 7. Relationship between vehicle speed and distance from object at which displacement began.

TABLE 2

ANALYSIS OF VARIANCE FOR ANGULAR CHANGE

Source of Variation	Sum of Squares	d. f.	Mean Square	F
Between vehicle speeds (VS)	17.3	2	8.65	4.62
Between drivers (D)	7.1	4	1.78	-
Interaction: VS × D	34.9	8	4.36	2.33
Error: within treatments	56.2	30	1.87	-
Total	115.5	44		

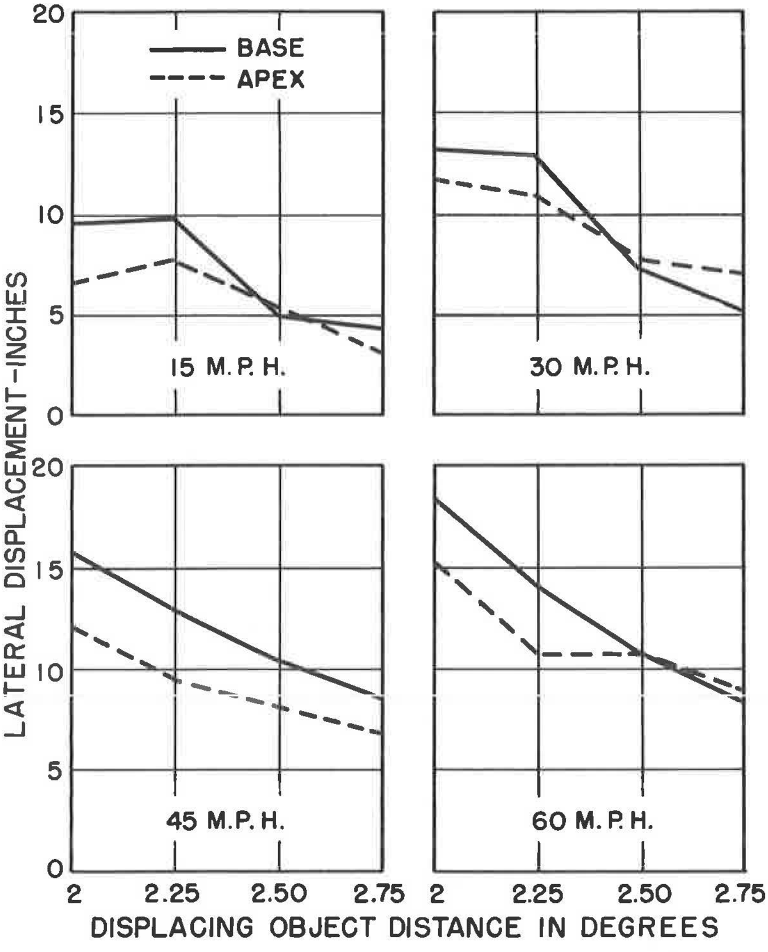

Figure 8. Effect of three highest vehicle speeds on angular change (three closest object distances combined).

The final result of this investigation concerns the spatial relations between the contours of the displacing objects. It was hypothesized that displacement would be greater when the base of the triangle was nearest the path of travel than when the apex was so located. The analysis of variance in Table 1 shows that there was a significant difference between object orientation. In Figure 8, displacement is plotted as a function object location for each orientation and for each speed. The difference between the base and apex orientation increases with speed of travel and decreases as object distance increases. Again, the results offer verification for the hypothesis that lateral displacement should be dependent on the geometric characteristics of the displacing object.

ANALYSIS

The data clearly indicate that a model of lateral displacement based on the rate of change of visual angle accounts best for the obtained results. The three hypotheses originally specified for this model were validated and thus, as the model predicts, there was a direct relationship between the magnitude of displacement and travel speed. A second hypothesis, that lateral displacement would begin at a longitudinal distance that was functionally related to vehicle speed, was also confirmed by the data. Third, it was hypothesized that the determining factor in displacement would be the derivative of the visual angle which would be constant over all conditions. The results of this study offer strong confirmation of this hypothesis.

Thus, the study leads to an explanation of lateral displacement that is based on the driver's ability to detect the rate of change of visual angle of objects near his path of travel. The problem for a driver approaching an object near his path of travel is one, from a perceptual standpoint, in which, phenomenally, the image of the object moves across the retina. However, this model is actually a special case in the general field of the visual perception of velocity. The major differences are that (a) the angular velocity of the target in the driving situation is nonlinear and (b) the visual angle subtended by the object itself increases as the observer approaches.

From this viewpoint, it is worthwhile to compare the angular velocity at which displacement begins with the classical research one on the threshold for visual velocity. The work of Brown (1) indicated absolute thresholds in the range of 1.0 to 10.0 min of arc per second, whereas the more recent work by Rock (5) indicated an absolute threshold range of 0.2 to 0.5 min of arc per second with luminance carefully controlled. In the the present experiment, the range of angular velocity at the beginning of displacement was from 4 to 40 min of arc per second. It is obvious, therefore, that the driver is responding to the presence of an object near his path of travel at a point where its angular velocity is at his absolute threshold.

Within the framework of this model, it is possible to define the process of displacement. If the driver, traveling at a certain speed, increases his fixation distance along the roadway, two things occur. One, the angular velocity of elements in his field of view decreases rapidly. Eventually all elements become subthreshold, regardless of their lateral separation. Two, objects located at increasing distances from the path of travel are seen outside the near fovea. Beyond this 2° to 4°, sensitivity to velocity decreases rapidly. Thus, there is a visual operating field, essentially conical, determined by a physiological characteristic and a physical function which defines the limiting size of this field. This is shown in a slightly different fashion in Figure 9. As fixation distance increases on the abscissa, the lateral position of an object must increase rapidly to maintain a visual velocity threshold. With a visual field of 3°, it may be seen, that at 60 mph, at a distance of 300 ft, objects more than 16 ft from the driver's path are outside his visual field. Conversely, all objects less than 14 ft, although within the operating field have subthreshold angular velocity at this distance. Actually, it is only lateral locations within the hatched area that have a highly detectable angular velocity at 60 mph. Thus, as a driver approaches an object lying within his visual operating field at this speed, at a distance of about 300 ft, if there is no detectable component of angular velocity, the object will appear to be in his path, and he will begin to displace.

The process for detecting lateral position becomes a fairly direct one for the driver. He must adjust his point of fixation to that distance at which there is a sharp decrease in angular velocity for objects at the margins of this visual field. This point is available from a variety of cues in the driving environments such as pavement texture and shoulder contrast.

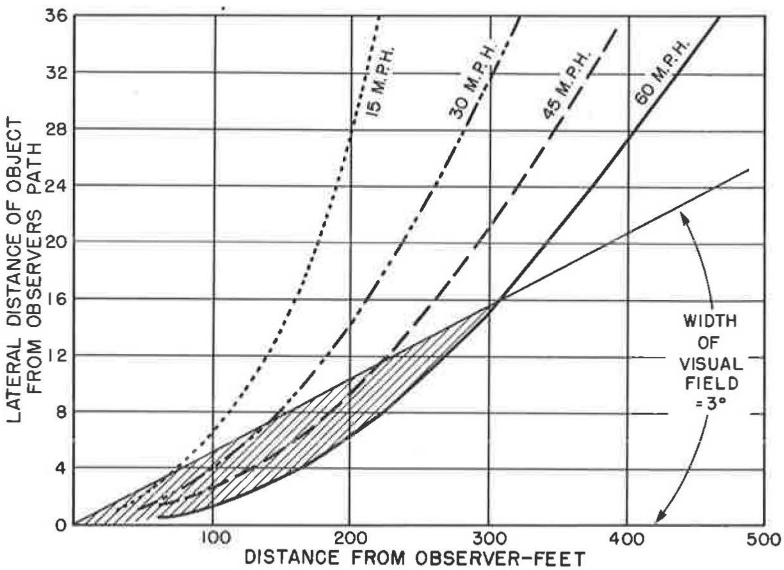

Figure 9. Visual velocity threshold contours at four speeds.

As obstructions first enter his field, the driver is able to make a simple binary judgment. If the obstruction has a detectable lateral movement it cannot be in his path, and no displacement is necessary. If it has no detectable lateral velocity, it is located in his path, and hence he begins to displace.

These considerations indicate that the driver is given a very small margin of time and distance within which to operate on objects located laterally along the path of travel. Assuming no restrictions in sight distance, he has only 3 to 4 sec in which to decide whether a displacement is necessary and how much is required. By operating at the absolute threshold of angular velocity, the driver not only has a stable reference for detection but also maximizes the time available for object location as well as the time for making compensatory steering responses.

It would seem reasonable to expect that those factors found from classical research to influence the perception of visual velocity would be applicable to lateral displacement. Thus, the object size may be expected to influence displacement because of the effect of stimulus size on visual velocity (1). This factor of size as it affects lateral displacement has been studied by Case et al. (2). They found that there was a significant effect on the displacement starting point and also the magnitude of the displacement as a function of the displacing object's size.

It may also be expected that the shape of the stimulus will influence the visual perception of velocity. The results of this study demonstrated that there was a significant reduction in displacement of approximately 15 percent when the apex of the triangle was oriented toward the driver's path of travel. Phenomenally, of course, these results imply that the apex-oriented object has a higher visual velocity than does the base-oriented one. The higher the velocity, the less will be displacement because displacement occurs in relationship to perceived velocity of the displacing object in this model.

The effect of shape has been studied by Motokowa (4) by means of electrical stimulation of the eye. His findings bear directly on the effects on lateral displacement found in this investigation relative to the triangular displacing object orientation. His work suggests that the physiological correlate of visual velocity is the amount of suppression of retinal response exerted on the retinal pathway through which the image of the moving object has passed.

This concept, called retrograde suppression, can account for most of the perceptual results in the study of visual velocity. Thus, Motokowa suggests that as a moving stimulus passes across the retina, a field is generated about that object which suppresses activity in the area removed from the immediate vicinity of the stimulus itself. Thus, as a stimulus moves across the retina, it generates retinal activity as it proceeds and acts to extinguish or neutralize the retinal activity in the path through which it has already passed. Hence, the lower the velocity, the more intense the stimulus; or the larger the object, the greater will be the degree of this retinal suppression—all leading to a perception of lower angular velocity. In essence, the strength of the suppressing stimulus is the correlate of the perception of velocity.

The intensity of the suppression is also related to the nature of the contours of the stimulus. Other experimentation by Motokowa (3) has shown that the strength of the field about an object is determined by the contours of that figure as well as its size and brightness. For a triangle, as used in the present displacement study, the field of activity is at a minimum at the intersection of the figure contours. Consequently, the strength of the field that acts as a suppressor on trace activity in the retina is at a minimum. The perceived velocity of the figure will be a maximum with that orientation. It is, then, in the basis of the differences in fields of suppression that the reduction in lateral displacement obtained in this study can be explained when the apex is oriented closest to the driver's path of travel.

Every attempt was made to obtain a maximum displacement in the design of this study. It was initially predicted that the magnitude of displacement in this study would exceed that obtained by Case et al. (2) or Taragin (6) because an effective 25-ft lane width was employed with no other obstacles in the driver's path. This prediction was not borne out in the study. Actually, the magnitudes of displacement were one-half to one-third less than reported in the field studies just mentioned. Two reasons may account for this unexpected result. One is in the nature of the displacing objects. In this study, the absolute size of the object was 15 sq ft, which is considerably smaller than the displacing objects used by Case et al., whose minimum and maximum sizes were 28 and 64 sq ft, respectively. In Taragin's study, two of the objects were considerably larger than the triangles used in this experiment. In terms of the model of displacement proposed in this paper, it would be expected that the apparent velocity of the displacing object will be greater for the smaller object and hence appear farther from the driver's path of travel.

A second condition concerns the factors influencing the driver's ability to judge his line of travel accurately. In this study, the reflective strip that was placed on the pavement to measure lateral position was clearly visible to the driver subject. All five drivers appeared to orient themselves relative to this marking so that it was nearly centered under the vehicle. In essence, the striping served as a direct reference by which the driver could define his path of travel. By having a stable reference at which the driver may fixate, the detection of movement of an object near his projected path should be improved. With no such reference for fixation, the driver's point of regard may be expected to vary laterally. This should reduce the accuracy of his estimation of the apparent velocity of the object and hence add ambiguity about the judgment of object location. It seems reasonable that such uncertainty would amplify a driver's response to the displacing situation, leading to a greater magnitude of displacement. If this explanation is valid, it should be possible to reduce the magnitude of lateral displacement in a field situation by providing the driver with a tracking reference line. A test of such a hypothesis is currently under way at the Bureau of Public Roads.

It is interesting, relative to the model, to examine the Interstate standard that requires all roadside objects to be a minimum of 6 ft from the travel lane. At this separation, the object will have a highly detectable angular velocity for distances up to 300 ft from a driver traveling 60 mph. This is consistent with the data in this study, as shown in Figure 10. What the Interstate standard for the location of shoulder objects actually does, then, is to insure that within the visual operating field of the driver all fixed objects shall generate a suprathreshold rate of angular change. It is obvious from the present study that this design standard is applicable and valid only for highways in which travel speed is approximately 60 mph. Where the highway speed limit is substantially lower, a closer positioning may be tolerated. The data in Figure 10 clearly show that the object may be within 2 ft of the edge of the lane at very low speeds.

It also becomes apparent why objects located close to the roadway may affect highway capacity. Given a situation in which there are two lanes of traffic of fairly high volume traveling at around 40 mph, what happens when an obstruction is placed on the shoulder, sufficiently close to the travel lane? In terms of the model proposed here, drivers are responding to objects at the maximum distance from the object which their speed permits. Because the amount of displacement is directly dependent on speed, a driver may reduce displacement by reducing his travel speed, which in addition, increases the time he has for locating the shoulder object. If, because of traffic opposing him, the driver must eliminate or minimize displacement, he will have to reduce his travel speed. In so doing, he minimizes both the probability of collision with a shoulder object and encroachment in the opposing traffic lane. One obvious consequence of this process is to limit the capacity of the lane.

A final aspect of this investigation relates to the more general problem of the visibility of stationary objects on or near the highway. This problem, especially acute at night, has received considerable attention in the safety field for many years. In general, it has been conceived primarily as a problem in object detection. From the results of the present study, it would seem reasonable that not only the detection of an object is important, but also the ability of the driver to locate that object relative to the path of travel. If the driver detects the object, it is also necessary to ascertain a collision or near-collision course. Obviously, the brightness of the object or its contrast with its surroundings, object size, and its shape are fundamental factors in this dynamic localizing process. For example, one would predict on the basis of the model that a small object located close to the roadway would generate a greater relative visual velocity than a larger one. Thus, a car parked on the shoulder in which the oncoming driver perceived only the reflection from an unlighted taillight would be far more likely to be placed outside his path of travel than would the whole vehicle illuminated by a street light. The same problem also arises when there is headlight glare from oncoming cars which effectively reduces the contrast of the roadside object. Thus, the problem of visibility of roadside objects involves more than simple detection of the object's presence. Any thorough analysis of this problem must include not only detection but also the accuracy of roadside object location as well as the driver's ability to locate himself in his path of travel.

SUMMARY

This study was an attempt to analyze certain of the underlying factors that cause the lateral displacement of a vehicle away from a roadside object. The investigation was conducted in daylight and under free field conditions. For several conditions of object location and vehicle speed, the lateral position of the vehicle was measured continuously over a 5,000-ft specially prepared test track.

The findings indicate that lateral displacement is a special case in the field of visual velocity perception. Relative to the observer, the displacing object effectively moves laterally across the retina with a definable angular velocity. Drivers react to this apparent velocity of the object by determining when and how much they should displace on the basis of the time and distance at which that velocity increases sharply.

The results were related to previous work carried out by other investigators interested in the lateral displacement phenomenon. They offer rationalization for the effects of lateral displacement on highway capacity and as an important consideration in collision avoidance under low illumination levels and headlight glare.

REFERENCES

1. Brown, J. F., "The Thresholds for Visual Movement." Psychol. Forsch., 14:249-268 (1931).
2. Case, H. W., Hulbert, S. F., Mount, G. E., and Brenner, R., "Effect of a Roadside Structure on Lateral Placement of Motor Vehicles." HRB Proc., 32:364-370 (1953).
3. Motokowa, K., "Field of Retinal Induction and Optical Illusion." J. Neurophysiol., 13:413-426 (1950).

4. Motokowa, K., "Retinal Traces and Visual Perception of Movement." J. Exp. Psychol., 45:369-377 (1953).
5. Rock, M. L., "Visual Performance as a Function of Low Photopic Brightness Levels." J. Appl. Psychol., 37:449-454 (1953).
6. Taragin, A., "Driver Behavior as Affected by Objects on Highway Shoulders." HRB Proc., 34:453-472 (1955).