STOP AHEAD and STOP 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 the STOP AHEAD sign in warning drivers of an upcoming, unexpected, partially concealed STOP sign and intersection during daytime and nighttime driving conditions. The driving performance and eye-scanning behavior of 39 subjects was studied as they approached an intersection (from the north and southbound directions) of two two-lane rural roads where they were required to stop. Each test driver was subjected to only one condition, which was the same for both intersection approaches (day or night, with or without the STOP AHEAD sign) and belonged to a group of three to six experienced or inexperienced drivers. The results show few statistically significant differences in driver eye-scanning and control behavior (velocity, longitudinal deceleration, gas pedal deflection, lateral lane position, and brake activation) between Run 1 and Run 2 and between inexperienced and experienced drivers. However, the test drivers approached the STOP sign with lower average velocities and lower average longitudinal decelerations near the STOP sign at night when the STOP AHEAD sign was present than when it was not present. Despite this fact, 10 of the test drivers were unable to come to a complete stop at the intersection (eight of the improper stops occurred when the STOP AHEAD sign was present). Although the STOP AHEAD sign seemingly influenced the test drivers' behavior at night, it is concluded that STOP AHEAD signs with STOP AHEAD written on their face do not give drivers adequate visual stimulus to prepare them to stop when approaching an unexpected, partially concealed intersection.

According to Allington (*1*), it is imperative that a stop indicator be visible for a distance equal to the stopping sight distance to allow drivers to complete all perception and decision-making functions and then comfortably decelerate their vehicles to a stop before reaching the stop indicator. Allington recommends stopping sight distances of 450 ft for an approach speed of 50 mph and 625 ft for an approach speed of 60 mph. However, because of physical obstructions or the geometric configuration of the roadway, it is often impossible to place STOP signs so that they can be seen this far in advance. According to section 2*C*-3 of the *Manual of Uniform Traffic Control Devices* (*2*), in rural areas warning signs (including the STOP AHEAD sign) should be placed approximately 750 ft in advance of a hazardous condition. Section 2*C*-15 further states that STOP AHEAD signs (either *W*3-1 with STOP AHEAD written on its face or *W*3-1*a* with the red octagonal symbol) should be used on an approach to a STOP sign that is not visible for a sufficient distance to allow a motorist to bring a vehicle to a stop at the STOP sign. Also, according to this section, the STOP AHEAD sign may be used for emphasis when there is poor observance of the STOP sign.

The effectiveness of the STOP AHEAD sign has been questioned and previous studies have explored the effectiveness of various devices, most notably flashing yellow beacons, which would improve the effectiveness of the STOP AHEAD sign. One such study by Lyles (*3*) evaluated signs for hazardous rural intersections. His results showed that regulatory speed zone configurations and lighted warning signs were more effective than traditional unlighted warning signs in reducing motorists' speeds in the vicinity of the intersections. Goldblatt (*4*), in a study on the operational effects of various types of continuously flashing and vehicle-actuated flashing traffic control devices, found that the use of continuously flashing intersection beacons along stopped approaches encourages speeds that are lower than speeds achieved by STOP signs or vehicle-actuated warning devices. Goldblatt also found that when vehicle-activated flashing beacons were placed on top of a STOP AHEAD sign, which was placed in advance of a simple STOP sign, drivers began braking sooner and had a lower speed variance than they did when a beacon was not present. However, when a beacon was installed at the downstream intersection these results became less significant.

Although the literature review revealed studies on improvements to STOP AHEAD signs, no study was found that focused strictly on the determination of the effectiveness of the STOP AHEAD sign. Therefore, it was the objective of this study to determine the effectiveness of the 36 × 36-in. diamond-shaped yellow STOP AHEAD sign with the words STOP AHEAD written on its face in 7-in.-high black letters in warning drivers of a STOP sign at an unexpected, partially concealed intersection. The effectiveness of the STOP AHEAD sign was to be measured in terms of a test driver's control actions and eye-scanning behavior. This study was to account for numerous variables that might affect the results, including the driving experience of the test drivers, short-term familiarity with the roadway, as well as daytime and nighttime driving conditions.

METHOD

Test Drivers

A total of 39 test drivers took part in the experiment and were divided into one of two groups based on their driving experience (either experienced or inexperienced drivers). The 21

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experienced, licensed drivers (12 male, 9 female) had an average age of 22 yr and had driven an average of 44,000 mi during an average of 6 yr. The 18 inexperienced licensed drivers (10 male, 8 female) had an average age of 17 yr and had driven an average of 4,000 mi during an average of 2 yr. All test drivers 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 test drivers also underwent a limited health evaluation. The results of these tests indicated that all test drivers had normal visual acuity and reaction times and were in good health. None of the test drivers were familiar with the road or the experimental vehicle. All test drivers were paid and told only that the study involved driving on two-lane rural roads without being informed of 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. This vehicle contains better than 30 instruments and mechanisms that are combined into a system that allows the experimenter to monitor and record a driver's eye movements, as well as time, distance, speed, lateral lane position, steering wheel position, gas pedal deflection, brake activation, and the vertical, longitudinal, and lateral accelerations of the car (sampling rate of 60 hertz). Further description of the experimental car and equipment, including the in-car corneal reflection technique television eye-scanning system, has been published earlier by Zwahlen (*5*).

Experimental Test Sites

In order to make the results of this study widely applicable it was necessary for the chosen site to meet the following criteria:

1. The intersection was to have fairly low average daily traffic (ADT),
2. The intersection was to have 55 mph approaches,
3. The intersection was to be equipped with STOP signs without previously existing STOP AHEAD signs,
4. No raised reflective pavement markers or post delineators were to be installed at the intersection,
5. The approaches to the intersections were to be fairly straight for a few miles (no curves), and
6. The intersections themselves were to be unexpected, partially concealed, and not visible at distances much greater than 1,000 ft.

The intersection of Ohio State Route 188 and Ohio State Route 674 located northeast of Circleville, Ohio, fulfilled all of these criteria and was chosen as the experimental site. Experimental runs were made on both the northbound and southbound approaches to this intersection while traveling on State Route 674, which divides rolling farmland. The northbound approach to this intersection is a straight approach. However, a small hill, over which the road crosses, obscures the intersection completely until the vehicle is within 1,000 ft of the intersection (visible for 965 ft when traffic is present in the intersection and visible for 919 ft when there is no traffic in the intersection). The southbound approach to this intersection is straight with no obstructions and so the intersection can be seen for a relatively long distance (visible for 1,962 ft when traffic is present in the intersection and visible for 1,761 ft when there is no traffic in the intersection). Both the north- and southbound approaches are on slight downgrades (4 percent northbound and 2.5 percent southbound). The ADT on State Route 674 on the north side of the intersection was 1,086 in both directions. No accidents occurred at this intersection during a recent 6-yr period.

The specific intensity was measured at a –4 degree entrance angle and a 0.2 degree observation angle for each of the 36-in. high, octagonal red STOP signs and the new 36 × 36 in. diamond-shaped yellow STOP AHEAD signs. The red background on the high-intensity sheeting STOP sign on the northbound approach had an average specific intensity of 44.0 $cd/ft^2/fc$ and the silver letters on this sign had an average specific intensity of 337.5 $cd/ft^2/fc$. The red background on the high-intensity sheeting STOP sign on the southbound approach had an average specific intensity of 23.4 $cd/ft^2/fc$ and the silver letters on this sign had an average specific intensity of 303.8 $cd/ft^2/fc$. The engineering grade yellow STOP AHEAD signs had a measured average specific intensity of 61.0 $cd/ft^2/fc$ (northbound) and 67.2 $cd/ft^2/fc$ (southbound).

According to Table S-1 of the Ohio *Manual of Uniform Traffic Control Devices* (*6*), the STOP AHEAD sign was to be placed 750 ft before the intersection, assuming that the drivers approach at 55 mph and come to a complete stop at the intersection. Therefore, the STOP AHEAD sign on the southbound approach was placed at 757 ft before the intersection. However, the STOP AHEAD sign on the northbound approach was placed 832 ft before the intersection to avoid obstructions that would have diminished the sign's visibility had it been placed 750 ft in advance of the intersection.

Experimental Procedure and Design

Before the test driver study began, a local familiar driver study was completed that involved the inconspicuous videotaping of 215 vehicles traveling northbound on State Route 674, and 263 vehicles traveling southbound on State Route 674 as they approached the intersection of State Routes 674 and 188 during both daytime and nighttime conditions. All vehicles that were videotaped were used in the analysis. Because State Route 674 is not a major through road and is not normally used by drivers from other areas of the state, it was assumed that a very high percentage of the videotaped vehicles were driven by local drivers who were familiar with the intersection. During this study there were no STOP AHEAD signs along either of the intersection approaches. Time and distance data and the points of brake light activation were recorded. Calculations were then made to determine velocities, decelerations, and points of first-brake application at various distances from the STOP sign. The local familiar driver data was collected to provide base-line data that could be compared with the test-driver data.

The test-driver study involved the continuous recording of the test drivers' eye-scanning behavior and vehicle measures as they drove northbound and then southbound along a typical stretch of a rural two-lane highway, which included the 674-188 intersection. The subjects were randomly assigned to one of eight groups so that each group had either experienced or inexperienced test drivers and as near a half male and a half female representation as was possible. Although it was originally planned for a group of six to be tested under each condition, some nighttime conditions were tested with fewer test drivers because of the frequent existence of ground fog at the test locations. Each of the eight groups were then subjected to a different experimental condition; that is, they would be either "experienced" or "inexperienced" drivers, drive during the daytime or nighttime (using low beams), and drive through the intersection when it was equipped with both the STOP signs and the STOP AHEAD signs, or when it was equipped with only the STOP signs. Each test driver drove the experimental car along Ohio State Route 674 for about 30 to 45 min during which eye scanning behavior, as well as speed, longitudinal deceleration, gas pedal deflection, brake activation, and lateral lane position of the car were recorded continuously so that the experimental purpose (to study the 674-188 intersection) was not apparent. All test drivers were asked to follow the test route twice to allow the experimenters to evaluate the effects of short-term familiarity on driver performance.

This procedure then enabled the experimenters to evaluate the effects of the following independent variables:

- Time of day (level of illumination, day versus night),
- Driver experience (inexperienced versus experienced),
- Presence or absence of the STOP AHEAD sign, and
- 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:

- Speed (mph),
- Gas pedal position (0–7 idle, 69–73 fully deflected),
- Brake pedal activation (on or off),
- Longitudinal acceleration (ft/sec/sec),
- Lateral lane position (ft), and
- Eye movement measures (foveal and near foveal or slightly peripheral eye fixations on STOP AHEAD signs and STOP signs).

The design variables that might influence performance measures and were beyond the control of the experimenter included:

1. Traffic (ahead in opposite or in the same direction),
2. Background luminance during the nighttime,
3. Road surface condition (debris, pot holes, etc.),
4. Condition of edge lines and center lines,
5. Visibility (haze, dust, and light fog),
6. Environment (foliage, height of crops, and grass along the highway),
7. Temperature and humidity, and
8. Position of the sun, level of daytime illumination, glare, and cloud cover.

RESULTS

Vehicle Measures

Detailed eye scanning and vehicle measure results for individual test drivers and groups are given by Zwahlen (5). In order to obtain compact results from the vehicle measures data, it was necessary to choose a few points along the intersection approach that would indicate a driver's behavior at the approach to the intersection. For this reason the velocity, gas pedal deflection, and lateral position of the experimental vehicle were analyzed at 1,300, 298, and 50 ft before the intersection on the northbound approach and at 1,360, 359, and 100 ft before the STOP sign on the southbound approach. These distances represent the position of the experimental vehicle just as it entered the approach to the intersection, about midway between the STOP AHEAD sign and the intersection and just before the intersection. However, the longitudinal deceleration was analyzed at 175, 63, and 38 ft before the STOP sign on the northbound approach and 175, 88, and 63 ft before the intersection on the southbound approach. Because classical t and F tests indicated very few statistically significant differences in comparisons of experienced and inexperienced drivers as well as in comparisons of Runs 1 and 2, these conditions were combined to achieve larger sample sizes.

Shown in Table 1 are data on speed at selected distances from the STOP sign combined with data on experienced and inexperienced test drivers and Runs 1 and 2. It can be seen from this table that during the day there seemed to be relatively little, if any, difference in the speed of the experimental vehicle as the test drivers approached the intersection, regardless of whether or not it was equipped with the STOP AHEAD sign. However, at night (when a driver's sight distance is presumably lower because of less favorable illumination) the drivers approached the intersection 2.4 to 9.1 mph slower when the STOP AHEAD sign was present than when it was not (statistically significant for the two points closest to the intersection on both the north and southbound approaches).

It should be noted that on the northbound approach at the 1,300-ft mark the test driver's average speed was 2.4 mph slower when the STOP AHEAD sign was present, and at the 1,360-ft mark on the northbound approach the test driver's average speed was 3.7 mph slower when the STOP AHEAD sign was present (statistically significant at the 0.05 level). This speed difference occurred even though most of the test drivers would not have been able to read clearly individual letters displayed on the STOP AHEAD signs at these distances because the visual angle for the 7-in.-high black letters on the STOP AHEAD sign was 4.3 min of visual arc on the northbound approach and 3.7 min of visual arc on the southbound approach. It might be noted that, because of the position of the STOP AHEAD signs, the 1,300-ft distance from the STOP sign to the experimental car for the northbound approach and the 1,360-ft distance from the STOP sign to the experimental car for the southbound approach are equal to distances from the experimental car to the STOP AHEAD sign of 468 and 543 ft respectively. Therefore, these speed differences suggest that the subjects were responding to the presence of the warning signs along the side of the road or to the pattern of the two words and were most likely unaware of or guessing at the exact message displayed on the sign.

TABLE 1 SPEED AT SELECTED DISTANCES FROM STOP SIGN

	Velocity (mph) by Distance from Sign											
	1,300 ft		298 ft		50 ft		1,360 ft		356 ft		100 ft	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Northbound												
With STOP AHEAD												
Day (*N*=22)	53.9	2.1	39.6	3.4	18.6	4.3	–	–	–	–	–	–
Night (*N*=14)	49.8	2.8	37.1	4.2	13.0	5.0	–	–	–	–	–	–
Without STOP AHEAD												
Day (*N*=23)	53.7	2.3	41.0	4.1	18.7	5.2	–	–	–	–	–	–
Night (*N*=11)	52.1	3.4	44.5	4.0	22.1	6.6	–	–	–	–	–	–
Southbound												
With STOP AHEAD												
Day (*N*=23)	–	–	–	–	–	–	50.2	3.2	39.7	3.2	25.2	3.6
Night (*N*=16)	–	–	–	–	–	–	44.7	2.6	35.4	4.0	19.7	3.7
Without STOP AHEAD												
Day (*N*=24)	–	–	–	–	–	–	49.1	2.7	38.3	3.0	22.8	3.6
Night (*N*=12)	–	–	–	–	–	–	48.3	3.1	39.4	4.5	23.2	4.1

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2. Dashes indicate data not applicable.

Again referring to Table 1, it can be seen that while the STOP AHEAD sign was present the test drivers maintained higher average speeds during the daytime than they did during the nighttime when the STOP AHEAD sign was present (statistically significant at the 0.05 level at five of the six positions along the intersection approaches). However, when the STOP AHEAD sign as absent this relationship did not exist. In fact, the only statistically significant difference at the 0.05 level occurred at the 298 ft distance point for the northbound approach, where it was found that the average nighttime speed was statistically higher than the average daytime speed.

Furthermore, Table 1 shows that all average nighttime speeds after the STOP AHEAD sign were higher than the average daytime speeds. This might be expected because at 359 ft before the STOP sign the visual angle subtended by the eye was 28.7 min of visual arc for the 36-in. high STOP sign and at 298 ft before the STOP sign the visual angle subtended by the eye was 34.6 min of visual arc. Therefore, under favorable lighting conditions, the test drivers should have been able to locate and identify the unique octagonal red STOP sign and therefore reduce their speed regardless of whether the STOP AHEAD sign was present. At night, however, when lighting conditions were not as favorable and no STOP AHEAD sign was present, the STOP sign and the intersection may not have been easily distinguishable at this distance. The test drivers would therefore have been unaware that they were approaching a STOP sign and an intersection and would have had no reason to begin reducing their speed in order to stop.

It can be seen from Table 2, which shows the average distance and standard deviations of first brake activation, merging data of experienced and inexperienced test drivers and Runs 1 and 2, that on the average the subjects first applied their brakes when they were within 509 to 702 ft from the STOP sign. No statistically significant differences or trends exist that would indicate that the test drivers began braking sooner when the STOP AHEAD sign was present than when it was not.

Shown in Table 3 are the gas pedal position averages and standard deviations at selected distances from the STOP sign, merging data of experienced and inexperienced test drivers and Runs 1 and 2. This shows that the average gas pedal deflections were between 14.6 and 26.4 as the drivers began to approach the intersection (1,300 ft before the STOP sign for the northbound approach and 1,360 ft before the STOP sign for the southbound approach). By the time the test drivers reached the point about midway between the position of the STOP AHEAD sign and the intersection (359 ft before the STOP sign in the southbound approach and 298 ft before the STOP sign for the northbound approach) the average gas pedal deflections ranged from 5.2 to 7.3, regardless of whether the STOP AHEAD sign was present. This indicates that the gas pedal was being deflected very slightly, if at all, by the time the test drivers were within 298 ft of the STOP sign on the northbound approach and 359 ft of the STOP sign on the southbound approach, because values for the gas pedal deflection from 0 to 7 indicate no pressure and deflection.

TABLE 2 DISTANCE FROM STOP SIGN AT FIRST BRAKE ACTIVATION

	Distance (ft)	
	Avg	SD
Northbound		
With STOP AHEAD		
Day (*N*=22)	583	114
Night (*N*=14)	509	107
Without STOP AHEAD		
Day (*N*=23)	619	198
Night (*N*=11)	436	97
Southbound		
With STOP AHEAD		
Day (*N*=23)	639	118
Night (*N*=16)	571	127
Without STOP AHEAD		
Day (*N*=24)	675	154
Night (*N*=12)	702	266

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2.

Presented in Table 4 are the longitudinal deceleration averages and standard deviations at selected distances from the STOP sign, merging data of experienced and inexperienced test drivers and Runs 1 and 2 for both the north- and southbound approaches. From this it can be seen that, on the average, when the STOP AHEAD sign was present, the test drivers accepted

TABLE 3 GAS PEDAL POSITION AT SELECTED DISTANCES FROM STOP SIGN

	Gas Pedal Deflection[a] by Distance from Sign											
	1,300 ft		298 ft		50 ft		1,360 ft		359 ft		100 ft	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Northbound												
With STOP AHEAD												
Day (*N*=21)	21.7	8.4	6.2	0.6	6.0	0.6	–	–	–	–	–	–
Night (*N*=14)	14.6	8.2	5.8	1.2	5.2	0.9	–	–	–	–	–	–
Without STOP AHEAD												
Day (*N*=23)	25.7	8.3	6.0	0.7	5.7	0.6	–	–	–	–	–	–
Night (*N*=11)	22.9	10.8	5.4	1.6	4.6	1.9	–	–	–	–	–	–
Southbound												
With STOP AHEAD												
Day (*N*=23)	–	–	–	–	–	–	20.4	14.6	6.2	0.6	6.1	0.6
Night (*N*=16)	–	–	–	–	–	–	21.0	9.8	7.3	6.1	5.6	0.8
Without STOP AHEAD												
Day (*N*=24)	–	–	–	–	–	–	15.2	9.7	6.1	0.7	5.9	0.7
Night (*N*=12)	–	–	–	–	–	–	26.4	15.1	5.2	2.2	4.8	1.9

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2. Dashes indicate data not applicable.
[a]Gas pedal deflection: idle, 0–7; at kickdown, 61–62.

TABLE 4 LONGITUDINAL DECELERATION AT SELECTED DISTANCES FROM STOP SIGN

	Longitudinal Deceleration (ft/sec^2 by Distance from Sign							
	175 ft		63 ft		38 ft		88 ft	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Northbound								
With STOP AHEAD								
Day (*N*=21)	5.5	1.7	8.3	4.2	7.8	3.5	–	–
Night (*N*=14)	5.4	2.9	7.0	1.9	6.5	3.3	–	–
Without STOP AHEAD								
Day (*N*=23)	5.4	2.1	7.7	3.4	8.0	2.7	–	–
Night (*N*=11)	5.5	2.3	10.2	4.9	11.4	4.7	–	–
Southbound								
With STOP AHEAD								
Day (*N*=23)	4.2	1.7	7.1	2.8	–	–	6.8	3.3
Night (*N*=16)	4.2	1.4	6.2	2.5	–	–	4.5	3.0
Without STOP AHEAD								
Day (*N*=24)	4.2	1.5	7.5	3.1	–	–	6.7	4.9
Night (*N*=12)	4.3	1.8	7.0	3.5	–	–	7.2	2.8

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2. Dashes indicate data not applicable.

higher longitudinal decelerations at the first two distance points when the STOP AHEAD sign was present than they did when the STOP AHEAD sign was not (statistically significant at the 0.05 level for the 88-ft distance point on the southbound approach only).

It can also be seen from Table 4 that when the STOP AHEAD sign was present the test drivers were able to use lower longitudinal decelerations at the final distance point (statistically significant at the 0.05 level for the 38-ft distance point on the northbound approach). Therefore it would seem that when a STOP AHEAD sign was present the test drivers produced higher longitudinal decelerations farther from the intersection so that they did not have to decelerate as quickly closer to the intersection as they did when a STOP AHEAD sign was not present. It is also shown in this table that at nighttime when the STOP AHEAD sign was not present the test drivers found it necessary to accept higher average longitudinal decelerations than they did when the STOP AHEAD sign was present (statistically significant at the 0.05 level in 3 of the 6 cases tested) in order to stop at the intersection.

Throughout the experiment the test drivers were able to maintain good lateral control over the experimental vehicle. This can be seen from Table 5, which shows the distance measured from the inside of the right edge line to the center of the experimental vehicle. Values from this table indicate that on the average the vehicle was roughly in the center of the approximately 10-ft-wide lane. It can also be seen that the values for the standard deviation were all reasonably small (between 0.4 and 1.1 ft), which would indicate that all of the drivers were driving at about the same place in the lane.

In 11 of the 156 intersection approaches completed in this study, the test drivers failed to bring the vehicle to a complete and proper stop before entering the intersection (one subject came to an improper stop on both the north- and southbound approaches to the intersection). Nine of the improper stops were made by test drivers who were driving when the STOP

TABLE 5 LANE TRACKER POSITION AT SELECTED DISTANCES FROM STOP SIGN

	Lane Tracker Position (ft) by Distance from Sign											
	1,300 ft		298 ft		50 ft		1,360 ft		359 ft		100 ft	
	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD	Avg	SD
Northbound												
With STOP AHEAD												
Day (*N*=21)	4.9	0.4	5.2	0.6	5.1	0.6	–	–	–	–	–	–
Night (*N*=14)	5.1	0.9	5.5	0.6	5.4	0.8	–	–	–	–	–	–
Without STOP AHEAD												
Day (*N*=23)	5.0	0.4	5.1	0.6	4.8	0.4	–	–	–	–	–	–
Night (*N*=11)	5.2	0.5	5.8	0.5	5.8	0.7	–	–	–	–	–	–
Southbound												
With STOP AHEAD												
Day (*N*=23)	–	–	–	–	–	–	5.0	0.4	5.3	0.5	4.6	0.5
Night (*N*=16)	–	–	–	–	–	–	4.5	0.4	5.6	0.5	4.8	1.0
Without STOP AHEAD												
Day (*N*=24)	–	–	–	–	–	–	5.0	0.7	5.1	0.6	4.2	0.4
Night (*N*=12)	–	–	–	–	–	–	4.5	0.5	5.9	0.4	4.9	1.1

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2. Dashes indicate data not applicable.

AHEAD sign was present and only two of the improper stops were made when the STOP AHEAD was not present. Four of the improper stops were made during the day and seven improper stops were made at night. All 11 of the improper stops were made during the first experimental loop (Run 1) with 8 of the improper stops occurring on the northbound approach to the intersection. It should be noted that although test drivers were chosen who were completely unfamiliar with this stretch of highway, the northbound approach of Run 1 would have been the first time they had encountered this unexpected, partially concealed intersection. During the "local familiar" driver study only one vehicle failed to stop at the intersection. This occurred at night. The alarming incidence of improper stops made by the test drivers might be partially attributable to the small light beam that was projected into the subject's right eye as part of the eye-monitoring system. This small light caused a slight visual obstruction and this obstruction may have made it difficult for the drivers to see the signs clearly through the right eye, especially at large distances.

The speed maintained by the test drivers is compared in Figures 1 and 2 with the speed maintained by the local familiar drivers as each of the groups approached the intersection equipped with a STOP sign without a STOP AHEAD sign. Figure 1, which shows the test drivers' and the local familiar drivers' average velocities on the southbound intersection approach during the day, is representative of the velocities of the two groups of drivers for both day and night conditions on the southbound approaches as well as the day condition on the northbound approach. From this figure it can be seen that the test drivers displayed a tendency to drive about 2 to 4 mph slower than the local familiar drivers as they approached the STOP sign during daytime driving conditions on the south-

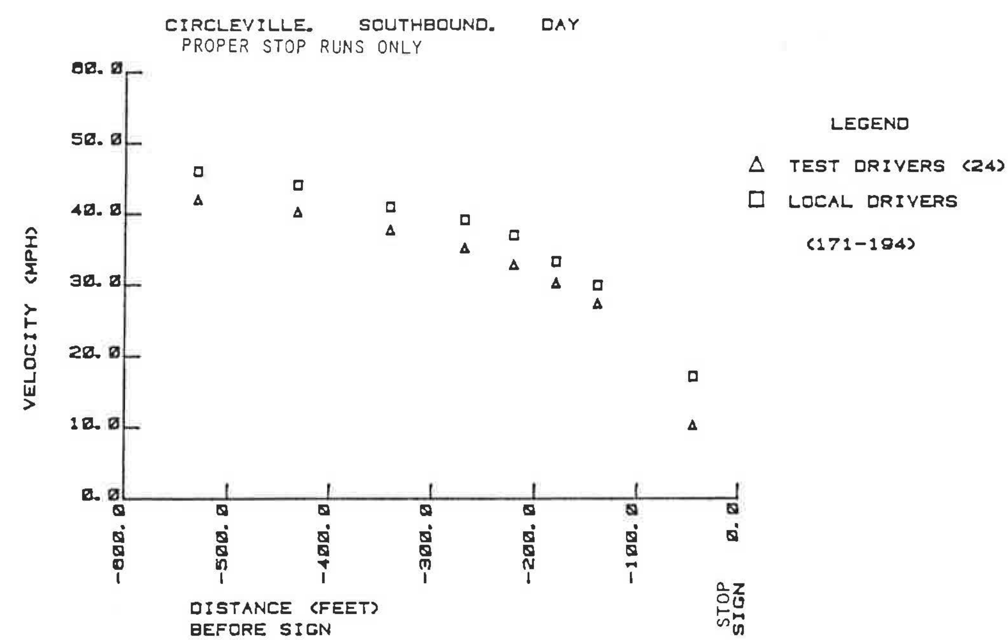

FIGURE 1 Comparison between test and local familiar drivers for northbound approach to intersection during day.

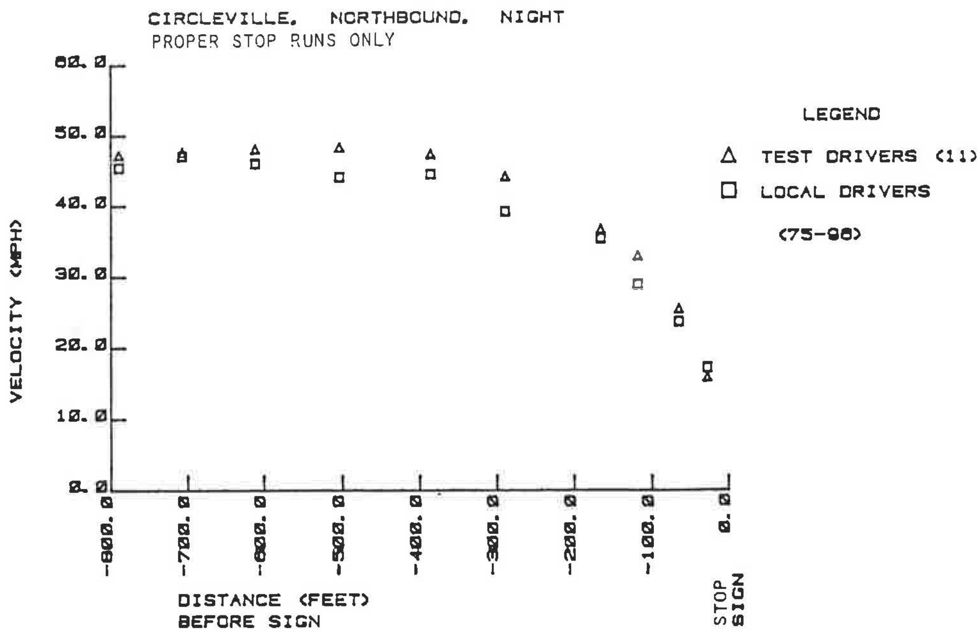

FIGURE 2 Comparison between test and local familiar drivers for southbound approach to intersection at night.

bound approach. This was also true for the southbound approach at night and the northbound approach during the day. T-tests at the 0.05 level showed that in 17 of the 20 intersection approaches tested for these three conditions, the test drivers drove slower than the local familiar drivers. This may indicate that the test drivers maintained lower than normal speeds because of their wariness of the unfamiliar roadway, their uneasiness at being observed by the experimenter, or restrictions imposed by the monitoring system. However, looking at Figure 2, which compares the velocities of the two groups of drivers as they approached the intersection in the northbound direction at night, it can be seen that the test drivers approached the STOP sign with a speed of up to 5 mph faster than the average approach speed of the local familiar drivers (statistically significant at 5 of the 10 positions along the intersection approach). In fact, the test drivers' average speed was higher than the speed of the local familiar drivers at all distance points except 28 ft before the intersection, where the test drivers' average speed was about 1 to 2 mph slower than the local familiar drivers' average speed.

EYE SCANNING

During the data-reduction process, the test drivers' eye-scanning behavior was analyzed in terms of when and where the test drivers were looking at the STOP AHEAD sign and the STOP sign from 1,600 ft before each sign to the sign of interest. Shown in Table 6 are the eye-scanning results for the STOP AHEAD sign, merging data of experienced and inexperienced test drivers and Run 1 and Run 2 on both the north- and southbound approaches to the intersection and for both daytime and nighttime conditions. This table indicates that the test drivers looked at this sign an average of 1.45 to 2.77 times, with an average duration of between 0.65 and 0.82 sec.

The first- and last-look distances shown in Table 6 appear to be highly variable within any condition, as shown by the values

TABLE 6 EYE-SCANNING SUMMARY RESULTS FOR STOP AHEAD SIGN

	Day		Night	
	North	South	North	South
No. of runs	24	24	18	18
Total no. of looks	66	51	26	50
Looks per subject				
Avg	2.73	2.13	1.45	2.77
SD	1.86	1.53	0.71	1.82
Look duration (sec)				
Avg	0.70	0.65	0.66	0.82
SD	0.58	0.67	0.39	0.61
First-look distance (ft)				
Avg	813	680	294	743
SD	493	244	16	715
Average first-look (sec)	10.9	9.3	4.8	9.5
First-look visual angle (min of arc)				
7-in. letter	2.5	2.9	6.8	2.7
36-in. sign	12.7	15.2	35.1	13.9
Last-look distance (ft)				
Avg	291	330	205	431
SD	192	189	52	763
Average last-look time (sec)	4.1	4.6	3.3	4.8
Last-look visual angle (min of arc)				
7-in. letter	6.9	6.1	9.8	4.7
36-in. sign	35.4	31.3	50.3	23.9

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2.

for the standard deviation, which range from 16 to 763 ft. It can be seen that when the drivers first looked at the STOP AHEAD sign the visual angle for the 36 × 36-in. sign was between 12.7 and 35.1 min of visual arc. Given these values, the driver should have been able to distinguish the presence and the shape of the sign. However, the visual angle for the 7-in.-high letters ranged from only 2.5 to 6.8 min of visual arc. With these small visual angles it is not likely that the drivers were able to read the individual letters displayed on the STOP AHEAD sign at these first-look distances. However, most drivers could probably see the pattern of the two words and were probably able to guess the message on the diamond-shaped warning sign.

The last-look distances in Table 6 show that the test drivers looked away from the STOP AHEAD sign for the last time at an average distance of between 205 and 432 ft. Given these last-look distances, the visual angles for the 7-in.-tall letters on the STOP AHEAD sign were between 4.6 and 9.8 min of visual arc. These rather small visual angles indicate that it would have been somewhat difficult for the subjects to have read the individual letters in the words "STOP AHEAD," which were written on this sign when they looked away from it for the last time. However, the subjects were probably able to interpret the meaning of the sign based on the pattern of the words. In order to obtain a visual angle of 20 min of visual arc for 7 individual letters, which would allow a driver with 20/20 vision to comfortably read each letter in the two words displayed on the STOP AHEAD sign, a driver would have to be about 100 ft in front of the sign.

The average last-look times in Table 6 show that the test drivers look away from the STOP AHEAD sign for the last time an average of 3.3 to 4.8 sec before they reach the STOP AHEAD sign. From these results it would seem that the test drivers thought they had acquired the information that was displayed on the sign or that other stimuli in the driving environment were more important.

Shown in Tables 7 and 8 are the eye-scanning summary results for the STOP signs on the north- and southbound approaches to the intersection, merging data of experienced and inexperienced test drivers and Run 1 and Run 2. The results displayed in these tables are rather similar to those shown in Table 6, with the exception that the number of looks per test driver is much higher for the STOP sign than for the STOP AHEAD sign (3.65 to 6.40 looks per test driver for STOP signs as opposed to only 1.45 to 2.77 for STOP AHEAD signs). It is likely that the test drivers looked at the STOP sign more often than they did at the STOP AHEAD sign because the STOP sign is an important and unique sign that may serve as a convenient stationary visual target that allows the test drivers to monitor their position, speed, and deceleration as they bring their vehicles to a stop. It can also be seen that the visual angles for the last-look distances were larger for the STOP sign than for the STOP AHEAD sign. This is because the size of the letters on the STOP sign are 5 in. taller than the letters on the STOP AHEAD sign, as well as shorter last-look distances for the STOP sign.

TABLE 7 EYE-SCANNING SUMMARY RESULTS FOR STOP SIGN ON NORTHBOUND APPROACH

	With STOP AHEAD		Without STOP AHEAD	
	Day	Night	Day	Night
No. of subjects	24	18	24	12
Total no. of looks	108	101	154	44
Looks per subject				
Avg	4.50	5.60	6.40	3.65
SD	3.36	3.14	3.07	2.39
Look duration (sec)				
Avg	0.62	0.75	0.55	0.63
SD	0.50	1.02	0.59	0.50
First-look distance (ft)				
Avg	686	676	780	696
SD	230	218	142	193
Average first-look (sec)	13.6	14.9	15.1	12.0
First-look visual angle (min of arc)				
12-in. letter	5.0	5.1	4.4	4.9
Sign	15.0	15.3	13.2	14.8
Last-look distance (ft)				
Avg	153	158	198	232
SD	125	123	151	180
Average last-look time (sec)	4.4	5.4	5.3	5.0
Last-look visual angle (min of arc)				
12-in. letter	22.5	21.8	17.4	14.8

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2.

TABLE 8 EYE-SCANNING SUMMARY RESULTS FOR STOP SIGN ON SOUTHBOUND APPROACH

	With STOP AHEAD		Without STOP AHEAD	
	Day	Night	Day	Night
No. of subjects	24	18	24	12
Total no. of looks	102	83	141	48
Looks per subject				
Avg	4.28	4.60	5.88	4.00
SD	2.68	2.64	2.50	2.99
Look duration (sec)				
Avg	0.55	0.70	0.66	0.37
SD	0.45	0.83	1.35	0.45
First-look distance (ft)				
Avg	881	593	1,026	640
SD	339	208	381	263
Average first-look time (sec)	16.9	15.7	19.7	16.2
First-look visual angle (min of arc)				
12-in. letter	3.9	5.8	3.4	5.4
Sign	11.7	17.4	10.1	16.1
Last-look distance (ft)				
Avg	211	162	209	156
SD	154	100	113	68
Average last-look time (sec)	5.9	6.4	6.1	7.3
Last-look visual angle (min of arc)				
10-in. letter	16.3	21.2	16.4	22.0

NOTE: Data from experienced and inexperienced drivers were combined with data from Runs 1 and 2.

Comparing the results shown in Tables 7 and 8 in each of the four cases shown, the first-look distances for the STOP sign were shorter when the STOP AHEAD sign was present than when the STOP AHEAD sign was not (not statistically significant). In fact, the first-look distances that were recorded during the day without the presence of the STOP AHEAD sign actually indicate that the drivers looked at the STOP sign before they reached the STOP AHEAD sign had it been present. The first-look distances also seem to have been slightly shorter (although statistically not significant) during the day than at night.

CONCLUSIONS

Based on the results of this study, diamond-shaped STOP AHEAD signs with the words "STOP AHEAD" written in 7-in.-high letters across the face do not provide a strong and reliable enough stimulus to prepare a driver to stop at an intersection if this intersection requires a full stop and is unexpected and partially concealed. However the STOP AHEAD sign appears to elicit some limited changes in driving behavior, including lower approach velocities at night and lower longitudinal decelerations near the STOP sign. Further research should be conducted to find more effective methods of warning drivers of intersections requiring a full stop that are unexpected and partially concealed.

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