Experimental Isolation of the Driver's Visual Input

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•AN UNDERSTANDING of the driver's visual input provides a rational basis for many aspects of highway design. Knowing what information the driver uses, we can design roads which insure that he receives this information. Since no experimental technique existed by which the visual factors in driving could be isolated, their nature has been mainly the subject of conjecture.

From a scientific viewpoint, the isolation of visual input is both important and baffling. This information used by the driver sets off an action sequence which eventuates in the steering, braking, and acceleration of the car itself. Without knowing the stimulus which first triggers the driver's reactions, the consequent reactions are not easily understood. And when man's input has been specified, driving itself will be to a considerable extent described. But the problem is difficult. The binocular field presents an enormous amount of information. We do not have communication lines to the driver's eyes or brain allowing us to determine how he selects and sorts this sensory input. If we ask the driver what he is responding to, we obtain suggestive, but in no sense trustworthy answers.

A technique to determine what features of the road and terrain the driver is responding to is presented in this study. The method involves having the driver guide the car while looking through a device containing a small aperture. By decreasing the visual field, the essential information, whatever it is, cannot be seen at once, i.e., the driver is forced to obtain this information in separate visual fixations. A continuous film record is made of the driver's field of view which is later analyzed to indicate the center of his visual aim and the content of each fixation. The essential information he is using is easily identified in each separate restricted fixation. (This technique may also be used to determine the aircraft pilot's perceptual input, and may be applicable, with modifications, to problems of human console design.) This approach has advantages over eye camera techniques which provide a record of fixation position. The eye camera does not show the contribution of peripheral vision, nor does it provide a means of distinguishing essential from nonessential information.

BACKGROUND

Various sorts of information have been suggested as underlying the maneuvers of driving (2, 3, 4, 5). A general listing, made by a race driver and the editor of a scientific magazine who evaluated the attention paid to conspicuous features of the environment, may be taken as representative (6):

Race driver	Rank	Editor
View of the road ahead	1	View of the road ahead
Seat of the pants feel (transverse accelerations)	2	View of the car ahead
Tachometer	3	Feel of steering wheel
Feel of steering wheel	4	View of the road edge
Engine sound	5	Speedometer
View of the road behind	6	View of the road behind

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Race driver	Rank.	Editor
Oil pressure gage	7	Seat of the pants feel (transverse accelerations)
View of the car ahead	8	Engine sound
View of the road edge	9	Blinking lights
Smells	10	Tire noise
Tire noise	11	Smells
Blinking lights	12	Oil-pressure gage
Speedometer	13	—

The view of the road ahead was assigned first place by both raters. Otherwise, there is a considerable lack of conformity in the ratings of the race driver and editor, possibility reflecting a real difference in approach to driving.

A rigorous experimental method is obviously required to determine what the driver is actually looking at and responding to. Michaels and Cozan (5) have been perhaps the first to use rigorous experimental methods to validate a driving input. In field tests using lateral movement detectors, they showed that the driving response is inversely related to the sidewise drift of the approaching object or vehicle.

APPARATUS

An aperture device was developed which restricted the driver's vision and recorded his visual fixation positions. This device has the following main parts (Fig. 1):

1. Head helmet—Large plastic football helmet with frame supports to hold aperture and fiberglass pulpit. An inflatable bladder fills the space between helmet and head and holds the helmet firmly in place.
2. Aperture observation tube—Tube 3½ in. in length, 1 in. in diameter. The tube can be raised or lowered to accommodate the observer's eye. Aperture disks of varying size may be fitted on the end of the tube. A circular screen covers peripheral areas of the driver's field, and an eye patch fits on his unused eye.
3. Camera—8-mm camera mounted coaxially with the aperture tube. The camera has automatic (photoelectric) shutter and battery powered feed. Zoom lens is set at 8-mm focal length. Speed of camera is slowed to 11 frames per sec. The 25-ft film roll gave 178 sec of record, enough to cover the experimental course.

THE DRIVERS

Ten volunteers (7 male, 3 female) from the Bureau of Public Roads served as test drivers. All subjects had vision rated good enough to drive without glasses. The drivers ranged in age from 19 to 38; mean age was 27.7 years. Number of years of driving experience ranged from 1 to 24, with a mean of 10.3 years.

DRIVING COURSE AND TEST VEHICLE

A curved 2-lane road at Fairbank Research Center, with low traffic density, served as test course (Fig. 2). It was 22 ft in width, had a 4-in. wide yellow center strip and was paved in blacktop. The shoulders of the road were planted in grass. The 2,805-ft length included a left and right curve. A "Carryall" station wagon was used as test vehicle. To permit headroom for the helmet, the front seat of the vehicle was removed and a low cushion substituted for it. The test drivers could see over the hood without difficulty.

PROCEDURE

The procedure included both practice and experimental phases. The program was carried out in a single hour session.

Practice and Familiarization Phase

The driver was instructed that he would be required to guide the car with restricted vision. He then practiced on a curved and hilly course (not the test course) first without

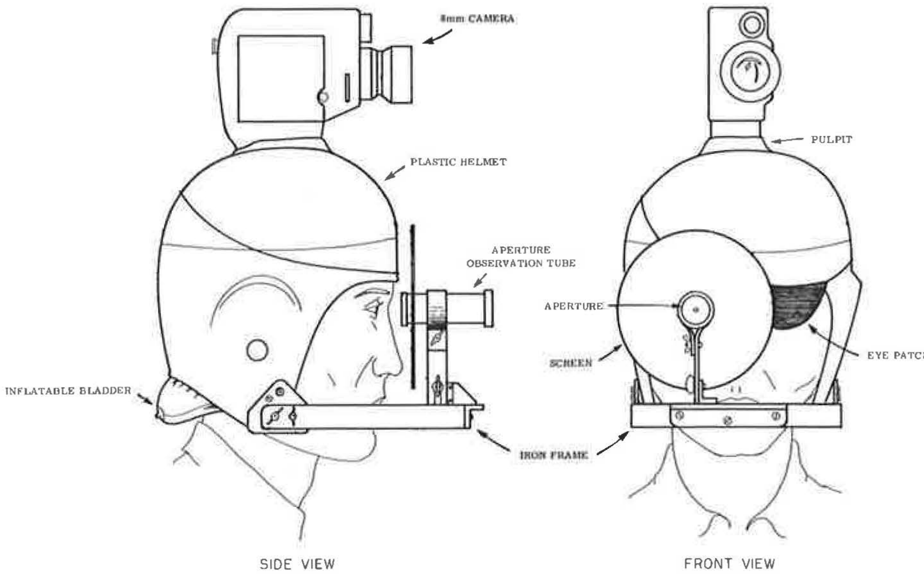

Figure 1. The aperture device.

the aperture device, and later with it. After practice, he was asked 3 questions:

1. On the left curves, what did you look at mainly?
2. On the right curves, what did you look at mainly?
3. Was there any consistent pattern of movement of fixations from side to side or backwards and forwards that you adopted?

Experimental Phase

The driver operated in this phase with (a) open vision, (b) a large (9¾ deg) aperture, and (c) a small (4 deg) aperture.

Open Viewing. —This condition was intended to provide a comparison of aperture driving with normal driving. The observer continually reported his visual fixation position on a tape recorder. After driving, the observer was asked the 3 questions listed under practice and familiarization.

Large Aperture Viewing. —The comparison of this condition with the small-aperture conditions which followed permitted an analysis of size effects. The procedure included calibration of the aperture device and data collection.

Calibration of the Aperture Device. —The driver centered-in the aperture, using the image of a 2-in. square piece of white paper tacked to a tree situated about 50 ft away. The experimenter then adjusted wooden uprights until they appeared exactly on the left and right limits of the driver's field of view (Fig. 3). The experimenter made a brief film record of the adjustment and cautioned the driver not to shake the helmet. The center spot and stakes appeared later on the developed film and thus indicated the center and limits of the driver's field of view.

Data Collection. —The driver drove the course while a continuous film record of his visual fixations and a tape recording of his verbal identifications of position were taken. Camera and tape recordings were synchronized by the experimenter who periodically interrupted the lens field, simultaneously producing an auditory signal. After the trial, the driver was asked what he looked at on the left and right curves.

Small Aperture Viewing. —The small aperture condition showed the driver's visual behavior under the stress of extreme information limitation. The procedure was

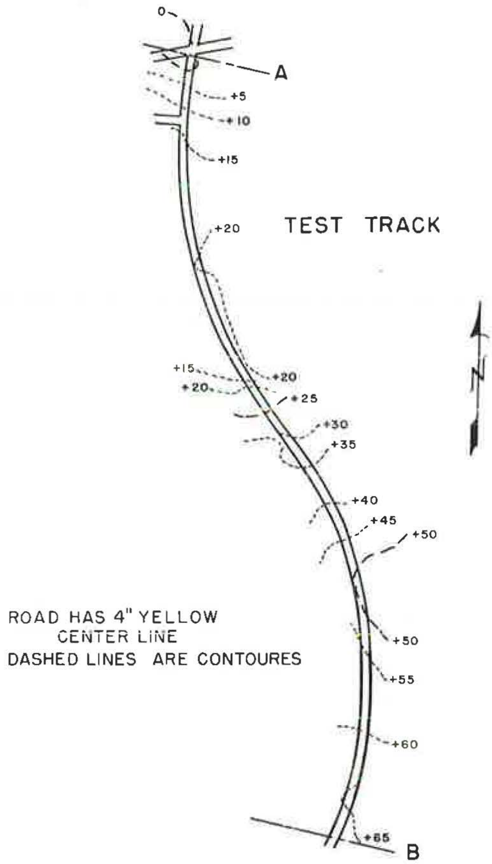

Figure 2. The experimental course.

essentially the same as that in the large aperture condition. Four drivers started at the A end of the track, four at B (Fig. 2). Sequence 1 and Sequence 2 (5 drivers each) were as follows:

Open viewing	A — B — A	B — A — B
Large aperture	B — A — B	A — B — A
Small aperture	A — B — A	B — A — B

The variation in starting position provided a replication of the procedure.

ANALYSIS—FIXATION AREA AND FIXATION POSITION

Each driver's record was divided into separate fixations, i.e., visual positions held until another was clearly assumed. Duration of each fixation was determined from its film length, using the known rate of film movement. A total of 3,305 separate fixations were analyzed on the 4,152 inches of film recorded by the 10 drivers.

The records were considered from the viewpoint of fixation area and fixation position. The area of fixation described the most inclusive road region covered in the 4 deg (small) or 9¾ deg (large) aperture. This analysis may be clarified by the sample areas shown in Figure 4. The "whole road" area implied that both left and right edges of the road were included in the fixation. The "left lane" included

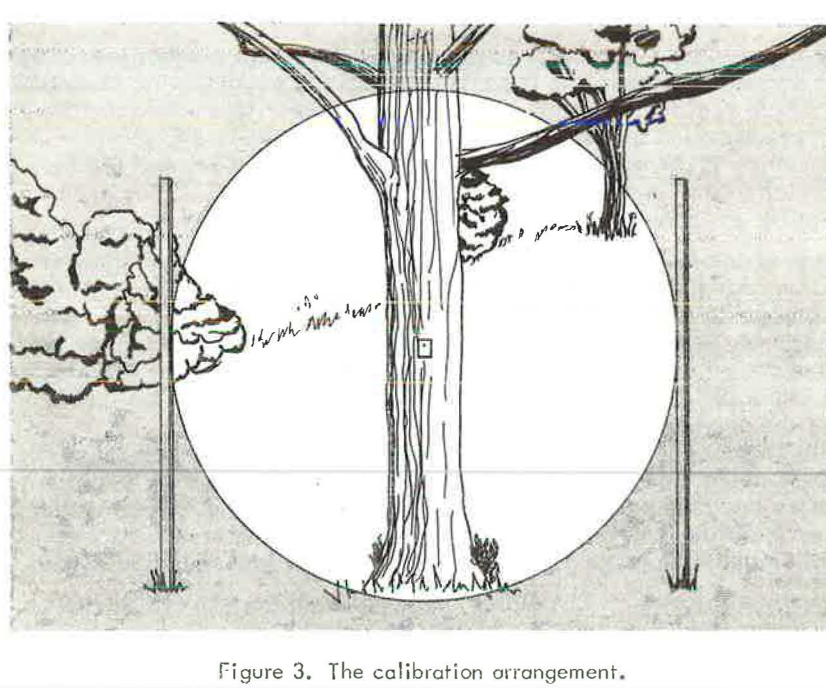

Figure 3. The calibration arrangement.

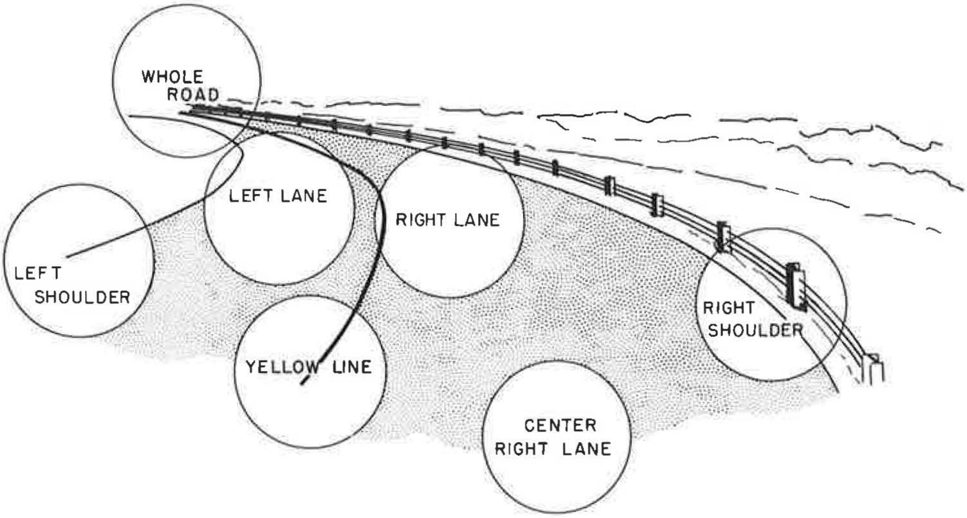

Figure 4. Sample fixation areas.

the left edge and center line, "right lane" covered the center line and right edge. The "yellow line," "left shoulder" and "right shoulder" designations required that visual fixation cover these features singly. In a few instances the fixations were coded as "center of the left lane" or "center of the right lane." These areas did not include an edge or the center line.

Fixation position designated the center of the fixation circle, which usually fell on the left shoulder, yellow line, right shoulder, or center of the right or left lane. Distance from the driver's eye was determined by noting on the film editor the width of the road at the center of aim. This width could then be compared with precalibrated road widths at 50, 100 and 150 ft from the camera. The fixations could be classified as less than 50 ft, 50-100 ft, 100-150 ft, or greater than 150 ft.

RESULTS

Essential Information Used by the Driver

The essential information, as revealed by the drivers' fixations, is the road edges and centerline. The importance of these features is shown by the summary results of fixation area and position given in Tables 1 and 2. It is significant that 96.4 percent of small aperture viewing and 99.8 percent of large include an edge or center of the road. (Fixation times coded under "other areas" may not have included an edge or the center.)

The fixation position data given in Table 2 confirm the importance of edge and centerline information. It appears that 80.9 percent of the large aperture fixations and 85.7 percent of the small fell on edges or the centerline. Fixations not on these features include "center of right lane," "center of left lane" and "trees on left and right." In view of the legitimate demands on the driver's attention of signs and passing cars, it is noteworthy that so high a proportion of fixations centered on the road and edge borders.

The road edges and centerline are also referred to in taped verbal statements made by the drivers on-route, summarized in Table 3. Statements such as "now my eye is on the yellow line" or "right shoulder—near" are coded as referring to the road. Such statements as "my vision just shifted back out where the sign is on the curve," or "there is an electric pole in front of us" are coded as not referring to the road. It may be seen that 96.3 percent of the small aperture comments, 95.5 percent of the large, and 87.2 percent of the comments with no aperture, referred to the road. The answers to the questions asked at the conclusion of each run support the same conclusion. All 10 drivers stated that they used the yellow line, and 9 of the 10 mentioned the right

TABLE 1

TIME ON VARIOUS FIXATION AREAS
(Summary—10 Drivers, Combined Left and Right Curves)

Aperture	Distance (ft)	Left Lane		Yellow Line		Right Lane		Whole Road		Other Areas[a]		Total	
		Sec	%	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%
Large	>150	51.82	4.30	2.58	0.21	140.84	11.70	486.42	40.38	—	—	681.66	56.59
	100-150	26.58	2.20	3.08	0.26	53.41	4.43	156.77	13.02	—	—	239.84	19.91
	50-100	12.98	1.08	4.41	0.37	63.02	5.23	155.07	12.87	1.00	0.08	236.48	19.63
	<50	3.45	0.29	5.60	0.46	12.15	1.01	24.56	2.04	0.82	0.07	46.58	3.87
	Total	94.83	7.87	15.67	1.30	269.42	22.37	822.82	68.31	1.82	0.15	1,204.56	100.00
Small	>150	179.22	14.27	75.21	5.99	355.49	28.31	197.09	15.70	19.23	1.53	826.24	65.80
	100-150	25.32	2.02	46.60	3.71	97.87	7.80	33.13	2.64	13.13	1.04	216.05	17.21
	50-100	8.67	0.69	52.91	4.21	102.65	8.17	11.38	0.91	11.04	0.88	186.65	14.86
	<50	0.86	0.07	8.41	0.67	14.31	1.14	1.34	0.10	1.85	0.15	26.77	2.13
	Total	214.07	17.05	183.13	14.58	570.32	45.42	242.94	19.35	45.25	3.60	1,255.71	100.00

[a] Left shoulder, center left lane, center right lane, right shoulder.

TABLE 2

TIME ON VARIOUS FIXATION POSITIONS
(Summary—10 Drivers, Combined Left and Right Curves)

Aperture	Distance (ft)	Left Shoulder		Yellow Line		Right Shoulder		Center Right Lane		Center Left Lane		Trees, Left & Right		Total	
		Sec	%	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%
Large	>150	150.28	12.47	129.19	10.72	340.89	28.30	44.15	3.67	10.19	0.85	6.96	0.58	681.66	56.59
	100-150	37.82	3.14	58.49	4.86	83.81	6.96	41.37	3.43	18.16	1.50	0.19	0.02	239.84	19.91
	50-100	12.01	1.00	49.06	4.07	85.28	7.08	83.90	6.96	6.22	0.52	—	—	236.48	19.63
	<50	—	—	12.53	1.04	15.28	1.27	18.59	1.54	0.19	0.02	—	—	46.58	3.87
	Total	200.11	16.61	249.27	20.69	525.26	43.61	188.01	15.60	34.76	2.89	7.15	0.60	1,204.56	100.00
Small	>150	104.49	8.32	357.60	28.48	252.88	20.14	87.41	6.96	10.71	0.85	13.15	1.05	826.24	65.80
	100-150	18.50	1.47	80.34	6.40	77.80	6.20	34.04	2.71	5.37	0.43	—	—	216.05	17.21
	50-100	2.72	0.22	79.91	6.36	79.11	6.30	21.65	1.72	3.26	0.26	—	—	186.65	14.86
	<50	0.33	0.03	12.53	1.00	10.39	0.82	2.93	0.23	0.59	0.05	—	—	26.77	2.13
	Total	126.04	10.04	530.38	42.24	420.18	33.46	146.03	11.62	19.93	1.59	13.15	1.05	1,255.71	100.00

TABLE 3

ON-ROUTE IDENTIFICATION OF FIXATION POSITIONS
(10 Drivers, Tape Recorder Data)

Driver	Open Viewing		Large Aperture		Small Aperture	
	Total No. Statements	Referring to Road	Total No. Statements	Referring to Road	Total No. Statements	Referring to Road
E. C.	7	4	13	10	9	7
G. W.	28	26	15	14	11	11
D. U.	11	6	13	13	9	9
G. R.	23	22	34	34	38	38
L. H.	3	3	9	9	15	15
S. B.	33	33	65	65	58	58
G. P.	16	14	11	11	22	20
R.O'C.	37	32	60	59	105	103
B. C.	18	14	30	24	30	27
F. T.	11	9	15	14	25	22
Total	187	163 (87.2%)	265	253 (95.5%)	322	310 (96.3%)

shoulder at least once during the trials. The remaining comments referred mainly to anticipation and alignment.

The finding that the driver depends upon road edges and the centerline for guidance has a number of implications for highway research. The desirability of marking these highway edges is shown. Poor road edge contrast will affect the safety of the driver and the movement of traffic, particularly at night or in fog. These findings also have a bearing on lateral guidance theories. The suggestion is supported that steering the car involves the maintenance of an acceptable steady-state visual condition and the nulling of deviations from an acceptable state (2). The theory that the visual feedback for steering is the slewing and sideslipping movements of road boundaries is also supported (2). However, present findings do not themselves prove these theories to be correct. The findings also have implications for the direction of future research. Visibility studies should be undertaken of road edges and centerlines under conditions of night and fog. Such researches would assess the penalty of adverse visibility conditions and show the advantages of highway markings, reflectors, luminaires and other devices. The visibility of lane and edge markings may be assessed through available formulas involving luminance, size, and background contrast (1).

How Drivers Obtain Essential Information; Forward Reference Distance

Although all drivers guided the vehicle by reference to the road edges and the centerline, the manner in which information was obtained differed. The variation in approach is clearly illustrated in individual records given in Tables 4 to 15. Driver G. P. (Tables 4 to 7) tended to view the yellow centerline at a distance beyond 150 ft, thus including the yellow line or right lane in the field of view of the small aperture and the entire road in the large. G. W. (Tables 8 to 11) looked mainly at the right shoulder. A third approach was taken by R.O'C. (Tables 12 to 15) who shifted fixations between the centerline and the right shoulder. His main center of viewing was beyond 150 ft. These records refute the notion that a common sequence of viewing is shared by all drivers.

It has been proposed that the driver has a fixed forward fixation distance which increases with vehicular speed (8). If the driver did not look ahead to compensate for man-vehicle reaction, he could not meet the current situation. Forward reference distance should increase with vehicular speed to compensate for increased stopping time.

To test the validity of the forward reference formulation, correlations were computed on the 10 test drivers between speed and average forward reference distance. Driver speed was obtained by determining the film time between known points on the course. Distance divided by time then indicated rate. The average forward reference distance was obtained by averaging fixation distances.

TABLE 4

DRIVER G.P.—FIXATION AREA TIME WITH SMALL APERTURE, COMBINED LEFT AND RIGHT CURVES

Distance (ft)	Left Lane		Yellow Line		Right Lane		Whole Road		Left Shoulder		Right Shoulder		Total	
	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%
>150	35.47	23.9	37.73	25.5	18.61	12.6	38.96	25.8	7.12	4.8	2.63	1.8	139.82	94.4
100-150	—	—	4.67	3.1	—	—	—	—	—	—	—	—	4.67	3.1
50-100	—	—	2.45	1.6	—	—	0.70	0.5	—	—	0.11	0.1	3.26	2.2
<50	—	—	0.41	0.3	—	—	—	—	—	—	—	—	0.41	0.3
Total	35.47	23.9	45.26	30.5	18.61	12.6	38.96	26.3	7.12	4.8	2.74	1.9	148.16	100.0

TABLE 5

DRIVER G.P.—FIXATION POSITION TIME WITH SMALL APERTURE, COMBINED LEFT AND RIGHT CURVES

Distance (ft)	Left Shoulder		Yellow Line		Right Shoulder		Total	
	Sec	%	Sec	%	Sec	%	Sec	%
>150	3.26	2.2	124.11	83.3	12.45	8.4	139.82	94.4
100-150	—	—	4.67	3.1	—	—	4.67	3.1
50-100	—	—	3.15	2.1	0.11	0.1	3.26	2.2
<50	—	—	0.41	0.3	—	—	0.41	0.3
Total	3.26	2.2	132.34	89.3	12.56	8.5	148.16	100.0

TABLE 6

DRIVER G. P.—FIXATION AREA TIME WITH LARGE APERTURE, COMBINED LEFT AND RIGHT CURVES

Distance (ft)	Yellow Line		Whole Road		Total	
	Sec	%	Sec	%	Sec	%
>150	0.82	0.7	111.43	93.3	112.25	94.0
100-150	0.89	0.8	4.67	3.9	5.56	4.7
50-100	—	—	1.19	1.0	1.19	1.0
<50	—	—	0.37	0.3	0.37	0.3
Total	1.71	1.5	117.66	98.5	119.37	100.0

TABLE 7

DRIVER G.P.—FIXATION POSITION TIME WITH LARGE APERTURE, COMBINED LEFT AND RIGHT CURVES

Distance (ft)	Left Shoulder		Yellow Line		Right Shoulder		Trees		Total	
	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%
>150	27.69	23.2	39.60	33.2	43.74	36.6	1.22	1.0	112.25	94.0
100-150	.74	0.6	3.22	2.7	1.60	1.4	—	—	5.56	4.7
50-100	—	—	1.19	1.0	—	—	—	—	1.19	1.0
<50	—	—	.37	0.3	—	—	—	—	0.37	0.3
Total	28.43	23.8	44.38	37.2	45.34	38.0	1.22	1.0	119.37	100.0

TABLE 8

DRIVER G. W.—FIXATION AREA TIME WITH SMALL APERTURE, COMBINED LEFT AND EIGHT CURVES

Distance (ft)	Right Lane		Whole Road		Total	
	Sec	%	Sec	%	Sec	%
>150	8.23	8.4	7.12	7.2	15.35	15.6
100-150	30.40	30.8	3.15	3.2	33.55	34.0
50-100	47.15	47.9	0.11	0.1	47.26	48.0
<50	2.37	2.4	—	—	2.37	2.4
Total	88.15	89.5	10.38	10.5	98.53	100.0

TABLE 9

DRIVER G. W.—FIXATION POSITION TIME WITH SMALL APERTURE, COMBINED LEFT & RIGHT CURVES

Distance (ft)	Left Shoulder		Yellow Line		Right Shoulder		Center Right Lane		Total	
	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%
<150	0.41	0.4	2.74	2.8	12.20	12.4	—	—	15.35	15.6
100-150	—	—	0.26	0.2	32.92	33.4	0.37	0.4	33.55	34.0
50-100	—	—	0.11	0.1	47.15	47.9	—	—	47.26	48.0
<50	—	—	—	—	2.37	2.4	—	—	2.37	2.4
Total	0.41	0.4	3.11	3.1	94.64	96.1	0.37	0.4	98.53	100.0

TABLE 10

DRIVER G.W.—FIXATION AREA TIME WITH LARGE APERTURE, COMBINED LEFT AND RIGHT CURVES

Distance (ft)	Right Lane		Whole Road		Total	
	Sec	%	Sec	%	Sec	%
<150	32.66	30.8	64.20	60.7	96.86	91.5
100-150	7.34	7.0	0.56	0.5	7.90	7.5
50-100	0.52	0.5	0.52	0.5	1.04	1.0
<50	—	—	—	—	—	—
Total	40.52	38.3	65.28	61.7	105.80	100.0

TABLE 11

DRIVER G. W.—FIXATION POSITION TIME WITH LARGE APERTURE, COMBINED LEFT AND RIGHT CURVES

Distance (ft)	Left Shoulder		Yellow Line		Right Shoulder		Center Right Lane		Total	
	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%
>150	13.72	13.0	6.86	6.5	72.65	68.6	3.63	3.4	96.86	91.5
150-100	—	—	—	—	7.90	7.5	—	—	7.90	7.5
50-100	—	—	0.52	0.5	0.52	0.5	—	—	1.04	1.0
<50	—	—	—	—	—	—	—	—	—	—
Total	13.72	13.0	7.38	7.0	81.07	76.6	3.63	3.4	105.80	100.0

TABLE 12

DRIVER R.O'C.—FIXATION AREA TIME WITH SMALL APERTURE, COMBINED LEFT AND RIGHT CURVES

Distance (ft)	Left Lane		Yellow Line		Right Lane		Whole Road		Total	
	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%
>150	53.45	31.5	10.94	6.4	56.64	33.3	31.17	18.4	152.20	89.6
100-150	1.74	1.0	2.19	1.3	13.16	7.7	—	—	17.09	10.0
50-100	—	—	—	—	0.63	0.4	—	—	0.63	0.4
<50	—	—	—	—	—	—	—	—	—	—
Total	55.19	32.5	13.13	7.7	70.43	41.4	31.17	18.4	169.92	100.0

TABLE 13

DRIVER R.O'C.—FIXATION POSITION TIME WITH SMALL APERTURE, COMBINED LEFT AND RIGHT CURVES

Distance (ft)	Left Shoulder		Yellow Line		Right Shoulder		Center Right Lane		Center Left Lane		Total	
	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%
>150	22.28	13.1	57.90	34.1	42.00	24.7	28.20	16.6	1.82	1.1	152.20	89.6
100-150	0.07	0.0	4.82	2.8	9.68	5.7	2.52	1.5	—	—	17.09	10.0
50-100	—	—	—	—	0.63	0.4	—	—	—	—	0.63	0.4
<50	—	—	—	—	—	—	—	—	—	—	—	—
Total	22.35	13.1	62.72	36.9	52.31	30.8	30.72	18.1	1.82	1.1	169.92	100.0

TABLE 14

DRIVER R.O'C.—FIXATION AREA TIME WITH LARGE APERTURE, COMBINED LEFT AND RIGHT CURVES

Distance (ft)	Right Lane		Whole Road		Total	
	Sec	%	Sec	%	Sec	%
>150	20.80	16.2	72.39	56.1	93.19	72.3
100-150	7.12	5.5	27.58	21.4	34.70	26.9
50-100	1.07	0.8	—	—	1.07	9.8
<50	—	—	—	—	—	—
Total	28.99	22.5	99.97	77.5	128.96	100.0

TABLE 15

DRIVER R.O'C.—FIXATION POSITION TIME WITH LARGE APERTURE, COMBINED LEFT AND RIGHT CURVES

Distance (ft)	Left Shoulder		Yellow Line		Right Shoulder		Center Right Lane		Total	
	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%
>150	13.61	14.4	12.49	9.7	60.20	46.7	1.89	1.5	93.19	72.3
100-150	4.97	3.9	5.56	4.3	21.09	16.3	3.08	2.4	34.70	26.9
50-100	—	—	—	—	0.18	0.1	0.89	0.7	1.07	0.8
<50	—	—	—	—	—	—	—	—	—	—
Total	23.58	18.3	18.05	14.0	81.47	63.1	5.86	4.6	128.96	100.0

Separate figures were obtained on the drivers who started at the 2 ends of the course. Correlations of 0.55 and - 0.37 were found for the small aperture, and - 0.52 and 0.15 for the large (N = 5). These results indicate no systematic relation between average forward reference distance and vehicular speed. The average fixation distance of 142 ft, which was the same for both apertures, seems larger than required to respond at average speeds of 13.4 mph (small aperture) or 14.7 mph (large aperture). Even if a relation were found between average forward reference distance and speed, it would not be very meaningful, in view of the variability of the fixation positions. The driver looks far ahead of the car and then, seemingly in disregard of anticipation requirements, he may check his alignment with the road. This variability and the adjustment of fixation to particular road conditions makes the concept of average forward reference distance largely an abstraction.

Left and Right Curves

The fixation pattern differed somewhat on left and right curves (Tables 16 to 19). The point of fixation in distant vision deserves special attention. Signs and other visual aids should presumably be located where the motorist's eye tends to fall. When drivers viewed through the large aperture, their eye fell 6.48 ft from the right edge of the road (left curve, average of fixations beyond 150 ft). The corresponding figure for the right curve was 8.91 ft. The figures for the small aperture are 6.95 and 10.38 ft. The average shifts in fixation position are statistically significant at the 0.01 level (t-test). Apparently the eye moves to the left on a right hand curve; but on the average, it does not cross into the opposing lane. The results support the placement of signs on the right side of the road.

Perceptual Anticipation and Alignment

Most records show continuous visual shifts, forward to the limit of the road and backward toward the vehicle. The record of E.C. illustrates these movements (Fig. 5). On the left curve, rapid fixation movements occur between positions beyond 150 ft and those less than 50 ft. These shifts also occur along the right shoulder when the driver is on a right curve. Forty-eight percent of all drivers' fixations with the small aperture and 55 percent with the large cross the zone borders at 50, 100, or 150 ft. These movements may be explained by the contradictory requirements of perceptual anticipation and vehicular alignment. Perceptual anticipation requires the driver to look far ahead to get a general idea of conditions which will have to be met. Alignment behavior requires viewing close up to insure that the vehicle is on the road.

The drivers mentioned anticipation and alignment in explaining how they guided the car. The record excerpts illustrate these activities:

Question: How did you guide yourself on the right curve?
Answer: Well, I just saw the same thing. My vision would go out to the curve. I'd see as much as I could and then come back again. One time I stayed out too long and I was out of the road. (O: G.P., small aperture)

Question: Was there any pattern of movement?
Answer: Just that I . . . you look ahead frequently to see the whole situation, then come back to your immediate points of reference. I wanted to see what was ahead and then put myself within the lane by something closer—center-line or shoulder line. (O: R.O'C., small aperture)

Question: How did you guide yourself on the left curve?
Answer: Going into a left turn, generally I was looking at the center strip and the curvature in the distance along the left side of the road. And as I approached the curve—got into the curve—I was looking generally at the center strip and the right side of the shoulder. (O: N.M., standardization procedure, no aperture)

TABLE 16

TIME ON VARIOUS FIXATION POSITIONS
(Summary—10 Drivers, Large Aperture)

Curve	Distance (ft)	Left Shoulder		Yellow Line		Right Shoulder		Center Right Lane		Center Left Lane		Trees, Left & Right Sides		Total	
		Sec	%	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%
Left	>150	49.86	7.91	88.34	14.02	192.06	30.50	19.05	3.03	8.63	1.37	6.59	1.04	364.53	57.87
	100-150	14.68	2.33	37.66	5.98	47.89	7.60	25.02	3.97	17.05	2.71	0.19	0.03	142.49	22.62
	50-100	6.79	1.08	35.45	5.63	15.89	2.52	42.22	6.70	4.52	0.72	—	—	104.87	16.65
	<50	—	—	9.82	1.56	1.45	0.23	6.56	1.04	0.19	0.03	—	—	18.02	2.86
	Total	71.33	11.32	171.27	27.19	257.29	40.85	92.85	14.74	30.39	4.83	6.78	1.07	629.91	100.00
Right	>150	100.42	17.47	40.85	7.11	148.83	25.90	25.10	4.37	1.56	0.27	0.37	0.07	317.13	55.19
	100-150	23.14	4.03	20.83	3.62	35.92	6.62	16.35	2.85	1.11	0.19	—	—	97.35	16.94
	50-100	5.22	0.91	13.61	2.37	69.39	12.07	41.68	7.25	1.70	0.30	—	—	131.60	22.90
	<50	—	—	2.71	0.47	13.83	2.41	12.03	2.09	—	—	—	—	28.57	4.97
	Total	128.78	22.41	78.00	13.57	267.97	46.63	95.16	16.56	4.37	0.76	0.37	0.07	574.65	100.00

TABLE 17

TIME ON VARIOUS FIXATION AREAS
(Summary—10 Drivers, Large Aperture)

Curve	Distance (ft)	Left Lane		Yellow Line		Right Lane		Whole Road		Other Areas[a]		Total	
		Sec	%	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%
Left	>150	5.41	0.85	2.58	0.41	135.72	21.55	220.82	35.06	—	—	364.53	57.87
	100-150	6.52	1.04	3.08	0.49	53.41	8.48	79.48	12.61	—	—	142.49	22.62
	50-100	3.60	0.57	4.41	0.70	52.42	8.32	43.44	6.90	1.00	0.16	104.87	16.65
	<50	1.19	0.19	5.23	0.83	6.67	1.06	4.11	0.65	0.82	0.13	18.02	2.86
	Total	16.72	2.65	15.30	2.43	248.22	39.41	347.85	55.22	1.82	0.29	629.91	100.00
Right	>150	46.41	8.08	—	—	5.12	0.89	265.60	46.22	—	—	317.13	55.19
	100-150	20.06	3.49	—	—	—	—	77.29	13.45	—	—	97.35	16.94
	50-100	9.38	1.63	—	—	10.60	1.85	111.63	19.42	—	—	131.60	22.90
	<50	2.26	0.39	0.37	0.07	5.48	0.95	20.45	3.56	—	—	28.57	4.97
	Total	78.11	13.59	0.37	0.07	21.20	3.69	474.97	82.65	—	—	574.65	100.00

[a]Left shoulder, center left lane, center right lane, right shoulder.

TABLE 18

TIME ON VARIOUS FIXATION POSITIONS
(Summary—10 Drivers, Small Aperture)

Curve	Distance (ft)	Left Shoulder		Yellow Line		Right Shoulder		Center Right Lane		Center Left Lane		Trees, Left & Right Sides		Total	
		Sec	%	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%
Left	>150	33.40	4.50	174.56	23.50	176.97	23.83	56.08	7.55	10.71	1.44	11.20	1.51	462.92	62.33
	100-150	11.23	1.51	53.56	7.21	35.55	4.79	14.86	2.00	5.38	0.73	—	—	120.58	16.24
	50-100	2.37	0.32	64.17	8.64	58.05	7.81	7.71	1.03	3.00	0.40	—	—	135.30	18.20
	<50	0.33	0.04	12.34	1.66	8.86	1.19	1.90	0.26	0.59	0.08	—	—	24.02	3.23
	Total	47.33	6.37	304.63	41.01	279.43	37.62	80.55	10.84	19.68	2.65	11.20	1.51	742.82	100.00
Right	>150	71.10	13.87	183.05	35.69	75.92	14.80	31.32	6.11	—	—	1.96	0.38	363.35	70.85
	100-150	7.27	1.42	26.76	5.22	42.26	8.24	19.16	3.73	—	—	—	—	95.45	18.61
	50-100	0.33	0.06	15.75	3.07	21.06	4.11	13.94	2.72	0.26	0.05	—	—	51.34	10.01
	<50	—	—	0.19	0.04	1.51	0.29	1.04	0.20	—	—	—	—	2.74	0.53
	Total	78.70	15.35	225.75	44.02	140.75	27.44	65.46	12.76	0.26	0.05	1.96	0.38	512.88	100.00

TABLE 19

TIME ON VARIOUS FIXATION AREAS
(Summary—10 Drivers, Small Aperture)

Curve	Distance (ft)	Yellow Line		Left Lane		Whole Road		Right Lane		Other Areas[a]		Total	
		Sec	%	Sec	%	Sec	%	Sec	%	Sec	%	Sec	%
Left	>150	53.34	7.18	21.53	2.90	68.84	9.27	310.69	41.83	8.52	1.15	462.92	62.33
	100-150	37.03	5.00	6.64	0.89	12.93	1.74	56.00	7.54	7.98	1.07	120.58	16.24
	50-100	43.19	5.80	2.70	0.36	6.82	0.92	77.59	10.45	5.00	0.67	135.30	18.20
	<50	8.41	1.13	0.86	0.12	1.15	0.15	12.79	1.72	0.81	0.11	24.02	3.23
	Total	141.97	19.11	31.73	4.27	89.74	12.08	457.07	61.54	22.31	3.00	742.82	100.00
Right	>150	21.87	4.26	157.70	30.75	128.25	25.01	44.82	8.74	10.71	2.09	363.35	70.85
	100-150	9.57	1.87	18.68	3.64	20.20	3.94	41.85	8.16	5.15	1.00	95.45	18.61
	50-100	9.72	1.90	5.96	1.16	4.56	0.88	25.06	4.89	6.04	1.18	51.34	10.01
	<50	—	—	—	—	0.18	0.04	1.52	0.29	1.04	0.20	2.74	0.53
	Total	41.16	8.03	182.34	35.55	153.19	29.87	113.25	22.08	22.94	4.47	512.88	100.00

[a]Right shoulders, left shoulders, center right lane, center left lane.

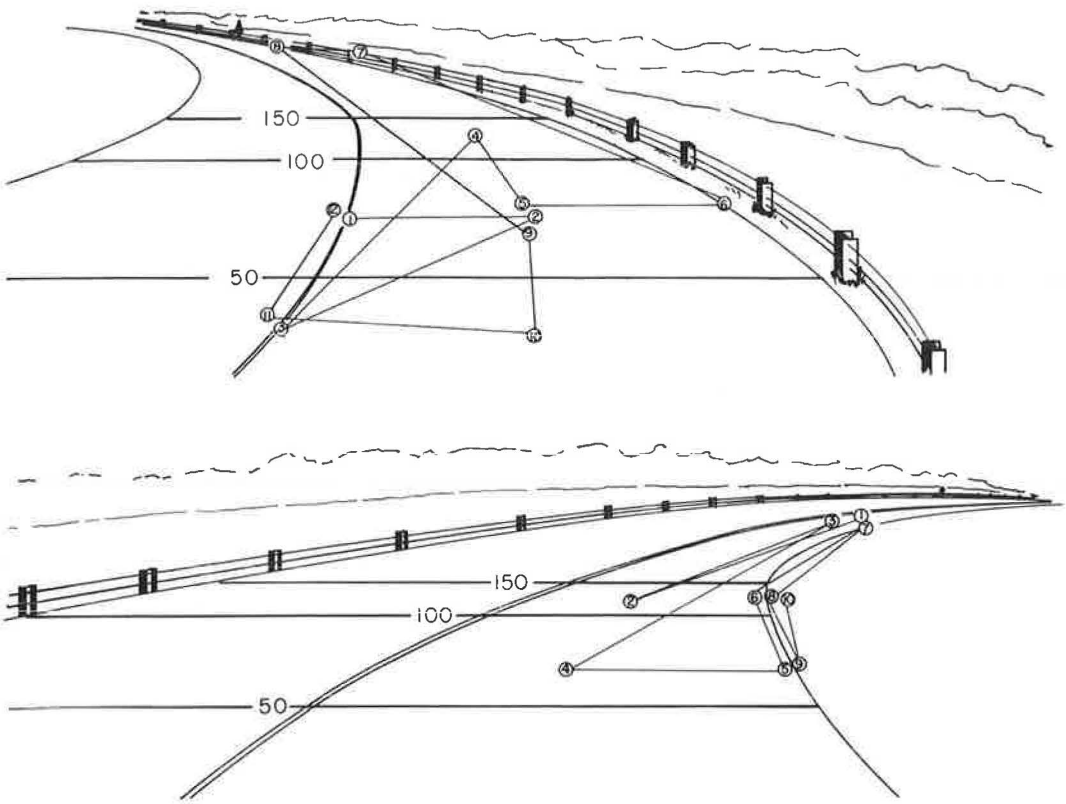

Figure 5. Anticipation and alignment (Driver E.C.).

Methodological Problems

Two methodological problems arising in this study are (a) the adequacy of introspective data (on-route statements of fixation, answers to questionnaires) for indicating the driver's visual input, and (b) the effects of the stress imposed by limiting information with the small aperture.

The on-route statements and the questionnaire data were suggestive—as far as they went. The main shortcoming of the introspective data was its incompleteness. The 3,305 separate film fixations obtained permitted a reliable analysis of the distribution and sequence of eye positionings. In contrast, the 563 statements given on-route and the 20 questionnaire responses offered only a skeletal indication of what was going on. However, introspective data did offer confirming evidence of the validity of the film analysis, and were valuable in revealing the drivers' purposes in perceptual anticipation and alignment. These uses and limitations of introspective data are similar to those generally encountered in experimental work. The complexity of fixation data has been noted in previous eye camera studies (9).

The adaptation made by drivers to the stress of limited information is revealed by a comparison of small and large aperture results given in Tables 1 and 2. In looking through the small aperture, drivers mainly fixated the yellow line (42.2 percent of the time, Table 2) and the right shoulder (33.5 percent) enabling them to track the yellow line, or view the whole right lane. In looking through the large aperture, drivers could see the entire road, and this inclusive feature was used 68.3 percent of the time (Table 1). The right lane also had high usage (22.4 percent) as it could be covered even when the driver looked close to the car. The records seem to indicate that the driver selects a view which permits him to do the job. Under stress it may be as simple as holding fast to the yellow line and tracking it, as in the record of G. P. (Tables 4 to 7). However, the driver prefers to see more of the road, even in the small aperture condition, the entire right lane was viewed 45.4 percent of the time (Table 1) and the entire road 19.4 percent.

APPLICATIONS TO HIGHWAY DESIGN

The experimental evidence of this study leads to a number of suggestions for the design of highway markings. The experimental evidence must be weighed along with considerations of cost, public acceptance, current usage, etc., before it can be applied. But experimental findings have special status, for they are perhaps less subject to debate than other considerations.

1. Since drivers use the road edges and center lane marker to guide the vehicle, these features should be visible to the driver.

Results of this experiment provide a rationalization for edge and center lane markings. The question remains which features should be emphasized by being specially marked. The evidence indicates that driving can be done using only the centerline (Table 1, small aperture) and this might lead to the recommendation that it alone be presented. However, drivers prefer to see the right lane and the entire road, as evidenced by the high total time spent on these features (Table 1). Factors other than those considered in this experiment will dictate road marking policy. For example, road edges differ in luminance and contrast, and hence in their need to be painted. Where contrast is low or where there is heavy night usage, edge markings are recommended. Where 2-way traffic is heavy, a centerline should be used.

2. Curve markings (signs, fences, and edge markings) should be positioned on the right edge of the road on both left and right curves.

The analysis of fixations on curves indicates that a driver tends to shift his distant fixation to the left on a right curve. However, the movement is not large enough to move the average fixation position across into the opposing lane. Hence, highway markings should presumably be presented on the right side of the road.

3. The driver should always be given sufficient unimpeded view ahead to satisfy his anticipation requirements.

The driver's need to anticipate conditions ahead has been recognized in traffic regulation and guidance, as well as road design manuals, and comes out clearly in the data of this experiment. Little is known about perceptual anticipation requirements in the variety of situations met on the highway, and further research in this area may be quite fruitful.

SUMMARY AND CONCLUSIONS

A technique to determine what features of the road and terrain the driver is responding to is presented in this study. The method involves having the driver guide the car while looking through a device containing a small aperture. By decreasing the visual field, the essential information, whatever it is, cannot be seen at once, i.e., the driver is forced to obtain this information in separate visual fixations. A continuous film record is made of the driver's field of view, which is later analyzed to indicate the center of his visual aim and the content of each fixation. Using this aperture device, visual positional data were obtained on 10 drivers who followed a 2-lane low traffic density road. The film records provided 3,305 separate fixations, which were coded for position, distance from the eye, and duration. The following conclusions were reached on the basis of the analysis:

1. The essential information required by the driver is provided by the road edges and center lane marker. It was found that 98.2 percent of the fixations made using the small aperture, and 100 percent of those made with the large, included at least one of these road features. The drivers' on-route statements of fixation position and the answers to a questionnaire also indicated the importance of the road edges and lane marker.

2. Although all drivers utilized the road edges and centerline to guide the vehicle, the manner in which this information was obtained differed from subject to subject. The film records refute the notion that the driver has a fixed point of forward reference, or that a common pattern of viewing is shared by all drivers.

3. In going from a left to a right curve, the position of fixation tended to shift in the opposite direction, i.e., from right to left. However, the average point of fixation beyond 150 ft did not cross the centerline into the opposing lane.

4. The hypothesis is presented that the persistent pattern of fixation movements forward to the limits of the road and back again to the vehicle are explained by the contradictory requirements of perceptual anticipation and vehicular alignment with the road.

5. Methodological problems concerning the adequacy of introspective data for determining the driver's visual input, and the stress of small aperture viewing, are discussed.

6. The implications of these results for the placement of signs and highway markings are presented.

The conclusions in 3 and 4 should be tested, if possible, with eye camera techniques.

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