Visibility of New Pavement Markings at Night Under Low-Beam Illumination

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Three independent field studies investigating the nighttime detection distances of yellow and white-painted and taped pavement markings of varying widths under low-beam illumination were undertaken. Different centerline and edge line configurations, typically used on highways, were tested. The objective of Study 1 was to obtain exploratory pavement marking visibility field data for detecting the begin and end of a continuous pavement marking line as a function of line width, material, color, and lateral position of the line. Study 2 was conducted to determine the visibility distance of the onset of a left or a right curve (244-m radius) along a tangent section marked with a continuous white taped edge line placed at approximately 1.83 m to the right of the car, as a function of line width. Study 3 was conducted to determine the detection distances for the begin and end of yellow taped pavement marking configurations having different widths, placed on the left side of the vehicle representing a typical centerline on a two-lane rural highway. The results of Study 1 indicate no statistically significant differences ($\alpha = 0.05$) for the average begin or end detection distances using a line width between 0.1 and 0.2 m. The results for Study 2 indicate that there is a statistically significant difference in the average detection distance ($\alpha = 0.05$) between a 0.1- and a 0.2-m-wide right edge line for a left curve. The results of Study 3 indicate that the double solid line configuration provides statistically significantly ($\alpha = 0.05$) longer average detection distances when compared with the other configurations for all three widths (0.05, 0.1, and 0.2 m). Overall in Study 3, the end detection distances were significantly ($\alpha = 0.05$) longer than the begin detection distances.

The Ohio Manual of Uniform Traffic Control Devices for Streets and Highways (*1*) defines pavement markings as traffic control devices used on the surface of a roadway to regulate, warn, and guide the motorists. Pavement markings are applied for centerlines, edge lines, no-passing zones, and others as discussed previously (*1, 2*). Ethen et al. (*3*) conducted a subjective evaluation in the field using pavement markings with a broad range of retroreflectance. Allen et al. (*4*) provided basic relationships that related visibility range, stripe-to-skip length, and luminance contrast to the driver's lateral vehicle control. They suggested a minimum pavement marking contrast of 2. Serres (*5*) developed a correlation between subjective ratings and line retroreflectance. He concluded that a line retroreflectance below 150 cd/m^2/lux is unacceptable to the median viewer and that a line should be repainted if a retroreflectance of less than 100 mcd/m^2/lux is measured. In addition, a study conducted by Graham et al. (*6*) found that more than 90 percent of subjects rated a retroreflectance of 93 mcd/m^2/lux as adequate or more than adequate for nighttime driving.

None of these studies provide actual nighttime visibility distances for different pavement marking configurations and different line widths. CIE Publication 73 (*7*), on the basis of prior research, quotes that a minimum preview time of 5 sec would be a conservative but a safe criterion to allow efficient, anticipatory steering behavior. The publication suggests that a minimum preview time of 3 sec, however, would be more applicable in practice. The publication further states that the visibility distance of continuous pavement marking lines is defined as the distance ahead of the driver at which the luminance contrast between the pavement markings and the road surface is equal to the threshold contrast of the driver. The report then describes a number of mathematical relationships that were developed to calculate the visibility distances of various pavement markings. However,one can question the adequacy of the CIE pavement marking visibility model in terms of (*a*) the use of a poor threshold contrast approximation; (*b*) the assumption that the target (pavement marking) is a rectangle (transformed into a circle with equivalent area) rather than a perspectively seen line; (*c*) not accounting for the lateral position of the line with respect to the longitudinal vehicle axis; (*d*) not considering the color of the line; and (*e*) not considering pavement marking configurations (double solid lines, solid-dashed combinations, single solid lines, and dashed lines with different stripe and gap lengths).

A study conducted by McLean et al. (*8*) investigated the driver steering control (tracking) performance for straight-lane driving. It was found that the far-sight distance needed for drivers to adequately steer the car in a traffic-free environment to be about 21.3 m. This preview distance appeared to be independent of the two speeds 32 and 48 kph, that were used in the study.

Sorensen (unpublished data, 1993) evaluated average detection distances of pavement marking edge lines of three different widths, 0.5, 0.3, and 0.15 m under various conditions of illumination. According to Sorensen, an average detection distance of 129 m for a vehicle traveling at 100 kph on the basis of the conservative CIE preview time estimate of 5 sec cannot be achieved, but a preview time of 3 sec may be feasible.

A study conducted by Harkey et al. (*9*) investigated the effect of permanent and nonpermanent pavement markings on driver performance during the day and night. The study was conducted on a multilane freeway using the following nonpermanent lane line configurations: (*a*) 0.6-m stripes with 11.6-m gaps, (*b*) 1.2-m stripes with 11-m gaps and the full complement of markings: 3.1-m stripes with 9.1-m gaps as lane line. This configuration also included edge lines. The first two patterns were temporary markings, whereas the third was a permanent marking used for comparison with the former two types. The effectiveness of the pavement markings was measured in terms of lateral deviation of the vehicle in the lane, vehicle speed within the test segment, number of edge line and lane line encroachments, and number of erratic maneuvers. Harkey et al. (*9*) concluded that drivers performed better with the 3-m/9.1-m stripe/gap lane line markings including edge lines during both the day and the

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night. Because the consecutive adjoining highway sections used in the study were not tangent sections and had different geometric alignments and one section also included edge lines and a bridge structure, it is not clear from the study what influence the various geometric alignments had on the results and whether there was an order of presentation effect in the results caused by the fixed sequential method of data collection.

Hall (*10*) evaluated the effectiveness of 0.2-m-wide edge lines in terms of their run-off-the-road (ROR) accident-reducing potential. It was concluded that the 0.2-m-wide edge lines do not have a significant effect in terms of ROR accident reduction at night on straight or curve sections with or without opposing traffic.

The superiority of wider edge lines is still inconclusive. All of the studies mentioned earlier used one of the following to investigate the effectiveness of the pavement marking stripes: subjective ratings, photometric retroreflectivity measurements, driver lateral position maintenance performance, preview, or accident analyses. None of the studies has provided average detection distances in terms of detecting the begin or end of a pavement marking line or the begin of a curve ahead. For this reason three exploratory nighttime pavement marking detection studies under low-beam illumination conditions were conducted at Ohio University, Athens, Ohio.

OBJECTIVES OF THE THREE STUDIES

The objective of Study 1 was to obtain exploratory pavement marking nighttime visibility field data for detecting the begin and end of a continuous pavement marking line as a function of line width, material, color, and lateral position of the line. The results will be needed primarily to assist in the development of a pavement marking nighttime visibility model for continuous lines and of an experimental methodology to evaluate the visibility of pavement markings.

The objective of Study 2 was to obtain exploratory pavement marking nighttime visibility data under low-beam conditions to determine the visibility distance to detect the onset of a left or a right curve with a 244-m radius along a tangent section marked with a continuous white edge line placed at approximately 1.83 m to the right of the car as a function of line width.

The objective of Study 3 was to obtain the nighttime average detection distances under low-beam illumination conditions for the begin and end of various yellow centerline pavement marking tape configurations using various widths.

METHOD

Study 1: Detection of the Begin and End of Continuous Pavement Marking Lines

Experiment

The following treatments (independent variables) were used in Study 1:

1. 10-m-wide white pavement marking tape located about 1.83 m to the left and right sides of the longitudinal car axis;
2. 13-m-wide white painted pavement marking located about 1.83 m to the right side of the longitudinal car axis;
3. 13-m-wide yellow painted pavement marking located about 1.83 m to the left side of the longitudinal car axis;
4. 20-m-wide white pavement marking tape located about 1.83 m to the left side of the longitudinal car axis;
5. 20-m-wide white painted pavement marking located about 1.83 m to the left and right sides of the longitudinal car axis; and
6. 25-m-wide white painted pavement marking located at about 1.83 m to the right side of the longitudinal car axis.

The dependent variable was the detection distance of the begin and end of these treatments.

Subjects and Experimental Vehicle

A total of seven young, healthy college students (five men and two women, average age, 23.1 years, normal vision) participated in the experiment of Study 1. A 1976 Datsun B210 with H6054 headlamps was used as experimental car in Study 1.

Experimental Site

The experiment was conducted on an old unused airport runway in Athens, Ohio. The runway was about 23 m wide and 500 m long. A two-lane state highway with moderate traffic runs parallel about 61 m away from the runway. During the course of the experiment the experimental car was driven in the eastbound direction (relatively dark background). A number of luminaires, a few illuminated advertising signs, and other light sources were within the field of view, especially in the left half of the field of view. Figure 1*a* shows the site and the layout of the pavement markings for the Study 1 experiment.

Experimental Design

A randomized block experimental design was used in Study 1. Each subject was tested under each condition in four replications. One subject finished only three replications. Each condition was randomized within a block of eight runs in such a way that each condition appeared exactly once within that block. Therefore the total number of observations for each condition was 27 (six subjects with four replications each and one subject with three replications).

Experimental Procedure

The subjects accelerated the car to a speed of about 8 to 16 kph. As soon as the subject reported seeing the begin of the straight single pavement marking line, a sandbag was dropped onto the runway by the experimenter riding in the car. The sandbag distance was then recorded. The same method was used for the detection of the end of the pavement marking lines. As soon as the run was completed, the subject drove back to the west end of the runway to prepare and position the car for another run. The average time needed to complete 32 runs for each subject was about 1 hr 15 min.

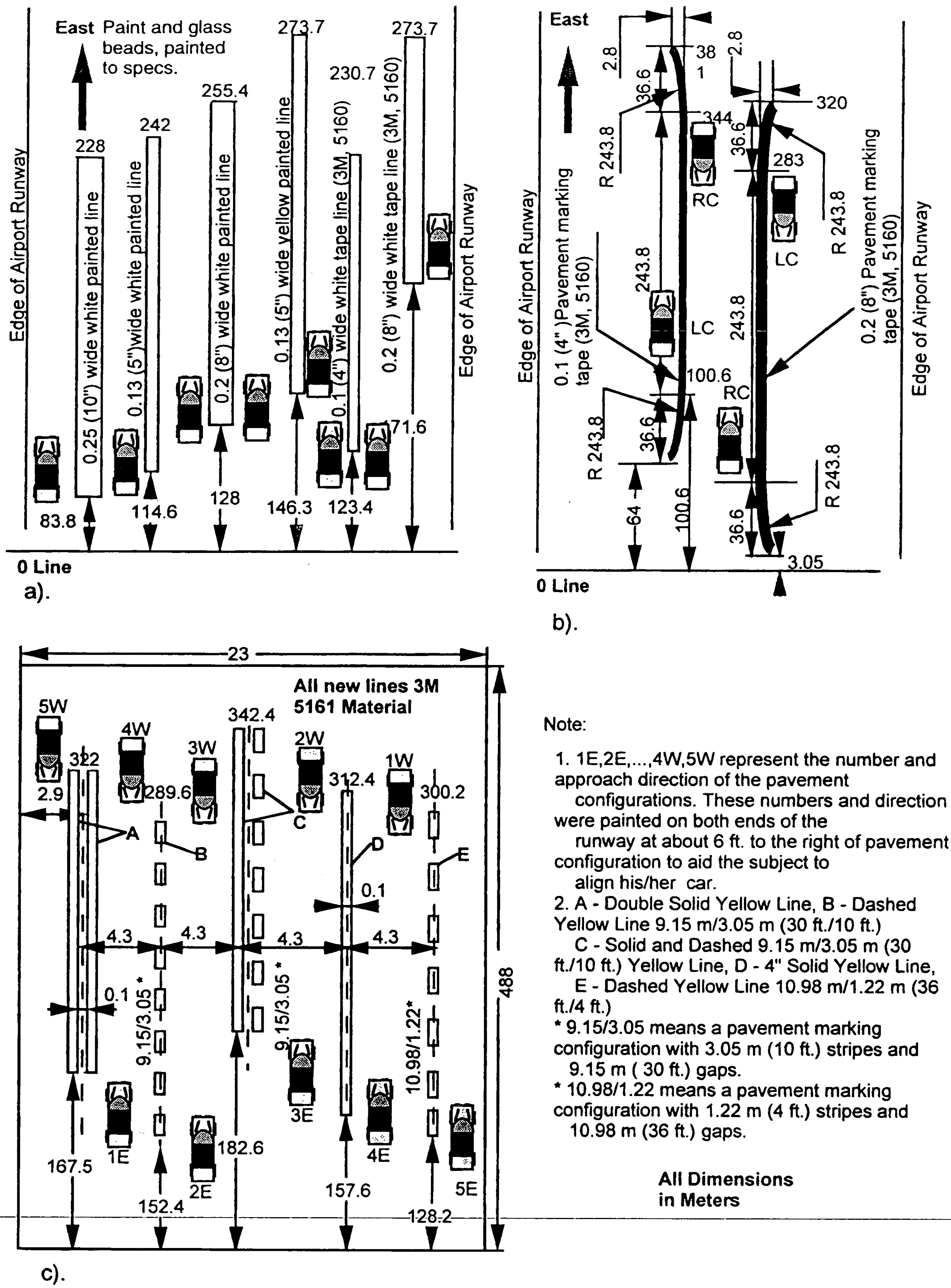

FIGURE 1 Layout for detection of begin and end of single new retroreflective pavement marking lines in Study 1: (*a*) begin and end of single new retroreflective pavement marking lines in Study 1; (*b*) begin of a curve along a single new retroreflective pavement marking tape line in Study 2; (*c*) begin and end of new pavement marking lines in Study 3.

Study 2: Detection of the Begin of a Right or a Left Curve

Experiments

A left or a right curve with a radius of 244 m along a tangent section was simulated with a continuous white edge line placed at approximately 1.83 m to the right of the car. The pavement marking tape material was white 3M-5160 (Ecolux, 86.5 degrees entrance angle, 1 degree observation angle, RL = 1000 mcd/m^2/lux). The experiments investigated three different line widths (independent variables):

1. 0.05 m
2. 0.1 m
3. 0.2 m

Experiments 1 and 2 investigated all three widths, whereas Experiment 3 investigated only the 0.1- and 0.2-m-wide markings. The dependent variable was the detection distance of the onset of the curve marked with the above treatments.

Experimental Site

The three experiments of Study 2 were conducted at the same site as that used in Study 1. Figure 1*b* illustrates the site and the typical layout of the pavement markings for Experiment 3 of Study 2.

Subjects and Experimental Vehicles

Three subject groups, each one of which consisted of 16 (8 men and 8 women) young and healthy subjects were used for the three different experiments conducted as part of Study 2 (average age, 20.9 years, standard deviation 0.77 years, normal vision). A Chevrolet Cavalier (1986) with H9006 low-beam headlamps was used as the experimental car in Study 2.

Experimental Design

A randomized block design was used for the experiments in Study 2. In each of the three experiments, the subjects were tested under each condition in two replications. Every condition was randomized within a block of four runs in such a way that each condition appeared exactly once within a block. Therefore, the total number of observations in an experiment for each condition was 32 (16 subjects, two replications).

Experimental Procedure

The experimental procedure was similar to the one used in Study 1. For each run, the pavement marking line would appear on the right side of the car. Unlike in Study 1, the subjects had to report when they detected the begin of either a left or a right curve (about 1.83 m to the right of the longitudinal car axis).

Study 3: Detection of the Begin and End of Five Different Pavement Marking Line Configurations Placed in the Center of the Road Using Different Line Widths

Experiments

Three independent nighttime field experiments were conducted under low-beam illumination as part of Study 3. The following treatments were used (independent variables):

1. Double solid lines, 0.05, 0.1, and 0.15 m wide;
2. Single solid line and a dashed line with a stripe length of 3.05 m and a gap length of 9.14, 0.05, 0.1, 0.15 m wide;
3. Dashed line with a stripe length of 3.05 m and a gap length of 9.14, 0.05, 0.1, and 0.15 m wide;
4. Dashed line with a stripe length of 1.22 m and a gap length of 10.97, 0.05, 0.1, and 0.15 m wide; and
5. 0.10-m-wide single solid line; baseline comparison between groups.

The treatments were observed in the eastbound and westbound directions. The pavement marking tape material was yellow 3M-5161 (Ecolux, 86.5 degrees entrance angle, 1 degree observation angle, RL = 650 mcd/m^2/lux). The dependent variable was the detection distance of the begin and end of these treatments.

Experimental Site

The three experiments of Study 3 were conducted at the same site as that used in Studies 1 and 2. Figure 1*c* shows the site and the layout.

Subjects and Experimental Vehicles

Three different subject groups consisting of 10 young and healthy subjects each (normal vision), were used for the three different experiments conducted as part of Study 3. Eight men and two women participated in Experiment 1, five men and five women participated in Experiment 2, and seven men and three women participated in Experiment 3.

Experimental Design

Study 3 used a randomized block experimental design. Each subject was tested under each condition in two replications. Further, all subsequent configurations were completely randomized for each of the subjects in an experiment. Each condition was randomized within a block of 10 runs in such a way that each condition appeared exactly once within that block of an experiment. Therefore, the total number of observations in an experiment for each condition was 20 (10 subjects, 2 replications each).

Experimental Procedure

The experimental procedure used in Study 3 was similar to the ones used in Studies 1 and 2. The selected pavement marking configuration always appeared to the left of the car. Unlike in Studies 1 and 2, the subjects had to report when they detected the begin and end of the five straight yellow pavement marking configurations from the east as well as from the west.

RESULTS

Study 1

The statistical tests indicate that the average begin and end detection distances for a continuous pavement marking line are not statistically significantly different. However, one can observe a slight tendency of the average begin detection distance to be longer than the end detection distance. Further, it appears that the 0.1-m white pavement marking tape located on the left side of the car does not provide an average end detection distance that is statistically different from the average end detection distance provided by the 0.2-m-wide white tape.

Table 1 shows the average detection distances and the standard deviations for the different pavement marking configurations used in Study 1 for each replication. It can be seen from the table that there is no appreciable difference in the average detection distances among the four replications for any of the configurations tested. This implies that there is no learning effect when the pavement marking configurations were viewed for the second, third, or fourth time. Because of this it is possible to consider the combined data from the four replications in the statistical analysis. Figure 2*a* shows the average detection distance as a function of the width of the pavement marking lines. It can be seen that there is no significant difference among the distances needed to detect either the begin or end of the 0.13-, 0.20- and the 0.25-m-wide continuous white painted lines located to the right of the car. Moreover, the figure also shows that the average end detection distances are always slightly longer than the average begin detection distances. The results of Study 1 also indicate that the average begin and end detection distances for white continuous taped lines located to the left or right of the car are slightly but not significantly ($\alpha = 0.05$) longer than the average begin and end detection distances for the corresponding continuous white painted lines. The average begin and end detection distances for lines located to the right of the car are slightly but not significantly ($\alpha = 0.05$) longer than the average begin and end detection distances of the corresponding lines located to the left of the car. The average detection distances for the 0.13-m-wide yellow painted pavement configuration are shorter than the average detection distances of all the other pavement marking configurations used in Study 1. Figure 3*a* shows a typical psychometric curve for the detection distances of the 0.1-m-wide pavement marking tape located 1.83 m to the left of the longitudinal car axis. The figure indicates that 95 percent of the selected drivers can detect the begin of the 0.1-m-wide marking at a distance of about 81 m and the end at a distance of about 73 m. Figure 3*a* also illustrates that the begin detection distances are relatively close to the end detection distances for the 0.1-m-wide line.

Study 2: Detection of Begin of Right or Left Curve

The statistical tests conducted on the average detection distance data obtained from the three experiments in Study 2 indicate that there is no significant difference between the average detection distance of a right curve marked with a new 0.1-m-wide line and a right curve marked with a new 0.2-m-wide line placed on the right side of the car. For the left curve, however, there is a significant difference at the 0.05 level. Table 2 indicates the average curve-begin detection distances for Replication 1 using all three new pavement marking configurations (0.05, 0.1, and 0.2-m-wide white tape located about 1.8 m to the left or right side of the car). As indicated in Table 2 and Figure 2*b*, the average curve-begin detection distances for the left curve are always shorter than the average curve-begin detection distances for the corresponding right curve. Further, it can be seen that by increasing the width from 0.05 to 0.2 m, the average detection distances are longer by about 21 m for the left curve and 22 m for the right curve.

Figure 3*b* shows a typical psychometric curve for the detection distance of the right and the left curve. As seen in the figure, 95 percent of the selected drivers can detect the onset of a left curve at a distance of about 67 m and the onset of a right curve at a distance of about 81 m. Similar detection distances can be obtained from the psychometric curve for any other selected probability of detection value.

Study 3: Detection of Begin and End of Five Different New Pavement Marking Line Configurations Placed in Center of Road Using Different Line Widths

Statistical tests were conducted on the data obtained from the three experiments in Study 3 (0.05-, 0.1-, and 0.2-m-wide centerline configurations). As expected, in all three experiments it was found that the configuration type is significant, with the double solid line configuration having the longest average detection distance in the three experiments. Overall, it can be seen that the average end detection distance for the used pavement marking configurations was significantly longer than the average begin detection distance.

Tables 3 through 5 show the average detection distances for the 0.05-, 0.1-, and the 0.2-m-wide pavement marking configurations used in Experiments 1, 2, and 3, respectively. It can be seen from the tables that, for all three widths, the double solid-line configurations showed the longest average begin and end detection distances. Moreover, for the three widths tested, the dashed-line configuration with a stripe length of 1.2 m and a gap length of 12.27 m shows almost always the shortest average begin and end detection distance. Further, for all three widths tested, the solid-dashed line combination has a longer average detection distance when compared with the average detection distance for the two single dashed line or the single continuous line configurations.

Tables 3 through 5 also show the average detection distances for the 0.1-m solid-line configuration, which was the only common configuration for all three subject groups. This 0.1-m configuration provided average begin and end detection distances, both east- and westbound, across the three different experiments that are fairly close to each other. This would indicate that despite different vehicles with different low beams, no single subject group had a superior detection performance when compared with the other two subject groups, thus allowing a comparison of the results across the three experiments of Study 3. It can be seen from Figure 2*c* that for both eastbound and westbound traffic, there is a tendency for the 0.2-m-wide pavement new marking configurations to provide somewhat longer detection distances than can be obtained with the corresponding 0.05- and 0.1-m configurations. Unlike in Study 1 where new wider painted lines with glass beads did not necessarily

TABLE 1 Average Detection Distances and Standard Deviations for Different New Pavement Marking Configuration and Replication

No.	Pavement Marking Configuration	Replication	N	Average in meters	Std. Dev. in meters
1	0.101 m (4") Left, Begin White Tape	1	7	118.17	21.08
		2	7	119.97	25.06
		3	7	122.64	31.96
		4	6	118.97	29.78
2	0.101 m (4") Left, End White Tape	1	7	118.79	36.15
		2	7	120.07	26.59
		3	7	118.54	23.59
		4	6	110.10	26.54
3	0.101 m (4") Right, Begin White Tape	1	7	114.42	21.54
		2	7	118.66	27.39
		3	7	120.07	22.09
		4	6	112.88	24.06
4	0.101 m (4") Right, End White Tape	1	7	124.22	34.56
		2	7	116.88	23.39
		3	7	120.87	28.82
		4	6	98.36	35.45
5	0.127 m (5") Left, Begin Yellow Paint	1	7	90.64	18.10
		2	7	81.94	20.03
		3	7	93.05	19.86
		4	6	81.45	19.53
6	0.127 m (5") Left, End Yellow Paint	1	7	95.17	29.90
		2	7	89.93	30.03
		3	7	94.42	21.97
		4	6	78.71	22.23
7	0.127 m (5") Right, Begin White Paint	1	7	108.83	21.60
		2	7	103.21	19.94
		3	7	103.68	14.17
		4	6	108.37	27.19
8	0.127 m (5") Right, End White Paint	1	7	123.48	26.24
		2	7	120.00	26.85
		3	7	112.16	17.24
		4	6	98.79	15.63
9	0.203 m (8") Left, Begin White Paint	1	7	95.72	17.02
		2	7	96.99	22.88
		3	7	100.11	21.59
		4	6	96.28	21.30
10	0.203 m (8") Left, End White Paint	1	7	104.98	32.55
		2	7	101.97	29.57
		3	7	105.66	25.13
		4	6	91.20	18.78
11	0.203 m (8") Right, Begin White Paint	1	7	110.21	18.69
		2	7	102.85	19.27
		3	7	100.77	17.88
		4	6	99.92	18.37
12	0.203 m (8") Right, End White Paint	1	7	116.01	27.73
		2	7	110.13	27.30
		3	7	110.48	19.60
		4	6	100.04	22.18
13	0.203 m (8") Left, End White Tape	1	7	119.00	31.39
		2	7	110.45	26.18
		3	7	113.40	24.24
		4	6	99.07	31.99
14	0.254 m (10") Right, Begin White Paint	1	7	95.48	26.72
		2	7	94.67	21.43
		3	7	94.88	20.98
		4	6	93.54	16.52
15	0.254 m (10") Right, End White Paint	1	7	114.13	24.60
		2	7	115.50	33.26
		3	7	116.47	22.75
		4	6	108.42	26.20

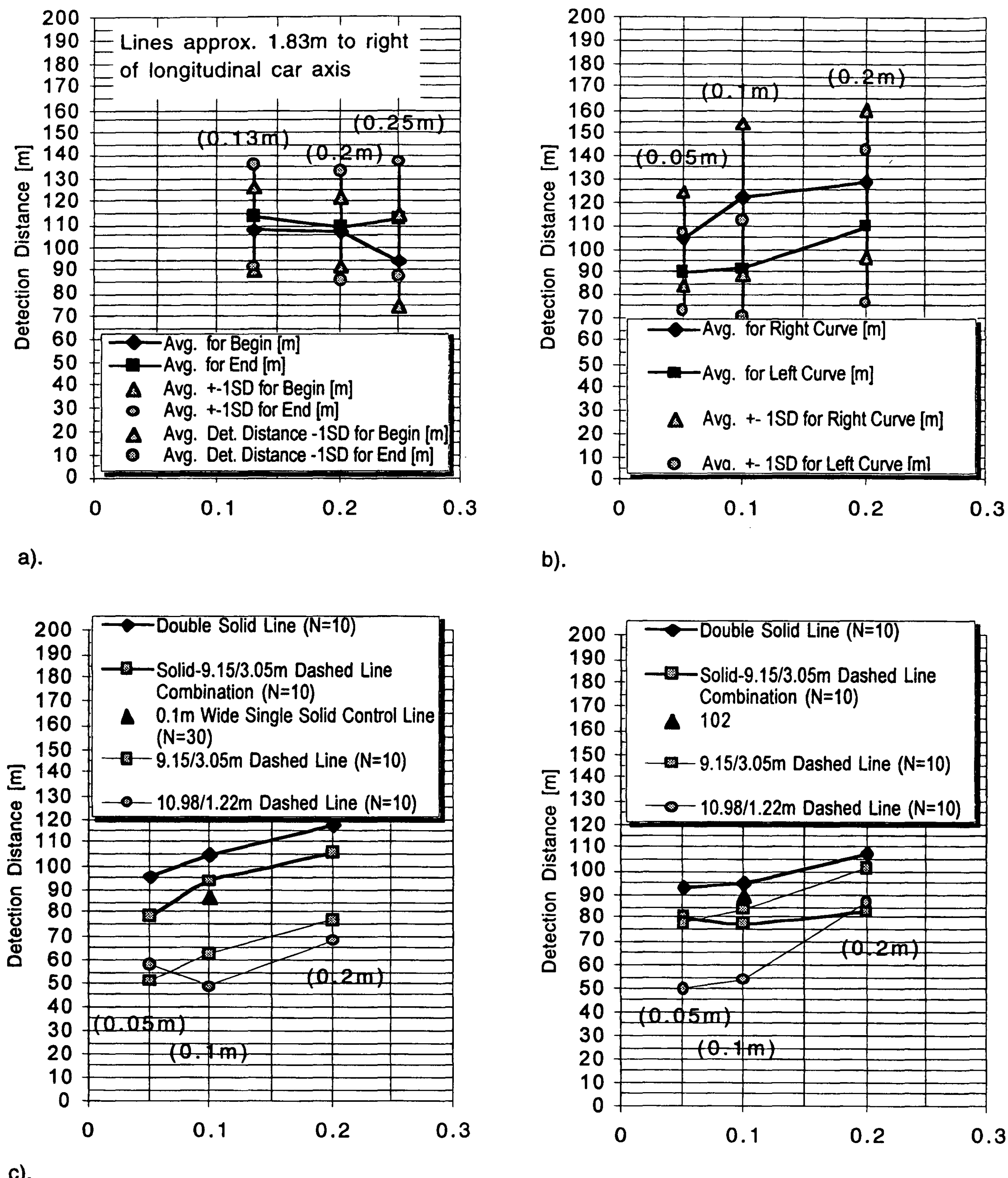

FIGURE 2 Average detection distances and standard deviations as a function of pavement marking width: (*a*) Study 1—new white continuous painted lines with glass beads; (*b*) Study 2—new white continuous tape 1.83 m to right of longitudinal car axis; (*c*) Study 3—new yellow tape 1.83 m to left of longitudinal car axis, eastbound (left) and westbound (right), Replication 1.

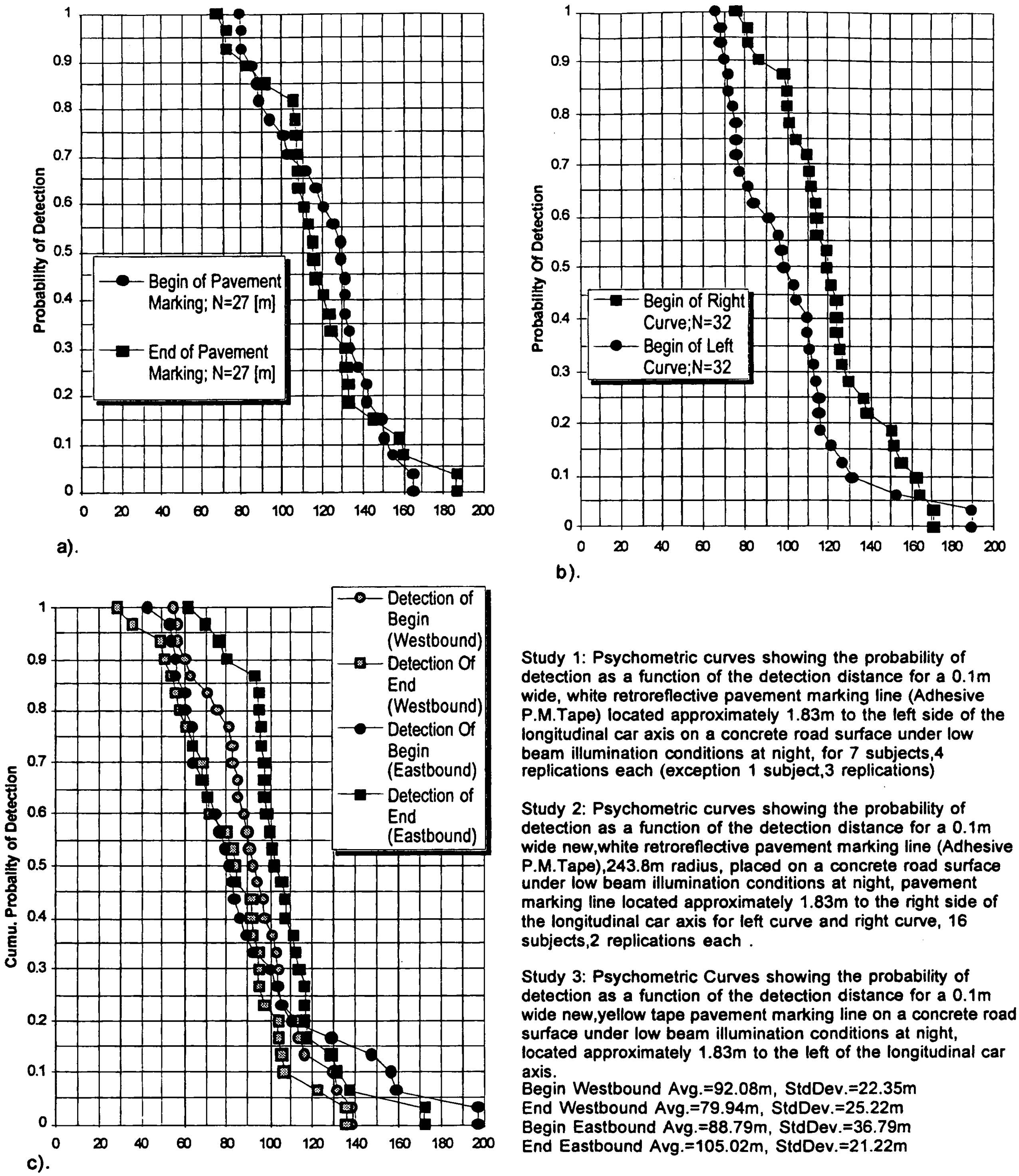

FIGURE 3 Psychometric curves (*a*) for Study 1, (*b*) for Study 2, (*c*) for Study 3.

provide longer detection distances, the moderate width effect found in Study 3 may be explained by the consistent pavement marking tape quality when compared with the less uniform paint and glass bead application in Study 1. The configuration of the pavement markings, on the other hand, has a much stronger effect on the average detection distance than the stripe width. For the east direction (Figure 2*c*), the double solid line appears to provide the longest average detection distance followed by the solid-dashed line combination, the 0.1-m single solid line, and the two single dashed lines. The dashed-line configurations, 9.15/3.05 m and 10.98/1.22 m, are relatively close to one another in terms of average detection distances. Based on Figure 2*c*, the dashed-line configuration of 9.15/3.05 m does not provide longer detection distances than that of 10.98/1.22 m when using the 0.05-m-wide lines. Also, if one con-

TABLE 2 Average Detection Distance for Begin of a Curve Using Different Pavement Marking Configurations, Replication 1 (N = 16)

Expt. No.	Width and Type of Pavement Marking	Average and Standard Deviation Detection Distances for the Begin of the Curve in Meters			
		Left		Right	
		Avg.	SD.	Avg.	SD.
1 (8M,8F)	2" White Tape	90.00	18.23	105.93	19.97
2 (8M,8F)	4" White Tape	91.40	22.63	121.19	35.78
3 (8M,8F)	8" White Tape	110.74	32.90	128.22	33.65

siders the standard deviations of the average detection distances, it is evident that both dashed-line configurations produce similar results in terms of average detection distances.

For the west direction (Figure 2*c*), where there are a number of luminaires in the field of view of the drivers, the double solid-line configuration again provides the longest detection distances across all line widths used. The 0.1-m single solid line, the solid-dashed line combination, and the dashed-line configuration of 9.15/3.05 m produce almost the same average detection distance when using the 0.1-m-wide lines. The dashed configuration of 10.98/1.22 m provided average detection distances that are considerably shorter than the ones provided by the other configurations, when stripes 0.05 and 0.1 m wide were used. For 0.2-m-wide stripes the dashed-line configuration of 10.98/1.22 m appears to provide average detection distances that are fairly close to the average detection distances obtained for the dashed-line configuration of 9.15/3.05 m.

Figure 3*c* shows a typical example of a psychometric curve for the average detection of the begin and end of the 0.1-m-wide configuration for Replication 1. The figure indicates that 95 percent of the selected drivers can detect the begin of the 0.1-m new yellow taped pavement marking line in the west direction at a distance of about 57 m and the detection of the end at a distance of about 36 m. For the east direction these distances are about 54 m to detect the begin and about 70 m to detect the end.

COMPARISONS, SUMMARY, AND CONCLUSIONS

It was found that the begin of a right curve marked with a 0.1-m-wide continuous white taped line (Study 2) provides an average detection distance that is almost equal to the average begin detection distance of a 0.1-m-wide white continuous taped line (Study 1). On the basis of this observation, it would seem reasonable in a pavement marking visibility model, to use the average detection distance calculations on the basis of the begin of a white line placed to the right side of the car to predict the average detection distance for the begin of a curve. Because there appears to be a significant difference between the average detection distances of a left and a right

TABLE 3 Average Detection Distances and Standard Deviations in Meters for 0.05-m-Wide New Yellow Tape Pavement Marking Configurations

Type of line			Replication 1			Replication 2			Replication (1+2)			East & West (Rep. 1)	
			Avg.	SD.	N	Avg.	SD.	N	Avg.	SD.	N	Avg.	SD
Double line													
	Begin	East	95.55	16.74	10	103.72	25.11	10	99.64	21.19	20		
		West	93.19	18.52	10	100.11	18.39	10	96.65	18.31	20	94.37	17.23
	End	East	107.18	25.49	10	103.28	29.79	10	105.23	27.06	20		
		West	93.52	21.20	10	97.38	31.40	10	95.45	26.15	20	100.35	23.87
Solid-Dashed line (9.15/3.05)													
	Begin	East	78.13	14.95	10	87.05	21.71	10	82.59	18.71	20		
		West	80.37	16.92	10	83.33	17.21	10	81.85	16.68	20	79.25	15.58
	End	East	90.05	19.60	10	101.76	36.42	10	95.90	29.09	20		
		West	93.17	19.91	10	92.53	26.91	10	92.85	23.04	20	91.61	19.30
0.1 m Wide Solid Line													
	Begin	East	80.01	28.19	10	81.82	14.49	10	80.92	21.83	20		
		West	91.77	19.55	10	100.38	22.77	10	96.08	21.12	20	88.50	24.37
	End	East	99.24	19.11	10	105.24	21.38	10	102.24	19.97	20		
		West	76.99	31.88	10	81.94	29.28	10	79.46	29.9	20	90.85	28.01
Dashed line (9.15/3.05)													
	Begin	East	51.12	17.46	10	62.58	26.20	10	56.85	22.45	20		
		West	78.74	17.02	10	80.49	18.70	10	79.61	17.42	20	64.93	21.96
	End	East	67.98	27.58	10	66.68	16.24	10	67.33	22.04	20		
		West	88.41	20.99	10	77.19	29.58	10	82.80	25.61	20	78.19	26.05
Dashed line (10.98/1.22)													
	Begin	East	58.11	18.92	10	56.38	18.84	10	57.25	18.40	20		
		West	50.69	17.90	10	60.24	16.41	10	55.46	17.42	20	54.40	18.33
	End	East	68.23	31.37	10	73.31	40.04	10	70.77	35.11	20		
		West	73.71	44.36	10	92.31	37.76	10	82.70	41.21	20	70.97	37.50

9.15/3.05 means a pavement marking configuration with 3.05 m stripes and 9.15 m gaps.
10.98/1.22 means a pavement marking configuration with 1.22 m stripes and 10.98 m gaps.
West direction has brighter background (luminaires of parking lot, etc.) than east direction

TABLE 4 Average Detection Distances and Standard Deviations in Meters for 0.1-m-Wide New Yellow Tape Pavement Marking Configurations

Type of line		Replication 1			Replication2			Replication (1+2)			East & West (Rep. 1)	
		Avg.	SD.	N	Avg.	SD.	N	Avg.	SD.	N	Avg.	SD
Double line												
Begin	East	105.43	24.89	10	116.41	24.66	10	110.92	24.76	20		
	West	95.57	19.86	10	109.97	14.13	10	102.77	18.33	20	100.50	22.49
End	East	121.02	16.57	10	118.70	18.43	10	119.86	17.10	20		
	West	103.52	15.88	10	115.31	17.61	10	109.45	17.36	20	112.27	18.17
Solid and Dashed line (9.15/3.05)												
Begin	East	94.70	27.43	10	107.89	22.34	10	101.30	25.27	20		
	West	78.99	16.36	10	88.16	11.33	10	83.58	14.48	20	92.44	23.41
End	East	109.28	21.79	10	112.59	15.84	10	110.93	18.61	20		
	West	106.48	15.43	10	109.28	14.82	10	107.88	14.79	20	109.41	18.43
0.1 m Wide Solid line												
Begin	East	77.33	14.63	10	87.1	13.96	10	82.22	14.79	20		
	West	89.73	22.28	10	108.11	12.78	10	98.92	20.03	20	83.53	19.42
End	East	102.19	14.58	10	111.79	9.69	10	106.99	13.01	20		
	West	83.73	31.79	10	88.4	10.86	10	86.06	23.24	20	92.96	25.87
Dashed line (9.15/3.05)												
Begin	East	62.59	18.13	10	75.51	15.65	10	69.05	17.77	20		
	West	84.69	17.37	10	100.76	17.64	10	92.73	18.93	20	73.64	20.67
End	East	69.96	17.03	10	79.17	19.60	10	74.56	18.48	20		
	West	83.69	15.39	10	88.84	13.67	10	86.26	14.41	20	76.83	17.30
Dashed line (10.98/1.22)												
Begin	East	49.58	15.78	10	61.06	7.39	10	55.34	13.37	20		
	West	55.53	8.12	10	66.81	8.99	10	61.17	10.15	20	52.55	12.59
End	East	63.00	15.15	10	74.41	13.93	10	68.70	15.33	20		
	West	91.05	27.11	10	87.05	23.50	10	89.05	24.78	20	77.03	25.77

9.15/3.05 means a pavement marking configuration with 3.05 m stripes and 9.15 gaps

10.98/1.22 means a pavement marking configuration with 1.22 m stripes and 10.98m gaps

West direction has brighter background (luminaires of parking lot, etc.) than east direction

TABLE 5 Average Detection Distances and Standard Deviations in Meters for 0.203-m-Wide New Yellow Tape Pavement Marking Configuration

Type of Line		Replication 1			Replication2			Replication (1+2)			East & West (Rep. 1)	
		Avg.	SD.	N	Avg.	SD.	N	Avg.	SD.	N	Avg.	SD.
Double line												
Begin	East	116.91	21.64	10	132.39	23.73	10	125.61	22.36	20		
	West	109.34	15.28	10	117.44	11.29	10	113.73	13.12	20	113.12	18.64
End	East	135.51	20.49	10	142.40	33.22	10	138.88	26.70	20		
	West	116.40	32.17	10	134.28	35.65	10	125.27	32.42	20	125.96	28.02
Solid and Dashed line (9.15/3.05)												
Begin	East	106.06	22.55	10	117.44	23.23	10	111.75	23.03	20		
	West	83.58	22.70	10	91.66	15.99	10	87.62	19.55	20	94.82	24.86
End	East	120.97	29.44	10	128.76	31.71	10	124.86	30.05	20		
	West	125.64	30.01	10	140.62	40.42	10	133.13	35.49	20	123.30	29.03
0.101 Wide Solid line												
Begin	East	82.61	32.07	10	88.12	31.36	10	85.37	31	20		
	West	94.91	26.8	10	98.42	29.22	10	96.68	27.35	20	88.76	29.45
End	East	113.84	27.26	10	115.62	37.35	10	114.73	31.84	20		
	West	105.84	42.82	10	97.23	38.92	10	101.45	40.08	20	109.84	35.18
Dashed line (9.15/3.05)												
Begin	East	75.85	25.90	10	82.53	23.39	10	79.19	24.26	20		
	West	103.28	24.02	10	114.98	32.74	10	109.13	28.59	20	89.56	28.09
End	East	83.78	24.78	10	89.08	30.19	10	86.43	27.02	20		
	West	104.70	36.84	10	108.11	35.06	10	106.41	35.04	20	94.24	32.39
Dashed line (10.98/1.22)												
Begin	East	68.14	20.66	10	83.13	23.33	10	75.63	22.78	20		
	West	87.10	18.21	10	88.35	21.62	10	87.73	19.47	20	77.62	21.31
End	East	78.30	13.71	10	97.79	34.11	10	88.04	27.22	20		
	West	98.70	37.77	10	118.02	35.04	10	108.36	36.67	20	88.50	29.57

9.15/3.05 means a pavement marking configuration with 3.05 m stripes and 9.15 m gaps.

10.98/1.22 means a pavement marking configuration with 1.22 m stripes and 10.98 m gaps.

West direction has brighter background (luminaires of parking lot, etc.) than east direction curve, the pavement marking curve visibility model could be calibrated using the field data provided in this paper. A comparison made between the 0.13-m yellow painted line (Study 1) and the 0.1-m yellow taped line (Study 3) indicated that the average detection distance of the 0.13-m line is about 10 m longer.

A comparison made between the average detection distances for the begin and end of a 0.1-m-wide white taped line (Study 1) and a 0.1-m-wide yellow taped line (Study 3) indicated that the average begin and end detection distances of the white line are longer by about 38 and 35 m, respectively. These two comparisons indicate that the color of the pavement markings might have a significant influence on the average detection distances. The longest average detection distance for the begin of a pavement marking configuration found in Studies 1 through 3 is 125.61 m obtained for the 0.2-m double solid centerline configuration (two replications, east direction, detection of begin) used in Study 3. The shortest detection distance found in the studies is 55.46 m, which was obtained using the 0.05-m 10.98/1.22 m dashed centerline configuration (two replications, west direction, detection of begin). The 0.2-m double solid centerline used in Study 3 provides an average detection distance that is significantly longer than the average detection distance determined by Sorensen (unpublished data, 1993), which was about 109 m for a new 0.5-m-wide pavement marking (converted to automobile illumination as described by Sorensen). Most pavement marking configurations and line widths appear to provide average detection distances that are above the minimum required visibility distance value of 80 m recommended by Sorensen.

The visibility distance of 58 m for 2-year-old painted pavement markings under dry, clear weather conditions shown previously (*7*), appears to be close to the above-mentioned shortest detection distance value of 55.46 m, which was obtained using the new 0.05-, 10.98/1.22-m yellow dashed line.

Harkey et al. (*9*) found a significant driver performance difference between the 10.98/1.22-m dashed-line configuration and the 9.15/3.05-m dashed-line configuration, including edge lines. The results of Study 3, however, indicate no significant detection distance differences between comparable 10.98/1.22-m and the 9.15/3.05-m dashed-line configurations.

Detection distances have been established for the various configurations of 0.05-, 0.1-m, 0.13-, 0.2-m, and 0.25-m-wide pavement markings. Psychometric curves have been established to show the distances at which a certain percentage of population can detect a given pavement marking configuration. Such curves may have a practical importance in the establishment of minimum retroreflectivity standards for the application of pavement markings on highways and on resurfacing zones.

The generally longer distances for the detection of the end of the pavement markings can be attributed to the fact that the subjects already have visual contact with the line, which most likely simplifies the search for the end. For the detection of the begin of the markings, however, the subject has to visually search for the begin of the markings, which is a cognitively more demanding task, thus resulting in somewhat shorter visibility distances.

Overall, it appears that the pavement markings located to the right of the car are detected more easily and at distances farther away when compared with the corresponding markings placed to the left of the car. This could be attributed to the alignment of the automobile low beams, which point approximately 2 degrees down and 2 degrees to the right, thus favoring the right side. It also appears from the experimental results that the white pavement markings provide average detection distances that are slightly longer than the average detection distances for the yellow pavement markings, thus indicating that any other color than white for the markings will result most likely in a slight reduction of the detection distance. The results presented in this paper were obtained using young and healthy (those most close to ideal visual capabilities) drivers and should not be generalized to other driver age groups without applying proper visual adjustment factors.

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