

Advisory Speed Signs and Curve Signs and Their Effect on Driver Eye Scanning and Driving Performance

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The objective of this study was to determine the effectiveness of advisory speed signs used in conjunction with curve warning signs in Ohio. A total of 40 test drivers were used to drive an unfamiliar test route on a two-lane rural road that included two typical curves equipped with curve warning signs. Curve A was a left curve with a determined advisory speed of 40 mph and Curve C was a right curve with a determined advisory speed of 25 mph. The results of the test-driver study indicate that drivers, on the average, look about two times at a warning sign (fixation duration 0.5 to 0.6 sec). There are few consistent statistically significant differences in driver eye-scanning behavior and driver control behavior (velocity, lateral acceleration, gas pedal deflection, lane position, brake activation) between Run 1 and Run 2, between inexperienced and experienced drivers, between the presence and absence of advisory speed signs, and between day and night. The daytime velocities are in general somewhat higher than the nighttime velocities. It may be concluded that advisory speed signs are not more effective in causing drivers to reduce their speeds through curves than curve and turn signs alone. It appears that the bent black arrow in the yellow diamond of the curve or turn warning sign represents such a strong and primary visual stimulus that an advisory speed sign adds very little additional information for the driver. Therefore, it is recommended that advisory speed sign maintenance and especially new installations be given a low priority.

The state of Ohio has a highway network containing more than 19,000 of four-lane and two-lane highways. On the basis of the Ohio Department of Transportation's (ODOT) curve inventory, the two-lane rural system alone contains 18,093 curves. These curves have a median curvature between 10 and 11 degrees, an average curvature of 12 degrees with a standard deviation of 12.5 degrees and a mode of curvature of 9 degrees (2,517 curves, or 13.9 percent, have a 9-degree curvature). On many roads it is impossible to drive safely at 55 mph because of the curvature, and some are considered safe at speeds of only 25 mph or less. It will probably require decades before sufficient funding is available to eliminate these sharp and dangerous curves and to rehabilitate the older highways that have substandard alignment. Therefore, drivers must be alerted to upcoming hazardous curves through the use of warning signs.

ODOT now uses curve warning signs with or without advisory speed signs to warn drivers of an upcoming curve. (The *Ohio Manual of Uniform Traffic Control Devices* defines a curve sign as a warning sign with a curved arrow, intended for use on curves with recommended speeds between 30 and 50

mph, and a turn sign as a warning sign with an arrow bent at a right angle, intended for use on curves where the maximum safe speed is 30 mph or less. Both signs will be referred to as curve signs throughout this paper.) These signs are intended to give drivers adequate time to prepare to safely traverse an upcoming hazardous curve. Because of the frequency of such hazards, the use of curve warning signs with advisory speed signs is expensive and requires the efforts of traffic engineers, maintenance crews, and others who could be utilized in other areas.

Questions may then be raised with regard to the effectiveness of such practices, some of which are

Do motorists look at the advisory speed signs?

At what distances do they look and for how long?

How effective are curve warning signs in causing motorists to decrease speeds to safe levels throughout the curve?

Does the presence of advisory speed signs increase the effectiveness of the curve warning sign in bringing about adequate speed reductions throughout the curve?

LITERATURE REVIEW

Few prior studies were found that have been devoted to the effectiveness of curve warning signs with or without advisory speed signs. Ritchie (1), by recording the lateral acceleration and forward velocity measured at the time of peak lateral acceleration, investigated uninformed subjects' responses to curves with or without curve warning signs during daylight driving conditions only. The curve warning signs were presented either by themselves or in conjunction with an advisory speed sign on which the advisory speed ranged from 15 to 50 mph in increments of 5 mph (advisory speed signs with values higher than 50 mph were not investigated because the driver's responses could have been influenced by the state speed limit of 60 mph that existed at this time). Ritchie (1) found that drivers choose faster speeds on curves with curve warning signs than curves without curve warning signs and even faster speeds when advisory speed signs were presented with the curve warning sign. The speeds recommended on the advisory speed signs were lower than those chosen for negotiating the curves except in the case of the 45 and 50 mph signs, where the subjects chose speeds almost exactly the same as the advisory speeds. Lateral acceleration appeared to be a key variable in the driver's decision-making process. When a driver approached a curve that required a large speed reduction, he accepted lateral accelerations closer to the maximum than those accepted for curves that required smaller speed reductions.

Kneebone (2) reported on the effect of advisory speed signs used in conjunction with curve warning signs. He found that advisory speeds determined with ball-bank indicators were very close to the 85th-percentile speeds. Institution of curve warning signs with advisory speed signs in Australia was accompanied by a marked reduction in accidents and a reduction in the approach speeds of 2 to 3 mph. However, the average speed in the curves actually increased slightly.

In a study of minor highway improvements that contradicts the findings by Ritchie (1), Hammer (3) found that the placement of curve warning signs by themselves in advance of curves failed to produce significant accident reductions (five curves that were not previously equipped with curve warning signs were studied). However, when curve warning signs were used in conjunction with advisory speed signs, the results were different. (In 13 of the 15 curves studied, the curve warning and advisory speed signs were erected simultaneously, whereas in the two remaining cases the advisory speed sign was added to an already existing curve warning sign.) Significant reductions in accidents, especially ran-off-road accidents at night, did occur when the two signs were used together. It should be noted that the sample sizes in Hammer's study were rather small and the experimental design did not indicate any randomization scheme or controls. Further, no information was given about the environment-accident interaction, about other minor road improvements that may have been completed at the same time or immediately following the erection of the curve warning sign, about possible changes in average daily traffic volumes or about changes in the driver population, or both, that could have been primarily or partly responsible for Hammer's results.

Shinar et al. (4) found in a study on driver eye-scanning behavior that as drivers approached a curve they began concentrating their eye fixations less around the focus of expansion (the area of highest concentration for straight section driving) and more on the edge lines and the roadway close to the car. The authors reached the conclusion that warning signs should be placed before the beginning of the curve approach because near that point the driver is concentrating mainly on the roadway for directional and lateral placement cues rather than on the road surroundings.

The objective of this study was to determine the effectiveness of advisory speed signs used in conjunction with curve warning signs in Ohio on typical sharp and moderate curves for both inexperienced and experienced test drivers under both daytime and nighttime conditions.

METHOD

Subjects

A total of 40 subjects took part in the experiment and were divided into one of two groups on the basis of their driving experience (either experienced or inexperienced drivers). The 21 experienced licensed drivers (12 men, 9 women) had an average age of 22 years and had driven an average of 44,000 mi during an average of 6 years. The 19 inexperienced licensed drivers (11 men, 8 women) had an average age of 17 years and had driven an average of 4,000 mi during an average of 2 years.

All subjects were initially interviewed and required to fill out a biographical and driving questionnaire. Each subject was tested in the laboratory for (a) foveal vision (Bausch and Lomb vision tester) and peripheral vision (Landolt rings, 10 degrees horizontal, presented left or right) and (b) for simple (1 choice, 0 bits) and choice (8 choices, all equally likely, 3 bits) reaction times using a CR-200 Information Response Instrument (response uncertainty mode). The subjects also underwent a limited health evaluation. The results of these tests indicated that all subjects had normal visual acuity and reaction times and were in good health. None of the subjects were familiar with the road or the experimental vehicle. All subjects were paid and told only that the study involved driving on two-lane rural roads. They were not told the actual aim of the experiment.

Apparatus

An instrumented 1973 Volkswagen 412 with an automatic transmission and type 4000 low beams was used as the experimental vehicle in this study. This vehicle contains more than 30 instruments and mechanisms that are combined into a system allowing the experimenter to monitor and record a driver's eye movements while he or she is driving the car as well as time, distance, speed, lateral lane position, steering wheel position, gas pedal deflection, brake activation, and vertical, horizontal, and lateral accelerations of the car (sampling rate of 60 Hz). A further description of the experimental car and equipment has been published by Zwahlen (5).

Experimental Test Sites

In order to make the results of this study widely applicable it was necessary to choose curves representative of the rural two-lane system in Ohio with fairly low average daily traffic (ADT). The two curves chosen (Curves A and C) had an approach speed of 55 mph and were equipped with only curve warning signs (without advisory speed signs) and no raised reflective pavement markers or post delineators. Curve A required a small speed reduction for safe negotiation, whereas Curve C required a moderate to large speed reduction.

The westbound approaches to these two selected curves, which were located on SR-180 east of Laurelville, Ohio, were used. With the ball-bank indicator the advisory speed was determined to be 40 mph for Curve A (a 12.3-degree left curve with a radius of 465 ft and a superelevation of 8.6 percent) and 25 mph for Curve C (a 26-degree right curve with a radius of 220 ft and a superelevation of 9 percent). ODOT records place the ADT at 1,440 for Curve A (total count in both directions) and 930 for Curve C. Two accidents occurred on each curve between 1975 and 1981.

For this experiment the curve warning signs (both directions) were equipped either with or without an advisory speed sign. The specific intensity for an entrance angle of -4 degrees and an observation angle of 0.2 degrees was recorded for each of the curve warning and advisory speed signs. The W1-2L curve warning sign on Curve A (for westbound traffic) was 30 in. square, had an average specific intensity of 35.5 cd/(ft-candle \cdot ft 2) and could first be seen at 1,036 ft (measured from the

curve warning sign). The W1-1R curve warning sign on Curve C (for westbound traffic) was 30 in. square, had an average specific intensity of 67.6 cd/(ft-candle·ft²) and could first be seen at 953 ft. The advisory speed signs were 18 in. square with 8-in. numbers and had an average specific intensity of 61.4 cd/(ft-candle·ft²) for Curve A and 62.2 cd/(ft-candle·ft²) for Curve C (for westbound traffic).

Experimental Procedure and Design

Before the test-driver study began, a local familiar-driver study was completed that involved the inconspicuous videotaping of 339 vehicles on Curve A and 312 vehicles on Curve C as they approached the two curves of interest during both daytime and nighttime conditions. During this study the two curve approaches had only the existing curve warning signs without advisory speed signs. Time and distance data and points of brake light activation were recorded. Calculations were made to determine velocities and accelerations at various distances from the curves. These data gave the experimenters a standard with which to gauge the validity of the test-driver study results.

The test-driver study involved the continuous recording of the subject's eye-scanning behavior and vehicle measures as the subject drove for 30 to 45 min along a typical rural two-lane highway that included the two curves of interest. Subjects were randomly assigned to one of eight groups such that each group had either experienced or inexperienced subjects and as close to a half-men and half-women composition as possible. Although it was originally planned for a group of six to be tested under each condition, some nighttime conditions were tested only with fewer subjects because of frequent ground fog at the test locations. Each of the eight groups was subjected to one of the different conditions; that is, they would be experienced or inexperienced drivers, drive during the day or the night (using low beams), and drive through curves that had a curve warning sign either with or without an advisory speed sign. Both curves were equipped either with or without the advisory speed sign so that no subject was exposed to one curve with the advisory speed sign and one without the advisory speed sign. Also no subject drove the test route under more than one of the eight conditions. The subjects were asked to follow the test route twice to allow the experimenters to evaluate the effects of short-term familiarity on driver performance.

The independent variables are as follows: (a) time of day (level of illumination, day versus night), (b) driver capability (inexperienced versus experienced), (c) presence or absence of advisory speed sign, (d) degree of speed reduction required in curve (moderate to large = 30 mph or more; small = 10 to 15 mph), and (e) familiarity (Run 1 versus Run 2 or completely unfamiliar versus somewhat familiar).

The effects of the independent variables were measured using the following dependent variables (a) speed (mph), (b) accelerator pedal position (0–7, idle; 69–73, fully deflected), (c) brake pedal activation (on or off), (d) lateral acceleration (g), (e) lateral lane position, and (f) eye movement measures (foveal and near foveal or slightly peripheral eye fixations on curve signs and advisory speed signs).

The design variables that might influence performance mea-

asures and are beyond the control of the experimenter include (a) traffic (ahead in opposite or in the same direction, or both), (b) background luminance during nighttime, (c) road surface condition (debris, potholes, etc.), (d) condition of edge lines and center lines, (e) visibility (haze, dust, and light fog), (f) environment (foliage, height of crops, and grass along the highway), (g) temperature and humidity, and (h) position of the sun, level of daytime illumination, glare, and cloud cover.

RESULTS AND DISCUSSION

Vehicle Measures

Detailed vehicle-measure and eye-scanning results for individual subjects and groups have been given by Zwahlen (5). Certain points along the curves were selected for analysis in order to compare the vehicle measures for the different conditions. It was important that these points represented a balanced cross section throughout the approach and curve in order to obtain meaningful results. For this reason, the vehicle measures were analyzed at 500 ft before the curve warning sign, at the position of the sign, at the beginning of the curve, at the center of the curve, at the end of the curve, and 150 ft beyond the end

TABLE 1 SPEED AT SELECTED DISTANCES FROM CURVE SIGN FOR MODERATE CURVE (CURVE A): EXPERIENCED AND INEXPERIENCED SUBJECTS AND RUNS 1 AND 2

		WITH ADV. SPEED		WITHOUT ADV. SPEED	
		DAY	NIGHT	DAY	NIGHT
NO. OF SUBJECTS		24	12	24	19
-500.0	AVERAGE	51.23	48.21	51.48	47.29
	STD.DEV.	3.11	3.42	2.23	2.61
0.0	AVERAGE	50.69	48.13	51.02	46.26
	STD.DEV.	2.54	3.08	2.04	2.80
422.0	AVERAGE	47.80	44.13	47.77	44.34
	STD.DEV.	3.45	2.40	2.16	3.21
883.0	AVERAGE	43.67	42.04	43.63	41.19
	STD.DEV.	2.88	2.24	1.78	2.86
1344.0	AVERAGE	48.13	44.08	47.61	43.89
	STD.DEV.	2.90	3.26	2.68	2.42
1494.0	AVERAGE	49.46	45.29	48.69	44.82
	STD.DEV.	3.05	3.63	2.93	2.65

NOTE: VELOCITY IN MILES PER HOUR

-500.0 - 500 FEET BEFORE CURVE SIGN

0.0 - AT THE CURVE SIGN

422.0 - BEGINNING OF THE CURVE

883.0 - CENTER OF THE CURVE

1344.0 - END OF THE CURVE

1494.0 - 150 FEET AFTER THE END OF THE CURVE

of the curve. *F*- and *t*-tests were performed on the vehicle measures (including velocity, lateral acceleration, lateral lane position, and gas pedal deflection) at the 0.05 level at each of the selected distance points. These tests showed very few statistically significant differences between the first and second runs and between the experienced and inexperienced subjects. These data were then combined in order to achieve larger sample sizes and therefore more sensitive statistical tests.

Tables 1 and 2 show combined group speeds (averages and standard deviations) of the experimental vehicle at selected distance points from the curve warning sign for Curves A and C, respectively, during both nighttime and daytime and with and without the advisory speed sign. The tables indicate that the speed of the vehicle decreased about 3 mph for Curve A and 8 mph for Curve C from the beginning to the center of the curve and then increased rather quickly and consistently until the end of the curve for each of the four conditions.

Table 1 shows that the average speeds at the center of Curve A (883 ft), which were the minimum speeds for the entire curve, were 43.7, 42.0, 43.6, and 41.2 mph. Table 2 shows the average speeds at the center of Curve C (642 ft), the minimum speeds for the curve, were 32.7, 29.5, 33.2, and 32.3 mph. Note that the minimum speeds for Curves A and C are higher than their respective advisory speeds of 40 and 25 mph. In fact,

TABLE 2 SPEED AT SELECTED DISTANCES FROM CURVE SIGN FOR SHARP CURVE (CURVE C): EXPERIENCED AND INEXPERIENCED SUBJECTS AND RUNS 1 AND 2

		WITH ADV. SPEED		WITHOUT ADV. SPEED	
		DAY		NIGHT	
		DAY	NIGHT	DAY	NIGHT
NO. OF SUBJECTS		24	12	24	20
-500.0	AVERAGE	48.19	42.96	48.44	43.29
	STD.DEV.	2.93	3.47	4.00	3.68
0.0	AVERAGE	42.17	38.08	42.44	39.38
	STD.DEV.	2.36	2.78	1.96	3.14
270.0	AVERAGE	41.86	37.33	42.50	39.40
	STD.DEV.	2.50	3.01	2.76	2.90
642.3	AVERAGE	32.73	29.51	33.15	32.28
	STD.DEV.	1.62	2.71	1.75	3.19
1014.6	AVERAGE	38.11	35.67	39.52	37.25
	STD.DEV.	2.22	3.98	1.85	2.46
1154.0	AVERAGE	41.57	38.38	42.79	39.75
	STD.DEV.	2.26	4.40	1.95	2.65

NOTE: VELOCITY IN MILES PER HOUR

-500.0 - 500 FEET BEFORE CURVE SIGN

0.0 - AT THE CURVE SIGN

270.0 - BEGINNING OF THE CURVE

642.3 - CENTER OF THE CURVE

1014.6 - END OF THE CURVE

1154.6 - 140 FEET AFTER THE END OF THE CURVE

these average speeds and their corresponding standard deviations (between 1.6 and 4.4 mph) indicate that the use of the ball-bank indicator results in advisory speeds that are well below the 85th-percentile speeds, as discussed by Kneebone (2). Tables 1 and 2 also indicate that the speeds recorded during the day were always a few miles per hour higher than those recorded at night (statistically significant at the 0.05 level in 21 of the 24 cases), when the only source of illumination was the experimental car's low beams.

There appears to be little difference between the average speeds when the curve warning sign is presented by itself and when it is presented in conjunction with an advisory speed sign. There are no statistically significant differences (at the 0.05 level) between these two experimental conditions on Curve A (the moderate curve). However, a statistically significant speed difference does exist between these two conditions at the end of Curve C (the sharp curve) during the day (38.11 mph versus 39.52 mph) and also at the center of Curve C at night (29.51 mph versus 32.28 mph). In both of these instances the drivers maintained a slightly lower average speed when the advisory speed sign was present than when the advisory speed sign was not present. However, the average lateral acceleration values for the two conditions at the center of Curve C at night are not statistically significant (0.182 *g* versus 0.233 *g*). Consid-

TABLE 3 LATERAL ACCELERATION AT SELECTED DISTANCES FROM CURVE SIGN FOR MODERATE CURVE (CURVE A): EXPERIENCED AND INEXPERIENCED SUBJECTS AND RUNS 1 AND 2

		WITH ADV. SPEED		WITHOUT ADV. SPEED	
		DAY		NIGHT	
		DAY	NIGHT	DAY	NIGHT
NO. OF SUBJECTS		24	12	24	19
-500.0	AVERAGE	-0.008	0.021	-0.019	0.018
	STD.DEV.	0.033	0.021	0.055	0.019
0.0	AVERAGE	0.010	0.005	0.002	0.015
	STD.DEV.	0.033	0.020	0.053	0.016
422.0	AVERAGE	0.042	0.057	0.038	0.068
	STD.DEV.	0.033	0.014	0.051	0.017
833.0	AVERAGE	0.190	0.179	0.169	0.161
	STD.DEV.	0.048	0.026	0.059	0.056
1344.0	AVERAGE	0.011	0.024	0.008	0.024
	STD.DEV.	0.026	0.022	0.057	0.023
1494.0	AVERAGE	0.021	0.031	-0.005	0.017
	STD.DEV.	0.024	0.019	0.045	0.015

NOTE: LATERAL ACCELERATION IN *g*'S

POSITIVE ACCEL. INDICATES LEFT CURVE

-500.0 - 500 FEET BEFORE CURVE SIGN

0.0 - AT THE CURVE SIGN

422.0 - BEGINNING OF THE CURVE

883.0 - CENTER OF THE CURVE

1344.0 - END OF THE CURVE

1494.0 - 150 FEET AFTER THE END OF THE CURVE

ering the rather small magnitude of the average speed decrease and the accompanying average lateral acceleration decrease at the center of the curve, the effect of the advisory speed sign appears to be of a rather small practical importance.

Tables 3 and 4 show the lateral accelerations (averages and standard deviations) for the selected distance points on Curves A and C, respectively. On the basis of the instrumentation, left curves result in positive lateral acceleration values, whereas right curves result in negative lateral acceleration values. The highest average lateral accelerations (0.190 g for Curve A and 0.274 g for Curve C) were obtained at about the center of each of the curves and the average acceleration values for the other distance points were close to zero. If one computes the coefficient of variation (COV = standard deviation divided by average) for the lateral accelerations, it can be seen that the COV varies from 15 to 35 percent in the center of Curve A and from 24 to 40 percent in the center of Curve C. This variability is quite a bit higher than that found for the velocities where the COV was between 4 and 7 percent in the center of Curve A and between 5 and 10 percent in the center of Curve C. This then indicates that the drivers were able to markedly vary their lateral accelerations through fairly small steering wheel and

lateral vehicle position changes without significantly varying their speed at the center of the curve. Comparing the data in Tables 3 and 4, it can be seen that the average lateral accelerations on Curve C, which requires a larger speed reduction, were higher than they were on Curve A. Because of the differences in speed between day and night conditions, the average maximum accelerations were consistently slightly lower at night than during the day.

Tables 5 and 6 show the gas pedal deflection for the selected distance points for Curves A and C, respectively. Table 5 indicates that for Curve A the average gas pedal deflection was low as the subjects entered the curve; however, by the time they reached the center of the curve the subjects began to press the gas pedal down further. At night the gas pedal was deflected further when the subjects entered Curve A than it was during the day (statistically significant); however the gas pedal was deflected further at the center of Curve A during the day than it was at night (also statistically significant).

Table 6 shows that the subjects deflected the gas pedal only slightly when entering Curve C but then very slightly increased this deflection at the center of the curve during both the daytime and nighttime. The subjects then increased the gas

TABLE 4 LATERAL ACCELERATION AT SELECTED DISTANCES FROM CURVE SIGN FOR SHARP CURVE (CURVE C): EXPERIENCED AND INEXPERIENCED SUBJECTS AND RUNS 1 AND 2

		WITH ADV. SPEED		WITHOUT ADV. SPEED	
		DAY	NIGHT	DAY	NIGHT
NO. OF SUBJECTS		24	12	24	19
-500.0	AVERAGE	0.001	0.012	-0.007	0.003
	STD.DEV.	0.026	0.015	0.037	0.013
0.0	AVERAGE	0.068	0.035	0.037	0.034
	STD.DEV.	0.033	0.032	0.044	0.043
270.0	AVERAGE	-0.010	-0.012	-0.025	-0.010
	STD.DEV.	0.027	0.009	0.038	0.015
642.3	AVERAGE	-0.262	-0.182	-0.274	-0.233
	STD.DEV.	0.064	0.064	0.071	0.093
1014.6	AVERAGE	-0.039	-0.011	-0.037	-0.026
	STD.DEV.	0.055	0.022	0.052	0.025
1154.6	AVERAGE	0.016	0.019	0.010	0.014
	STD.DEV.	0.033	0.025	0.044	0.016

NOTE: LATERAL ACCELERATION IN g'S

NEGATIVE ACCEL. INDICATES RIGHT CURVE

-500.0 - 500 FEET BEFORE CURVE SIGN

0.0 - AT THE CURVE SIGN

270.0 - BEGINNING OF THE CURVE

642.3 - CENTER OF THE CURVE

1014.6 - END OF THE CURVE

1154.6 - 150 FEET AFTER THE END OF THE CURVE

TABLE 5 GAS PEDAL DEFLECTION AT SELECTED DISTANCES FROM CURVE SIGN FOR MODERATE CURVE (CURVE A): EXPERIENCED AND INEXPERIENCED SUBJECTS AND RUNS 1 AND 2

		WITH ADV. SPEED		WITHOUT ADV. SPEED	
		DAY	NIGHT	DAY	NIGHT
NO. OF SUBJECTS		24	12	24	19
-500.0	AVERAGE	32.88	34.08	33.01	36.32
	STD.DEV.	8.97	8.83	7.95	8.54
0.0	AVERAGE	16.40	6.22	18.53	14.23
	STD.DEV.	10.69	3.19	9.14	9.16
422.0	AVERAGE	6.25	16.50	6.47	18.39
	STD.DEV.	1.57	11.63	1.50	11.88
883.0	AVERAGE	42.81	22.63	39.29	29.17
	STD.DEV.	7.60	12.87	12.06	11.20
1344.0	AVERAGE	31.96	24.67	30.83	27.72
	STD.DEV.	10.63	8.90	6.73	9.33
1494.0	AVERAGE	26.92	21.55	25.84	21.56
	STD.DEV.	9.32	6.26	9.24	9.86

NOTE: GAS PEDAL DEFLECTION: IDLE 1-7, FULLY DEFLECTED POSITION 69-73

-500.0 - 500 FEET BEFORE CURVE SIGN

0.0 - AT THE CURVE SIGN

422.0 - BEGINNING OF THE CURVE

883.0 - CENTER OF THE CURVE

1344.0 - END OF THE CURVE

1494.0 - 150 FEET AFTER THE END OF THE CURVE

TABLE 6 GAS PEDAL DEFLECTION AT SELECTED DISTANCES FROM CURVE SIGN FOR SHARP CURVE (CURVE C): EXPERIENCED AND INEXPERIENCED SUBJECTS AND RUNS 1 AND 2

		WITH ADV. SPEED		WITHOUT ADV. SPEED	
		DAY	NIGHT	DAY	NIGHT
NO. OF SUBJECTS		24	12	24	20
-500.0	AVERAGE	14.46	20.34	10.65	15.35
	STD.DEV.	8.95	11.83	6.27	9.53
0.0	AVERAGE	26.92	24.09	31.24	26.78
	STD.DEV.	13.42	14.05	14.39	13.40
270.0	AVERAGE	12.07	13.75	10.96	22.20
	STD.DEV.	7.96	9.53	7.86	12.60
642.3	AVERAGE	17.08	18.63	15.43	17.58
	STD.DEV.	12.85	13.23	9.41	15.66
1014.6	AVERAGE	47.52	39.92	49.24	35.18
	STD.DEV.	8.48	17.54	11.17	11.53
1154.0	AVERAGE	44.08	27.55	36.59	26.22
	STD.DEV.	9.71	16.64	12.12	11.09

NOTE: GAS PEDAL DEFLECTION: IDLE 1-7, FULLY DEFLECTED POSITION 69-73

-500.0 - 500 FEET BEFORE CURVE SIGN

0.0 - AT THE CURVE SIGN

270.0 - BEGINNING OF THE CURVE

642.3 - CENTER OF THE CURVE

1014.6 - END OF THE CURVE

1154.6 - 140 FEET AFTER THE END OF THE CURVE

TABLE 7 LANE TRACK POSITION AT SELECTED DISTANCES FROM CURVE SIGN FOR MODERATE CURVE (CURVE A): EXPERIENCED AND INEXPERIENCED SUBJECTS AND RUNS 1 AND 2

		WITH ADV. SPEED		WITHOUT ADV. SPEED	
		DAY	NIGHT	DAY	NIGHT
NO. OF SUBJECTS		24	12	23	20
-500.0	AVERAGE	4.85	5.16	4.68	5.15
	STD.DEV.	.70	.59	.62	.56
0.0	AVERAGE	5.06	5.89	4.78	5.71
	STD.DEV.	.73	.26	.58	.66
422.0	AVERAGE	4.44	4.28	4.15	4.63
	STD.DEV.	.55	.41	.51	.47
883.0	AVERAGE	5.35	4.03	5.37	4.52
	STD.DEV.	.63	.74	.91	.91
1344.0	AVERAGE	4.92	4.74	4.56	4.80
	STD.DEV.	.50	.66	.54	.64
1494.0	AVERAGE	4.48	4.35	4.25	4.71
	STD.DEV.	.43	.49	.60	.35

NOTE: LANE TRACKER POSITION IN FEET

-500.0 - 500 FEET BEFORE CURVE SIGN

0.0 - AT THE CURVE SIGN

422.0 - BEGINNING OF THE CURVE

883.0 - CENTER OF THE CURVE

1344.0 - END OF THE CURVE

1494.0 - 150 FEET AFTER THE END OF THE CURVE

pedal deflection as they reached the end of the curve. The drivers entered Curve C with gas pedal deflections that were lower at night than they were during the day (statistically significant only for the beginning of the curve without the advisory speed sign), but once they had passed the center of the curve, they began to press the gas pedal down further at night than they did during the day (statistically significant for all conditions at the end of the curve and 150 ft after the end of the curve except for the end of the curve with the advisory speed sign).

Many of the subjects used their brakes in addition to the gas pedal to control their speed. During the daytime, 15 of the 24 drivers used their brakes in Curve A, whereas 22 of the 24 drivers used their brakes in Curve C. At night 8 of the 16 drivers used their brakes in Curve A, whereas 12 of the 16 drivers used their brakes in Curve C. For both curves all average brake application distances for both daytime and nighttime were between the curve sign and the center of the curve.

Tables 7 and 8 show averages and standard deviations of the lateral lane position of the car measured in feet from the inside of the edge line to the longitudinal center of the car. Table 7 shows that for Curve A, the lateral lane position was larger in

the center of the curve than at either end of the curve. It can also be seen that the higher speeds and lateral accelerations that were accepted by the subjects during the day were accompanied by increases in lateral lane position at the center of Curve A (statistically significant at the 0.05 level). Table 8 shows that, on the average, when the subjects entered Curve C, they positioned the experimental car left of the imaginary center of the right lane until they reached the center of the curve, at which point they swung toward the right and remained to the right of the imaginary center of the right lane throughout the remainder of the curve. However, considering the 9.2-ft lane width and 4.7-ft outside tire track width of the experimental car, the subjects were within their lane for all average values on both curves.

The average speeds of the vehicle when driven by test drivers and "local familiar" drivers on Curve A are compared in Figures 1 and 2. Because there were very few differences between the speeds of the test drivers exposed to the advisory speed sign and those who were not, the data for these two groups were combined for comparison with the data for the local familiar drivers. Figure 1 shows that both the test drivers and local familiar drivers decreased their speed by about 2 to 3

TABLE 8 LANE TRACK POSITION AT SELECTED DISTANCES FROM CURVE SIGN FOR SHARP CURVE (CURVE C): EXPERIENCED AND INEXPERIENCED SUBJECTS AND RUNS 1 AND 2

		WITH ADV. SPEED		WITHOUT ADV. SPEED	
		DAY	NIGHT	DAY	NIGHT
NO. OF SUBJECTS		24	12	24	20
-500.0	AVERAGE	4.32	4.28	4.12	4.71
	STD. DEV.	.56	.52	.50	.57
0.0	AVERAGE	5.44	4.47	5.13	5.31
	STD. DEV.	1.03	1.03	.58	.60
270.0	AVERAGE	5.49	5.33	5.48	5.45
	STD. DEV.	.63	.57	.69	.53
642.3	AVERAGE	4.60	4.96	4.27	5.46
	STD. DEV.	.84	.86	.79	.60
1014.6	AVERAGE	4.10	4.25	4.00	3.99
	STD. DEV.	.62	.48	.82	.76
1154.0	AVERAGE	4.24	4.08	4.13	4.77
	STD. DEV.	.42	.58	.71	.67

NOTE: LANE TRACKER POSITION IN FEET
 -500.0 - 500 FEET BEFORE CURVE SIGN
 0.0 - AT THE CURVE SIGN
 270.0 - BEGINNING OF THE CURVE
 642.3 - CENTER OF THE CURVE
 1014.6 - END OF THE CURVE
 1154.6 - 140 FEET AFTER THE END OF THE CURVE

mph before they reached the curve warning sign. However, once past the curve warning sign, the local familiar drivers, who had been going 50 mph 70 ft before the sign, reduced their speed to about 42 mph at the beginning of the curve, whereas the test drivers, who had been going 50 mph 70 ft before the sign, decreased their speed to about 48 mph at the beginning of the curve. This resulted in statistically significant speed differences for all distances after the curve warning sign had been passed. Figure 2 indicates that both groups of subjects maintained approximately the same average speeds at night until about 180 ft after they had passed the curve warning sign. From this point, the test drivers' speeds gradually increased, whereas the local drivers' speeds slowly decreased until the beginning of the curve, where their speeds were about 2 mph slower (statistically not significant) than the test drivers' speed.

The average speeds of the vehicle driven by the test drivers and the local familiar drivers on Curve C are compared in Figures 3 and 4. Figure 3 shows that both groups of drivers decreased their speed until about 185 ft before the curve warning sign. The data also show that during the day the local familiar drivers drove slightly faster than the test drivers on Curve C from 77 ft before the curve warning sign to 245 ft past the curve warning sign (statistically significant for all values between 77 and 185 ft) past the curve warning sign. Figure 4 shows that both groups of drivers decreased their speed at about the same rate when approaching the curve warning sign on Curve C at night to a point about 185 ft before the curve warning sign. Then the test drivers maintained a speed of about 37 mph, whereas the local familiar drivers actually increased their speed, reaching a maximum of about 43 mph, and then decreased their speed more rapidly heading into the curve. This resulted in speed differences that are statistically significant at the 0.05 level for only 121 and 185 ft past the curve warning sign. The results also indicate that the local familiar drivers tend to drive faster

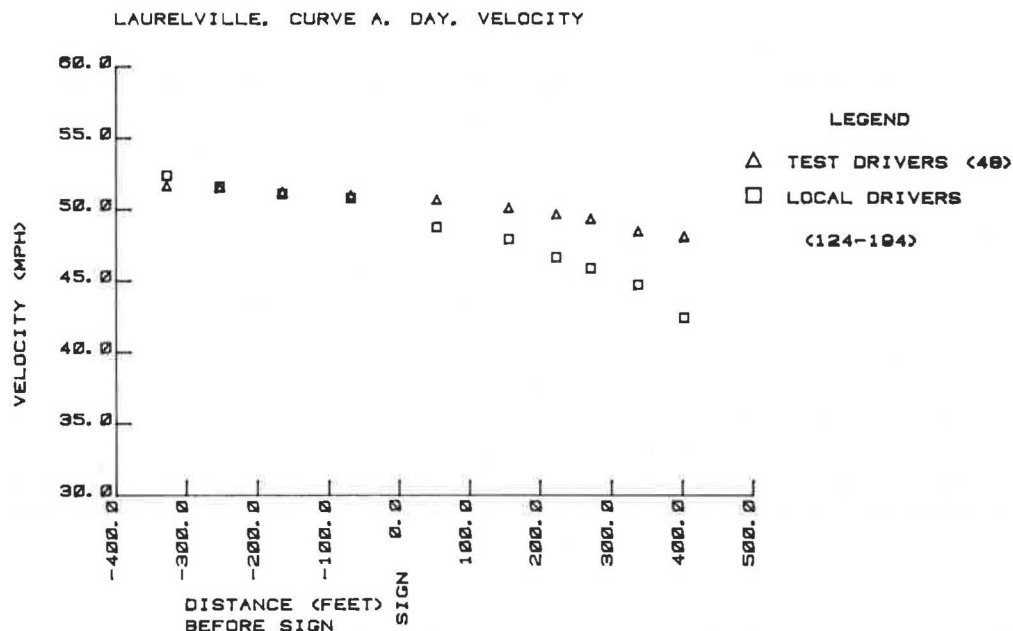


FIGURE 1 Comparison between local familiar and test drivers for Curve A during the daytime.

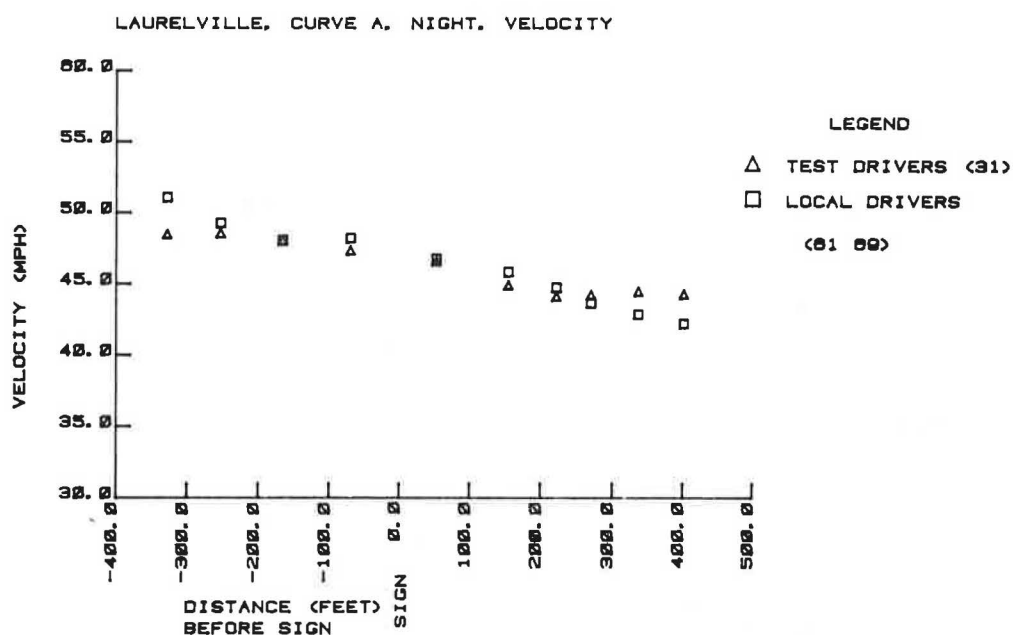


FIGURE 2 Comparison between local familiar and test drivers for Curve A during the nighttime.

around curves during the day than they do at night (statistically significant in 14 of the 19 cases tested).

Eye Scanning

Tables 9 and 10 present eye-scanning data for the curve signs on Curves A and C with and without the advisory speed sign for both daytime and nighttime conditions. These tables show

that the subjects looked at the curve warning sign an average of between 1.6 and 3.5 times, with an average look duration of 0.51 to 0.62 sec. The average fixation durations when the advisory speed sign was present were equal or slightly larger (statistically not significant at the 0.05 level) than when the advisory speed sign was not present for each of the four conditions.

Tables 9 and 10 also show the first- and last-look distances (averages and standard deviations). First-look distances were

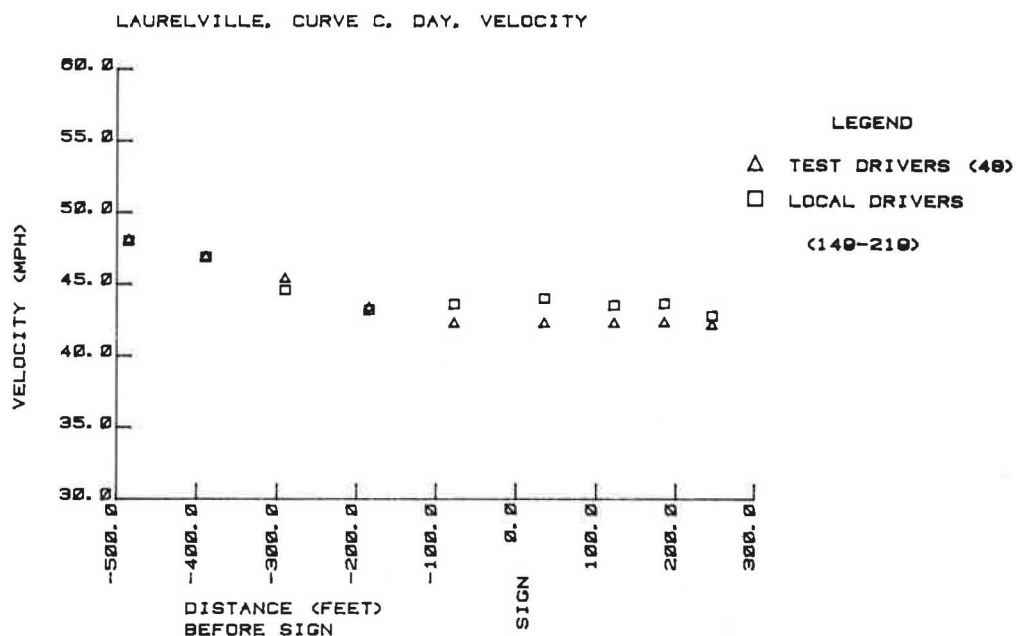


FIGURE 3 Comparison between local familiar and test drivers for Curve C during the daytime.

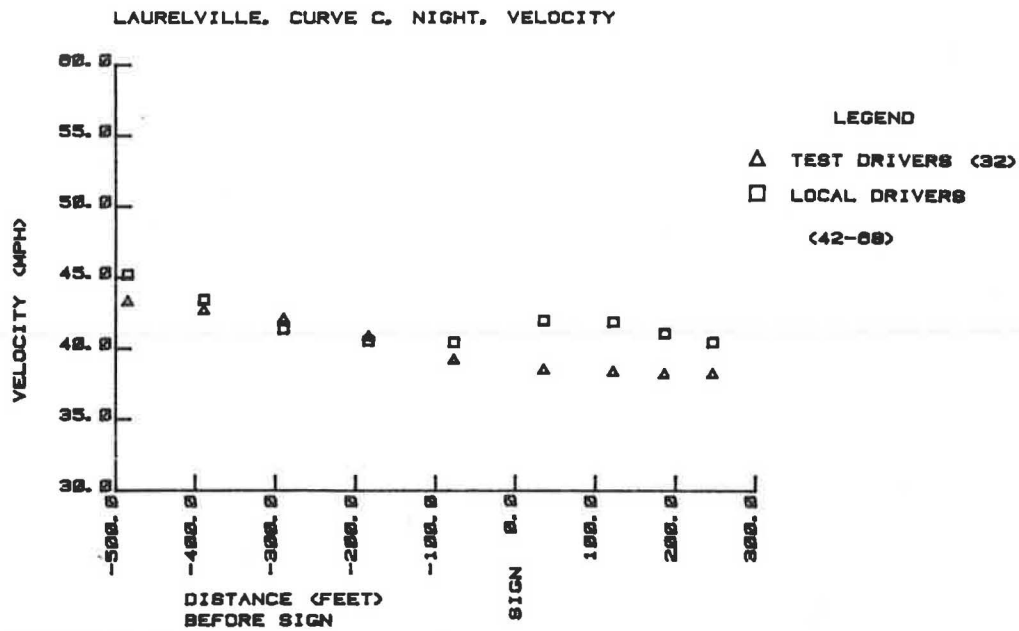


FIGURE 4 Comparison between local familiar and test drivers for Curve C during the nighttime.

TABLE 9 EYE-SCANNING SUMMARY RESULTS FOR MODERATE CURVE (CURVE A): EXPERIENCED AND INEXPERIENCED SUBJECTS AND RUNS 1 AND 2

	WITH ADV. SPEED		WITHOUT ADV. SPEED	
	DAY	NIGHT	DAY	NIGHT
NO. OF SUBJECTS	24	12	24	19
TOTAL NO. OF LOOKS	59	29	37	67
LOOKS/SUBJECT-AVERAGE	2.45	2.42	1.55	3.53
-STD.DEVIATION	1.59	0.90	1.06	2.39
LOOK DURATION - AVERAGE	0.58	0.61	0.51	0.58
-STD.DEVIATION	0.45	0.37	0.36	0.43
FIRST LOOK DIST.-AVERAGE	490.	502.	456.	563.
-STD.DEVIATION	157.	136.	158.	160.
FL VISUAL ANGLE (ARROW)	11.7	11.4	12.6	10.2
FL VISUAL ANGLE (NUMBERS)	4.7	4.6		
AVERAGE FIRST LOOK TIME	6.5	6.3	6.1	7.6
LAST LOOK DIST. -AVERAGE	232.	180.	291.	215.
-STD.DEVIATION	96.	87.	149.	117.
LL VISUAL ANGLE (ARROW)	24.7	31.8	19.7	26.6
LL VISUAL ANGLE (NUMBERS)	9.9	12.7		
AVERAGE LAST LOOK TIME	3.1	2.5	3.8	3.1

NOTE: ALL THE UNITS OF TIME ARE IN SECS., ALL DISTANCES ARE IN FEET
 AND ALL VISUAL ANGLES ARE IN MINUTES OF ARC.

FL = FIRST LOOK

LL = LAST LOOK

TABLE 10 EYE-SCANNING SUMMARY RESULTS FOR SHARP CURVE (CURVE C): EXPERIENCED AND INEXPERIENCED SUBJECTS AND RUNS 1 AND 2

	WITH ADV. SPEED		WITHOUT ADV. SPEED	
	DAY	NIGHT	DAY	NIGHT
NO. OF SUBJECTS	24	12	24	20
TOTAL NO. OF LOOKS	50	22	47	31
LOOKS/SUBJECT-AVERAGE	2.08	1.83	1.96	1.55
-STD.DEVIATION	1.35	0.85	1.67	1.10
LOOK DURATION - AVERAGE	0.62	0.51	0.48	0.51
-STD.DEVIATION	0.48	0.43	0.31	0.24
FIRST LOOK DIST.-AVERAGE	406.	248.	390.	265.
-STD.DEVIATION	209.	60.	192.	62.
FL VISUAL ANGLE (ARROW)	14.1	23.1	14.7	21.6
FL VISUAL ANGLE (NUMBERS)	5.6	9.2		
AVERAGE FIRST LOOK TIME	6.1	5.1	6.0	5.5
LAST LOOK DIST. -AVERAGE	212.	140.	201.	186.
-STD.DEVIATION	198.	46.	117.	50.
LL VISUAL ANGLE (ARROW)	27.0	40.9	28.5	30.8
LL VISUAL ANGLE (NUMBERS)	10.8	16.4		
AVERAGE LAST LOOK TIME	3.3	2.4	3.1	3.5

NOTE: ALL THE UNITS OF TIME ARE IN SECS., ALL DISTANCES ARE IN FEET
AND ALL VISUAL ANGLES ARE IN MINUTES OF ARC.

FL = FIRST LOOK

LL = LAST LOOK

defined as the distances measured from the curve warning sign to the point at which the driver begins to fixate his or her eyes (foveally, near foveally, or slightly peripherally) for the first time on the sign. Last-look distances were defined as the distances measured from the curve warning sign to the position where the driver moves his eyes away from the sign and does not look at it again. The visual angle when the driver was looking at either the approximately 20-in.-high black arrow on the curve warning sign or the 8-in.-high numbers on the advisory speed sign is given for both the average first-look distance and the average last-look distance in these tables. Also shown is the time it took for the experimental vehicle to pass the curve warning sign from the position of the average first-look distance and the average last-look distance.

From Tables 9 and 10 it can be seen that during the daytime, regardless of whether the advisory speed sign was present or not, the average first-look distances were considerably smaller than the maximum distances at which the signs were visible (1,036 ft for Curve A and 953 ft for Curve C). It was determined that the direction and angle of the 4-in.-wide black arrow (maximum symbol height about 20 in.) on the yellow curve warning sign could be distinguished during the daytime by a driver with 20/20 vision or better from 1,000 to 1,500 ft

(visual angles 5.7 and 3.8 min of arc), and when the advisory speed sign is present, the 8-in. black numbers on the 18 x 18-in. advisory speed sign can be read by a driver with 20/20 vision or better from about 500 to 600 ft away from the curve warning sign during the day. Therefore the drivers should have been able to clearly see the shape and direction of the arrow on the curve warning sign at these average first-look distances, although they may have had some slight difficulties in reading the numbers on the advisory speed signs when they were present.

Tables 9 and 10 show very different first-look distances for the two curves at night regardless of whether the advisory speed sign was used. This may be due to the different road geometries and the different low-beam illumination conditions that could have been present on the two curves. For Curve A one can see that the average first-look distances were actually higher at night than they were during the day, whereas the first-look distances for Curve C were somewhat smaller at night than they were during the day. Even if one assumed that the maximum distances at which the arrow symbol on the curve sign could be detected at night were about 50 percent shorter than during the daytime (due to less favorable illumination conditions), the drivers should still have had little difficulty in

distinguishing the shape and the direction of the arrow at the average first-look distances. However, considering the visual angles that apply to these average first-look distances during the night, it is rather doubtful that the drivers would have been able to read the advisory speed numbers shown on the advisory speed sign on Curve A but may have been able to read those displayed on the advisory speed sign on Curve C.

During the day when the curve warning sign was displayed alone, the average last-look distances were about 200 to 300 ft. Therefore, the visual angles were fairly large and the test drivers should have been able to perceive the shape and direction of the arrow on the curve warning sign very easily. These average last-look distances represent average driving times to the curve sign from 3.1 to 3.8 sec. When the curve warning sign was presented with the advisory speed sign, the average last-look distances during the daytime for the two curves were between 212 and 230 ft. The subjects should have been able to read the 8-in.-high numbers on the advisory speed signs easily, because at these distances the visual angles were between 9.9 and 10.0 min of arc. Again, these average last-look distances represent average driving times to the curve sign from 3.1 to 3.3 sec.

The average last-look distances at night, when the curve warning sign was displayed by itself, were 201 to 291 ft, with visual angles between 29 and 27 min of arc. Therefore the shape and direction of the arrow on the curve warning sign should be easily distinguishable by a driver with 20/20 vision or better. When the advisory speed sign was present, the last-look distances were 140 and 180 ft and their visual angles for the 8-in.-high numbers were 12.7 to 16.4 min of arc, which should be sufficient for the drivers to read the numbers on the advisory speed sign rather easily. Regardless of whether the advisory speed sign was present or not, the average last-look distances represent average driving times to the curve sign of between 2.4 and 3.5 sec.

In summary the results of this study indicate that the drivers first look at a curve warning sign with or without the advisory speed sign at a distance where they are close enough to the sign to be able to distinguish the shape and direction of the black arrow on the yellow background but may have some difficulty in reading the numbers on the advisory speed sign, if one is present. It appears that drivers prefer to acquire information from the road scene rather than from the warning signs when they are within about 2.5 to 3.5 sec from the warning sign. Although it would appear that the drivers should have acquired the information displayed on the signs, they still failed to slow

down enough to reach the determined safe advisory speed regardless of whether the advisory speed sign was present.

CONCLUSIONS

From the results of this study, it may be concluded that advisory speed signs are not more effective in causing drivers to reduce their speeds through curves than the curve signs alone. It appears that the bent black arrow in the yellow diamond of the curve sign represents such a strong and primary visual stimulus that an advisory speed plate adds very little additional information. Therefore, it is recommended that advisory speed sign maintenance and especially new installations be given a low priority.

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