MINIMUM REQUIREMENTS FOR ADEQUATE NIGHTTIME CONSPICUITY OF HIGHWAY SIGNS

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Final Report

Report No. UMTRI-88-8
February 1988

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTRI-88-8	PB88 179841/AS	

4. Title and Subtitle	5. Report Date
MINIMUM REQUIREMENTS FOR ADEQUATE NIGHTTIME CONSPICUITY OF HIGHWAY SIGNS	February 1988
	6. Performing Organization Code: 362829
7. Author(s): Paul L. Olson	8. Performing Organization Report No.: UMTRI-88-8
9. Performing Organization Name and Address: The University of Michigan Transportation Research Institute, 2901 Baxter Road, Ann Arbor, MI 48109-2150	10. Work Unit No.
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address: 3M Company, 3M Center, St. Paul, MN 55144	13. Type of Report and Period Covered: Final, 9/1/85 - 12/31/87
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A laboratory and field study were conducted to assess the minimum luminance levels of signs to ensure that they will be detected and identified at adequate distances under nighttime driving conditions. A total of 30 subjects participated in the field study, driving a car on public roads, and reporting when they could identify the test signs, which were positioned at random points along the side of the road. Variables considered were: surround complexity, subject age, retroreflective efficiency, and sign color. A study was also carried out to measure the effect of subject expectancy.

All of the independent variables, including color, were found to have an effect on sign conspicuity. For example, sign retroreflectivity had to be increased by a factor of about ten to achieve equivalent conspicuity when going from areas of low to high complexity, and a factor of about three to compensate for the effect of subject age. The colors red, orange, green, and blue had substantially greater conspicuity than did yellow with equivalent retroreflectivity. Possible reasons for the latter finding are discussed.

Minimum retroreflectivity recommendations are presented for stop signs, construction area warning signs, warning signs, and overhead guide signs, together with the rationale for their development.

17. Key Words	18. Distribution Statement
Signs, highway signs, conspicuity, color, driving age, visibility	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	114	MF; PC $19.95/$6.95

ACKNOWLEDGEMENTS

This was a complex project that could not have been carried out without the assistance of a number of people. Appreciation is gratefully extended to Henry Woltman of 3M, who monitored the project, provided technical data and equipment, and read and reread the final report, and to Michael Sivak of UMTRI who provided invaluable advice and read an early draft of the report. Dennis Battle, Ella Elias, and Leslie Pettis helped out in the field studies, placing signs, and enduring bugs, bad-tempered dogs, curious citizens, weather changes, and goofs by the experimenter without complaint. Their hard work, reliability, and cooperation made the field studies possible, and is very much appreciated.

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INTRODUCTION

Signs are a primary means of communicating a variety of important and useful items of information to drivers. As a first step in fulfilling this function, signs must come to the attention of approaching motorists. They must do so reliably, at an adequate distance, and under all reasonable operating conditions.

This attribute of signs is commonly referred to as "conspicuity." While most people agree that conspicuity refers to the attention-gaining characteristics of an object or condition, there are a number of specific definitions one may encounter, depending on the problem area. Hence, it is appropriate to begin this report by defining what the term means in the context of the work to be described.

A definition specifically oriented toward signing has been advanced by the CIE-Division 4 (1986). They define conspicuity as "the attribute of an object within a visual context which ensures that its presence is noticed at the pre-attentive level of processing." This definition introduces an important concept, that of driver expectancy. In most cases, it must be assumed that drivers do not expect to encounter a sign. As a consequence, when a sign enters their field of view, the driver's vision and conscious attention may be directed elsewhere. A conspicuous sign will be noted by the driver at an adequate distance even under these conditions.

Persons carrying out research or having an interest in applications require a more specific definition. For example, Cole and Jenkins (1980) define a conspicuous object as "one that will, for any given background, be seen with certainty ($p > 90\%$) within a short observation time ($t = 250$ ms) regardless of the location of the object in relation to the line of sight." This is an operational definition tailored to a specific research methodology. The key point is that it defines conspicuity in terms of a response level ($> 90\%$) and operating conditions. The choice of a response level is arbitrary but necessary, since the presumably ideal response level of 100% cannot be achieved in practice. For purposes of the current study the Cole and Jenkins definition will be modified somewhat and adequate conspicuity will be defined as that which yields 85% or better identification at a distance from the sign appropriate for the required response. An 85th percentile response criterion will be used because that is a common level in U.S. practice.

For obvious reasons conspicuity is an important attribute for road signs. This is true under both daytime and nighttime operating conditions. Over many years conventions have developed regarding the placement of signs and use of materials. Although the conventions vary from one jurisdiction to another, particularly as regards the application of the sign or choice of materials, long experience suggests that signs are critical for safety and may have inadequate conspicuity under certain conditions. A key question is when should signs be replaced because they are no longer adequately conspicuous? What part does the sign surround play? What of older drivers? These are difficult questions to address experimentally because of the great number of variables that must be considered, and the necessity of estimating the effect of a sign on a driver who does not expect it to be there.

Because of these problems, the few investigations of nighttime sign conspicuity that have been carried out have involved significant compromises. In general, the range of variables that has been examined is quite limited, and the issue of driver expectancy has been neglected altogether. Meaningful work can be done with a limited selection of variables because not all signs or situations are equally important, and reasonable a priori choices can be made to restrict the work to those that are judged to be important. However, unless the issue of subject expectancy is dealt with, the resulting data are likely to be optimistic. That is, sign retroreflectance recommendations based on such work will probably be lower than is actually required to achieve the desired response levels under real-world conditions. Hence, some effort to assess the effect of expectancy level is necessary.

The purpose of the investigation described in this report was to establish minimum candlepower values for all types of retroreflective signs in settings representative of cluttered urban, suburban, and dark rural environments, using subjects of all ages. The work was carried out in four stages:

1. The first stage was a laboratory study, which was designed to investigate certain relationships such as color, sign size, and the effects of borders and legends. The methods and results of the laboratory study are summarized in Appendix C.

2. Stage two was a field study in which measures were taken of the distance at which subjects could detect and identify the color of signs in real-world environments.

3. Stage three was an investigation designed to develop a correction for the expectancy level of the subjects in the field study.

4. In stage four the information gathered in the first three stages was analyzed in detail, and a variety of techniques were used to develop recommendations for

minimum retroreflectance specifications for different types of signs in a variety of settings.

FIELD STUDY

Introduction

The field study was the primary data-gathering effort in the sign conspicuity program. Its purpose was to develop information on the relative nighttime conspicuity of signs in a real-world setting. The test was run on public roads, with the subject driving. The test signs came in different retroreflectances and colors, and were presented in environments of varying complexity. Measures were made of the distance at which subjects could distinguish the signs and identify their color.

Method

Independent variables. The independent variables in the study were: (1) the retroreflective properties of the sign, (2) sign color, (3) sign surround complexity, and (4) subject age.

Five levels of retroreflective efficiency were available in one color (yellow). These ranged from SIA 750 to SIA 16. Three of these were used in each of the levels of surround complexity.

Yellow was the primary sign color used in the study. Three measures were taken from each subject on each of the yellow signs used at each level of surround complexity. Some data were also taken on signs that were orange, red, green, blue, and white. However, these other colors did not appear at all levels of surround complexity.

Three levels of surround complexity were used. These will be referred to as high, medium, and low complexity areas, respectively.

Subjects were classified into two age groups, young and old. The young subjects ranged in age from 20 to 46 years, the old subjects from 58 to 75 years. There were fifteen subjects in each age group, for a total of thirty. All were licensed drivers, and drove regularly at night.

Dependent variable. The dependent variable was the distance from the sign at which the subject could identify the test sign and its color.

Equipment. A number of blank signs were fabricated for use in this project. Each was 30 inches square. They were faced with retroreflective material in various grades and colors. Table 1 is a listing of the signs used.

TABLE 1

SIGNS USED IN FIELD STUDY

Type of Material	Color	SIA*
Cube-Corner	Yellow	750
Encapsulated Lens	Yellow	250
	Green	64
	Red	64
Enclosed Lens	Yellow	77
	Yellow	40**
	Yellow	16**
	Green	15
	Blue	11
	Red	41
	Orange	38
	White	115

* Retroreflectance at $-4°$ entrance and $0.2°$ observation angle.
** These values were arrived at by overprinting a dot pattern on standard enclosed-lens material.

The SIA values (Specific Intensity per unit Area, SIA, or Coefficient of Retroreflection, R') listed in Table 1 were measured before the field testing using an Advanced Retro Technology Model 920 Field Retroreflectometer. A number of measures were taken on each panel. Following the test, panels were measured in a photometric range in accordance with ASTM Standard E810-81 and were found to be slightly lower, but within 10 percent of the initial values. The differences are probably due to differences in test methods, and to slight scuffing of the panel surfaces that occurred in handling and transit.

The five yellow signs, with SIA values of 750, 250, 77, 40, and 16 respectively, were the basic set on which most of the data are based. Three of these were used at each level of site complexity. Each subject was exposed to each of the yellow signs three times in each complexity area.

In addition, in each complexity area, subjects were exposed once to each of three other signs having colors other than yellow. It was intended to use all colors at least once, and one color (green) in all three areas. Otherwise, the choice of signs in colors other than yellow in the different complexity areas was governed by the opportunity to investigate color differences with minimum differences in SIA. Where such comparisons were made the signs appeared at the same location within a given area. Table 2 is a listing of signs assigned to the different complexity areas.

TABLE 2

LISTING OF SIGNS BY COMPLEXITY AREA

High Complexity		Medium Complexity		Low Complexity	
Color	SIA	Color	SIA	Color	SIA
Yellow	750	Yellow	250	Yellow	77
Yellow	250	Yellow	77	Yellow	40
Yellow	77	Yellow	40	Yellow	16
White	115	Red	41	Blue	11
Red	64	Orange	38	Orange	38
Green	64	Green	64	Green	15

Note: All sign panels were 30 inches square.

The test vehicle driven by the subjects was a 1981 full-size station wagon. It was equipped with a distance measuring system that worked off the left-front wheel, producing 4 counts (1.74 feet or 0.53 meters per count) per revolution.

The test vehicle was also provided with a precision voltage control system, by means of which the lamps were operated at 12.8 volts throughout the test. The headlamps were number 6052's (large rectangular sealed beams, meeting FMVSS 108 requirements), mounted with their centers 30 inches above the pavement. They were aimed with calibrated mechanical aimers.

Test areas. The complexity of the surround in which a sign is placed can have a significant effect on the probability of its being detected and/or the distance at which it will be detected and identified. Three test areas were sought that represented what the investigators judged to be high, medium and low levels of complexity.

The high-complexity area was a busy, four-lane thoroughfare, lined on both sides with a variety of businesses. There was fixed illumination and a great number of lighted storefronts and advertising signs close to the road. It was about 1.5 miles in length. The speed limit was 40 mph on the westernmost part (about one mile), and 35 mph on the remainder. Figure 1 is a photograph of a representative portion of the area.

The medium-complexity area consisted of the east and west ends of the road containing the high-complexity area (total of about 1.5 miles) and about two miles of another road running parallel to it. There were no businesses in this area, and far fewer signs. About half of the route was equipped with fixed illumination. The speed limit was 45 on about half the section, 25 and 35 mph on the rest. Figure 2 is a photograph of a representative portion of the area.

The low-complexity section was a two-lane road in a rural area. There was no fixed illumination, no businesses, and few homes, those being set well back from the road. The section used was about four miles long. The speed limit was 55 mph. Figure 3 is a photograph of a representative portion of the area.

In each complexity area several sites were selected for displaying the signs. The following criteria were used:

a. A minimum 1,000-foot approach of straight and flat roadway.

b. A safe place to park the sign handler's car so that it would be out of sight of the subject.

c. Provide a representative sign surround.

A number of different sites were selected in each complexity area for displaying signs. Since no site was identical to any other site, there was the possibility of differences between signs being confounded by differences between sites. There was no way of completely avoiding this problem. However, the following steps were taken to minimize it:

a. In the preparation stage all sites were viewed under test conditions to make sure there were no obvious problems. Some sites were eliminated in this process. Adjustments to the sign position were made at others.

b. The three presentations of each yellow sign were made at different sites, minimizing the influence of any one site on a particular sign.

c. Signs having different SIA's were presented at the same site, thus allowing an unbiased estimate of the effect of SIA. However, the extent to which this could be done was limited, due to the necessity of keeping the subject uncertain concerning where signs would appear.

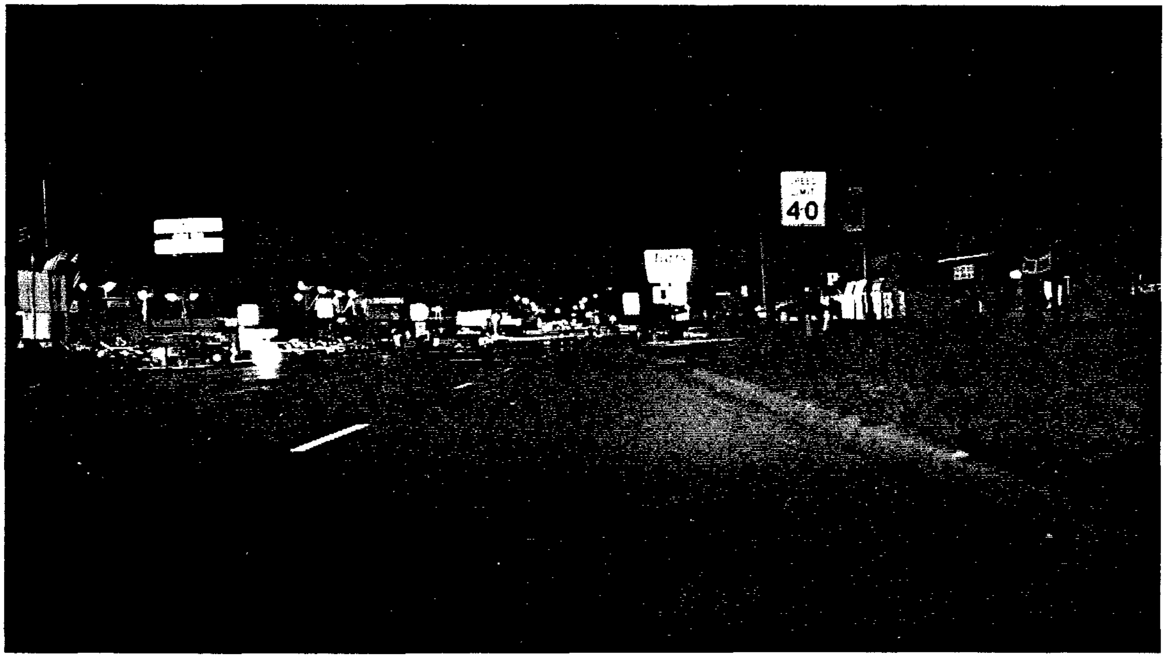

Figure 1. Photograph of high-complexity area.

Figure 2. Photograph of medium-complexity area.

Figure 3. Photograph of low-complexity area.

Means of the sign identification and color-discrimination distances measured at each site in each complexity area are given in Tables 3 and 4. An examination of these tables shows that task difficulty did vary from site to site within a given complexity area. In some cases the differences are fairly large. Clearly, the results that will be obtained in an investigation such as this depend in part on the specific sites at which the experimenter chooses to place the test stimuli. Thus, the results and recommendations to be presented later in this report provide guidelines only generally indicative of performance in different types of surroundings. Engineering judgment is necessary for situations that appear much different from those depicted in Figures 1–3.

Procedure. Subjects were run individually. Each was seated in the test vehicle and told to arrange the seat and mirrors to the best position. The instructions (see Appendix D) were then read. As part of the orientation process the subjects had the opportunity to see the six different color signs side by side at a distance of about 300 feet, using the illumination from the test vehicle's headlamps. The colors were named by the experimenter at that time.

When the instructions had been read and all questions answered, the subject was instructed to drive to the start point for the first area, following specific roads. Along the way two of the yellow signs were presented. This was to be certain the subjects understood the instructions, to allow them to become familiar with how the signs looked in the field, and to encourage them to always be on the lookout for signs. No data were taken on these two presentations.

The signs were positioned by experimental assistants. There were two of these individuals, each of whom was responsible for half of the test route. Each assistant had a car and a number of test signs. They drove from site to site, parked the car, selected the proper sign, positioned themselves next to the road, and watched for the test vehicle (which was distinctively marked with two yellow lights across the roof). When the test vehicle was identified they held up the sign at head height until it passed. They then returned to their car, stored the sign, and drove to the next site.

The subjects made six passes through each area. In the low-complexity area this was accomplished simply by making three round trips. In the other areas the subjects typically drove down one street through the high- and medium-complexity area, and then drove back through the medium-complexity area on the parallel street. Signs were encountered at random points on each pass and normally not at the same points on the following pass.

TABLE 3

MEAN SIGN IDENTIFICATION DISTANCES IN FEET AS A FUNCTION OF AREA COMPLEXITY AND SITE

Sign		Area Complexity																					
		High Site Number						Medium Site Number							Low Site Number								
Color	SIA	2	3	4	5	6	7	1	8	9	10	11	12	13	1	2	3	4	5	6	7	8	9
Y	750			828	977	1092																	
Y	250			836	780		588			798	887		852										
Y	77	458	760			633		767			670			666	1000			1265	946				
Y	40								523	676	602				748					857			847
Y	16															688					611	726	
W	115						457																
R	64		911																				
R	40											811											
O	40										824									1062			
G	64		889					844															
G	15																					1039	
B	11																1196						

TABLE 4

MEAN COLOR IDENTIFICATION DISTANCES IN FEET AS A FUNCTION OF AREA COMPLEXITY AND SITE

Sign		Area Complexity																					
Color	SIA	High Site Number						Medium Site Number							Low Site Number								
		2	3	4	5	6	7	1	8	9	10	11	12	13	1	2	3	4	5	6	7	8	9
Y	750			744	844	1018																	
Y	250			693	632		500			645	746		683										
Y	77	312	623			467		618			513			526	695			929	678				
Y	40								419	590	415				548					652			558
Y	16															457					335	442	
W	115						390																
R	64		793																				
R	40											433											
O	40										372									498			
G	64		817					865															
G	15																					820	
B	11																514						

When the subjects detected a sign they were required to call out "sign." The experimenter in the back seat then started a distance counter. When the subject could identify the color of the sign he/she called out the color, and the experimenter started a second counter if the identification was correct. If not, the counter was started when the subject made the appropriate correction, and the error was noted. Both counters were stopped as the sign was passed, and the experimenter wrote down the values and reset the counters.

Every effort was made to remain sufficiently isolated from other vehicles that the sign would be revealed by the test car's headlamps alone. This was generally not much of a problem in the low- and medium-complexity areas. However, it was a significant problem in the high-complexity area, where traffic flow was relatively high even late in the evening. Each time they entered the road subjects were advised to wait until other traffic had gone well past. Often it was necessary to ask the subject either to slow down to permit the gap between their own and lead vehicles to become greater, or to pull off the road and wait until traffic was clear. Using these techniques, on most occasions the sign was seen without interference from other traffic. Where there was interference a note was made of that fact. These data were deleted from the analysis.

In the low-complexity area the main problem was oncoming traffic. It was not possible to pace the test car to avoid glare from oncoming traffic. Instead these events too were noted, with the intent that they would be presented separately. However, the distances measured under glare were indistinguishable from those without glare and the data were combined.

Interpretation of recorded distances. In the analysis paradigm that will be used later, five steps will be assumed necessary for drivers in interacting with highway signs (Perchonok and Pollack, 1981). These are: (1) detection, (2) identification or recognition, (3) decision, (4) response, and (5) maneuver. The first two steps correspond to the four steps in visual perception described in ASTM F923-85, "Standard Guide for Understanding the Properties of High Visibility Materials for Individual Safety," i.e.: (1) detection, (2) fixation/attention, (3) recognition, and (4) localization.

The subjects in this study were required to: (1) detect the test signs, (2) identify them as test signs, and then (3) call out "sign." The experimenter then pressed a button to start the distance counter. With the exception of the reaction time of the experimenter in starting the counter, the values recorded in this study will be assumed to correspond to identification distance, or response distance for signs leaving no choice of response to the driver (e.g., a stop sign). Hence, the term "sign identification distance" will be used in the analyses to follow. The distance at which the subject could correctly discriminate the color of the sign will be referred to as "color identification distance."

In another section of this report a study is described that was concerned with the development of a correction for the expectancy levels of subjects involved in the field study. That study was conducted in such a way that it compensated for experimenter response time as well. Hence, no attempt will be made to apply such a correction to the results that will be presented in the next section.

Results

Sign identification distance. A summary of the sign identification distance results is given in Table 5. The values shown in this table are mean identification distances for all 30 subjects for each color and SIA level in each complexity area. For the yellow signs only, it will be noted that mean identification distance varied directly with SIA and inversely with site complexity. For colors other than yellow (with the exception of white), the main point of interest is that the mean identification distances are substantially greater than for the yellow sign having the most comparable SIA. This point will be raised again later under the heading "Color as a Factor in Sign Identification Distances." The presentation of results will begin with data obtained from the yellow signs.

Normal probability distributions of identification distances for all 30 subjects are shown in Figures 4, 5, and 6. There is one figure for each complexity area. These figures show the percentile associated with each identification distance for each sign SIA. For example, the 85th percentile distance (i.e., a distance exceeded on 85% of the trials) in the high-complexity area for the SIA 750 sign was about 500 feet. It was about 400 feet for the SIA 250 sign, and about 275 feet for the SIA 77 sign. This format will be used for all figures presented in this section of the report.

It is evident from Figures 4 through 6, as it was in Table 5, that sign identification distance varies both as a function of SIA and surround complexity. Figure 7 shows the relationship between identification distance and surround complexity for the SIA 77 yellow sign, the only one to appear in all three complexity areas. The differences are substantial. For example, for this particular sign the 85th percentile identification distances are about 275, 400 and 600 feet in the high-, medium-, and low-complexity areas respectively.

Figure 8 provides a comparison of the performance of the highest SIA sign in each complexity area. Although these signs span a range of nearly ten to one in terms of SIA, the associated luminance difference is required to provide equivalent performance in areas

TABLE 5

MEAN SIGN IDENTIFICATION DISTANCES FOR ALL SUBJECTS AS A FUNCTION OF SIGN COLOR AND AREA COMPLEXITY

Sign		Area Complexity		
Color	SIA	High	Medium	Low
Y	750	965		
Y	250	735	845	
Y	77	617	701	1070
Y	40		600	817
Y	16			675
W	115	457		
R	64	911		
R	40		811	
O	40		824	1062
G	64	889	844	
G	15			1039
B	11			1196

having different levels of background complexity. These data illustrate that a single type of retroreflective material cannot function adequately under all operating conditions.

The discussion so far has concerned data from all subjects involved in the study. This can be misleading, because performance differences between the young and older subjects were fairly large. Figures 9 through 14 provide a comparison of the performance of the two groups in each complexity area. As one example of the differences between the age groups, look at Figures 13 and 14, for the low-complexity area. Using the data from the young subjects, any of the signs tested (i.e., SIA 16, 40, and 77) would yield an 85th percentile identification distance of 500 feet. However, to accommodate the older subjects, only the SIA 77 sign met that criterion. The minimum SIA for new, yellow, enclosed-lens retroreflective material is 50. Interpolating from these data, a sign at SIA 50 would be

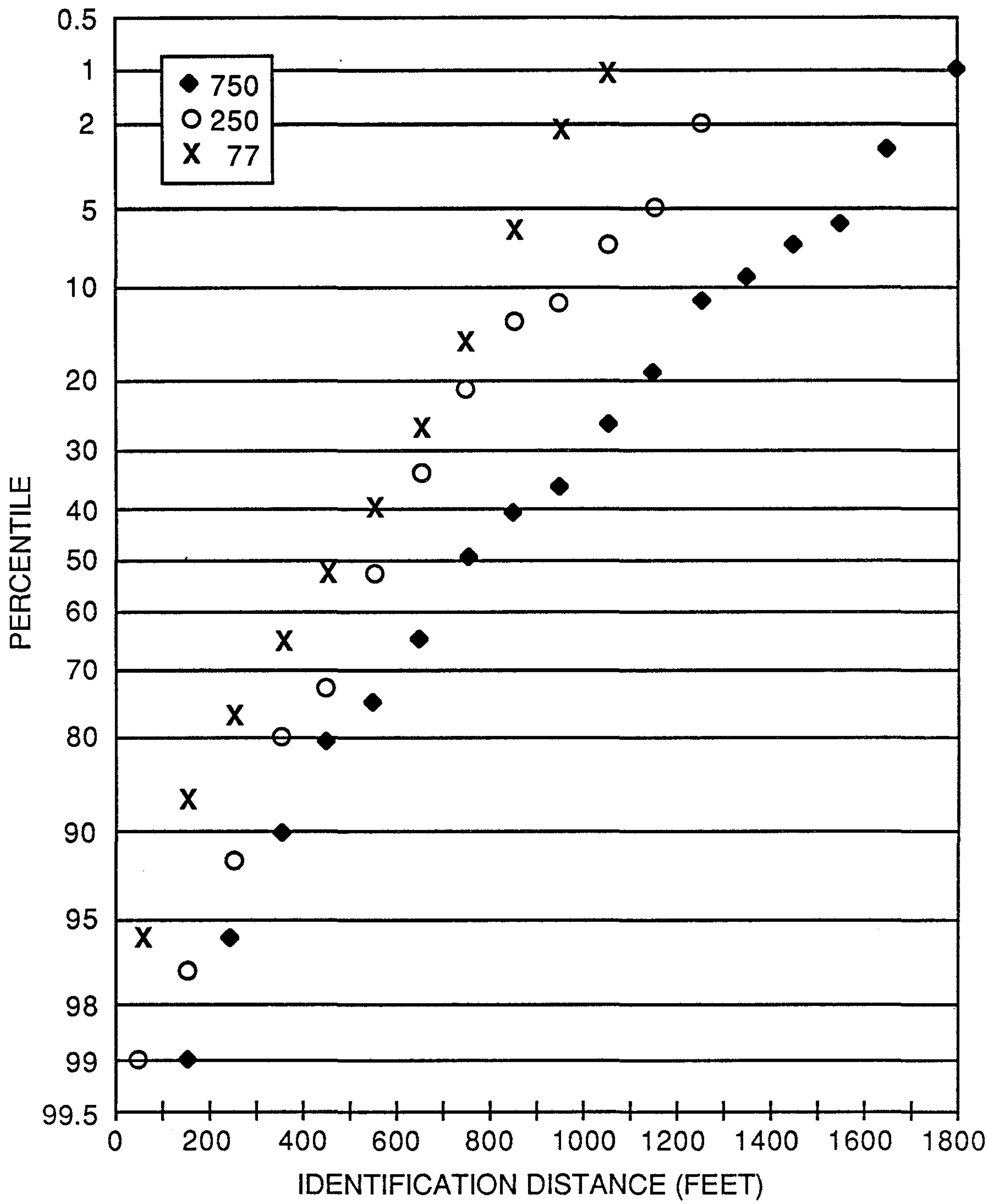

Figure 4. Normal probability distribution of sign identification distances in the high-complexity area.

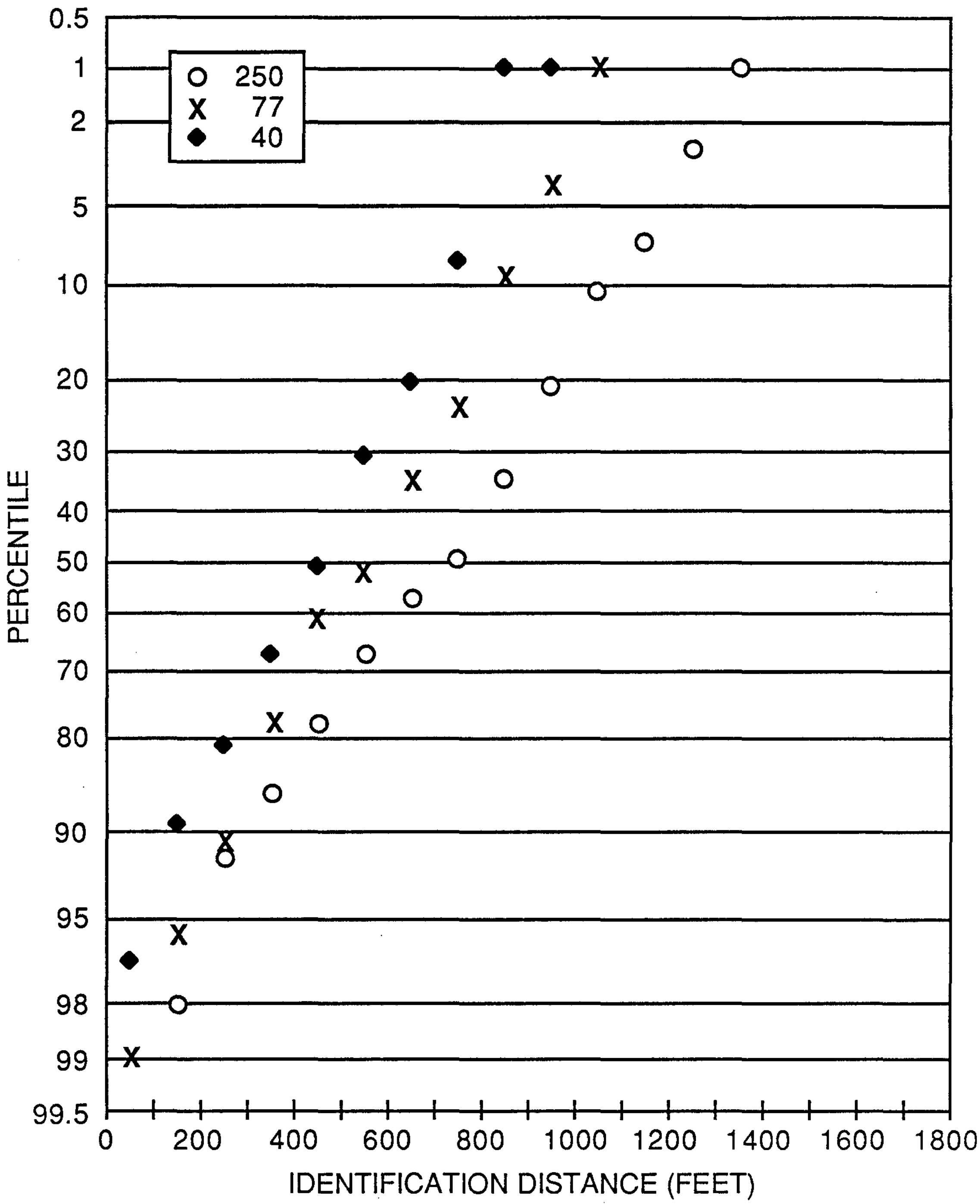

Figure 5. Normal probability distribution of sign identification distances in the medium-complexity area.

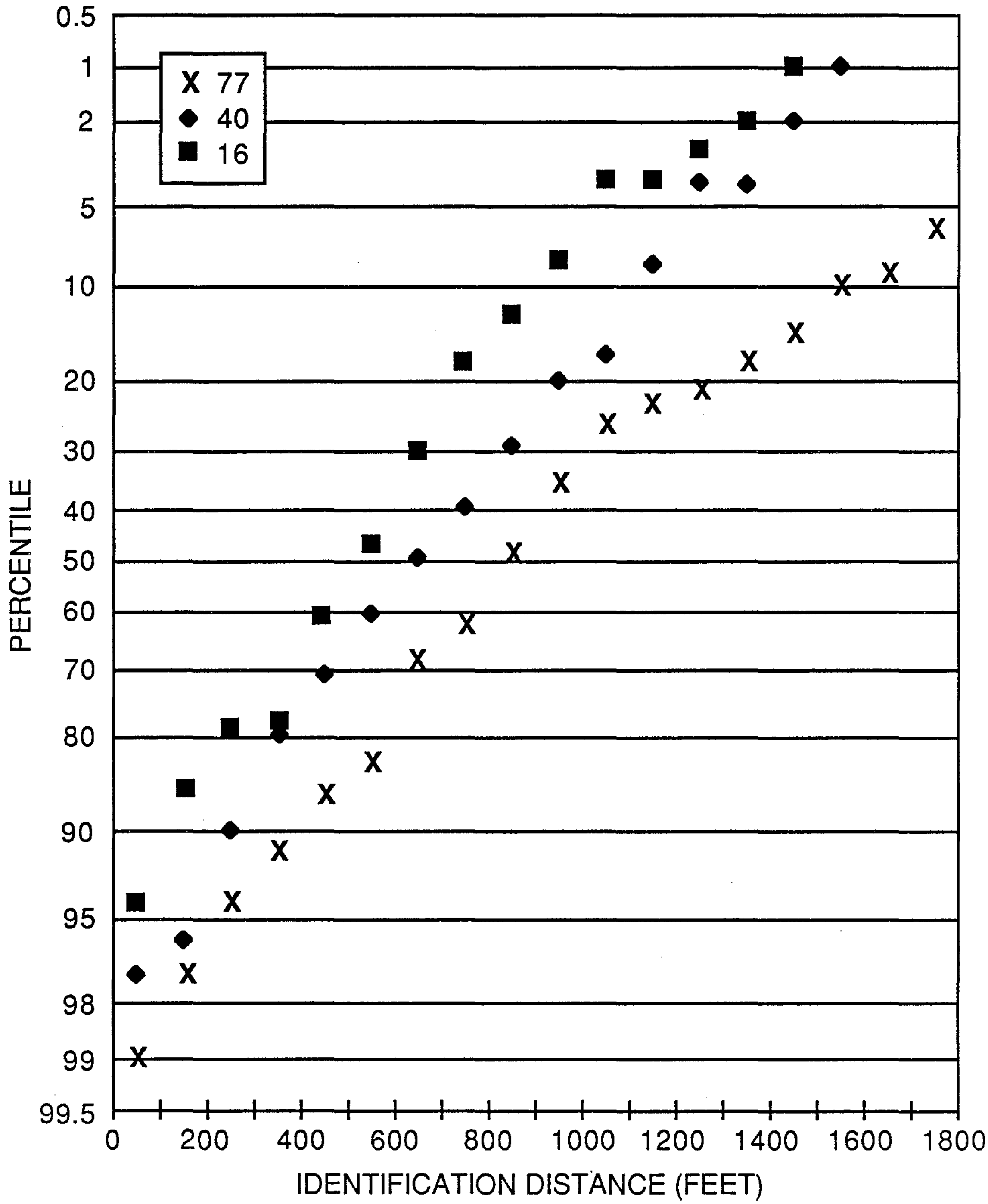

Figure 6. Normal probability distribution of sign identification distances in the low-complexity area.

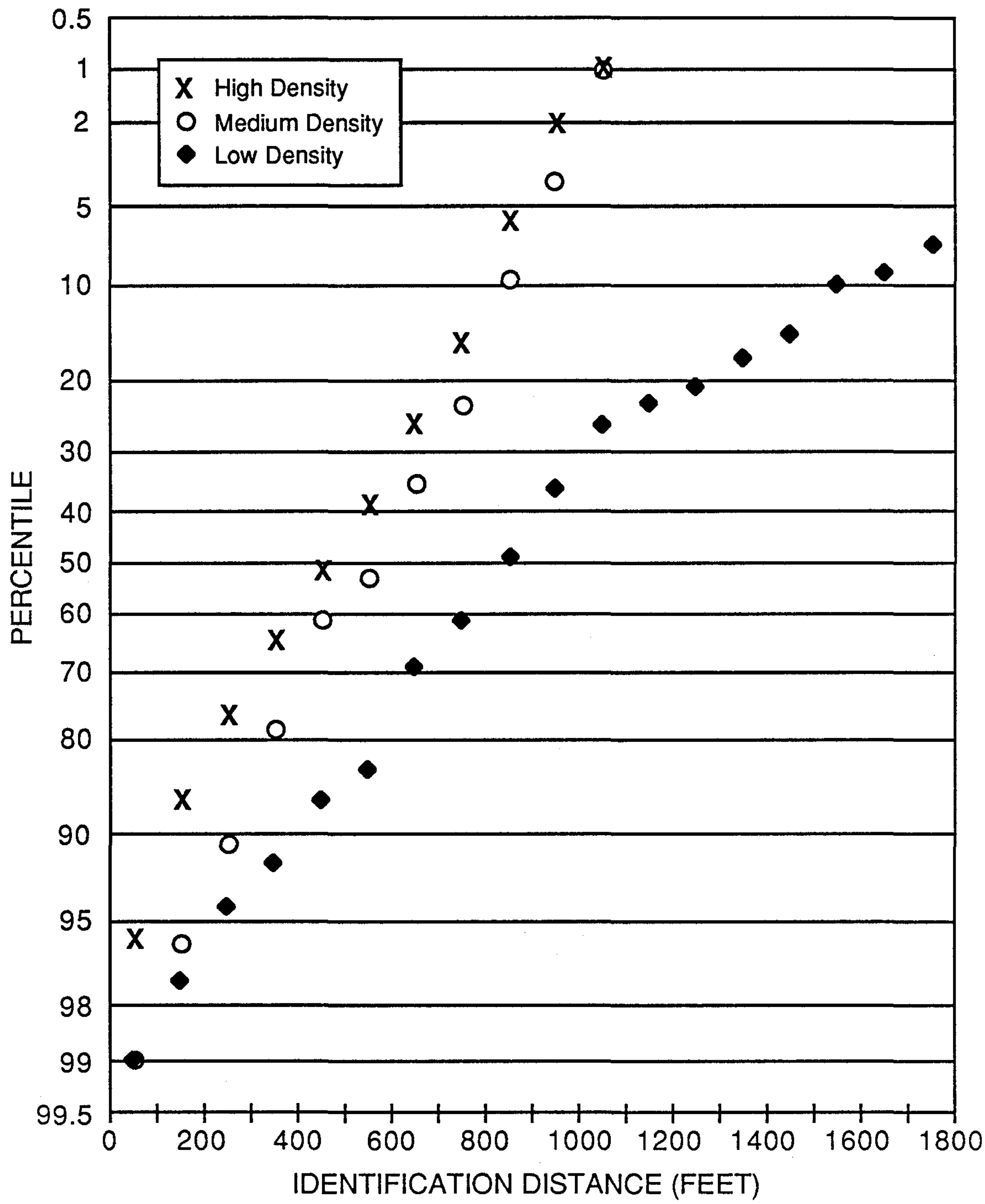

Figure 7. Normal probability distribution of sign identification distances for the yellow SIA 77 sign as a function of area complexity.

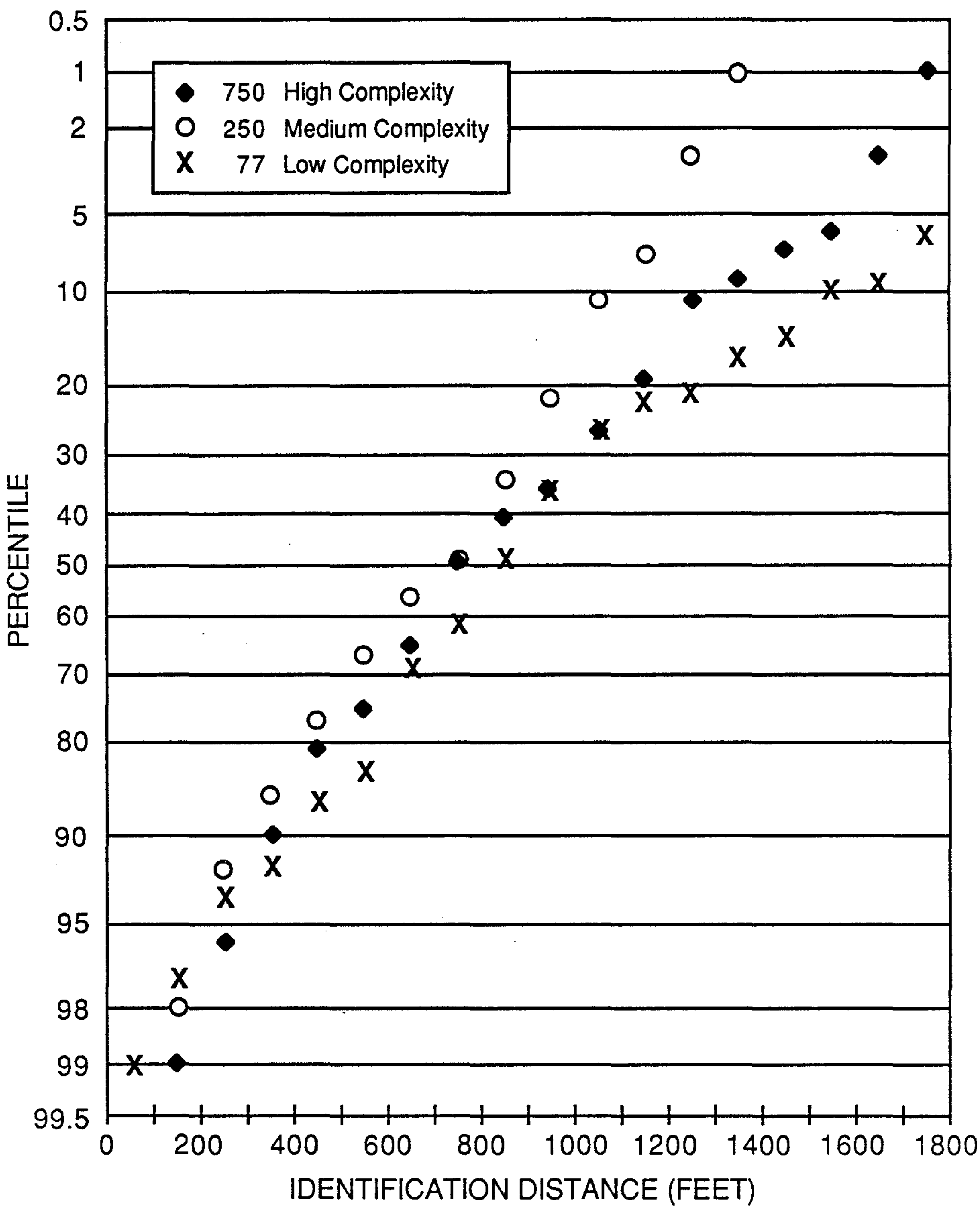

Figure 8. Normal probability distribution of sign identification distances for the highest SIA sign in each complexity area.

identified at less than 500 feet about 30% of the time by these older drivers. By the time the sign had aged to half its new minimum value, SIA 25, about 50% of identification distances by older drivers would be less than 500 feet.

Figure 15 provides a comparison between the two age groups for the SIA 77 sign in the high- and low-complexity areas. At the 85th percentile level, the differences in identification distance between the groups was 150–200 feet.

Figure 16 is a set of six plots, each of which is a comparison of the young subjects with one SIA sign and the older subjects with the next higher SIA sign. Plots a and b are for the high-complexity area, c and d are for the medium-complexity area, and e and f are for the low-complexity area. In order to achieve performance equivalent to the young subjects, the older subjects required signs having about three times greater SIA.

Color identification. Color identification errors were fairly common, particularly with certain signs. However, in most cases, the subjects corrected themselves prior to passing the sign. Table 6 lists the percent of trials on which the subjects initially correctly identified the color as a function of the sign color, SIA, and site complexity. These data are for all 30 subjects. For the yellow signs, identifications were correct about 90% of the time. (The yellow signs may have had an advantage in that the subjects knew that yellow would be the color most frequently used.) There is some evidence that errors were inversely related to sign brightness.

Color identification errors with the other signs were much more variable. In particular, the SIA 40 red (usual error: "orange"), the orange ("yellow"), and blue ("green") signs were associated with large numbers of errors. In many cases errors with the orange and blue signs were not corrected by the subject.

Table 7 lists the mean distance from each sign at which its color was correctly identified for all 30 subjects. Also shown as a percentage is the relationship between this value and the mean sign identification distance listed in Table 5. There is a high correlation between the percentage shown in Table 7 and the probability of a color identification error, as would be expected.

Figures 17 through 19 are normal probability distributions for color identification for all 30 subjects at the three levels of site complexity. The same trends are evident here as in the case of sign identification. Since color identification necessarily followed sign identification, the distances at a given percentile level are shorter.

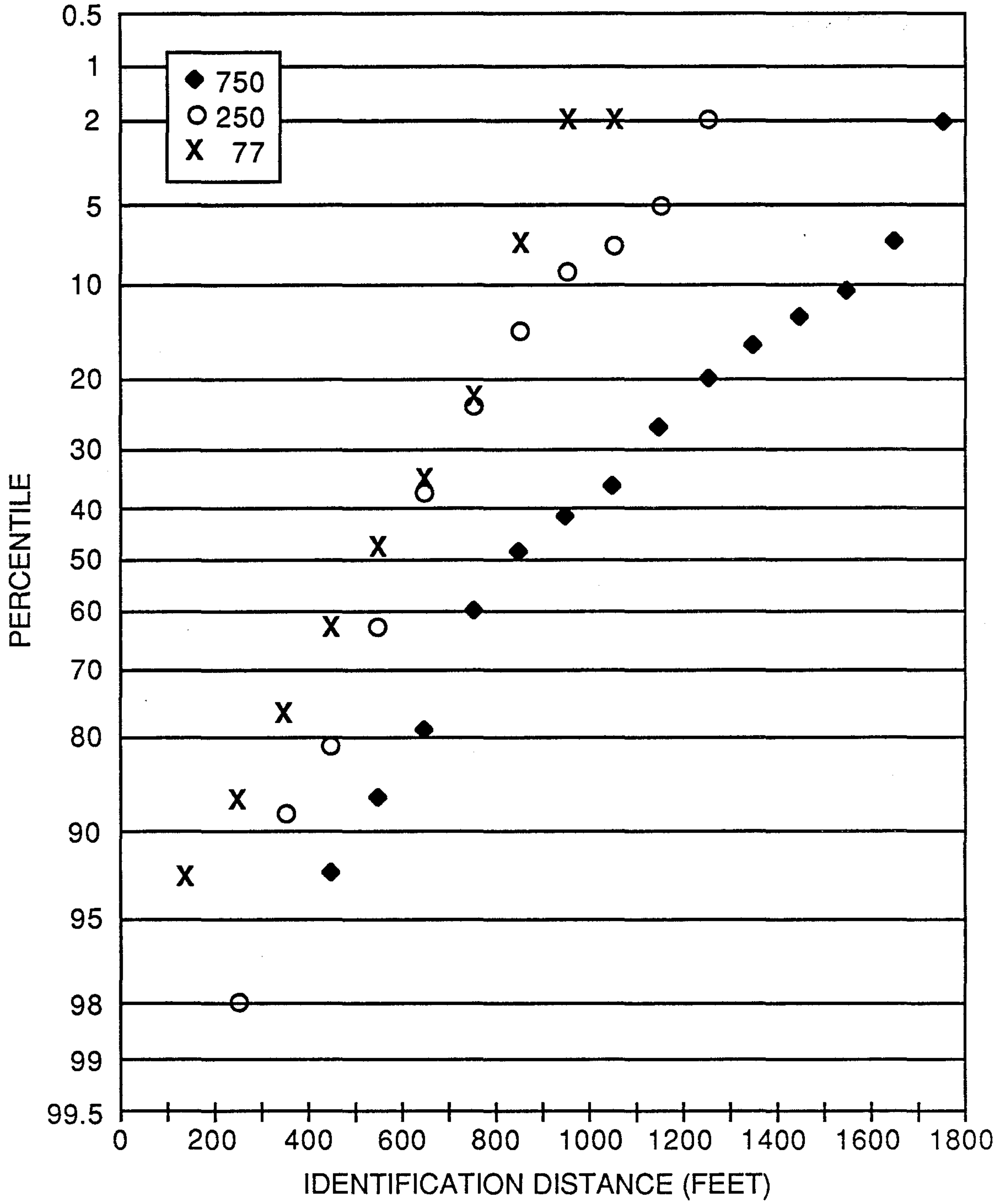

Figure 9. Normal probability distribution of sign identification distances for young subjects in the high-complexity area.

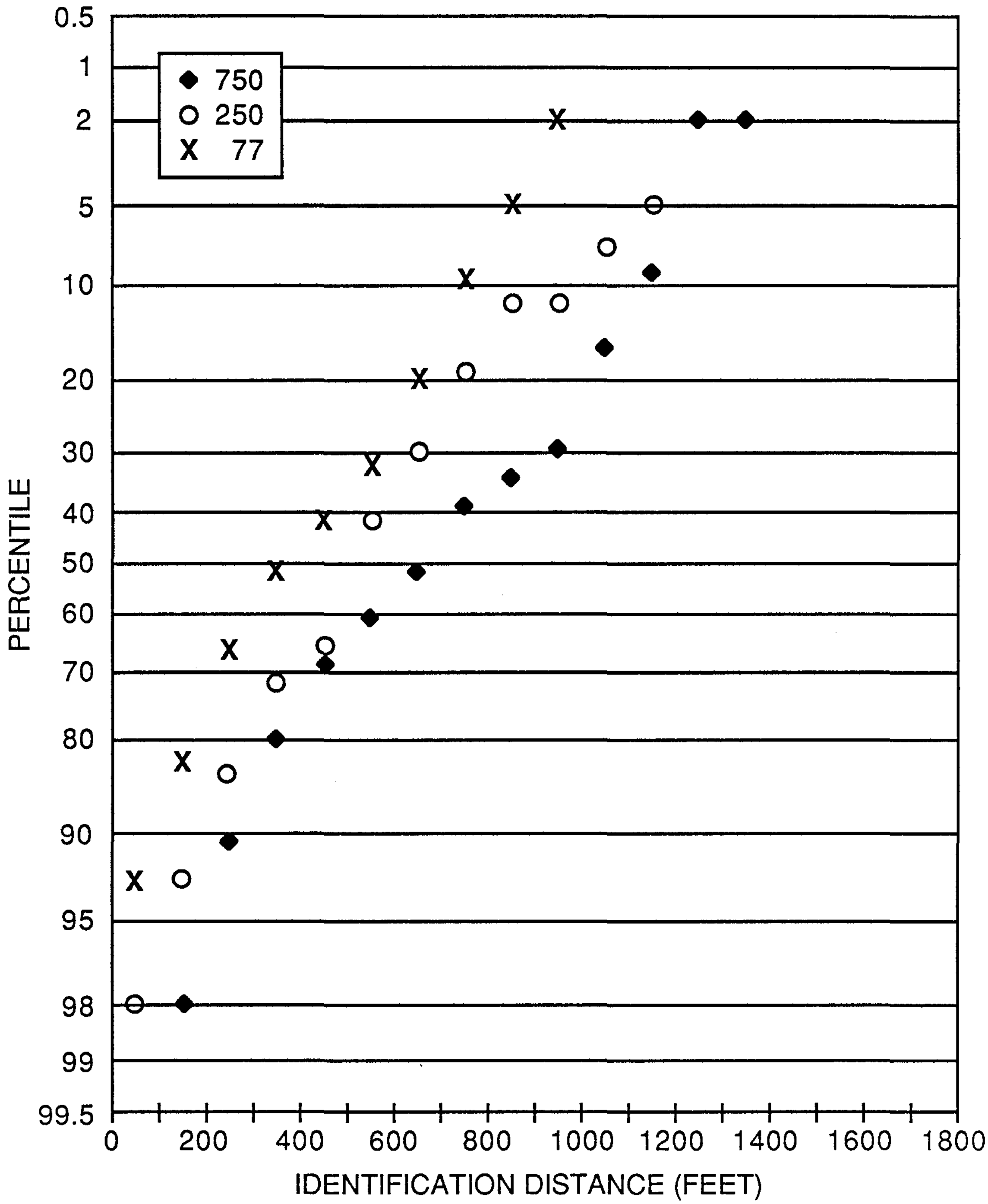

Figure 10. Normal probability distribution of sign identification distances for old subjects in the high-complexity area.

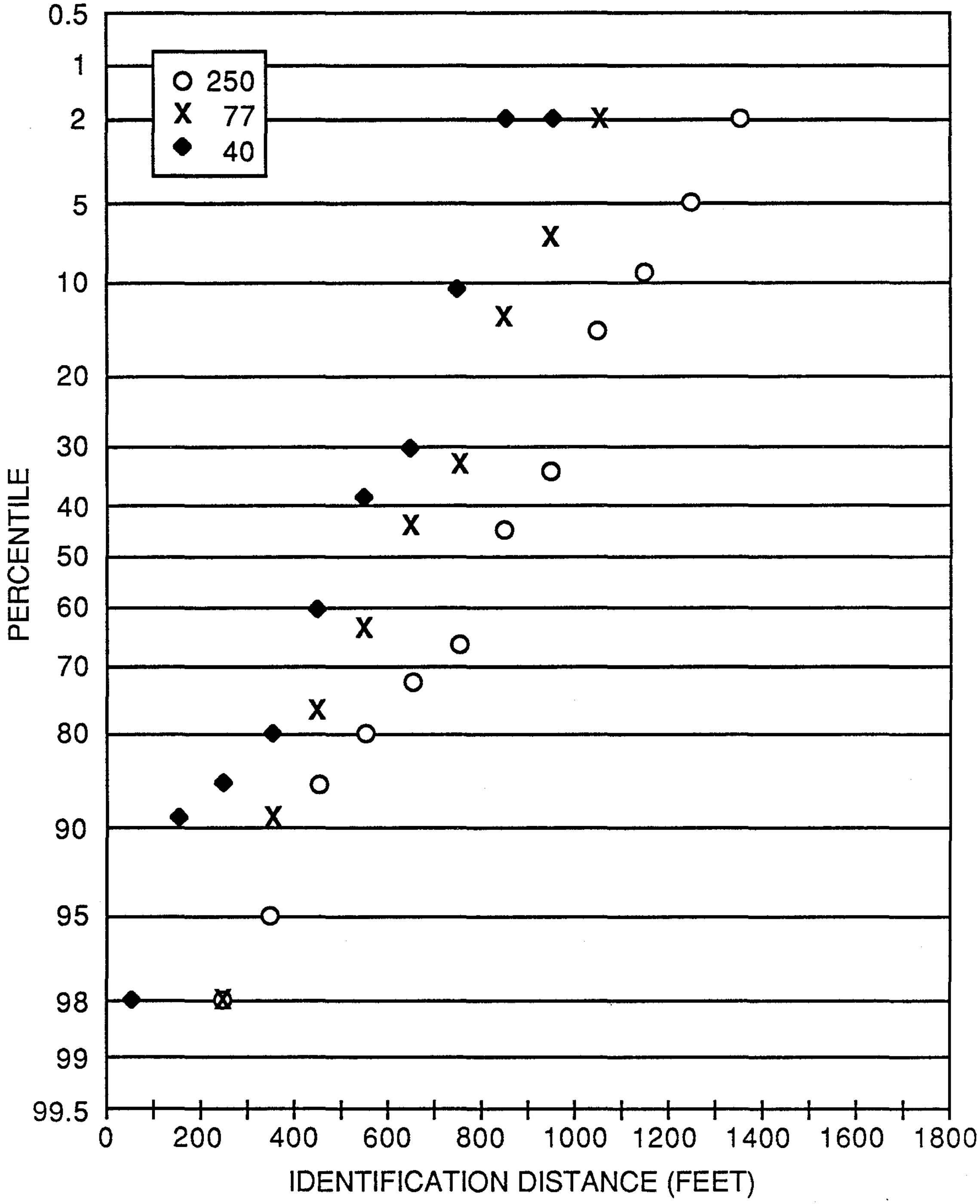

Figure 11. Normal probability distribution of sign identification distances for young subjects in the medium-complexity area.

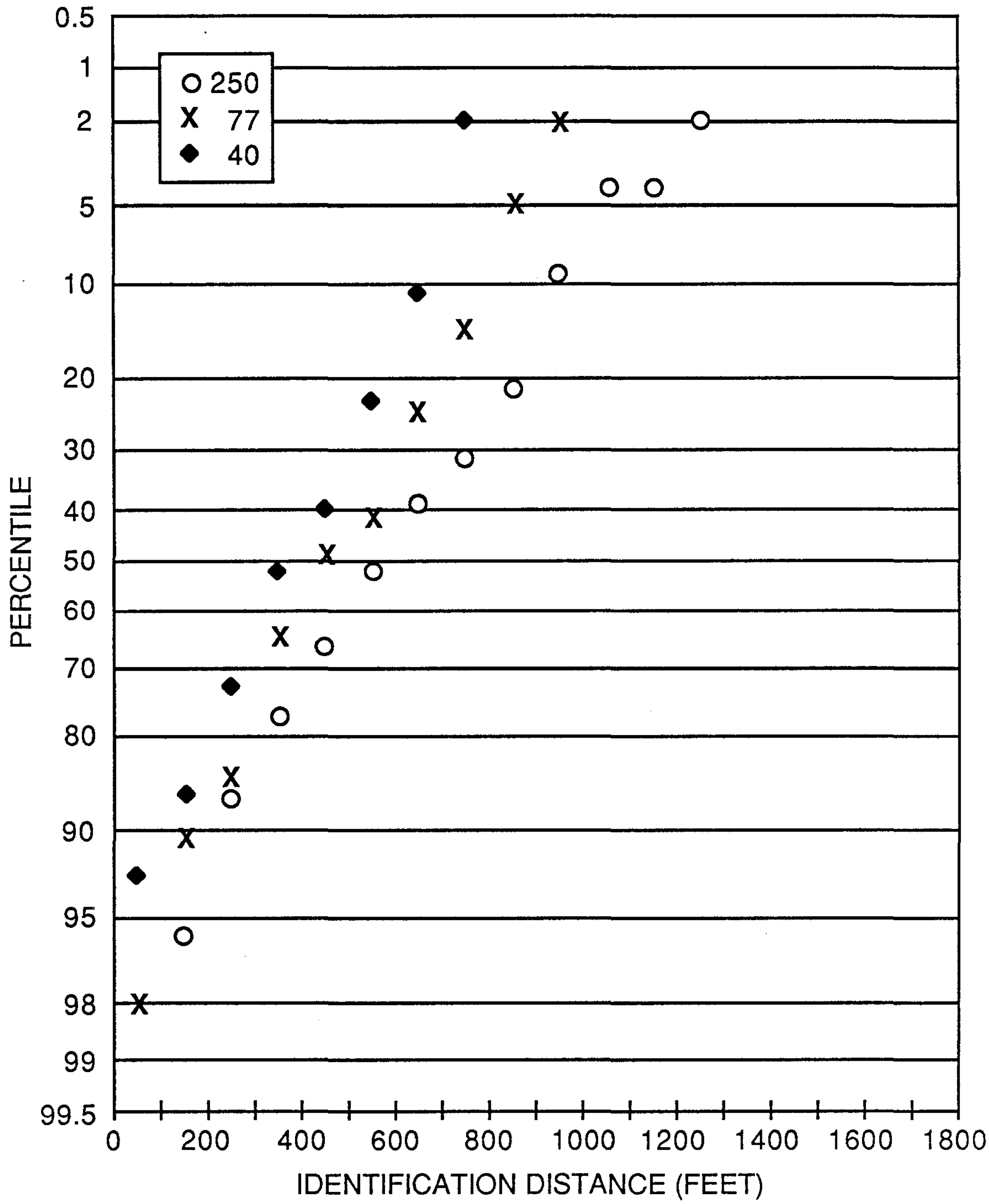

Figure 12. Normal probability distribution of sign identification distances for old subjects in the medium-complexity area.

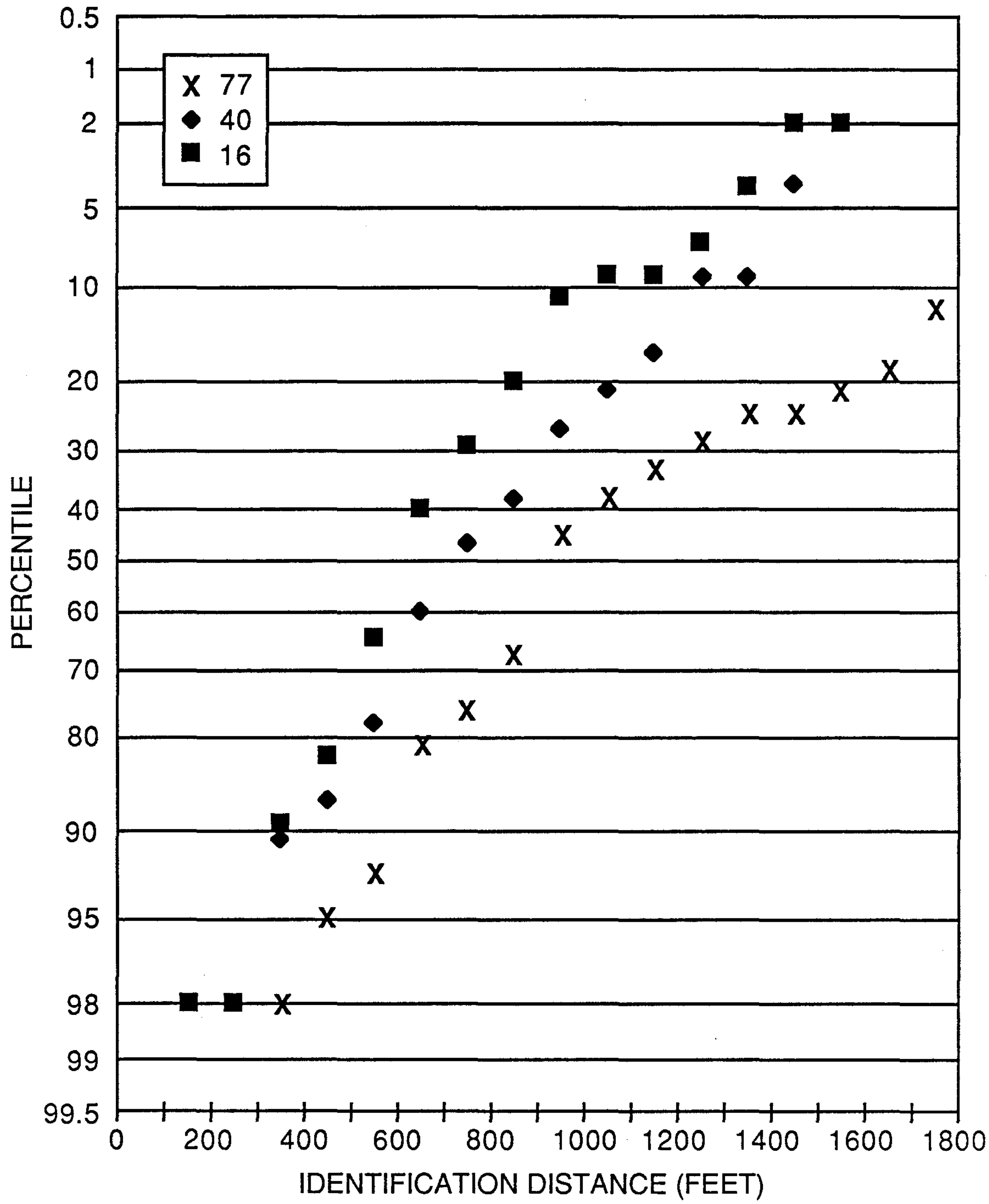

Figure 13. Normal probability distribution of sign identification distances for young subjects in the low-complexity area.

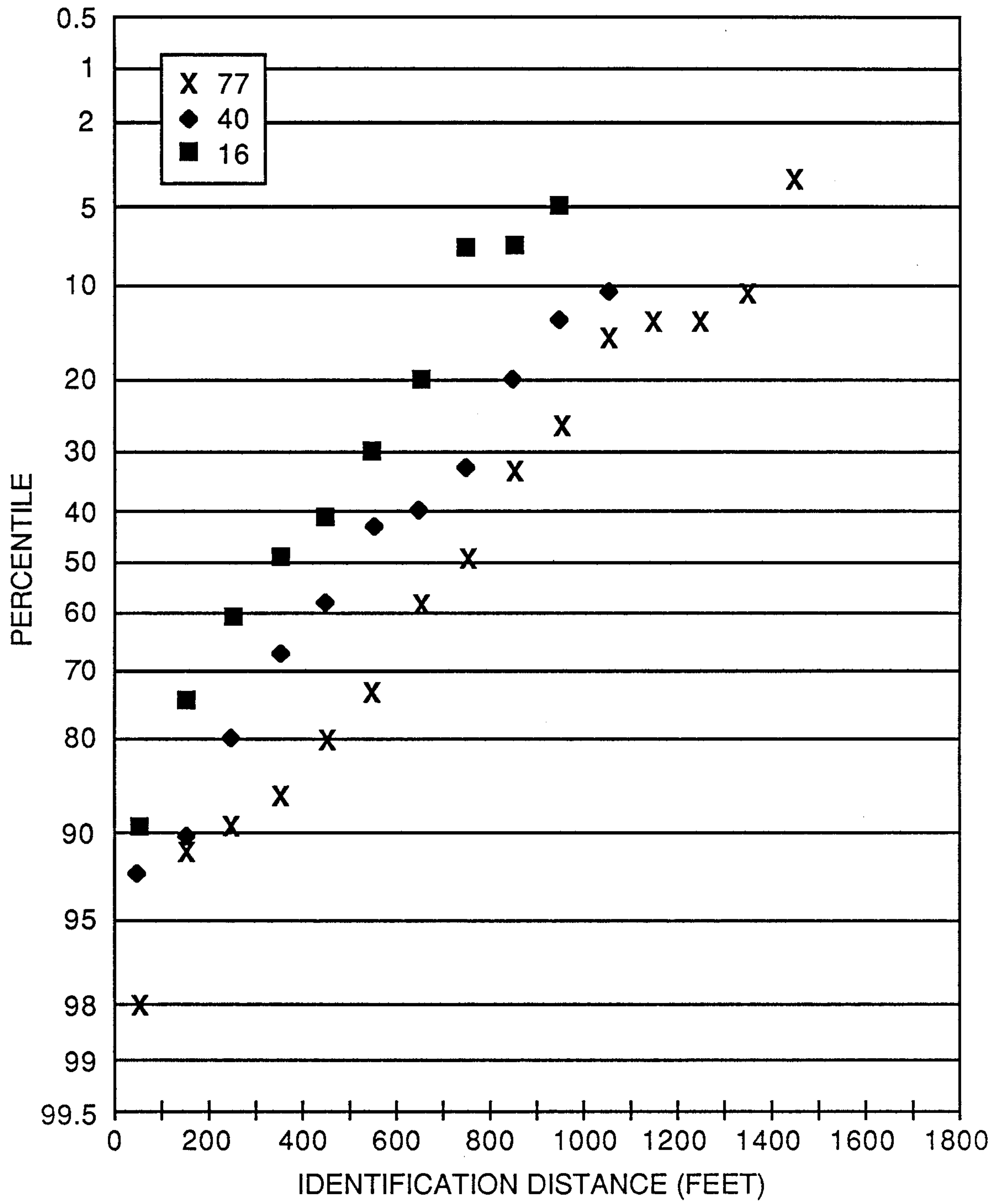

Figure 14. Normal probability distribution of sign identification distances for old subjects in the low-complexity area.

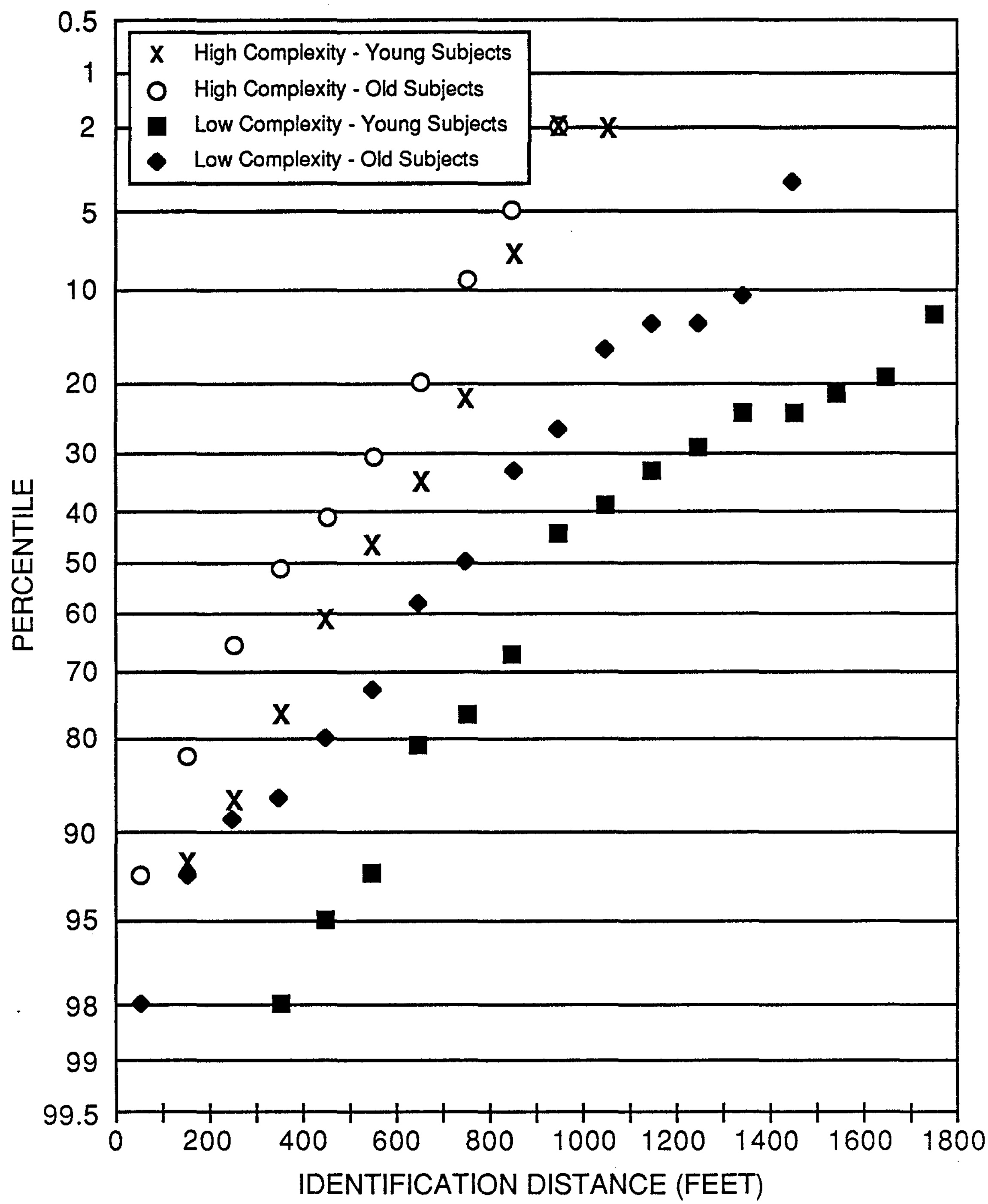

Figure 15. Normal probability distribution of sign identification distances for the SIA 77 sign by the young and older subjects at two levels of area complexity.

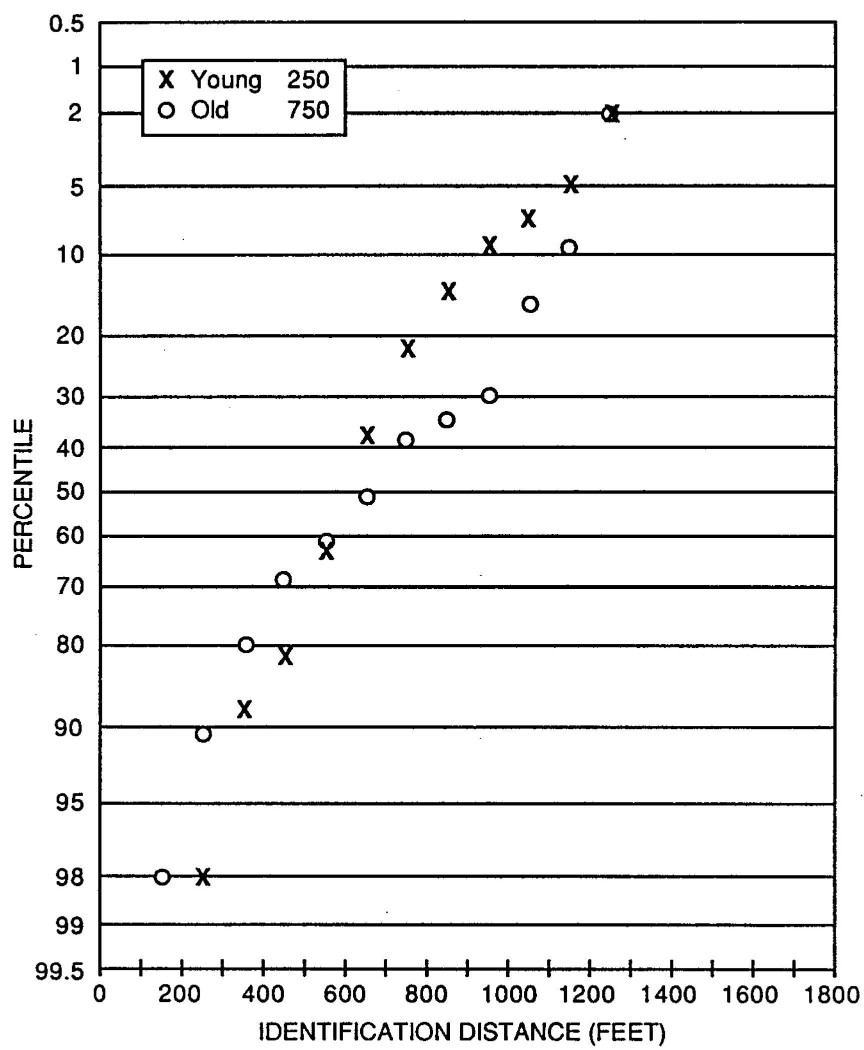

Figure 16a. A comparison of the performance of young and older subjects using different SIA signs in the high-complexity area.

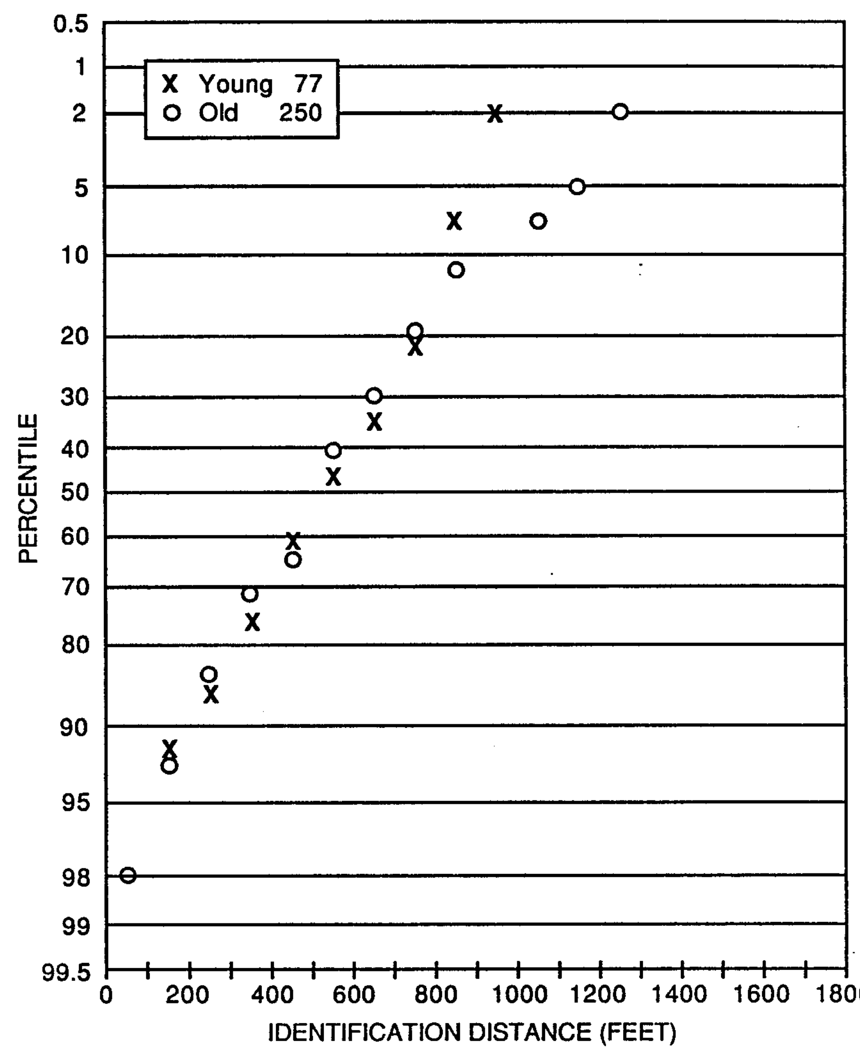

Figure 16b. A comparison of the performance of young and older subjects using different SIA signs in the high-complexity area.

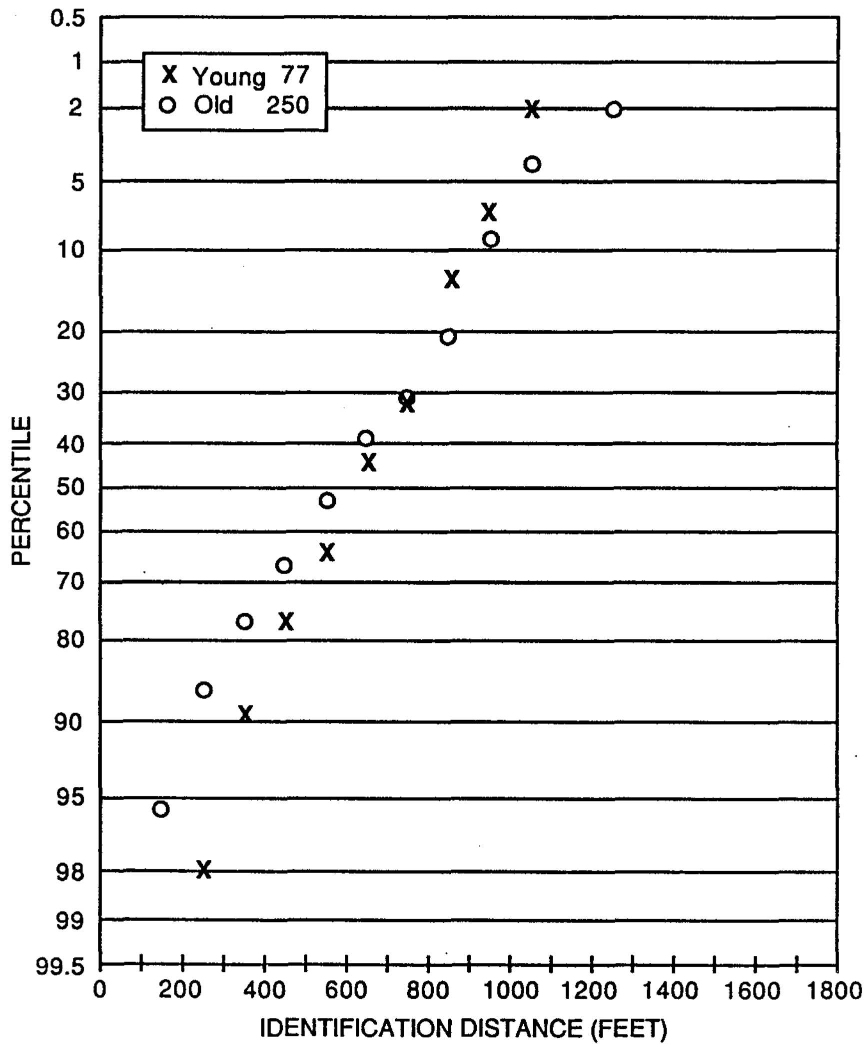

Figure 16c. A comparison of the performance of young and older subjects using different SIA signs in the medium-complexity area.

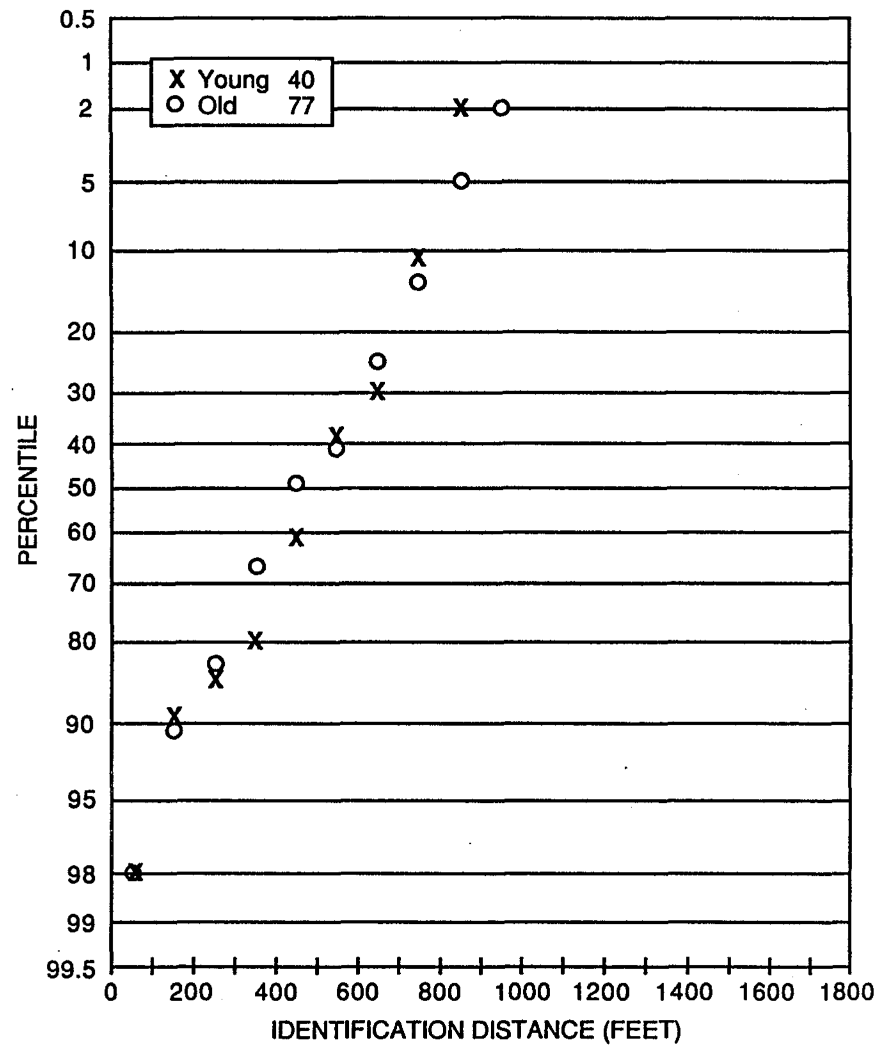

Figure 16d. A comparison of the performance of young and older subjects using different SIA signs in the low-complexity area.

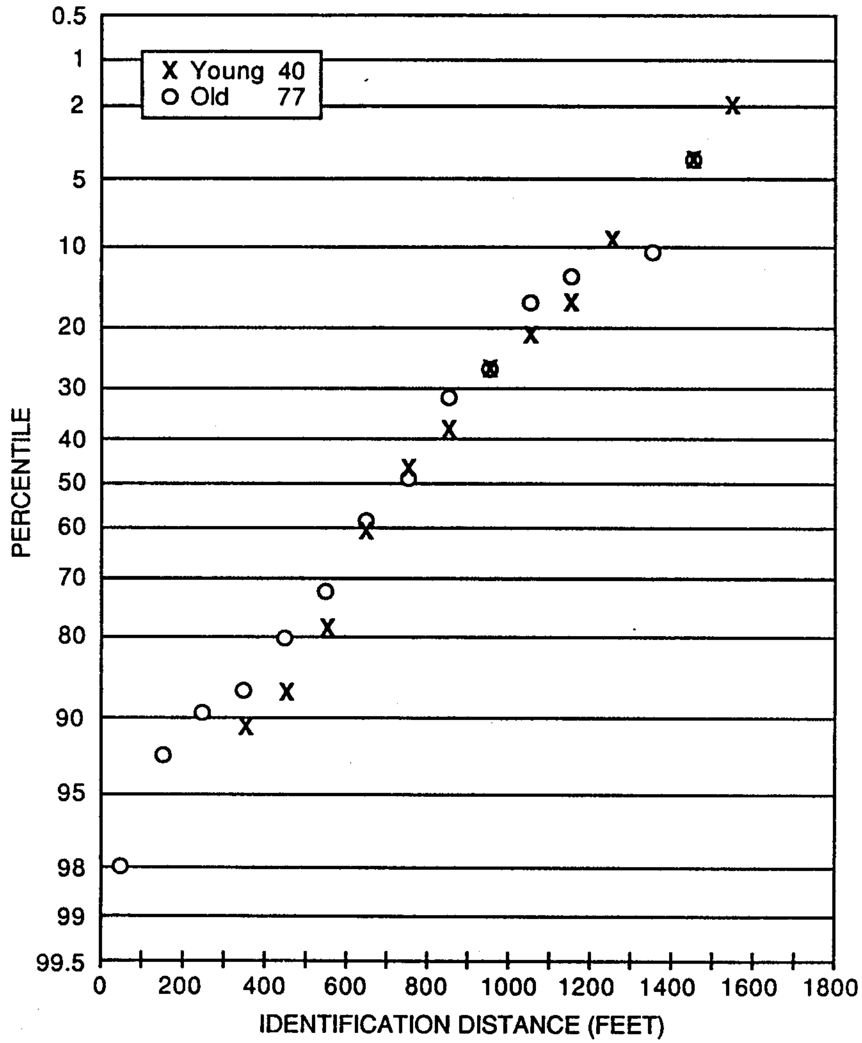

Figure 16e. A comparison of the performance of young and older subjects using different SIA signs in the low-complexity area.

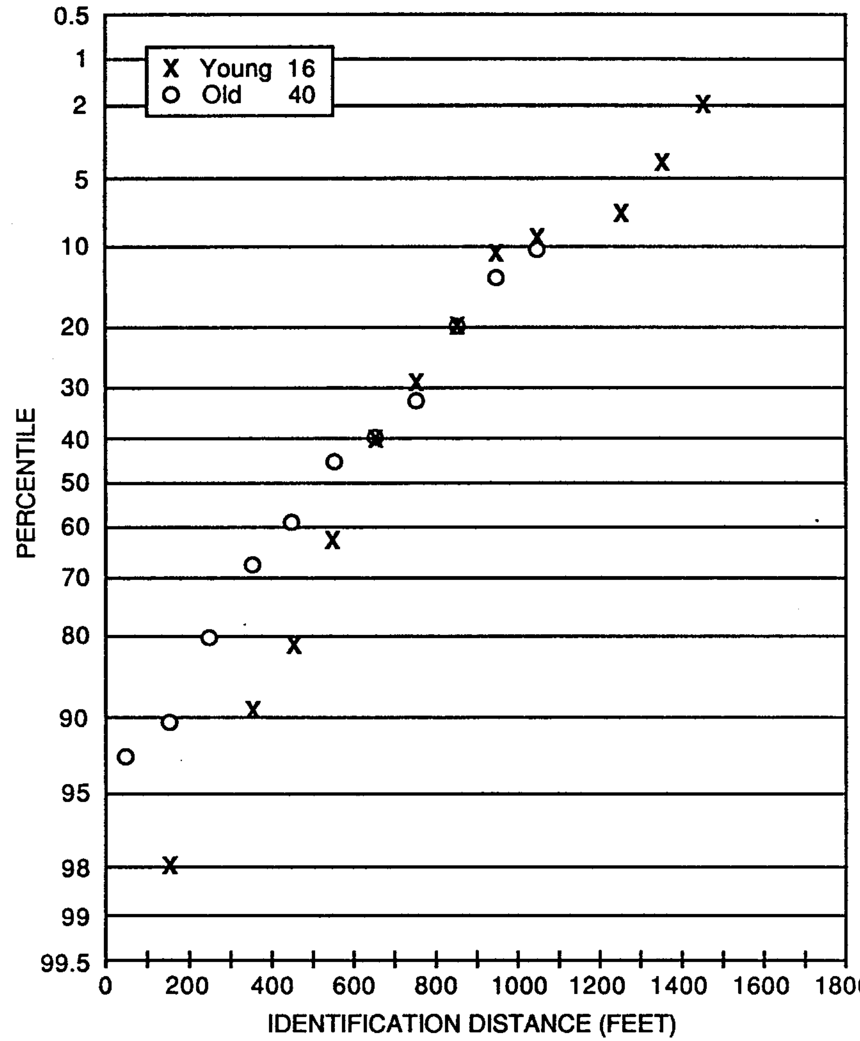

Figure 16f. A comparison of the performance of young and older subjects using different SIA signs in the low-complexity area.

TABLE 6

PERCENT OF TRIALS ON WHICH THERE WERE NO COLOR IDENTIFICATION ERRORS – ALL SUBJECTS

Sign		Area Complexity		
Color	SIA	High	Medium	Low
Y	750	98		
Y	250	86	91	
Y	77	82	89	88
Y	40		90	89
Y	16			81
W	115	97		
R	64	100		
R	40		56	
O	40		47	57
G	64	96	89	
G	15			86
B	11			31

Figure 20 is a comparison of differences in color identification distance as a function of area complexity for the SIA 77 yellow sign. The differences shown are largely a function of differences in sign identification distance.

Figures 21 through 26 illustrate differences between the young and older groups of subjects in color identification. The older subjects clearly did less well; the question is whether this difference is attributable to anything other than poorer sign identification performance. Figure 27 compares the young and older subjects' color identification on the SIA 77 yellow sign at two levels of area complexity. A comparison with its counterpart for sign identification distance, Figure 16, shows the same trends, and no clear evidence of poorer color identification on the part of the older subjects.

TABLE 7

MEAN DISTANCES AT WHICH CORRECT COLOR IDENTIFICATIONS WERE MADE – ALL SUBJECTS

Sign		Area Complexity					
		High		Medium		Low	
Color	SIA	Distance (feet)	%*	Distance (feet)	%*	Distance (feet)	%*
Y	750	868	90				
Y	250	604	82	691	82		
Y	77	467	76	552	79	767	72
Y	40			474	79	586	72
Y	16					411	61
W	115	390	85				
R	64	793	87				
R	40			433	53		
O	40			373	45	498	47
G	64	818	92	721	85		
G	15					820	79
B	11					514	43

*Color identification distance divided by sign identification distance listed in Table 5.

Table 8 is a further analysis of color performance on the yellow signs as a function of age. The older subjects had slightly more identification errors (49 compared to 46), and the percentage of identification distance was slightly lower as well (74% compared to 78%).

Table 9 provides a similar analysis, for colors other than yellow. Again, the number of errors differ only slightly. However, the percentage of sign identification distance differs by a larger amount than in the case of the yellow signs (67% compared to 79%).

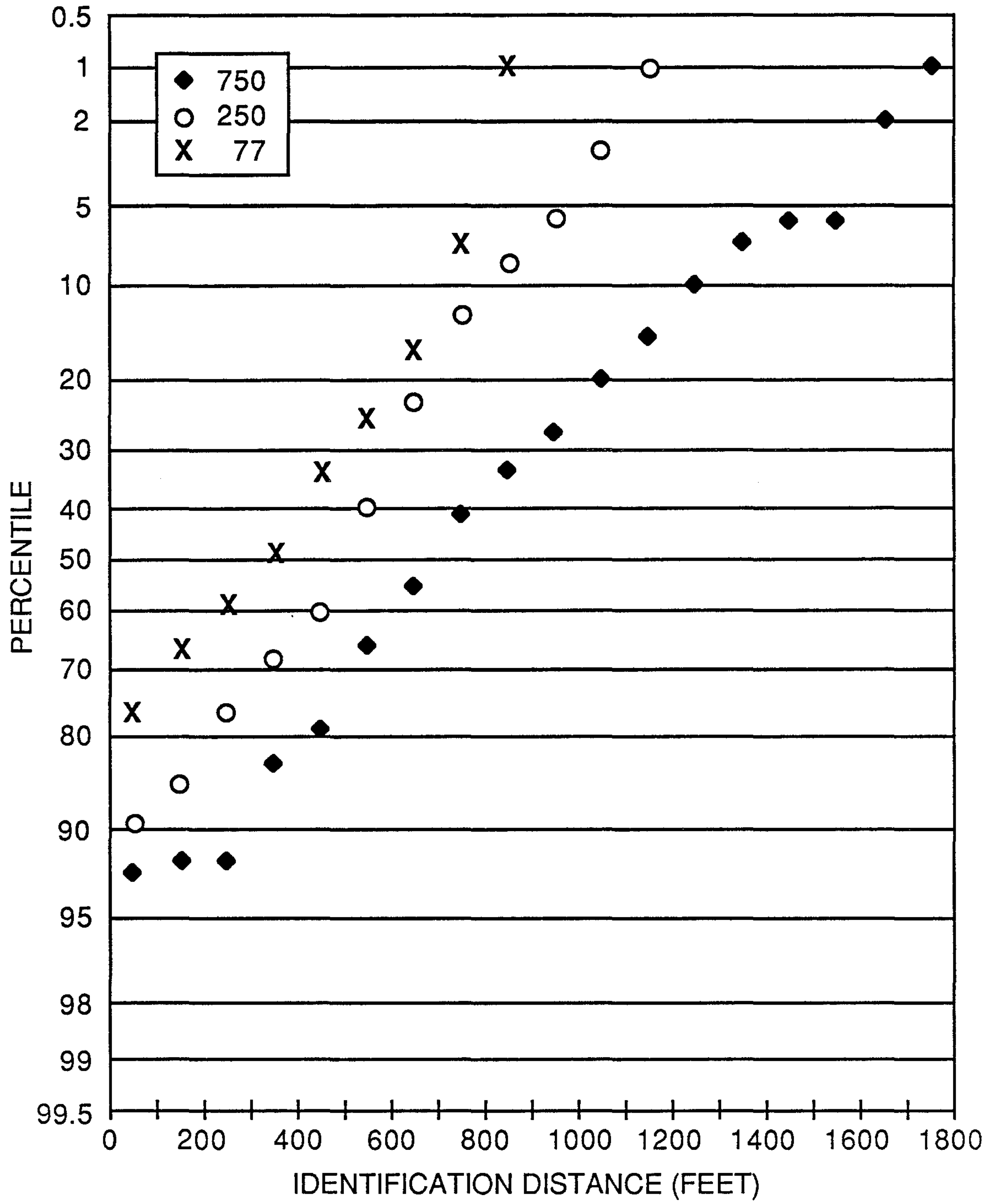

Figure 17. Normal probability distribution of color identification distances for the yellow signs in the high-complexity area - all subjects.

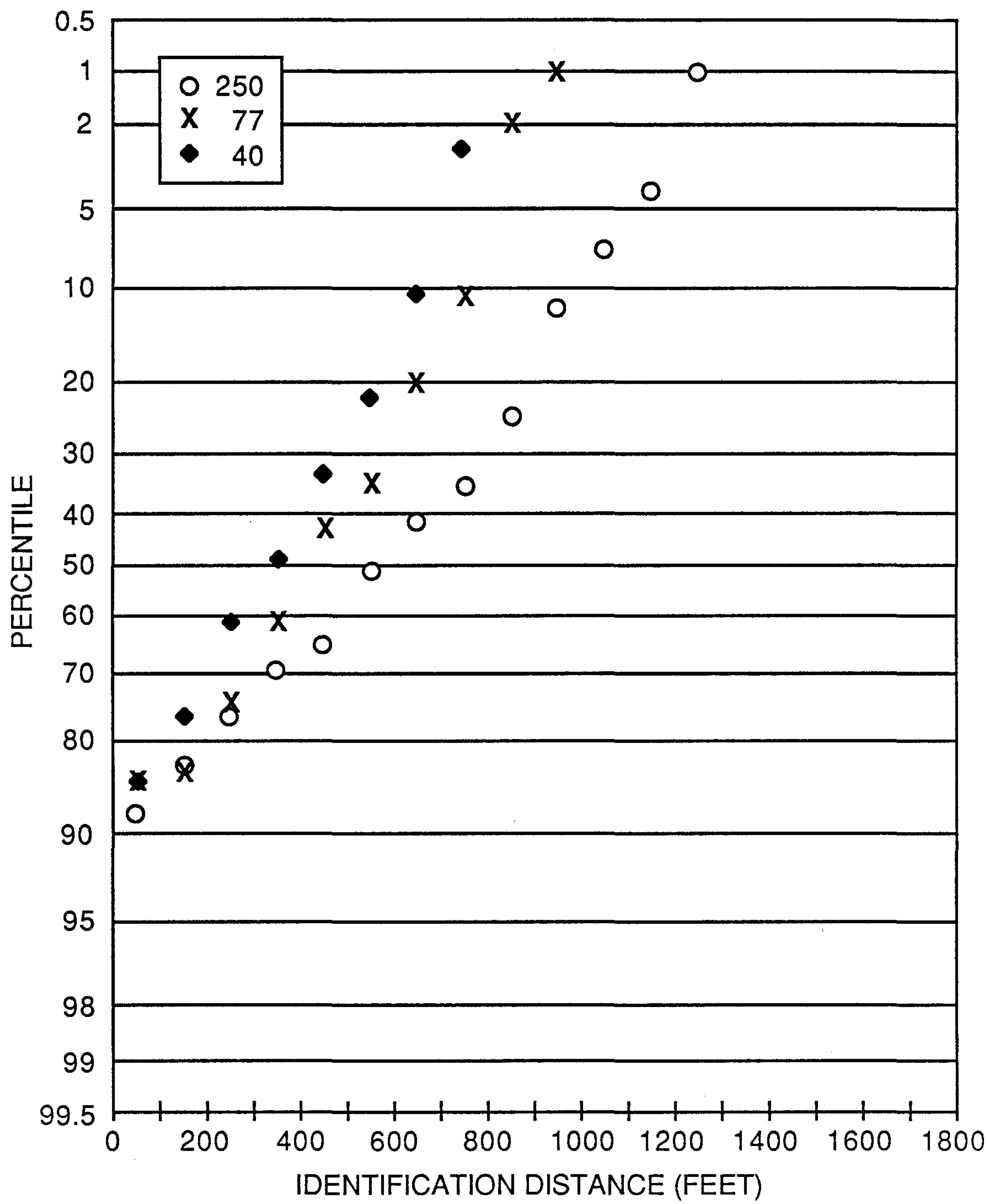

Figure 18. Normal probability distribution of color identification distances for the yellow signs in the medium-complexity area - all subjects.

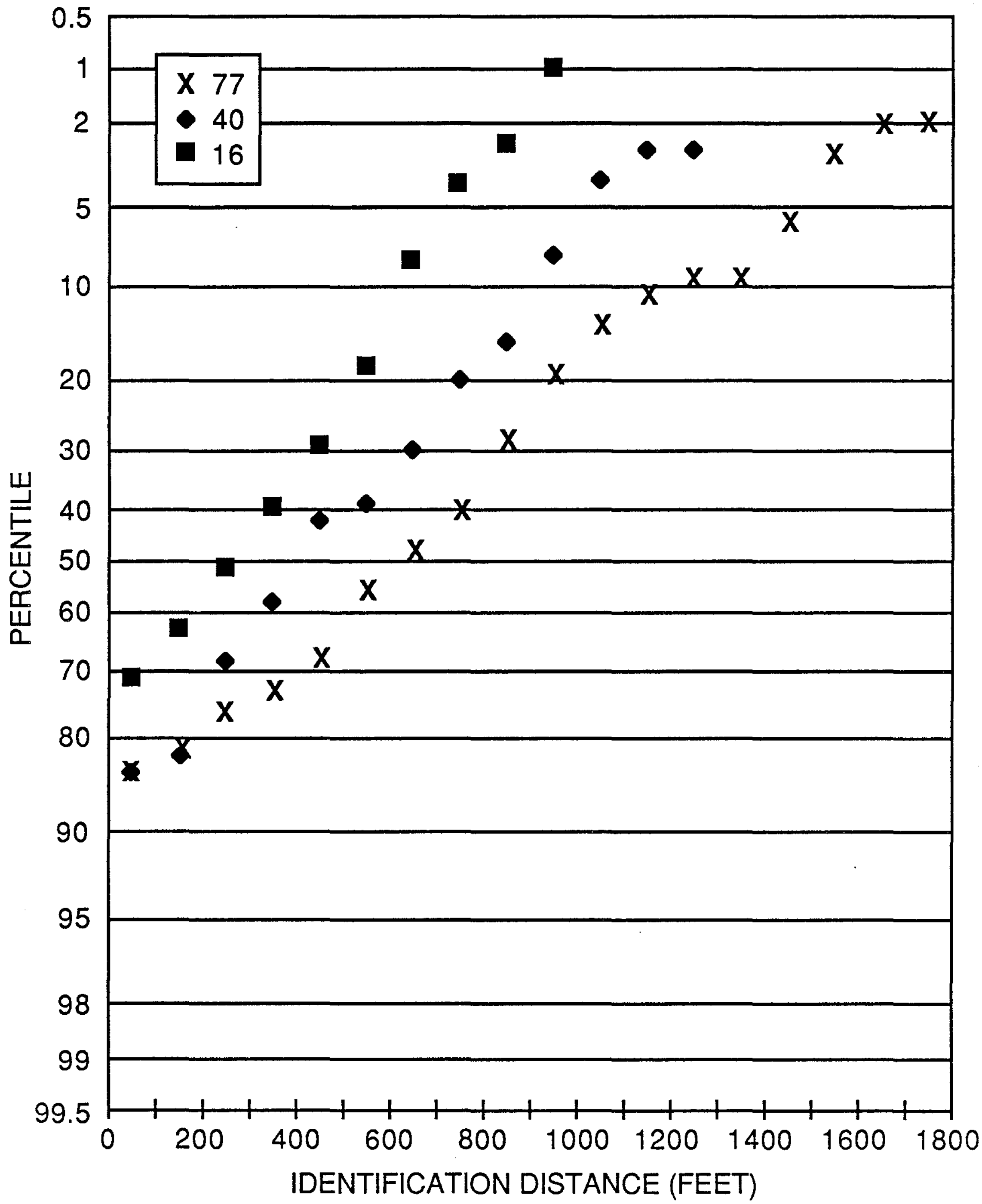

Figure 19. Normal probability distribution of color identification distances for the yellow signs in the low-complexity area - all subjects.

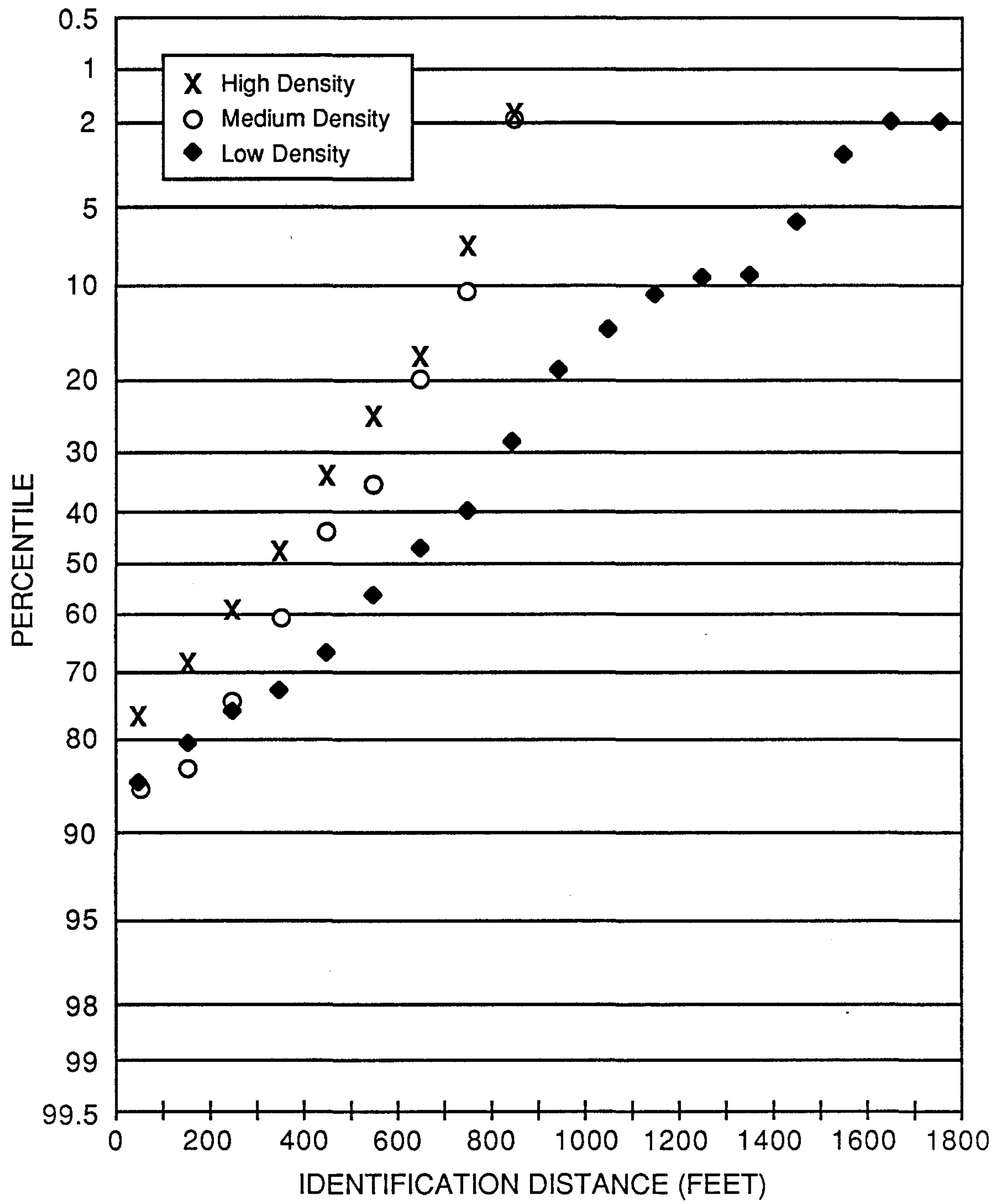

Figure 20. Normal probability distribution of color identification distances as a function of area complexity for the SIA 77 yellow sign - all subjects.

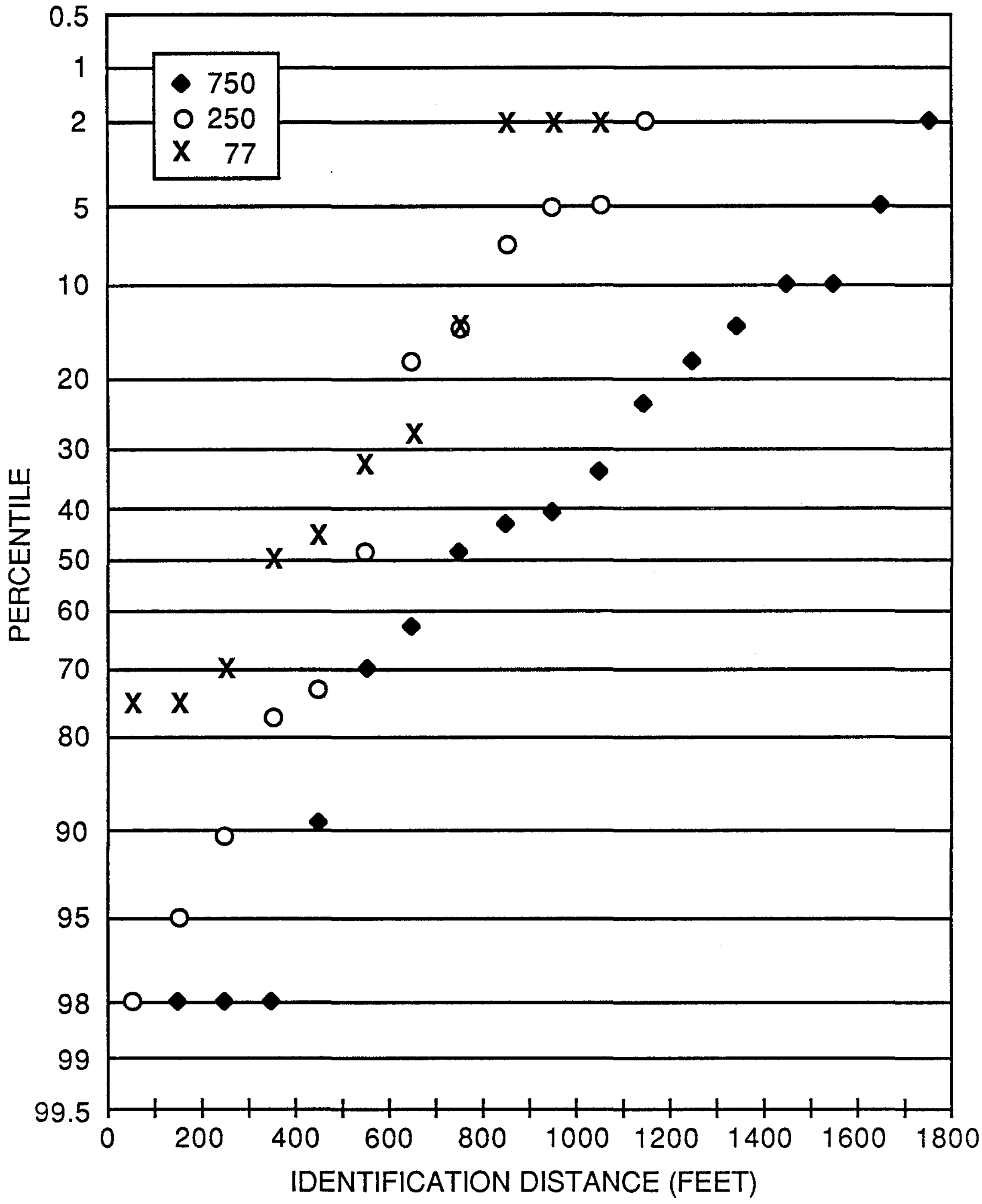

Figure 21. Normal probability distribution of color identification distances for the yellow signs in the high-complexity area - young subjects.

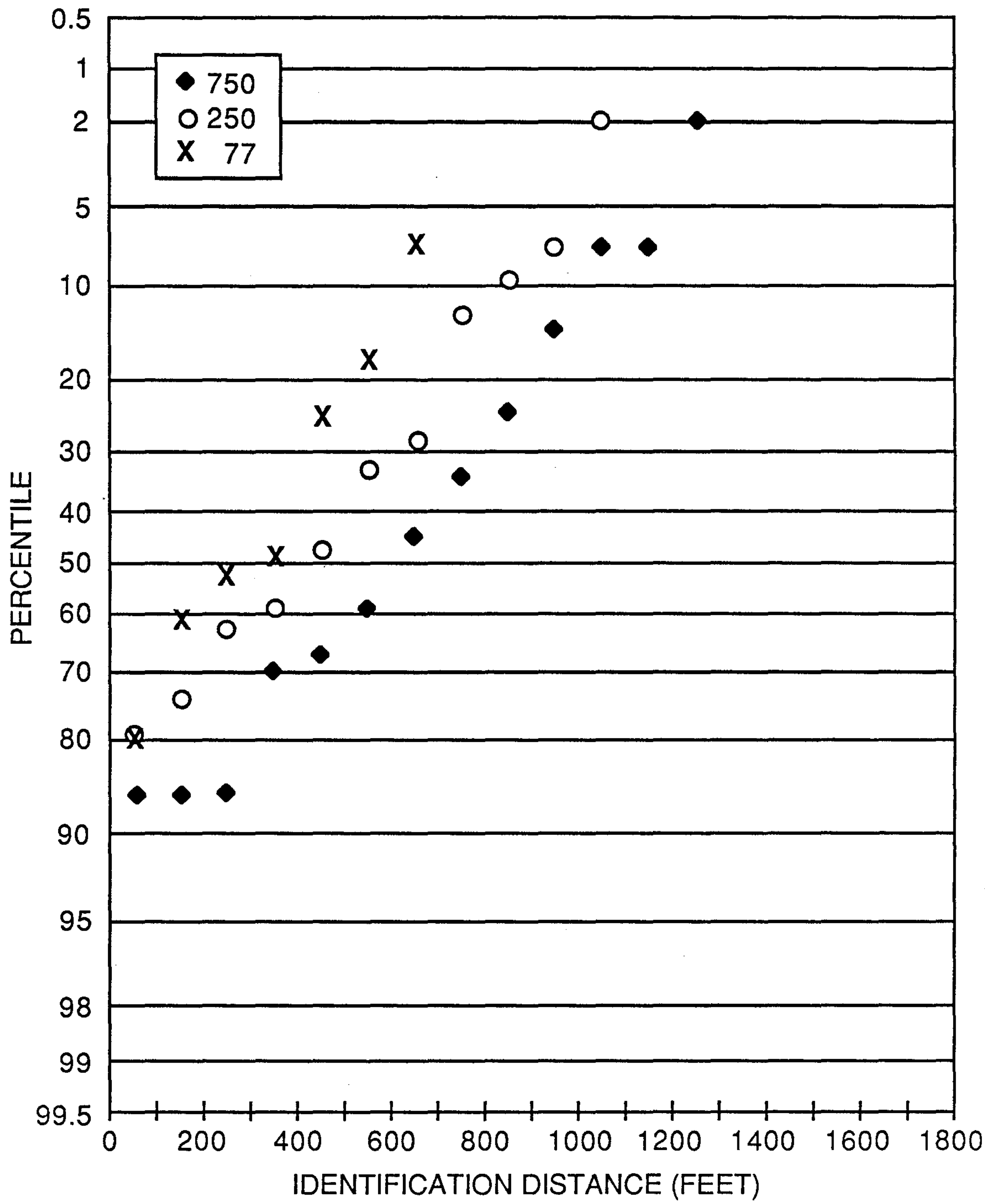

Figure 22. Normal probability distribution of color identification distances for the yellow signs in the high-complexity area - older subjects.

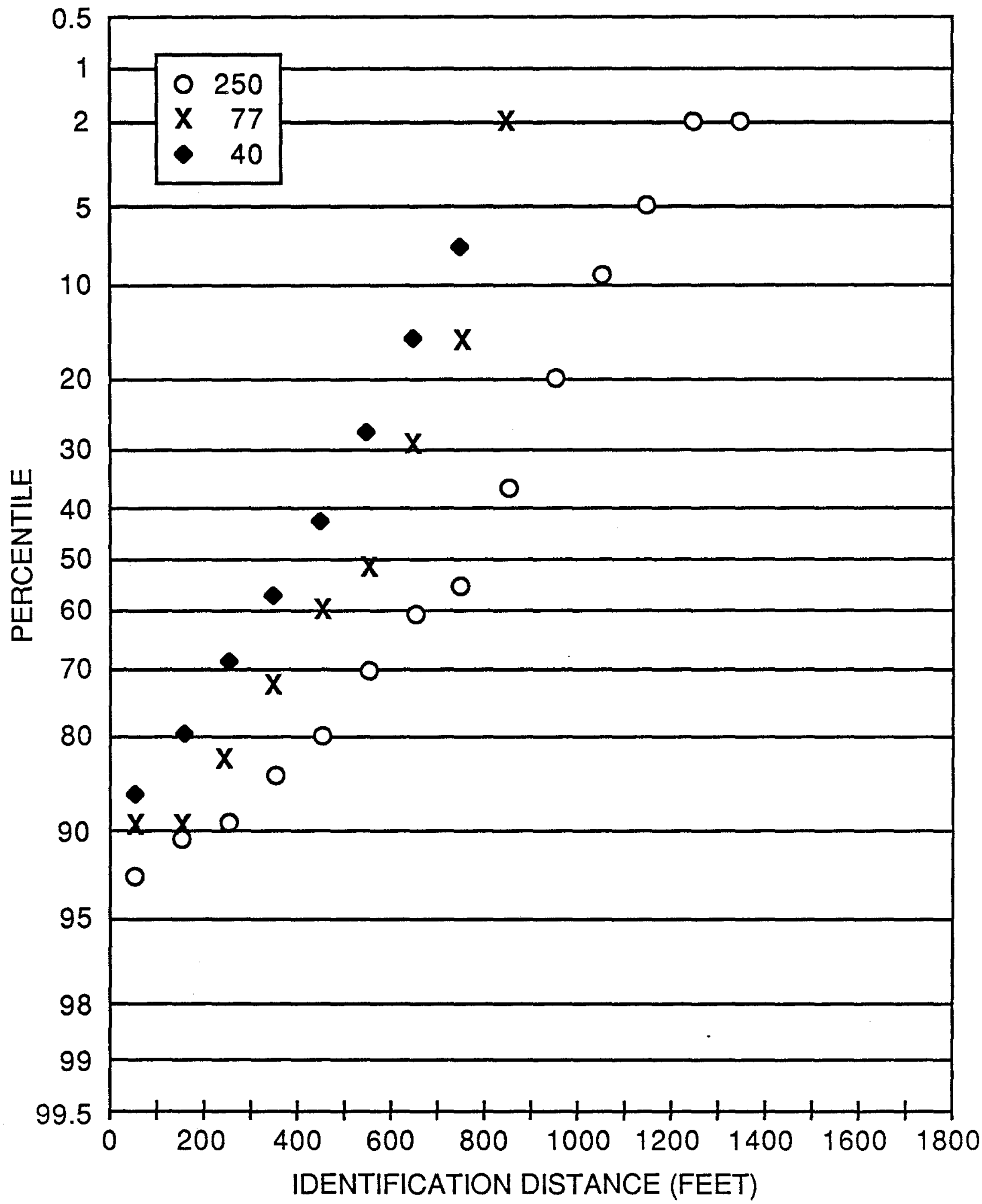

Figure 23. Normal probability distribution of color identification distances for yellow signs in the medium-complexity area - young subjects.

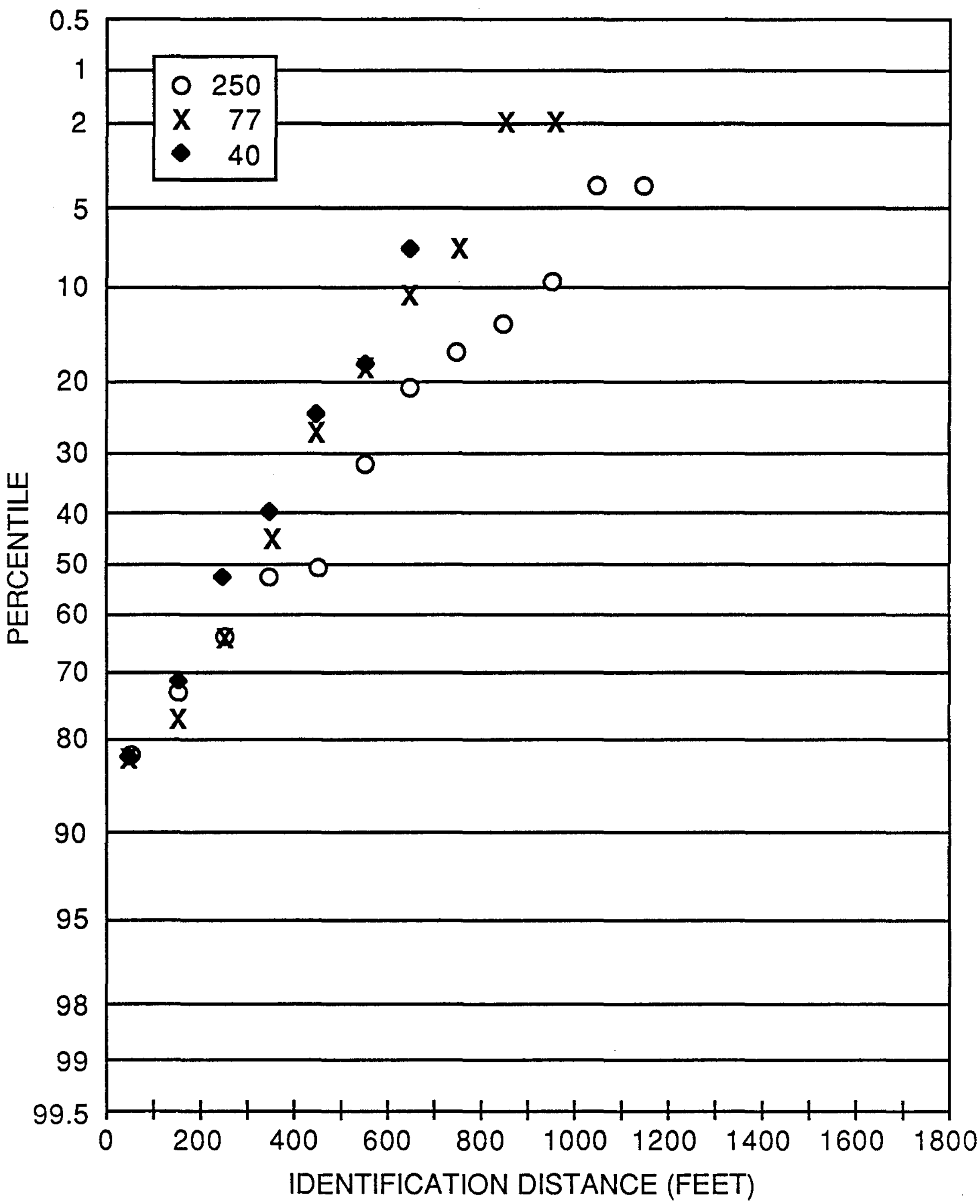

Figure 24. Normal probability distribution of color identification distances for the yellow signs in the medium-complexity area - older subjects.

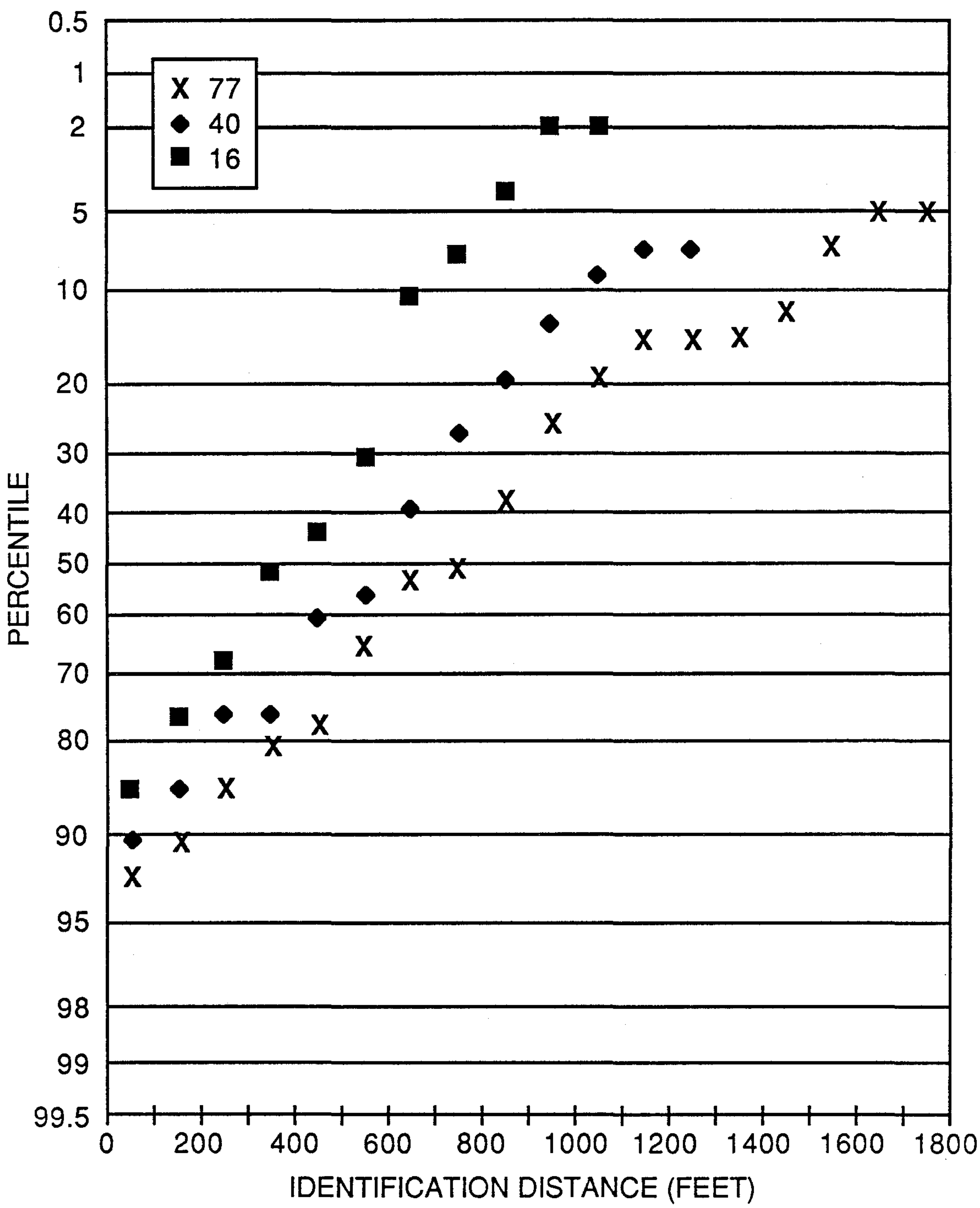

Figure 25. Normal probability distribution of color identification distances for the yellow signs in the low-complexity area - young subjects.

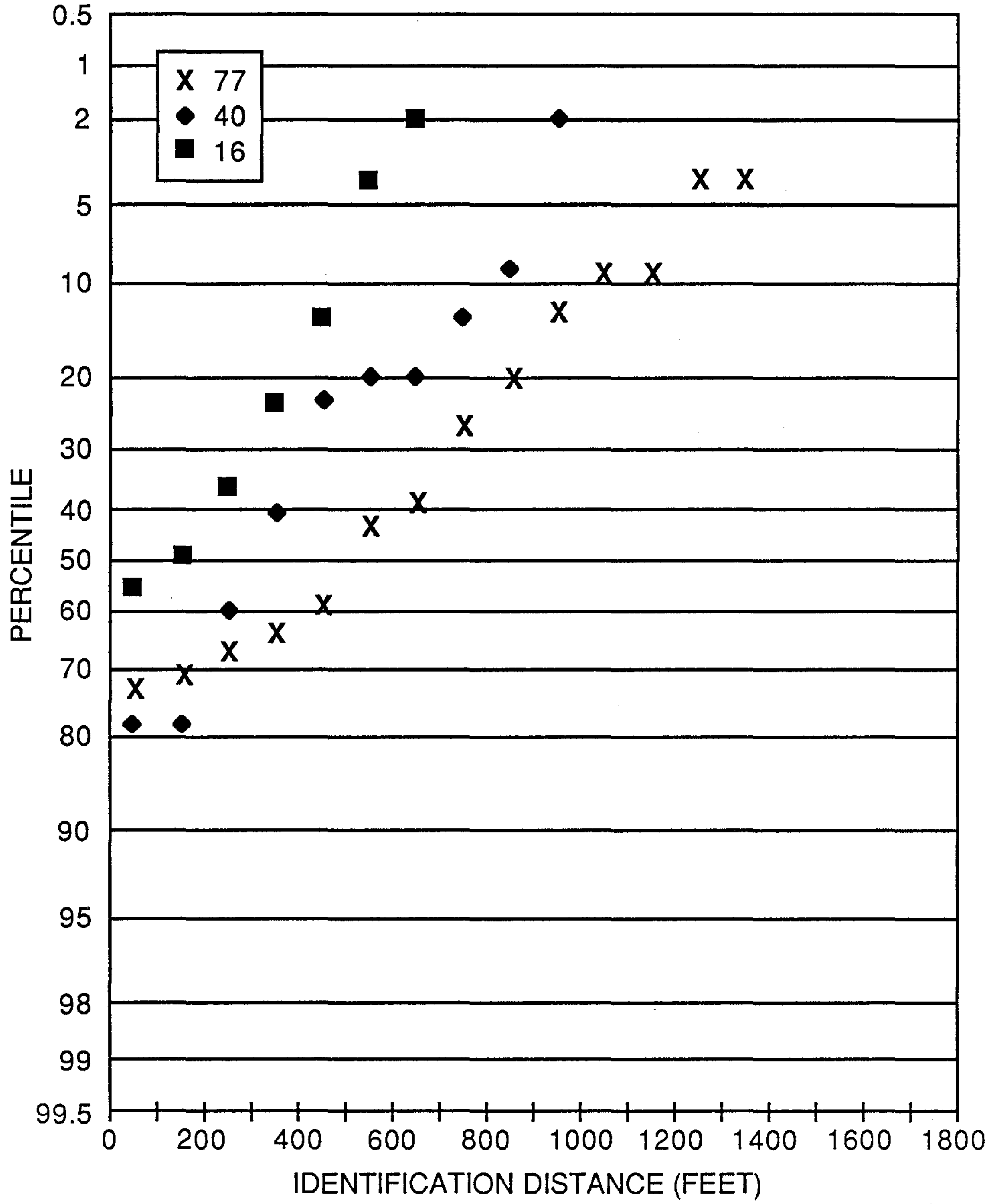

Figure 26. Normal probability distribution of color identification distances for the yellow signs in the low-complexity area - older subjects.

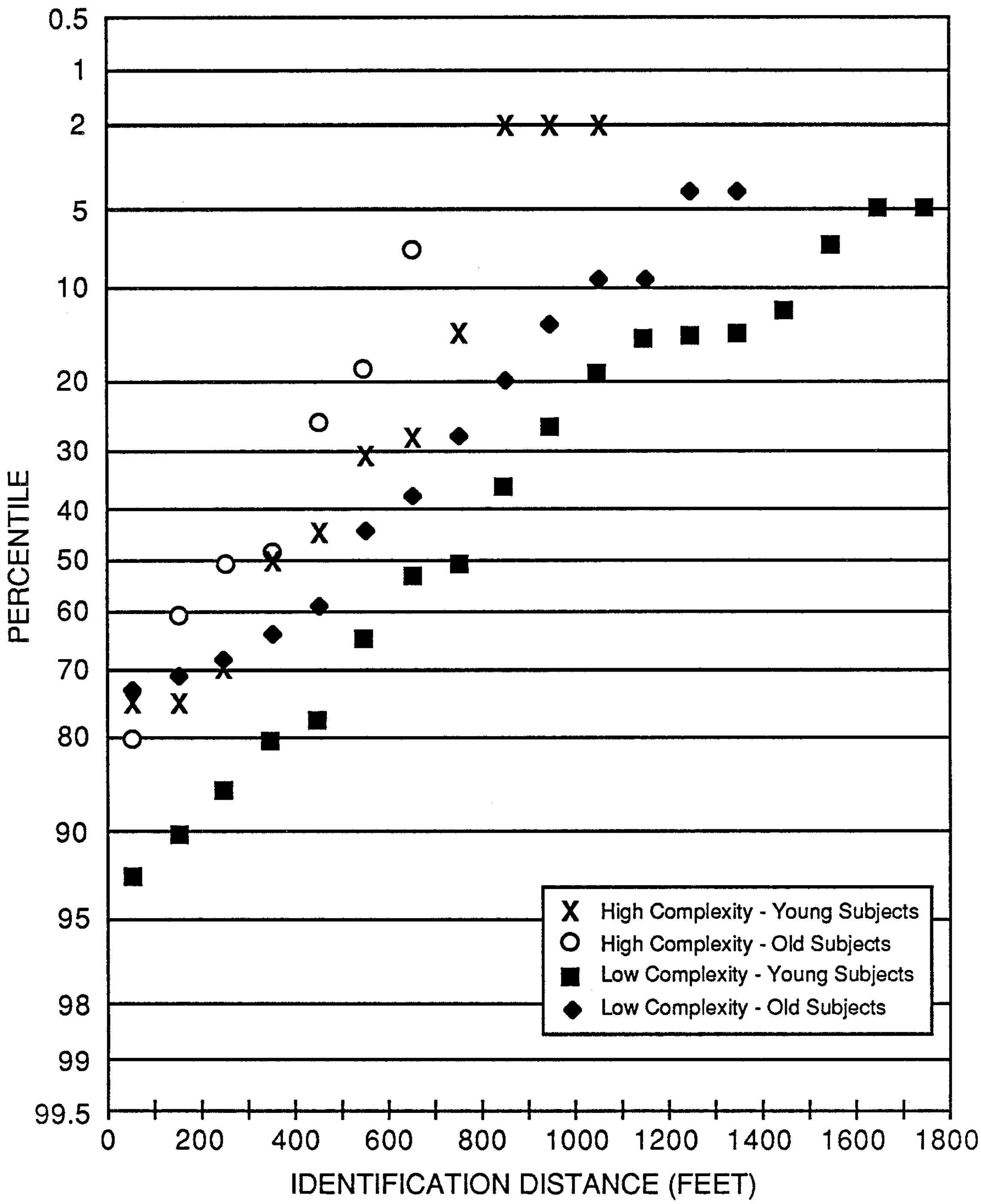

Figure 27. A comparison of color identification distance for young and older subjects at two levels of area complexity.

TABLE 8

A COMPARISON OF THE NUMBER OF COLOR IDENTIFICATION ERRORS AND THE PERCENT OF SIGN IDENTIFICATION DISTANCE AT WHICH COLOR IDENTIFICATION OCCURRED AS A FUNCTION OF SUBJECT AGE – YELLOW SIGNS

Area Complexity	SIA	Subject Age Groups			
		Young		Older	
		Number	%	Number	%
High	750	0	93	2	86
	250	4	86	8	79
	77	10	73	5	77
Medium	250	4	87	4	75
	77	6	81	4	77
	40	5	69	4	79
Low	77	5	71	6	71
	40	5	75	5	67
	16	7	63	11	56
Total		46	78	49	74

Color as a Factor in Sign Identification Distance

Earlier it was pointed out that colors other than yellow achieved substantially greater sign identification distances than did yellow signs having about the same SIA (see Table 5). An exception to this was the white sign. In the case of the white sign, it was felt that the site at which it appeared included a great deal of white in the surround, which may have affected its conspicuity. Hence, the identification distance associated with the white sign is possibly not representative. However, the sign identification distances associated with the red, orange, green, and blue signs were all substantially greater than those for yellow signs having approximately the same SIA. This result was very much unexpected.

Color has not been a subject of much interest in sign conspicuity. The first published investigation was by Odescalchi (1960). In this study subjects viewed a white and colored sign panel side by side and estimated how much larger or smaller the colored panel had to be to have the same conspicuity as the white panel. The results were:

TABLE 9

A COMPARISON OF THE NUMBER OF COLOR IDENTIFICATION ERRORS AND THE PERCENT OF SIGN IDENTIFICATION DISTANCE AT WHICH COLOR IDENTIFICATION OCCURRED AS A FUNCTION OF SUBJECT AGE – SIGNS OTHER THAN YELLOW

Color	SIA	Subject Age Groups			
		Young		Older	
		Number	%	Number	%
White	115	0	91	1	79
Red	64	0	94	0	79
Red	40	5	65	6	40
Green	64	1	93	3	84
Green	15	3	79	1	79
Orange	40	14	50	15	42
Total		23	79	26	67

Yellow	−10%
Red	+15%
Blue	+20%
Green	+40%

Forbes et al. (1968) reported that the colors red and yellow had sufficient conspicuity to compensate for their lower luminance. However, Jenkins and Cole (1979) examined the relative contribution of red, yellow, green, and blue to conspicuity and found that only green had a significant effect. They concluded that color does not provide any net gains in conspicuity. The role of color, according to Jenkins and Cole, is to aid in identifying the object and conveying limited information about it.

Thus, the available literature on the subject of color and conspicuity is sparse and not in agreement. There is certainly nothing in it to suggest differences such as were found in this study. Given this, a search began to find a plausible explanation for the results.

In the laboratory study described in Appendix C color differences were noted that were identified as probably arising from the change in spectral sensitivity associated with dark adaptation (the Purkinje shift). However, the Purkinje shift would favor blue and green, but work against red and orange. Hence, it cannot explain these data.

A form of color contrast is a possible explanation. It seemed to the experimenter that there was relatively more yellow in the various environments in which the test was conducted, in the form of lights, advertising signs and legitimate road signs. This would reduce the conspicuity of the yellow signs relative to the other colors, and may well account for at least part of the effect. However, although it was often confused with the yellow sign in terms of color identification, the orange sign also outperformed the yellow in terms of sign identification distance. Hence, it would appear that color contrast is not a complete explanation for the results.

Further review of the literature on the subject of brightness and color perception raised the possibility that the differences may be attributable to the same phenomenon that causes the judgements of brightness made by human observers to be influenced by hue. There have been a number of investigations of what is usually referred to as heterochromatic brightness matching (see, e.g., Wyszecki, 1986 or Cowan and Ware, 1987). A typical approach to research in this subject area requires subjects to adjust the luminance of a white surface until it appears to be the same brightness as an adjacent colored surface. When the match has been made to the satisfaction of the subject the two surfaces are photometered and the differences recorded. The results of this work have shown that the luminance of the white surface will usually be set higher than that of the colored surface. If the luminance of the reference surface (white in this case) is denoted by R, and the luminance of the colored test surface by T, the ratio R/T is generally greater than 1 when the subject judges the surfaces to be equally bright. The ratio increases with increasing saturation of the test surface. Interestingly, yellow is a color often cited as an exception to this rule. Experimental data show that the value of R/T typically stays close to 1 even as the saturation of a yellow surface approaches maximum.

In an effort to determine whether the phenomenon just described might account for the color results found in the field study, a laboratory color brightness investigation was conducted. This work is described in Appendix A. Briefly, the results are in accord with those from heterochromatic brightness matching studies in that colors such as red, orange, green, and blue were judged brighter, relative to yellow, than would be indicated based on their photometric performance.

The work on brightness as a function of color is suggestive, and may afford a complete explanation of the results of the study. However, experimental work to date has been concerned solely with the perception of brightness. The data from the field study conducted as part of this program indicate that colors such as red, orange, green, and blue also have inherently greater conspicuity per unit SIA than does yellow (and perhaps white) in the context of road signs. It is possible that factors other than brightness contribute to conspicuity as measured in this study.

In one important sense this is an exceedingly fortunate characteristic of the visual system. Within a given "family" of retroreflective materials white will have the greatest SIA. The dyes used to produce the various colors result in a loss of SIA that can be very significant, particularly in the case of red, green, and blue. Due to their reduced luminance, one may assume that these colors are at a disadvantage in terms of conspicuity. However, the data from this study indicate that there is little or no loss of conspicuity for these colors. Their attention-gaining characteristics are equivalent to yellow materials having much greater photometric performance.

The fact that conspicuity depends to a significant degree on sign color complicates the recommendations with which this program is ultimately concerned. Unfortunately, the study was not designed to systematically evaluate color, since major effects were not anticipated. Signs having colors other than yellow were generally matched at a particular site within a given complexity area with a yellow sign having approximately the same SIA. Where these comparisons are available, it is clear that the other colored signs (with the exception of white) were identified at much greater distance than the yellow sign. The red, blue, green, and orange signs in a given complexity area typically performed about equally well and on a par with the brightest yellow sign tested, which had anywhere from two to ten times greater SIA.

Lacking more definitive information on the effect of color, recommendations will be based on the assumption that orange, red, green and blue have conspicuity equal to that provided by yellow in the same family of materials. This is strongly supported by the data that were collected, and, if anything, is conservative. Further work on color effects should be carried out to better define the relationship.

Conclusions

In the field study subjects operated a motor vehicle in normal traffic and detected and identified test sign panels that they encountered at random intervals along the route. Independent variables were sign SIA, sign color, surround complexity, and subject age.

The following conclusions are based on the information gathered in the course of the field sign conspicuity study.

Sign SIA. There is a clear relationship between sign SIA and identification distance. Within the limits tested, the higher the SIA the greater the distance, on average, at which subjects identified the sign.

Surround complexity. Surround complexity had a major effect on sign conspicuity. However, the detrimental effect of complex surrounds can be overcome by use of more highly reflective materials.

Subject age. While there were substantial individual differences, in general, older subjects identified the same signs at significantly shorter distances than did young subjects. Under all conditions tested, the performance of older subjects could be made approximately equal to young subjects by increasing the sign SIA by a factor of three.

Color identification. The distance at which subjects could correctly identify the sign's color, and the likelihood of a color identification error, were affected by color and, to some extent, by SIA. Errors were most likely with the blue (usual error: "green") and orange ("yellow") signs. Errors were also frequent with a Type II red sign ("orange"), but not with a Type III red sign.

Color as a factor in conspicuity. Although the data are somewhat limited, the colors red, orange, green, and blue had substantially greater conspicuity than did yellow with equivalent SIA. Subjects detected and identified red, orange, green, and blue signs at distances equivalent to yellow signs with SIA values two to ten times greater.

THE DEVELOPMENT OF A CORRECTION FOR SUBJECT EXPECTANCY

Introduction

The identification distances in the field study described earlier were obtained from drivers whose expectations were different than they would be in the "real world." That is, subjects knew they were involved in a study, and they knew that the purpose of the study was to measure how well they could see certain types of signs. Almost certainly, these conditions would lead to sign identification distances that would average greater than would be the case if the subjects were engaged in normal driving. The question is how much of a correction should be applied to the experimental data to more accurately estimate real-world performance?

The only study in the literature that comes close to addressing such a question was reported by Roper and Howard in 1938. Roper and Howard had collected data on the detection distance to low-contrast targets in studies concerned with vehicle headlighting development. They were interested in determining the difference it would make in detection distance if the subject was not expecting the target. In their study subjects were invited to drive a car, supposedly for purposes of subjectively evaluating its lighting system. After a time they were told the test was complete and they should drive the car back to the start point. A mannequin had been placed in the road the subjects had to take. For the "surprise" trial a measure was made of the distance from the mannequin at which the subject released the car's accelerator preparatory to braking. The true purpose of the study was then explained to the subject and additional trials were run using the same car and target, but with the subject looking for the mannequin. On average, the subjects detected the mannequin at twice the distance in the alerted trials, as compared with the surprise trial.

The Roper and Howard data suggest that a substantial correction might be required for the field data in this study. However, their subjects' detection-identification task was a bit more straightforward, and the mannequin target offered much less contrast than do highway signs. Thus, the degree to which their data can be applied to the present situation is not clear, and it was thought desirable to conduct a similar study using signs as targets.

Method

Subjects in the field study had to detect the signs, identify them as test signs, and respond by saying "sign." The first two elements had to be present in the surprise portion

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of this study, along with a discernible response. A stop sign seemed to offer the only possibility. Drivers must detect and identify a stop sign, but there is no decision involved, given that the only option is to stop. Furthermore, the release of the accelerator preparatory to applying the brake offers a discernible response. The main problem is that the stop sign used in such a study must have sufficiently poor conspicuity so that the combination of vehicle speed and detection distance would be such as to require a prompt response from the subject once the identification phase was complete.

Equipment. The test vehicle and headlights used in the field study were used in this study as well. The distance measuring system was modified so that it could be initiated both by the subject releasing the accelerator and by the experimenter pressing a button.

Two new, 30-inch stop signs were obtained. These were made with type II retroreflective sheeting, and had been overprinted with a dot pattern to reduce their SIA to about 25% of new. However, pilot tests indicated that the signs were still being identified by the subjects at too great a distance to ensure a quick response. The signs were then coated with a clear, flat-finish material until their average SIA in the red areas was about 0.8, only slightly better than a diffuse reflector. This proved satisfactory for the purposes of this test.

Test site. A location was sought where the test could be safely and effectively carried out. A suitable site was located in a rural area some miles north of the Institute. The road was two-lane blacktop in good condition, had a speed limit of 55 mph, and was about 1.5 miles long. The "surprise" location of the stop sign was at the top of a rise, about one-half mile from the entry point.

Subjects. Ten subjects participated in the study. About half of them had participated in the original field study. Five of the subjects were young, ranging from 23 to 35 years of age, five were older, ranging from 60 to 73 years of age.

Procedure. Subjects were run individually. They were told that the purpose of the study was to take some measures of driver-vehicle performance while they drove the car on rural roads near the Institute. An experimenter in the back seat told them where to turn, what lane to use and informed them of speed limits. In this way they drove the car for a distance of about 10 miles.

Without the knowledge of the subject, two experimental assistants were also involved in the study. These individuals operated out of a second vehicle. They were kept informed of the subject's progress through the test route by the experimenter in the test vehicle, who surreptitiously keyed a radio microphone each time he gave directional instructions to the subject. Their job was to hold up the stop signs. They watched for the test car (which was marked with two yellow lights on its roof), and held up the sign until it passed.

When the test road was reached the subject was asked to turn right, and was instructed that the speed limit was 50 mph. The car began to ascend a shallow upgrade. At the crest the subject encountered one of the stop signs. When he/she released the accelerator the distance counter was started. This was put in hold by the experimenter when the sign was passed.

When the experimenter noted the counter start he advised the subject that the sign was a fake and that he/she should simply drive on by it. The subject was then directed to a parking area about one-half mile beyond the stop sign, where the true purpose of the study was explained. The subject then made one round trip on the test road, a total of about three miles, in the process of which test stop signs were encountered four times. The method used was the same as in the main field study, i.e., the subject called out "sign" when they identified the stop sign, the experimenter pressed a button to start the distance counter, and put the counter in hold as the sign was passed. When a "real" stop sign would be seen next the subject was so advised. Thus, if a stop sign was encountered without a prior warning from the experimenter the subject knew it was a test sign.

Results

From each subject one "surprise" and a maximum of four alerted trials were obtained. The distances recorded on each of these is listed in Table 10. The distances measured on the alerted trials were then averaged and the resulting value was divided by the distance recorded on the surprise trial. The ratio resulting from the last operation is shown in the right column of Table 10. Overall means are given at the bottom of the table.

An examination of Table 10 shows that response distances on the surprise trial ranged from a low of 271 feet to a high of 430 feet. All subjects averaged longer response distances when they were expecting to encounter the sign, although there is considerable variability in these results. However, seven of the subjects yielded ratios of surprise to alerted distances ranging from 1.36 to 1.72. Three of the subjects gave more extreme results of 1.08, 2.18 and 2.64. The mean ratio of 1.65 lies in the range covered by the majority of subjects, so may represent a reasonable approximation of a population correction factor.

TABLE 10

IDENTIFICATION DISTANCES TO A STOP SIGN RECORDED UNDER SURPRISE AND ALERTED CONDITIONS

Subject Number	Response Distances in Feet					Mean of Alerted Trials (A)	A/S
	Surprise Trial (S)	Alerted Trials					
		1	2	3	4		
1	392	—	748	—	597	673	1.72
2	332	435	600	437	452	481	1.45
3	348	—	531	677	532	580	1.67
4	303	566	473	432	564	509	1.68
5	291	482	812	729	1053	769	2.64
6	296	543	—	392	501	487	1.65
7	430	607	543	790	665	651	1.51
8	350	494	536	452	416	475	1.36
9	271	508	567	726	559	590	2.18
10	402	432	484	402	425	436	1.08
Mean	342					565	1.65

Figure 28 is a plot showing the distribution of responses on the surprise and alerted trials. The ratio of alerted to surprise identification distances at the 70th, 40th, and 20th percentiles is 1.64, 1.63, and 1.71 respectively. The approximately constant ratio is further evidence of the reasonableness of using a ratio of 1.65, and also indicates that the correction factor applies through a broad range of the distribution of responses.

Implications

The study compared the distance at which subjects detected, identified, and began to respond to an unexpected stop sign with the distance at which they could discriminate the same stop sign under conditions similar to those used in the field study carried out as part

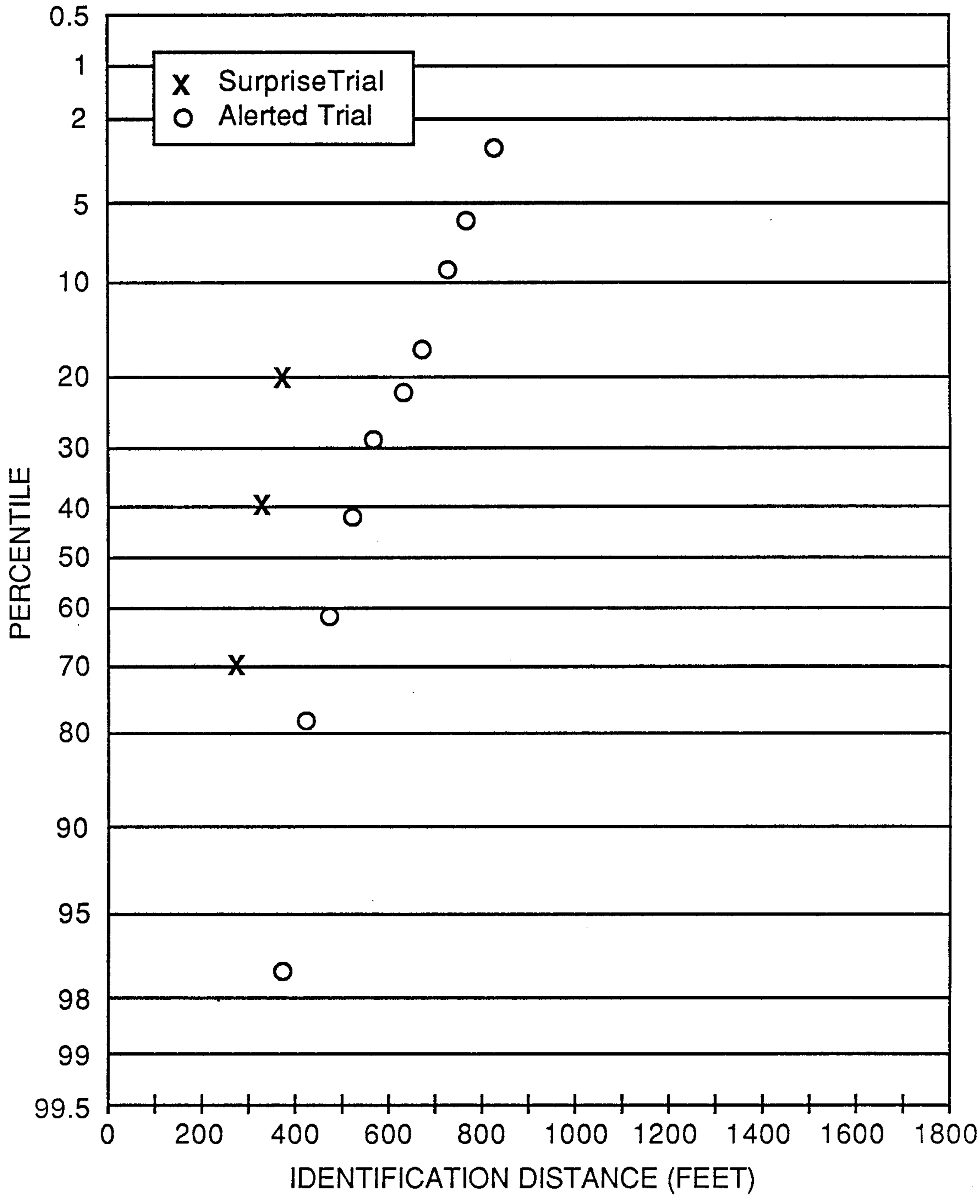

Figure 28. Normal probability distribution of responses on surprise and alerted trials.

of this program. Thus, the surprise encounter and the process used in the field study contained the same elements; the major difference was the expectancy of the subjects.

The data from this study indicate that the distances measured in the field study would have to be reduced by about 40% to compensate for the effects of driver expectancy. Furthermore, it appears that this correction applies equally well to all points on the distribution of identification distances.

RECOMMENDATIONS

Background

The field study described earlier found that a number of variables significantly affect the ability of drivers to detect and identify highway signs at night. This section will start with a discussion of the principal variables and how they will be utilized in the recommendations that follow.

In formulating the recommendations to be presented in this section an 85th percentile performance level will be utilized. There are two reasons. First, the 85th percentile is a common performance limit in traffic engineering. Second, the 85th percentile can be estimated with some accuracy from these data. A much higher level (e.g., 95th or 99th) is more difficult because of the limited number of measures (maximum of 90) per condition.

Sign SIA, surround complexity, and driver expectancy. Figure 29 illustrates the relationship between SIA and 85th percentile identification distance for the three levels of surround complexity, and includes a correction for driver expectancy. The recommendations for minimum SIA levels for all applications to be considered in this report can be traced back to this figure.

The figure was prepared by estimating the 85th percentile sign identification distance from the appropriate plots presented earlier. The resultant values were multiplied by 0.6 to correct for driver expectancy.

It will be noted that Figure 29 shows a minimum of four levels of sign SIA for each surround condition, although only three levels were actually tested. The extra data points are estimates of the performance of the SIA 40 level in the high-complexity area, the SIA 750 and 16 levels in the medium-complexity area, and the SIA 250 level in the low-complexity area. These estimates were derived by comparing the 85th percentile identification distances associated with these signs with those of other signs in areas where they were used, and then using that difference to estimate performance in areas where they were not used. For example, the 85th percentile identification distance of the SIA 40 sign was 75% and 76% of that of the SIA 77 sign in the medium- and low-complexity areas respectively. Hence, its estimated 85th percentile identification distance in the high-complexity area was established as 75% of that of the SIA 77 sign, or 122 feet. This process was repeated for the other three estimates.

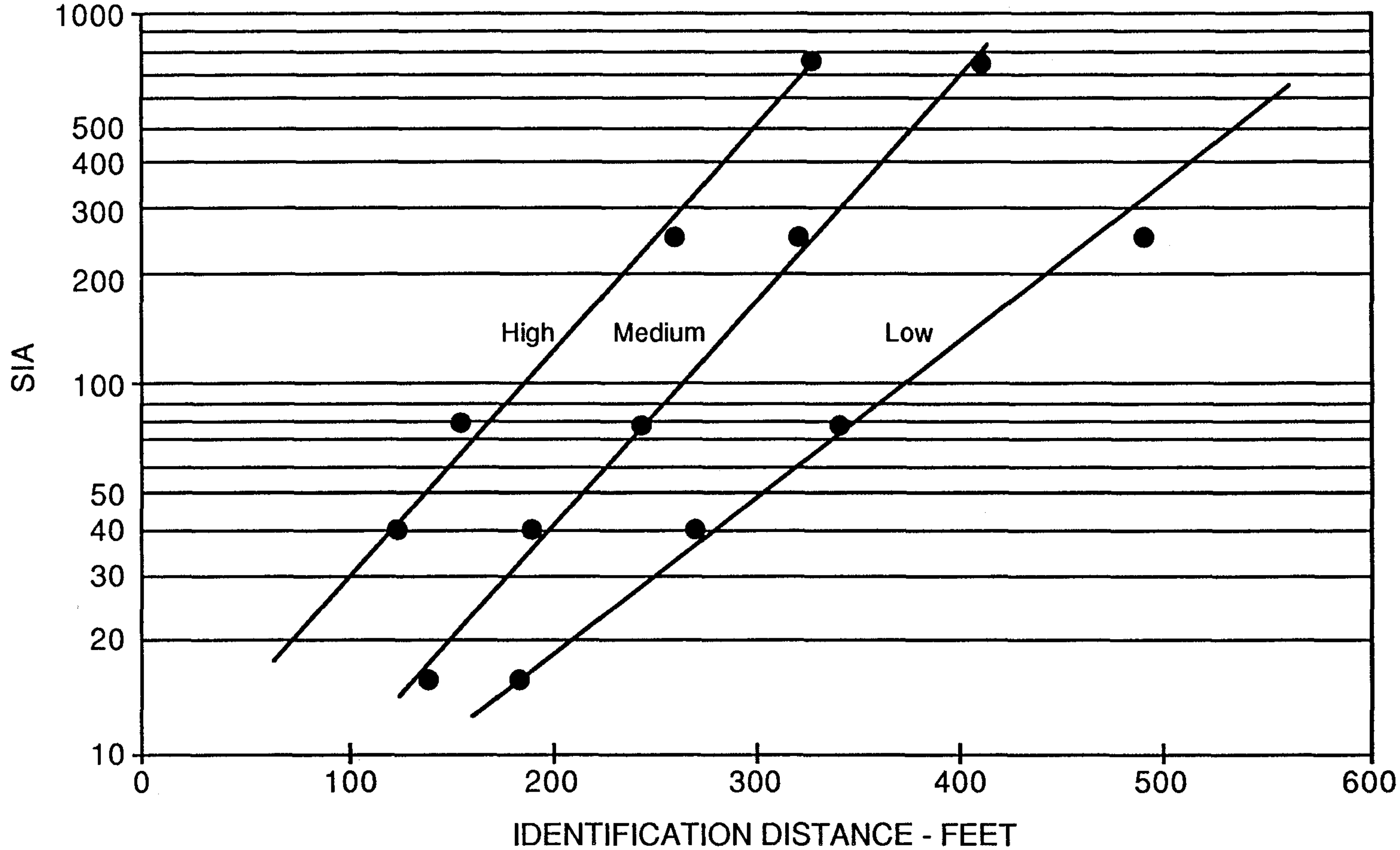

Figure 29. Eighty-fifth percentile sign identification distances for three levels of area complexity, corrected for driver expectancy. Yellow warning signs.

In the case of the high- and medium-complexity areas shown in Figure 29 the fit of these estimates to the empirical data is good, and the extrapolations are included in the visual best-fit line shown. In the case of the low-complexity area, the estimate of the 250 SIA is not as close as the others, and it was given no weight in drawing the best-fit line.

The 40% reduction in identification distance that results from the correction for expectancy makes a very large difference in the required SIA. This is illustrated in Figure 30, which repeats the information from Figure 29, but also shows what the relationships would be without a correction for expectancy. For example, in a high-complexity area, the data imply that an identification distance of 200 feet would require a minimum SIA of about 35. With the application of a correction for expectancy, the minimum SIA is about 120.

Driver age. The fact that there were large differences between the two age groups included in the study raises a question of how to weight the results for purposes of recommendations. Awadallah (1987) argues that the weighting should consider the percentage of nighttime miles driven by older individuals. He quotes information from a 1983 Personal Transportation survey conducted by the Federal Department of Transportation indicating that persons 55 and older account for about ten percent of nighttime miles and about 15 percent of daytime miles.

While some information is available concerning the visual characteristics of older persons, it is not clear that this includes those characteristics that determine the ability to detect and identify highway signs as night. Even if we could be sure this information was available, it seems reasonable that older persons who drive very much at night would tend to be those with better night vision. Thus, there is no way at present to accurately estimate the low-luminance vision characteristics of the population of persons who drive at night. It must also be remembered that the age composition of the population is changing. The percentage of people 55 and over is increasing. In addition, these people are enjoying better health and have more disposable income than in the past, so are likely to travel more. As a result of these known trends, setting standards based on present population characteristics could cause them to be outdated in the near future.

The older subjects who participated in this study were active and healthy individuals who drove regularly at night. Yet, it is apparent from the data that they are at a disadvantage relative to the younger subjects in detecting and identifying road signs. Given that the technology is available to make signs adequately conspicuous for this segment of the population, it seems unreasonable not to do so. For this reason Figure 29 is based on the results from all 30 subjects who participated in the field study.

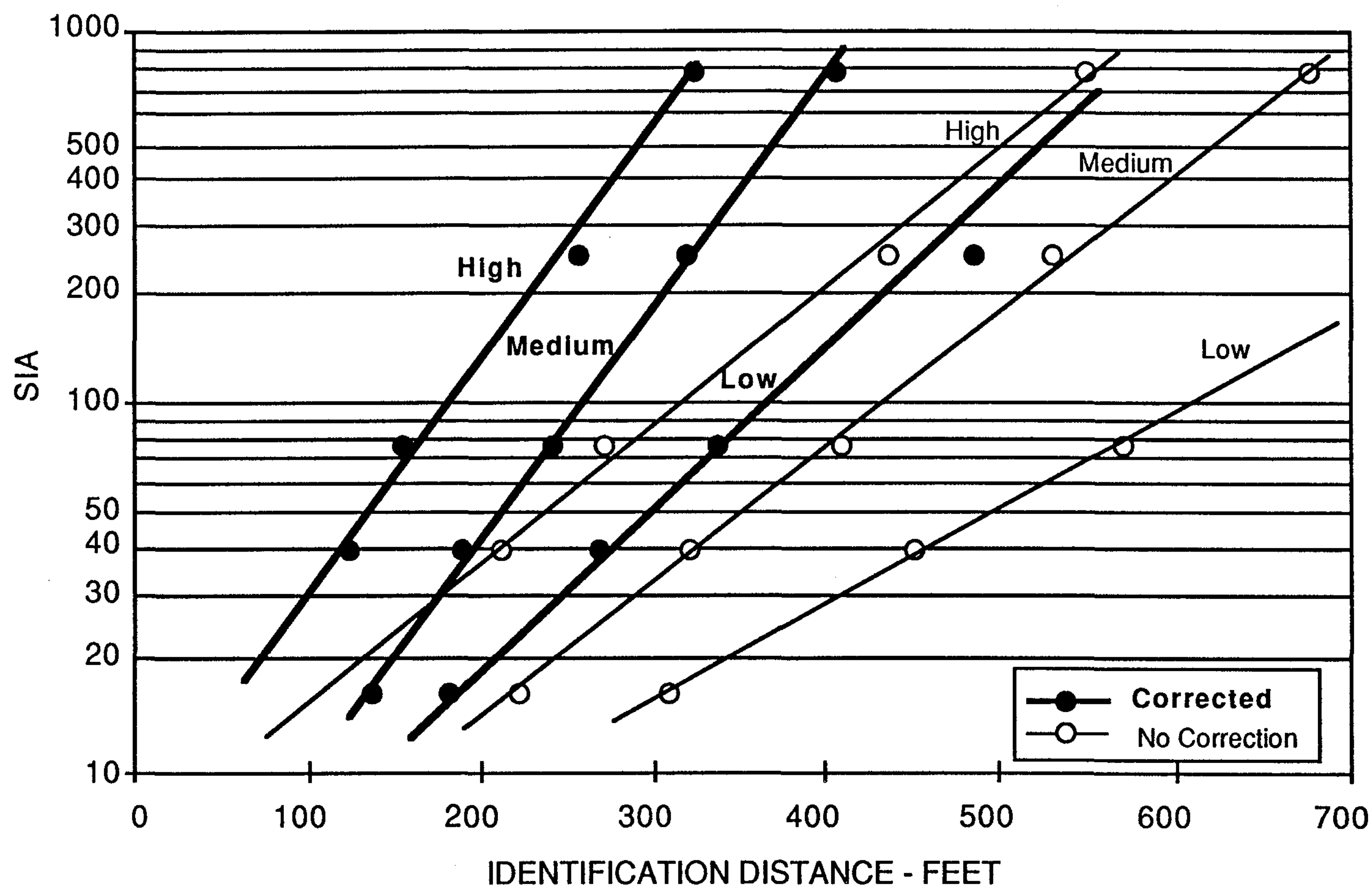

Figure 30. Eighty-fifth percentile sign identification distances for three levels of area complexity, with and without a correction for expectancy.

Sign background color. The results of the field study indicate that the effect of sign color is very significant. Until more precise data on the effect of color become available, it will be assumed that all colors within a given family of materials are as effective as yellow.

Figure 29 is based on data from yellow signs. In using it to derive recommendations for signs in colors other than yellow, adjustments are based on relative SIA's within the family of materials. For example, the SIA of a screened red is assumed to be 21% of that of yellow. If Figure 29 indicates that the minimum SIA of a yellow sign for a given application should be X, then the minimum for a red sign would be 0.21(X).

Sign size, borders and legends. The data from the field study are based on signs that are 30 inches square. Adjustments appropriate for signs that are much larger (e.g., guide signs) or smaller (e.g., street-name signs) can be made as indicated by the results of the laboratory study.

Yellow, orange, and white signs use black borders and legends, which would be expected to reduce their conspicuity by reducing their overall brightness. This effect would be most significant at longer distances where the sign approximates a point source. (For example, a 30-inch sign subtends about 0.3 degree at 500 feet.) The effect should be proportional to the percent of the surface area that is black. No precise data are available, but the portion of the faces of yellow, orange, and white signs that is black is estimated to range from 10 to 30%. A 15% figure will be taken as representative. The replacement SIA value of such signs will be adjusted by 15% in the recommendations that follow to allow for this effect.

Red, green, and blue signs have white borders and legends. Nominally, this should prove helpful, because it increases the effective SIA for the whole sign. However, barring use of borders and legends from a family of materials having higher overall SIA, the field data indicate that the benefits of the colored background outweigh the contribution of the white areas. Hence, no adjustments will be made to the recommendations for minimum values of red, green, and blue signs due to the effects of borders and legends.

Vehicle. The recommendations are based on the assumption of a single vehicle in the right-hand lane, using low-beam headlamps (of the type specified in FMVSS 108), in correct aim and driven at 12.8 volts. All glass will be assumed to be clean and clear.

Spatial location. Where a sign is located (to the right, left, or overhead), and how far it is from the path of travel, affects the amount of illumination reaching it from an approaching vehicle's headlamps. In order to generalize the data from the field study to locations other than the right edge of the road, a computer model was written to calculate their luminance. The field data could then be used to estimate minimum SIA values. The accuracy of the model was verified by use of the field photometric measurements. Other measures were made at 300 feet of sign panels in an overhead and left road-edge position, to verify its accuracy in these locations as well.

Types of signs. Recommendations will be based on a structure first defined by Perchonok and Pollack (1981). While many of the recommendations of those authors are somewhat arbitrary, they offer by far the best logical framework available at the present time.

Perchonok and Pollack classify signs into four categories, based on what the driver must accomplish prior to reaching them. These categories are:

Class I. The driver must accomplish all critical steps (i.e. detection, recognition, decision, response, and maneuver) prior to reaching the sign. A stop sign is an example of a class I sign.

Class II. The driver must accomplish all but the maneuver stage prior to reaching the sign. There are few signs in this category. Perchonok and Pollack cite the TURN OFF 2-WAY RADIOS sign (W22-2), as the only example in the MUTCD.

Class III. The driver must detect and recognize the sign, and reach a decision prior to reaching the sign. Response and maneuver, if any are necessary, can occur after the sign is passed. Most warning and guide signs fall into class III.

Class IV. The driver must only detect and recognize a class IV sign. Mileposts and general service signs are examples of this category.

Recommendations

In this section minimum SIA recommendations will be presented for stop, construction, warning, and overhead guide signs. These recommendations will provide guidance in themselves, and also serve as examples of how the data collected in this study can be utilized.

The reader should bear in mind that the examples offered are based on fairly optimum conditions. The signs are assumed to be clean, the weather is clear, and the road is straight and flat. Other assumptions concerning the vehicle have already been enumerated. In addition, there are a number of assumptions made in each calculation, which are described below.

Stop signs. Stop signs are class I signs (i.e., the required maneuver must be completed by the time the sign is reached). In preparing these recommendations it was assumed (1) that the distances given in Figure 29 are equivalent to response distance in the case of a stop sign, and (2) that the driver decelerates at a mean of 0.25 g. Table 11 gives the minimum SIA recommended for stop signs not accompanied by an advance warning sign or other supplemental device, for various traffic speeds and areas of different complexity.

TABLE 11

RECOMMENDED MINIMUM SIA VALUES FOR A STOP SIGN

Speed (mph)	Stopping Distance @ 0.25 g (feet)	Area Complexity		
		High	Medium	Low
65	569	*	*	150
60	484	*	*	71
55	407	*	155	30
50	337	170	63	14
45	272	70	25	8
40	215	30	11	4
35	164	16	5	3
30	121	8	3	2

*Supplemental warning required.

The values in Table 11 were derived as follows: First, red was assumed to be equal in conspicuity to yellow in the same family of materials. Then, for each stopping distance shown, Figure 29 was accessed to find the appropriate SIA for each level of area complexity. For example, for 121 feet in the high-complexity area, Figure 29 indicates an SIA of about 40. This value was multiplied by 0.21 to obtain the equivalent SIA for a screened red material, yielding an estimated minimum SIA of 8.

SIA values above 40 are not generally attainable with type III materials in red at present. At any point in the table where the minimum recommendations cannot be met some form of supplemental warning device (e.g., flasher or advance warning sign) should be employed.

Table 11 is based on a 30-inch sign. Larger or smaller stop signs would presumably be somewhat more or less conspicuous. No estimates are available from these data concerning how much of an adjustment should be allowed. Quite possibly the effect depends on the distance at which it is detected. If a sign is far enough away to be seen as a point source, a large sign would return more light and would appear brighter. Thus, conspicuity should be directly proportional to surface area. On the other hand, if the sign is seen as an extended source, judgments of brightness are based on luminance per unit area on the sign, and size may have little effect.

The results of this study indicate that detections were occurring when the sign subtended an angle of 0.7 degree or less. Generally speaking, this would place it in a range where both effects are operating. Thus, size could have an effect, but not in direct proportion to area.

Table 11 makes it clear that, except for low speeds and areas of low complexity, stop signs should use class III retroreflective materials and/or be accompanied by supplemental warning devices. It would also be desirable to point out that these recommendations are based on 85th percentile performance. This implies that 15% of drivers will respond at a shorter distance and will have to use a higher level of deceleration than 0.25 g to bring their vehicle to a stop.

A recent report on the conspicuity of stop signs (Morales, 1987) offers an opportunity for comparison. Morales used ten stop signs having different retroreflective properties in a field test involving twenty subjects of various ages. The test was run on a dark, private road. The signs were always presented at the same location. The distance from the sign at which the subjects "without any doubt" recognized a sign was measured on each run. Mathematical relationships between various retroreflective properties and recognition distance were developed, and recommended minimum SIA values prepared.

Morales' recommendations are based on what he calls "overall SIA," a measure that takes into account both the red and white areas of the sign. To obtain overall SIA one first measures the SIA in the red and white areas of the sign. The former value is multiplied by 0.76, the latter by 0.24, and the products summed. By this index a new type II stop sign that had SIA's of 120 and 16 in the white and red areas respectively would have an overall SIA of 41 ([120 x 0.24] + [16 x 0.76] = 41).

At first glance Morales' recommended minimum SIA values are generally much lower than those given in Table 11 for the low-complexity area. However, if the correction for expectancy is removed from the values given in Figure 29, the differences are much less. As an example, Table 12 has been prepared. In Table 12 the recommended minimum SIA values given in Table 11 for the low-complexity area were recomputed without the correction for expectancy and converted to overall SIA (assuming red to be 13% of white). An inspection of Table 12 shows the recommended minimum values for 40 and 45 mph to be very close. From 50 to 60 mph Morales' recommended minimums are actually somewhat higher.

TABLE 12

COMPARISON OF RECOMMENDED MINIMUM SIA VALUES FOR STOP SIGNS FROM TWO STUDIES

Speed (mph)	Stopping Distance @ 0.25 g (feet)	Minimum Overall SIA	
		Current Study*	Morales
65	569	46	40
60	484	29	40
55	407	17	40
50	337	11	18
45	272	8	10
40	215	6	6

*Calculated from data for low complexity area in Table 11 after removing correction for expectancy. Assumes red SIA is 13% of white SIA.

Given that the two studies were conducted in very different ways, the similarity shown in Table 12 is encouraging. However, it does seem clear that raw experimental data require an appropriate adjustment to compensate for the experimental subject's expectancy level.

Construction area signs. Orange series construction zone signs are mostly warning signs, a class that will be discussed next. However, some fall into class I, in that a maneuver must be completed by the time the sign is reached. An example is a lane closure sign, placed at the end of the available lane.

Table 13 gives the minimum recommended SIA's for such a sign as a function of area complexity and traffic volume. The latter variable assumes that it takes 8 seconds to check for traffic and make the lane change maneuver in light to medium traffic, and 9.8 seconds in medium to heavy traffic. These values are recommended by Perchonok and Pollack, based on a review of the literature.

TABLE 13

RECOMMENDED MINIMUM SIA VALUES FOR A CONSTRUCTION SIGN (orange) REQUIRING A LANE CHANGE

Speed (mph)	Traffic Volume							
	Light to Medium				Medium to Heavy			
	Required Distance (feet)	Area Complexity			Required Distance (feet)	Area Complexity		
		High	Medium	Low		High	Medium	Low
≥ 45		*	*	*		*	*	*
40	469	*	*	170	575	*	*	*
35	411	*	425	95	503	*	*	240
30	352	*	230	51	431	*	*	114
25	293	280	98	28	359	*	250	57

* Advance warning sign required.

The values in Table 13 were derived as follows: First, it is assumed that orange and yellow from the same family of materials have equal conspicuity. Then, for each required distance in the Table, Figure 29 was used to determine the appropriate SIA for a yellow sign. For example, for 293 feet in the low-complexity area, Figure 29 indicates an SIA of 45. This value is multiplied by 0.55 to obtain the equivalent orange SIA, and the result is multiplied by 1.15 to correct for the effect of borders and legends. The recommended minimum for 293 feet is an SIA of 28.

An examination of Table 13 makes it clear that there are relatively few cases where a single sign will serve. These occur largely at low speeds and in areas of low complexity.

Warning signs. Warning signs are class III devices, meaning that detection, identification, and some level of decision is required prior to reaching them. However, response and maneuver, if any, can take place after the sign is passed.

In developing recommendations for warning signs, a consideration is the complexity of the decision that must be made by the driver. Perchonok and Pollack distinguish three levels of decision complexity, low, medium, and high, assigning time values of 0.5, 2.5, and 4.5 seconds respectively. Table 14 is derived from Perchonok and Pollack's Table 19, and shows the assignment of decision complexity (hence decision time) as a function of the area complexity and number of choices created for the driver by the warning sign.

TABLE 14

DECISION COMPLEXITY AS A FUNCTION OF NUMBER OF POSSIBLE CHOICES AND AREA COMPLEXITY

Area Complexity	Number of Choices		
	0–1	2–3	≥ 3
Low	Low	Low	Medium
Medium	Low	Medium	High
High	Medium	High	High

Adapted from Perchonok and Pollack, 1981.

Table 15 lists recommended minimum SIA values for warning (yellow) signs as a function of area complexity and the number of options available to the driver. The values in this table were derived as follows: First, the speed in feet/second was multiplied by the appropriate decision time to obtain a decision distance. Figure 29 was then accessed to obtain an SIA. As a final step this value was multiplied by 1.15 to correct for the effect of borders and legends.

For orange series signs that fall under class III, an approximation of their minimum values can be obtained by multiplying the values in Table 15 by 0.55.

The lowest SIA listed in Table 15 is 15. This is primarily because extrapolations below 15 in Figure 29 are difficult. However, an SIA of 15 represents about 30% of the new minimum value of a yellow sign. By the time it reaches this level a sign would

TABLE 15

RECOMMENDED MINIMUM SIA VALUES FOR WARNING SIGNS (yellow) AS A FUNCTION OF AREA COMPLEXITY AND DECISION REQUIRED OF THE DRIVER

Speed (mph)	Area Complexity						
	Low		Medium			High	
	Number of Choices		Number of Choices			Number of Choices	
	0–3	3 or more	0–1	2–3	3 or more	0–1	2 or more
65	15	31	15	86	630	230	*
60	15	25	15	63	414	173	1115
55	15	21	15	52	276	144	750
50	15	17	15	38	180	110	520
45	15	15	15	29	126	80	345
40	15	15	15	23	80	63	230
35	15	15	15	17	52	52	150
30	15	15	15	15	35	38	100

* Supplementary devices required.

typically present a poor appearance night and day and be a candidate for replacement in any event.

Guidelines for warning signs have been prepared by Mace et al. (1985). They suggest that Type II yellow sheeting degraded to 36% of Federal specifications (i.e., an SIA of about 18) would be adequate for low-complexity sites. This compares well with the values given in Table 15, except for speeds of 55 mph or more in situations that face the driver with three or more choices.

At medium-complexity sites Mace et al. suggest that an SIA value of 36 may be the appropriate minimum. For many applications the recommendations in Table 15 are about half that value. For more complex choice situations this recommendation would be adequate for speeds of 50 mph or less, based on Table 15.

Mace et al. feel that Type III sheeting (SIA of 170) may be required in high-complexity areas. This compares well with the recommendations given in Table 15 for higher speeds, and when the driver has limited choices to make.

In sum, the recommendations for warning signs offered by Mace et al. compare reasonably well with those from this project.

Guide signs. Developing recommendations for guide signs is a more complex process than for the other types of sign considered up to this point. A number of assumptions must be made. These are:

1. Green is equal in conspicuity to yellow in the same family of materials.

2. The effect of the white border and legend on conspicuity is minimal.

3. The correction for driver expectancy does not apply. It will be assumed that drivers are searching for guide signs and their expectancy is approximated by that of the subjects in this study. Figure 31 has been prepared to estimate the SIA's without the correction for expectancy incorporated into Figure 29.

4. Guide signs are typically much larger than the signs used in the field study, and their larger size aids conspicuity. The only estimate of this effect comes from the laboratory study. Those data indicate that a correction of 2.4 would be appropriate (the threshold for the small green sign was double that of the medium green sign, which in turn was 20% greater than that of the large green sign).

5. Because of the distributional characteristics of low-beam headlamps, the level of illumination reaching an overhead guide sign will be a great deal less than the illumination reaching the test signs at the same distances. As noted earlier, a computer model was used to estimate the illumination levels appropriate for overhead signs.

6. Because of the position of overhead and many ground-mount guide signs, they are difficult to see when the car gets close to them. In addition, their luminance level begins to drop off rapidly as the car gets to within 2–300 feet. Therefore, it was assumed that the driver had to complete the reading task by 100 feet in front of the sign.

7. Reading time for a guide sign depends on the number of words contained on the sign. Mitchell and Forbes (1942) have estimated this time at 3 words/sec. Thus, the tables that present minimum recommended SIA's contain headings for 3, 6, and 9 words, representing 1, 2, and 3 seconds of travel time respectively.

The recommended minimum SIA's for an overhead guide sign are presented in Table 16. These values were derived as follows: First, the illumination reaching the overhead

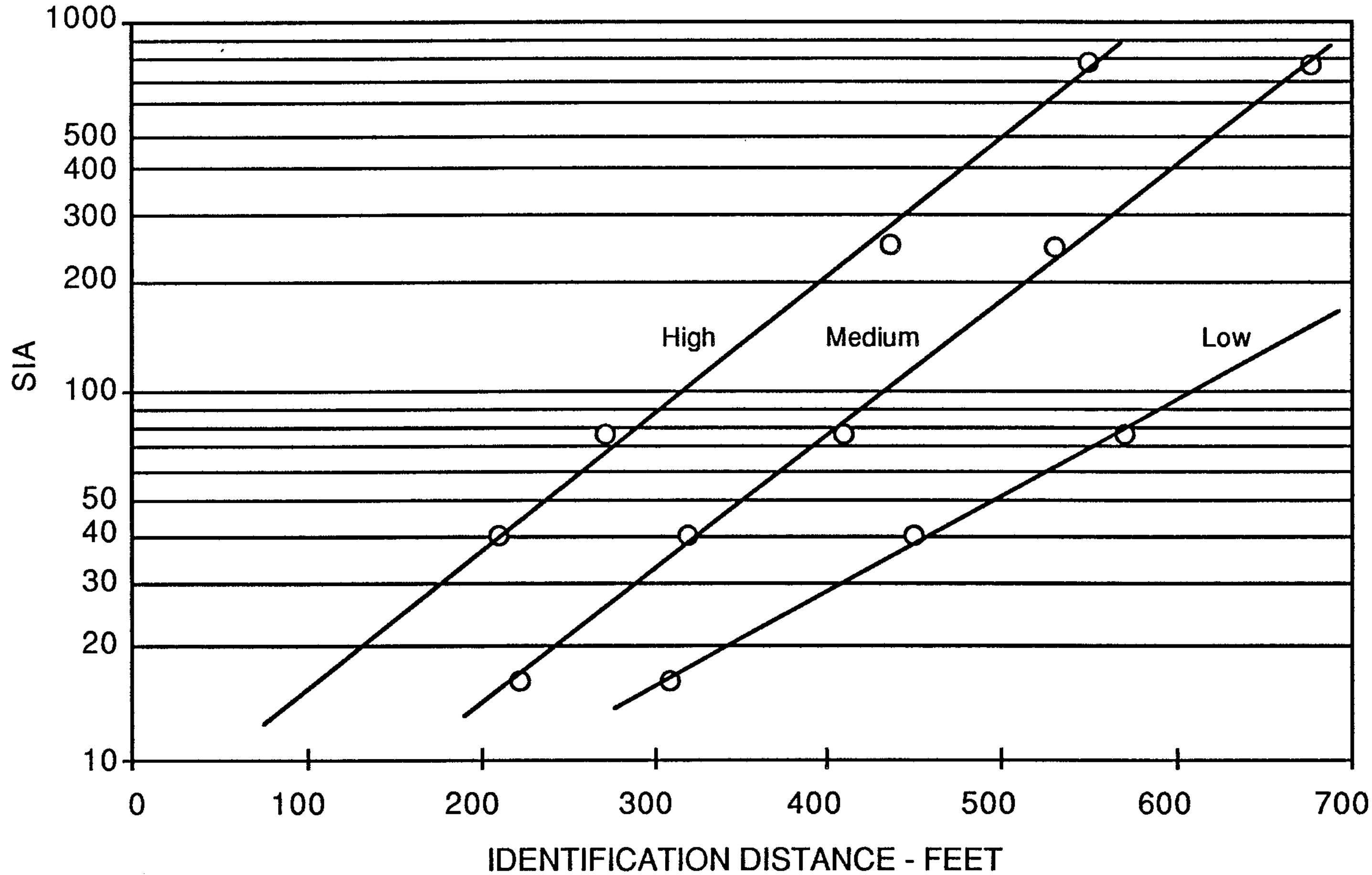

Figure 31. Eighty-fifth percentile sign identification distances for three levels of area complexity, no correction for driver expectancy. Yellow warning signs.

position was calculated. This was typically found to be about 10% of that reaching the test signs in the field study at the same distance. Thus, to achieve the same luminance level, the material on the overhead sign would have to have ten times the SIA. However, it is assumed that green has the same conspicuity characteristics as yellow in the same family of materials. Since green has about 23% of the reflectivity of yellow, the SIA value must be increased only by 2.3. The correction for size is 2.4, which nearly cancels out the correction for relative reflectivity. Thus, the values given in Figure 31 are a good estimate of the minimum SIA's for overhead signs, and were used directly in making up Table 16.

TABLE 16

RECOMMENDED MINIMUM SIA VALUES FOR AN OVERHEAD GUIDE SIGN

Speed (mph)	Area Complexity								
	Low			Medium			High		
	Words on Sign			Words on Sign			Words on Sign		
	3	6	9	3	6	9	3	6	9
70	8	15	27	13	31	70	35	82	200
60	8	13	22	12	25	54	32	70	150
50	7	11	17	11	20	37	28	54	100
40	7	9	13	10	15	25	25	40	68
30	6	8	10	8	12	17	22	33	46

Sign is assumed to be 20 feet high and centered over a roadway 24 feet wide.

An examination of Table 16 indicates that enclosed-lens materials would be appropriate on overhead guide signs only in areas of low complexity and with three or fewer words on the sign. More highly reflective materials, and/or multiple signs are appropriate in most cases.

Discussion

The recommendations offered in this section of the report are designed to provide guidance in making decisions concerning the type of materials to use, when to replace them, and the need for redundant or supplemental devices. The range of devices and situations considered here is limited. However, by using the logic illustrated, and the information contained in this report, estimates can be derived for other situations as well.

As is generally the case in any research project, questions remain to be answered. Further work should be done to clarify issues relating to sign size and color, for example. The latter issue is particularly intriguing, since it appears that color might be a major factor in conspicuity. The results of this study are only suggestive as regards color effects. Further work is required to define the relationships with precision.

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APPENDIX A. LABORATORY COLOR STUDY

Introduction

In the field conspicuity study described in the main portion of this report, it was noted that there were substantial differences in sign identification distance as a function of the color of the sign panels displayed. Specifically, signs in red, orange, blue, and green were detected and identified by the subjects at substantially greater distances than were signs in yellow having approximately the same SIA. In searching for an explanation of these findings, it was noted that they conform generally to the results of studies involving heterochromatic brightness matching. Data from these investigations indicate that judgments of brightness are influenced by hue and saturation.

The purpose of this study was to determine whether the results obtained in the field study could be duplicated under laboratory conditions. Actual signing materials were used as stimuli, and were presented at luminance levels that would be encountered in practice. The subjects were adapted to the mesopic range, as they would be in driving at night.

Method

Eight panels of retroreflective materials in six colors were used in this study. The panels were each one foot square. There were two white and two yellow panels, one of each being type II and the other being type III material. The other panels were blue, green, red, and orange, and were faced with type II material.

The test panels were illuminated by a 35 mm slide projector positioned just above the subject's head, and viewed at a distance of 120 feet. An aluminum blank in 35 mm size with a small hole drilled through was inserted in the slide position and used to restrict the illuminated area to a size just sufficient to cover the test panels. Luminance measures of each panel were made from the subject's eye position, using the photopic setting on the photometer. The results of these readings are given in Table A-1.

A pair-comparison approach was used. On each trial subjects were presented with two panels side by side. They were asked first to state which panel they thought was brightest. Next, they were asked to estimate how much brighter it was. The second response was in the form of a multiplier (e.g., 1.5, 2.0). Judgments of "equal" were allowed.

Nine subjects participated in the study. All were young (i.e., 20–25 years of age). None had been involved in any of the other field or laboratory investigations. Each subject viewed 28 pairs of panels, a process that took 15–20 minutes.

TABLE A-1

RESULTS OF PHOTOMETRIC MEASURES ON TEST PANELS

Color	Material Type	SIA ($-4° - 0.2°$)	Luminance (cd/m^2)
White	III	300	40.9
	II	108	14.3
Yellow	III	250	33.8
	II	85	10.8
Orange	II	44	5.14
Red	II	27	2.86
Blue	II	10	1.41
Green	II	17	2.28

Results

The results of the ratings are given in Table A-2. In this table the materials have been listed in order of their luminance, as measured with the photometer. Each cell entry for the photometric data (P) was derived by dividing the measured luminance (from Table A-1) of the panels listed vertically on the left by the measured luminance of the panels listed across the top. The entries labeled "E" in Table A-2 represent the mean ratios estimated by the subjects for each pair.

A comparison of the photometric and estimated ratios for each cell shows three points of interest:

1. In most cases the subjects estimated the brightness difference to be far less than the objectively-determined luminance difference.

2. In two cases where the subjects compared two panels of the same color (white and yellow) the estimated brightness differences are close to the photometric differences.

3. In two cases the subjects judged a panel of objectively lower luminance as being brighter than a comparison panel. These were the white and yellow type III panels, and the orange and red type II panels.

TABLE A-2

RESULTS OF LABORATORY COLOR BRIGHTNESS STUDY

Color	Material Type	P or E*	Test Panels Yellow III	White II	Yellow II	Orange II	Red II	Green II	Blue II
White	III	P	1.21	2.86	3.79	7.96	14.30	17.94	29.01
		E	0.79	2.56	2.19	3.19	2.46	2.69	3.69
Yellow	III	P		2.36	3.13	6.58	11.82	14.82	23.97
		E		2.17	3.02	3.33	2.64	3.50	3.44
White	II	P			1.36	2.78	5.00	6.27	10.14
		E			1.07	1.43	1.30	1.81	2.47
Yellow	II	P				2.10	3.78	4.74	7.66
		E				1.30	1.14	1.53	2.07
Orange	II	P					1.80	2.25	3.65
		E					0.88	1.24	1.70
Red	II	P						1.25	2.03
		E						1.37	1.64
Green	II	P							1.62
		E							1.28

P = Photometric ratio
E = Estimated Ratio

Figure A-1 is a plot comparing the photometric and estimated ratios obtained for the two types of white material. A great deal of research has shown that people tend to systematically underestimate luminance ratios in a test such as this. However, the relationship is typically monotonic when dealing with stimuli of the same color. The relationship in Figure A-1 is definitely not monotonic, and clearly shows the effect of color on judgments of brightness.

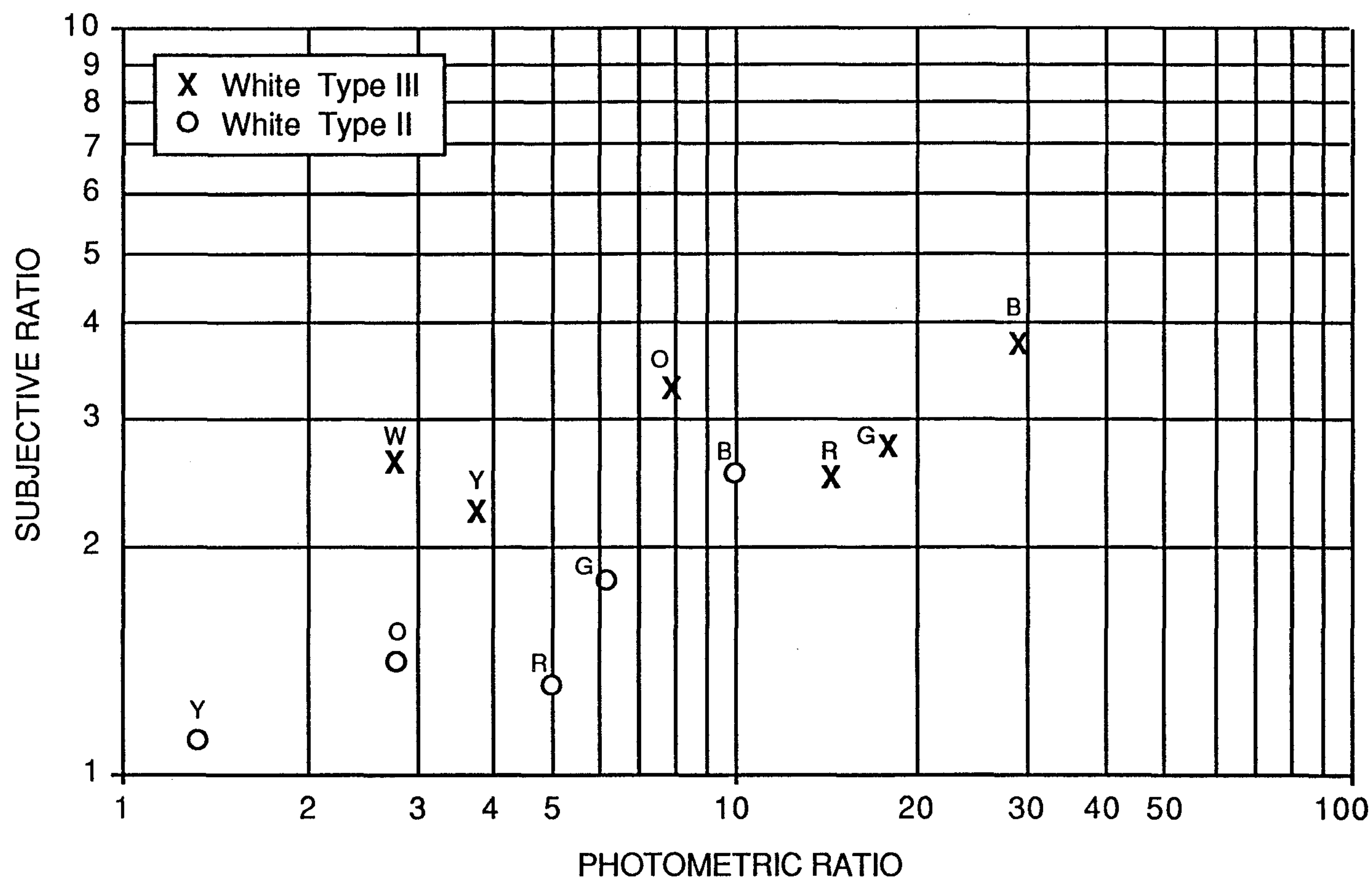

Figure A-1. Plot comparing photometric and subjective ratios resulting from comparisons with two types of white material.

Discussion

The results of the field study described in the main section of this report suggest that colors such as red, orange, green, and blue would be judged brighter than yellow in a test such as this one, when luminance was constant. Luminance in this test was governed by the SIA value of each panel, and each pair differed in luminance.

However, the results of the study strongly indicate that, had the luminance levels been equal, the red, orange, green, and blue panels would have been judged brighter than the yellow panels. This is consistent with the results of the field study and with what would have been expected based on heterochromatic bright ness matching studies.

The results of the laboratory study described in this section are consistent with the results of the field study as concerns color, and indicate that color is an important factor in sign conspicuity. Further work should be undertaken to more completely document the magnitude of the effect.

APPENDIX B. FIELD LUMINANCE MEASUREMENTS OF TEST SIGN PANELS

Photometric measures were taken of eight of the signs used in the study. A Model 1980A Pritchard Photometer was used. The photometer was set up at the rear of the test station wagon, shooting through the open back window, over the driver's position, through the windshield at the sign. The signs were placed about three feet to the right of the vehicle and at intervals from 100 to 1800 feet from the driver's eye point.

The test vehicle was parked about three feet from the right edge of the road. Using marks on the front and rear windows, it was aligned with the test road and put in park. Its headlamp control system was adjusted to 12.8 volts.

The signs were placed on a stand that supported them with their centers about five feet above the pavement. The longitudinal distances of interest were measured and marked on the pavement edge for easy reference.

Measurements began at the 100-foot interval. Readings were made of each of the test signs using the photopic setting on the photometer. The sign support was then moved to the 200-foot position, and the process repeated.

The results of the photometric measurements are given in Table B-1.

TABLE B-1

RESULTS OF FIELD PHOTOMETRIC MEASUREMENTS
(units are cd/m^2)

Color	SIA	Driver to Sign Distance (feet)						
		100	200	400	700	1000	1400	1800
White	115	1.37	28.5	24.1	11.1	5.90	2.98	1.95
Red	64	3.95	7.52	10.3	5.41	2.77	1.38	0.93
Orange	40	2.88	6.60	7.65	3.60	1.69	0.80	0.57
Yellow	750	10.20	37.9	101.3	55.1	29.0	14.00	10.70
Yellow	250	13.39	36.90	50.1	24.0	10.7	6.20	3.85
Yellow	77	5.02	12.7	16.4	7.57	3.69	1.80	1.21
Green	64	2.34	6.60	13.5	7.32	3.97	1.97	1.32
Blue	11	0.89	2.15	2.40	1.08	0.57	0.29	0.23

APPENDIX C. LABORATORY STUDY OF SIGN CONSPICUITY

LABORATORY STUDY OF SIGN CONSPICUITY

Introduction

The program began with a laboratory investigation. There are formidable difficulties in attempting to use laboratory techniques in an investigation of this type. While it was recognized that the absolute values of minimum luminance that would come from such a study would probably be much too low, it was hoped that certain useful comparisons could be made that would be very difficult to do in a real-world setting.

In this study subjects were presented with a still projection of a nighttime driving scene. A special projection screen was prepared in which principal elements were shown much as they were in the actual scene. Thus, the nature of the clutter, the luminance of important elements, and the level of adaptation of the subject were about the same in the laboratory as they would have been had the study been run at the site where the photographs were taken.

Four locations were selected in dark areas of the scene for the simulated signs. The signs were made using retroreflective material in various sizes and colors. The signs could be independently illuminated by a projector. Subjects were given brief looks at the scene with one of the signs illuminated at a predetermined level. By systematically changing the level of the sign illumination, thresholds could be determined for each of them.

High-Complexity Surround

The high-complexity surround was intended to represent a cluttered, urban environment, similar to that found in areas where there are many shopping areas close to the road, with high levels of lighting from many sources.

Method

Independent variables. The following independent variables were studied:

a. Sign size. Three sign sizes were used. All were scaled based on an assumed viewing distance of 500 feet. The "large" size represented a sign 15 feet high by 20 feet wide. The "medium" size represented a sign 7 feet by 15 feet. The "small" size represented a street name sign, 0.5 feet by 3 feet. The two larger signs were large enough to be seen as extended sources at the simulated 500-foot viewing distance. However, the small sign may have been seen as a point source (3 feet at 500 feet equals about one-third degree). The eye responds

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differently to extended and point sources, i.e., to luminance per unit area in the former case and total luminous flux in the latter case.

b. Color. Seven colors were used, i.e., green, yellow, orange, blue, white, black, and red. Green was used in all sign sizes. Black was used as a background color in one of the large signs. The other colors were used only in the medium size.

c. Text material. Three versions of the large sign were prepared. One was a blank green surface. Another simulated a green background with a white border and text. The third simulated a black (i.e. nonreflective) background with a white border and text. Figure C-1 illustrates the appearance of these signs with the simulated border and text.

d. Location. Four sign locations were used. One was in the center of the display, directly above the subject's eye fixation point. One was to the left about 15 degrees. Two were to the right, at about 15 and 25 degrees from the fixation point.

e. Subjects. A total of 26 subjects participated in this test. Of these 16 were younger (19–42 years of age), and 10 were older (65–83 years of age).

Dependent variable. The measure of performance was the level of sign luminance at which the probability of detection under the conditions of the test was 50%.

Equipment. A display was created that attempted to provide as accurate a representation of a real-world scene as possible. First, two series of photographs were taken of a busy street in a crowded shopping area. The photographs were edge-matched and showed the left and right sides of the area respectively. After the photographs had been processed they were projected and evaluated, and one from each series (i.e., a left and right side of the scene) was selected for use in the study.

A projection screen was created that was 12 feet wide and 8 feet high, forming a shallow "U." This allowed the unit to stand by itself, and kept all surfaces at more or less a constant distance from the subject. The surfaces were painted flat black.

The plan was that dark areas of the projected image would fall on the black portion of the screen, and retroreflective material would be placed on the screen in those areas where bright images occurred (e.g. signs, storefronts, streetlights, car lights). In order to minimize the observation angle, the projected scene was reflected by a mirror in front of the subject and then onto the screen. Figure C-2 is a photograph of the subject's table.

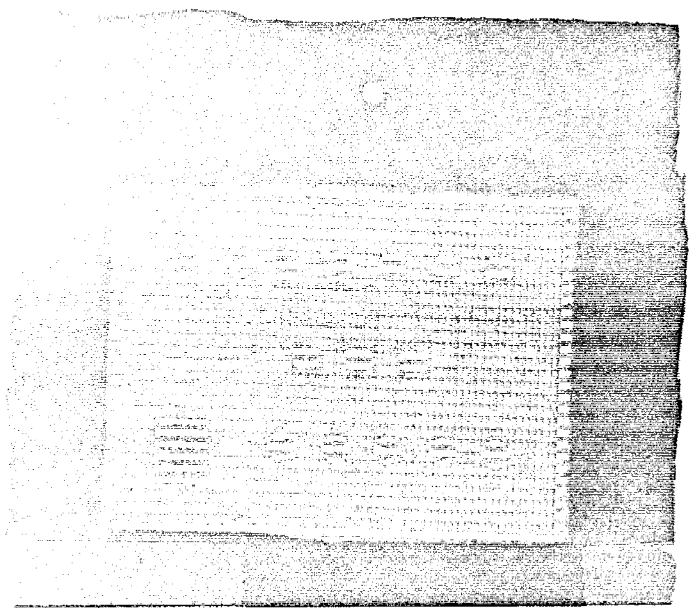

Figure C-1. Photograph of sign with border and simulated text.

The scene mirror is just to the right of center. The projectors (covered by shrouds to control stray light) are on the left. Figure C-3 is another view, showing a subject in place. The lens shutters of two of the projectors can be seen reflected in the mirror. The smaller, convex mirror near the bottom of the picture was part of the system for illuminating the signs and will be discussed later.

The first step in preparing the screen was to project the scene onto it and apply retroreflective sheeting in areas where bright images occurred. Figure C-4 shows how the screen looked with the sheeting in place.

Very bright images (i.e., four streetlamps and the headlights of two oncoming cars) were brought up to appropriate levels by causing the image to fall on small inspection mirrors, and then be reflected back in the subject's eyes. Neutral density filters were placed over the mirrors to achieve the required level of illumination at the eyes of the subject. Figure C-5 shows one of the mirrors.

A number of very bright items (primarily signs and storefronts) in the actual scene were photometrically measured in the field and then again in the laboratory simulation. It was not possible to arrive at an exact photometric match, but in many cases the simulation was close (i.e. within 20%) to the actual values. The poorest match was measured at about half the actual value.

The level of adaptation was determined by use of a Lux meter placed at the position of the camera lens, facing toward the scene. To reach the same level in the laboratory it was necessary to supplement the illumination from the scene by means of a small fluorescent lamp, mounted above the screen

In Figure C-4 a small television will be noted at the center of the screen. On this was displayed a simple tracking task that the subject was required to operate continuously during the test. Control was provided by a small knob located to the right of the subject. The knob could be turned right or left, much like a steering wheel, to keep the "road" centered on the TV screen. The subjects were told to keep their eyes on the TV at all times. Indeed, the difficulty level of the task was such that failure to do so would result in the road disappearing from the TV screen in short order.

Signs were made using enclosed-lens retroreflective material on six-inch square hardboard panels. Portions of the panel not covered by the sign material were covered by black velvet to minimize extraneous reflections. For the same reason, the immediate surround of each of the signs on the screen was covered by black velvet, as can be seen in Figure C-4. In many cases it was necessary to cover the retroreflective surface of the sign

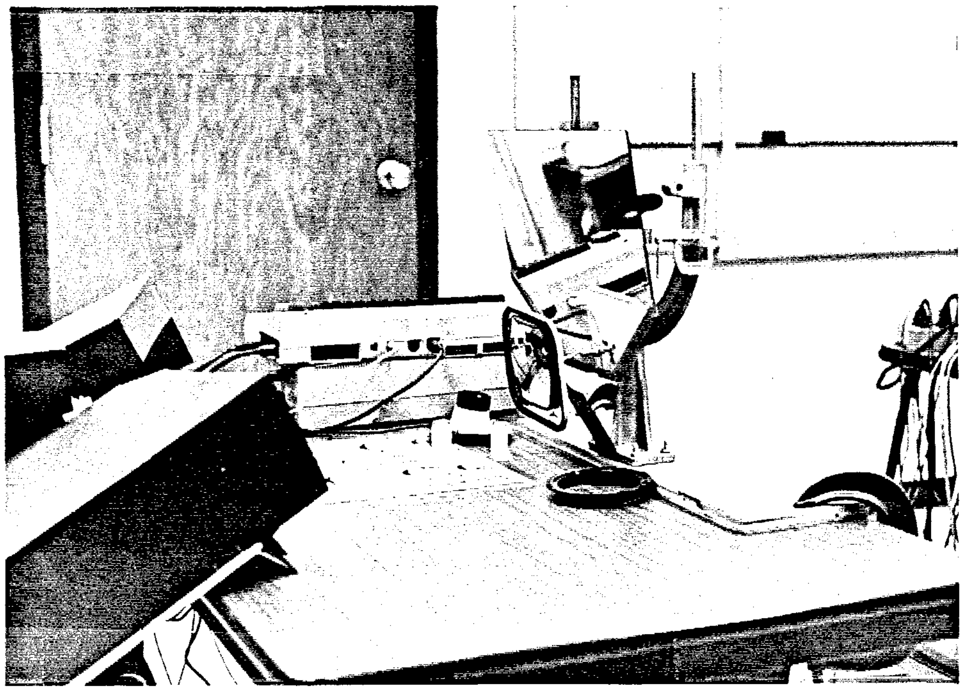

Figure C-2. Photograph of subject's table. Subjects were seated behind mirror to right.

Figure C-3. Photograph of subject's station, with subject in place.

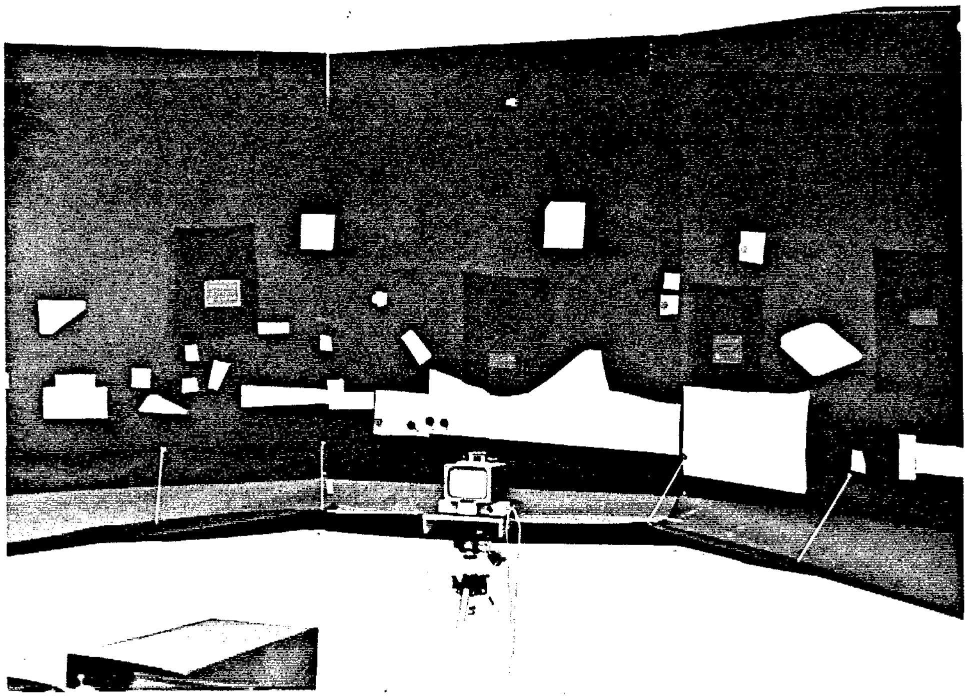

Figure C-4. Photograph of projection screen. White areas are retroreflective material.

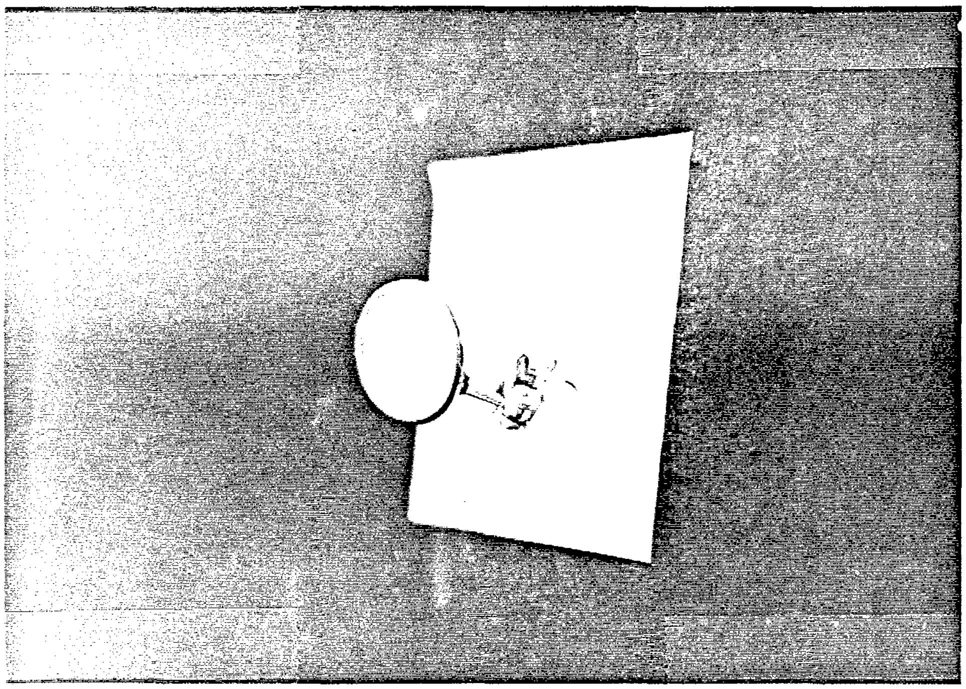

Figure C-5. Photograph of one of the mirrors used to provide high luminance levels from sources such as street lights and car headlamps.

with a special screening material (which can be seen in Figure C-1) so that it would not be visible to the subject except when specifically illuminated.

The signs were illuminated by a third 35 mm slide projector. Aluminum marks, cut to the same size as 35 mm slides, were placed in its slide tray. Holes 1/64" in diameter were placed in the mask to produce a beam that illuminated the immediate area of one of the signs. Four such masks were made, one for each of the sign positions. The beam from this projector was reflected in the convex mirror in front of the subject (shown in Figure C-3). The power to the bulb of this projector was routed through a variable transformer so that its output could be adjusted.

Photometry

Photometry was accomplished using a Spectra-Pritchard Model 1980-A. The photometer was set at the subject's position at the mid-point between where the subject's eyes would normally be located. A series of luminance readings was taken at various levels of projector output for each of the signs used in each of the sign positions.

Procedure

Subjects were run individually. After being seated at the table, the first step was to adjust the chin rest until they could just see the bottom of the TV screen over the top of the mirror in front of them. At this point the instructions were read (see Appendix D) and any questions answered. The tracking task was then turned on and the subject was given an opportunity to practice on that while the rest of the equipment was being readied.

The background scene was on continuously during the study. At intervals it was switched off for about one second, and then switched on again for 200 milliseconds with one of the signs illuminated to a predetermined level. The original scene, minus the sign, was then restored. At this point the subject had to indicate whether he/she had seen a sign and, if so, identify which one by number (1–4, left to right).

The staircase method was used in data collection. Using this procedure a failure to detect a sign on one trial resulted in its being presented at a higher level of brightness on the next trial. When a sign was detected it was presented at the next lower level of brightness on the next trial. A total of fifteen trials were run to establish the threshold for each sign for each combination of variables.

Each subject was given five tests, with different signs, under this condition. Because of the number of variables considered, it was not possible to run a fully-replicated design. Rather, a design was developed that made it possible to make comparisons among key variables of interest. Table C-1 is a listing of the signs that were used in each of the four positions on the screen. Note that the medium-size green sign was used as a reference in all four positions. Most of the other signs were used in only two positions. Exceptions were the signs with simulated legends and borders, which appeared in only one position.

Medium- and Low-Complexity Surround

The medium- and low-complexity surrounds were intended to simulate environments that might be characterized as "suburban," i.e., with some lighting, but much less clutter than the high-complexity surround, and "dark rural," i.e., with virtually no lighting or clutter.

The general approach was the same for the less complex surrounds as it was for the high-complexity display. The differences were in the display itself and in the simulated signs used.

For the surround scene at these levels photographs were taken of a lighted, four-lane, urban street. Except for the streetlights and a few vehicles, there were no other sources of illumination in the scene. This scene was projected on the screen and the bright areas surfaced with retroreflective material, as before. For the medium-complexity trials the scene projectors were run at maximum output. For the low-complexity trials they were turned down to the point where the streetlights in the scene could just barely be seen by the subject.

A different set of signs was made for these surround levels. These are listed in the lower portion of Table C-1. The "medium green" is the same as was used in the high-complexity study, and was included to provide a constant frame of reference. As before, all signs were scaled to a 500-foot viewing distance. The "small green" was 30 inches square, and was included to tie into the field study to follow. The "diamond" and "stop" signs were also 30-inch size. The "yield" sign was a standard 36-inch, and the "pennant" (intended to represent a no-passing sign) was 36 by 48 inches. All signs were blanks, showing only the appropriate background color.

Results

High-Complexity Surround

Ten older subjects were scheduled to participate in this phase of the study. Of these, one could not master the tracking task. Five of the remaining nine simply could not see the signs under any conditions, and no threshold detection data could be taken. The

TABLE C-1

LISTING OF SIGNS USED IN LABORATORY STUDY

Surround Complexity	Position 1 15° Left	Position 2 Center	Position 3 15° Right	Position 4 25° Right
High	Medium Green Large Green Large Green with White Legend & Border Medium Orange Medium Red	Medium Green Street Name – Green Medium White Medium Blue	Medium Green Large Green Large Black with White Legend & Border Medium Orange Medium Red	Medium Green Street Name – Green Medium White Medium Blue
Medium	Medium Green Yellow Diamond Yellow Pennant	Medium Green Red Stop Red Yield	Medium Green Small Green Yellow Diamond	Medium Green Yellow Diamond Red Stop
Low	Medium Green Yellow Diamond	Medium Green Red Stop	Medium Green Red Yield	Medium Green Small Green

mean thresholds for the four older subjects from whom data were obtained were typically two to three times higher than the mean for the younger subjects on the same stimuli. However, because there were so few older subjects, and because they represented only the best performers from the group, their data will not be discussed further in this section.

Table C-2 summarizes the results obtained from the younger subjects under this surround condition. The table shows the mean thresholds of each condition relative to the thresholds obtained from the medium green sign at the same positions. For example, the mean threshold for the large green sign at the leftmost position at which it appeared (position 1), was 0.080 cd/m^2. This value, divided by the mean threshold for the medium green sign at the same position (0.099 cd/m^2) equals 0.81, indicating the large green sign had to be only about 80% as bright as the medium green sign to reach threshold at that position. Other values in the table were developed the same way, i.e., by dividing their mean thresholds by that for the medium green sign at the same position.

Statistical significance levels are shown for each sign and position, based on a comparison with the medium green sign. (The sign test was used in these analyses. See Appendix A for a discussion of this test.) An exception is the green and white sign, where the p value is based on a comparison with both the medium and large green signs.

The differences in values shown for different positions are fairly large in some cases. However, the largest differences generally involve the 25-degree right location, which represents a rather unusual situation (a sign 500 feet away and 25 degrees off the center of the road would be more than 200 feet off the road). It may be appropriate to disregard the 25-degree right data.

There is some evidence in the table suggesting that there are conspicuity differences associated with color. Disregarding Position 4 data, the trends indicate that yellow, orange and red may require higher luminance levels, and blue may require lower luminance than green to achieve the same levels of conspicuity. However, the direction of the differences suggests that they may be due to the so-called Purkinje shift. The photometry was done with the instrument set at photopic levels. Since the data were taken at mesopic adaptation levels, some shift in sensitivity toward the blue end of the spectrum is to be expected.

One of the concerns of this study was the degree to which white borders and legends added to the conspicuity of a sign. These data indicate that the background of a retroreflective green sign with a white border and legend from the same family of materials (i.e., a brightness contrast of about 7:1) can have significantly less luminance

TABLE C-2

COMPARISON OF RELATIVE LUMINANCE LEVELS AT THRESHOLD – HIGH COMPLEXITY SURROUND

Sign	Position 1 15° Left	p ≤	Position 2 Center	p ≤	Position 3 15° Right	p ≤	Position 4 25° Right	p ≤
Medium Green	1.00		1.00		1.00		1.00	
Large Green	0.81	0.01			0.92	NS		
Green Street Name			2.21	0.01			3.53	0.01
Green & White (Background)	0.65	0.01*						
Medium White			0.99	NS			1.13	0.05
Medium Yellow			1.02	NS			1.43	0.01
Medium Orange	1.11	NS**			1.25	0.01		
Medium Red	1.26	NS			1.25	0.01		
Medium Blue			0.94	0.01			1.29	0.01

*This level of significance applies both to a comparison with the medium and the large green sign.
**NS = not significant.

than a blank green sign of the same size and achieve the same level of conspicuity. In these data the difference is about 20%.

Not shown in Table C-2 are the results associated with another sign having the same border and legend, but a black background. This sign was used to allow a direct comparison of a fully-reflectorized guide sign with one having a non-reflectorized background, but reflectorized border and legend. The results indicate that the white areas of the black-background sign would have to be about 1.75 times brighter than the white areas of the fully-reflectorized sign to achieve equivalent conspicuity.

Medium- and Low-Complexity Surrounds

Tables C-3 and C-4 summarize the results of the study for the medium-complexity surround for young and older subjects respectively. As in the case of Table C-2, the results show the ratio of thresholds of the sign listed to the medium green sign in the same position. It will be noted that the 25-degree right data are out of line compared with that from other locations, as they were in the high-complexity surround data summarized in Table C-2, and are subject to the same concerns discussed earlier. The differences shown are all statistically significant for both young and older subjects. The differences between signs are likely associated, at least in part, with different positions in the scene, because where direct comparisons are possible in the same position (as in the case of the yellow diamond and pennant signs) the differences are relatively small.

Table C-5 summarizes the results of the study for the low-complexity surround. This table is somewhat simpler than the others, since each sign appeared in only one position on the screen.

Discussion and Conclusions

It was hoped that the methodology developed for the laboratory study would provide data useful for the establishment of conspicuity standards. However, the threshold values obtained were so low (generally in the neighborhood of 0.1 cd/m^2) relative to what was thought reasonable for real-world applications that they cannot be used directly. Hence, the field study will be the primary source of this information.

The laboratory results will prove useful for comparative data, particularly the effect of sign size on conspicuity. This information will be utilized in the recommendations section of the report.

Age effects will be discussed in some detail in a later section of the report. For the present it should be noted that the older subjects who participated in the laboratory studies

TABLE C-3

COMPARISON OF RELATIVE LUMINANCE LEVELS AT THRESHOLD FOR YOUNG SUBJECTS -- MEDIUM COMPLEXITY SURROUND

Sign	Position 1 15° Left	$p \leq$	Position 2 Center	$p \leq$	Position 3 15° Right	$p \leq$	Position 4 25° Right	$p \leq$
Medium Green	1.00		1.00		1.00		1.00	
Small Green					2.00	0.01		
Yellow Diamond	3.94	0.01			2.84	0.01	5.07	0.01
Yellow Pennant	3.50	0.01						
Red Stop			2.61	0.01			7.13	0.01
Red Yield			3.04	0.01				

TABLE C-4

COMPARISON OF RELATIVE LUMINANCE LEVELS AT THRESHOLD FOR OLDER SUBJECTS – MEDIUM COMPLEXITY SURROUND

Sign	Position 1 15° Left	p ≤	Position 2 Center	p ≤	Position 3 15° Right	p ≤	Position 4 25° Right	p ≤
Medium Green	1.00		1.00		1.00		1.00	
Small Green					1.87	0.05		
Yellow Diamond	2.80	0.01			4.93	0.01	12.80	0.01
Yellow Pennant	2.92	0.01						
Red Stop			3.80	0.01			17.65	0.01
Red Yield			5.04	0.01				

TABLE C-5

COMPARISON OF RELATIVE LUMINANCE LEVELS AT THRESHOLD FOR YOUNG AND OLDER SUBJECTS – LOW COMPLEXITY SURROUND

Sign	Position in Scene	Young Subjects		Older Subjects	
		Ratio	p ≤	Ratio	p ≤
Medium Green		1.00		1.00	
Small Green	25° Right	0.54	0.01	1.75	NS
Red Yield	15° Right	2.13	0.04	5.47	0.01
Red Stop	Center	2.35	0.01	10.04	0.01
Yellow Diamond	15° Left	1.46	0.01	3.72	0.01

had a great deal more difficulty than did the young subjects. More than half of the older subjects were unable to complete the portion of the test that involved the high-complexity surround, because they could not detect the signs at their brightest setting. They could detect the signs in the less complex surround, but their thresholds were much higher.

APPENDIX D. SUBJECT INSTRUCTIONS

SUBJECT INSTRUCTIONS – FIELD CONSPICUITY STUDY

This is a study of the visibility of road signs under nighttime driving conditions. For the next two hours or so you will be driving this car on various roads near here, and we will be measuring the distance at which you can see and identify the color of certain signs. (Turn on lights.)

Leaning against the car in front of us you can see six blank signs. These are the kinds of signs we are using in the study and you should be looking for. Note the different colors: yellow, orange, white, green, blue, and red. (Turn off lights for a moment and turn them back on again.)

When you see the signs along the road they will be held up in the air as you see with the yellow one now. (Turn off lights.)

Except for occasions when I tell you not to worry about them, you should always be on the lookout for the test signs. When you spot one tell me by saying "sign." When you are sure about the color, call that out to me too. Once again, the possibilities are yellow, orange, white, green, blue, and red. If you find you made an error on the color call out the correct color as soon as you realize it. Most of the time the signs will be yellow, but you will encounter the other colors now and again, so you have to be alert.

The signs will occur along the roads we will be using at intervals ranging from about one-half mile to several miles. Of course, there are other signs out there too, placed by the highway department. You should respond only to our blank signs.

This study will be run on public roads. I have no control over other traffic, so please drive as you normally would, paying attention to other cars and watching for stop lights and stop signs. I'll give you directions on where to go, where to turn, and help you look for traffic, but you're driving the car, and you should not do anything that you consider unsafe.

In so far as possible we have to stay well behind other vehicles on the road. Otherwise you would see the signs in the headlights of vehicles ahead of us. Because of this, if there are other cars a short distance ahead of us, I may ask you to pull into a side street or parking area and wait until traffic clears. Or, if there is no traffic behind us, I may simply ask you to slow down for a while.

Do you have any questions?

SUBJECT INSTRUCTIONS – LABORATORY CONSPICUITY STUDY

In this study we are trying to determine how bright a highway sign has to be in order that approaching drivers will be sure to see it.

On the screen in front of you we will project an image of a nighttime driving scene. The photograph was taken in Ann Arbor, you may even recognize the area. Scattered throughout the scene, and normally not visible to you, are four signs. With the room lights on you can see them now, against their black fabric backgrounds. The signs are in different sizes and colors and some have simulated writing on them. We'll number the signs one through four, from left to right (demonstrate).

The way it will work is as follows: Normally the scene will be on with the signs not visible. Periodically I will turn the scene off for an instant. It will then come back on for one-half second, with one of the signs illuminated. The original scene will then be restored. If you saw or think you saw one of the signs, call off its number. If you didn't see a sign say "no sign." About half the time I would expect that you will not see the sign. Prior to starting the study I will give you a number of practice trials so that you will become familiar with the process.

The small TV in the center of the screen will present a simple tracking task, which I will turn on in a minute or two. Its a little bit like driving a car on a winding road. You control the task with the little knob to your right. Keep your eyes on the TV at all times. Please do not attempt to look at the signs when they are being presented.

The study consists of five sessions with different signs. Each session takes about 15 minutes to complete. At the conclusion of each session you can get up and stretch if you like while I set up the next configuration. At the start of each session I will highlight each sign for you so that you can see what it looks like.

Any questions?