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Relative Visibility of Increased Legend Size vs. Brighter Materials for Traffic Signs

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FOREWORD

This report will be of interest to traffic engineers and other persons responsible for the design, fabrication, and placement of traffic control signs on highways. There has been some controversy as to sign size, letter type and spacings, and the retroreflective brightness for various signs. This research examined the relative conspicuity and legibility of signs with different retroreflective materials containing legends using different stroke widths and other stylistic variations. Both younger and older subjects evaluated the test signs. Four studies were conducted. They were:

1. Testing of the legibility effects of retroreflectivity and stroke width--both day and night--using four types of materials, three sign colors, and different lettering types and stroke widths.

2. Comparison of the results of dynamic testing of conspicuity and legibility with the static tests of Study 1.

3. Determination of whether the legibility distance per letter height is constant over the various letter heights [this is known as the legibility index (LI)].

4. Evaluation of the effects of increasing and decreasing inter-letter spacings.

The study results provide guidelines on which LI's should be used for different sign types and sheeting materials.

Two copies of this report are being sent to each Region and six copies are being sent to each Division office. At least four of these copies sent to the Division should be sent on to the State highway agency.

Lyle Saxton, Director
Office of Safety and Traffic Operations
Research and Development

NOTICE

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16. Abstract

Static and dynamic legibility studies were conducted to investigate the effects of level of reflectivity, letter series, stroke width, letter spacing, font, letter height, and driver age. The dynamic study also considered the effect of sign size and retroreflectivity on the level of conspicuity.

As expected, driver age had the largest effect on both legibility and conspicuity. In fact, the daytime legibility for older drivers is almost as poor as night legibility. Level of retroreflectivity, letter series, and letter height all had a significant effect on legibility. Increases in letter height resulted in proportionate increases in legibility up to about 600 ft (183 m). In most cases, stroke width, letter spacing, and font were not significant; however, with fully retroreflective signs, a narrow stroke width significantly increased the legibility of high-contrast signs. Using spacing narrower than the standard spacing did significantly reduce legibility.

With regard to conspicuity, 36-in (0.91-m) signs with type I sheeting were found to have detection distances equivalent to 24-in (0.61-m) signs with type VII sheeting. Black-on-white signs were found to have much shorter detection distances than black-on-orange or white-on-green signs.

Cost comparisons (excluding life-cycle costs) using the data available suggested that larger signs with type I sheeting were less expensive than smaller signs with type VII material which provided similar performance. The effects of other materials with brightness between type I and type VII were not of significant magnitude to provide reliable cost evaluations.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

Figure No.

LIST OF TABLES

Table No.

INTRODUCTION

OBJECTIVES

The objective of this research was to determine, for older and younger drivers, the *relative* conspicuity and legibility of signs with different retroreflective materials containing legends using different stroke widths and other stylistic variations. With respect to legibility, the principal objective was to determine the font, stroke width, and spacing that would optimize legibility (particularly for older drivers) for each retroreflective material tested. With regard to conspicuity, the objective was to determine the detection/recognition distance under controlled and comparable visual surroundings for different materials and sizes of signs with the optimum legend stroke width.

It is generally believed that sign legibility may be increased by increasing sign luminance and contrast, increasing letter size, and manipulating letter stroke width and series. Less well known is the relative improvement obtained from manipulating any one of these factors and what, if any, other stylistic variations in sign design, such as letter font, make a difference. Most studies have manipulated size or luminance, but not both. Other problems with earlier research are that older drivers were often not represented, and furthermore, that the availability of new, brighter sheeting materials meant that the range and interactive effects of these materials had not been studied.

The objectives of this study were therefore directed toward two goals. First, the studies were intended to determine minimum size, retroreflectivity, and other requirements to accommodate, as much as possible, the needs of elderly drivers. Second, the studies were designed toward evaluating tradeoffs in size and retroreflectivity in order to establish the optimum or most cost-effective method to maximize legibility distance and/or conspicuity.

BACKGROUND

There are two perspectives from which to argue the importance of designing traffic signs to meet the needs of older drivers. The first, and perhaps more convincing, argument is contained in demographic data that document the growth in the size of older age groups relative to other age groups. The second argument is derived from consideration of accident data and the over-involvement of older drivers in accidents and fatalities. Both lead to the conclusion stated in a review of age-related diminished capabilities that "it is prudent to anticipate ways in which the present system of traffic control devices may fail to accommodate the special needs of this group of motorists."[1]

Although elderly drivers are known to be over-represented in traffic fatalities, the reasons behind this are far from certain.[2,3] Attempts to relate driver performance (measured by either accidents or violations) to age-related impairments or signing deficiencies do not suggest any single obvious course of remediation. A survey by the American Automobile Association (AAA) Foundation for Traffic Safety found that 25 percent of elderly drivers experienced problems reading traffic signs.[4] Of these, the most frequently reported problem (42 percent) was sign placement. Other problems, reported equally often, were size, clarity of lettering, and clarity of message. Signing deficiencies were also cited as the primary factor in 20 percent of sampled tort actions, second only to pavement deformities (22 percent).[5] When only those accidents involving a fatality or serious injury were considered, signing deficiency was the primary factor.

Research has shown that drivers require a minimum amount of luminance contrast for both conspicuity and legibility. Signs must first be detected (sometimes in a visually complex background) and then the information must be processed and understood. This should all happen before a sign has been passed, and sometimes (e.g., at a stop sign) with enough distance remaining to permit a vehicle maneuver (e.g., deceleration to a stop) before the sign has been reached.

During the past decade, the Federal Highway Administration (FHWA) has sponsored several research studies focused on establishing a minimum or replacement retroreflectance performance standard for traffic signs. Other research has been concerned with design standards for new signs, e.g., what size and material should be implemented in various situations. Developing such standards requires an estimate of driver requirements for visibility distance. An analytic framework for evaluating the adequacy of any sign was developed in an FHWA study.[6] The framework reflects the principles of supply and demand and is based on the simple observation that drivers demand a minimum time and, therefore, distance to process and respond to information and that the characteristics of signs, headlamps, and the highway determine how much distance and, therefore, time are supplied to the driver.

The Minimum Required Visibility Distance (MRVD) model for estimating the minimum detection and legibility distances that drivers require incorporates the findings of numerous researchers to make the best possible estimate of the distance requirements for sign legibility and conspicuity.[7] In this model, it is assumed that depending on the type of sign, the driver may need time to detect a sign, comprehend its message, make a decision, initiate a response, and implement or complete a vehicle maneuver before reaching the sign. The MRVD for older drivers may be considerably longer than for younger drivers because of diminished cognitive abilities and changes in motivation and risk-taking behaviors. Signs that require most or all of the MRVD components will, therefore, potentially be more affected by driver age than those that only need to be detected and read.

Without reference to MRVD, one might think that the special needs of older drivers for conspicuity and legibility are based solely on visual impairment. The concept of MRVD makes it obvious that factors such as reaction time, decision making, and problem solving increase the distance needed by the older driver to detect and read signs, and that these factors can create visibility problems for the older driver even when visual impairment is not considered. In general, older drivers not only have problems seeing what younger drivers can see at a given distance, but they also need to recognize and be able to read signs at greater distances to provide them with the additional time needed to respond in a safe manner.

In addition to estimating distance requirements, the MRVD model also determines the required legibility index (LI) for a sign based upon the required distance and the available letter height. Other researchers have used the LI (distance in feet at which a letter is legible for 1 in (2.5 cm) of letter height) to describe the relative legibility of different letter styles.[8] Under daytime conditions, series B and D were reported to have 80th percentile indexes of 33 ft/in and 50 ft/in (3.96 m/cm and 6 m/cm). Over time, the value of 50 ft/in (6 m/cm) of letter height has become a nominative, although arbitrary and disputed, standard.

The LI is important to the determination of the size requirement for a sign in a specific application. The following relationships were noted:[6]

Required Letter Size = MRVD / LI
or
Required LI = MRVD / letter size

Either the letter size or the LI may be manipulated to satisfy the basic distance requirement. From the standpoint of sign maintenance management, luminance and contrast cannot be expected to compensate for inadequate letter size, therefore, it is important that the required size be determined at the time of installation. However, contrast and luminance will have an effect on the LI, therefore, the required letter size may depend on the type of retroreflective sheeting as well as other factors that determine legibility, e.g., letter series and spacing. Signs of adequate size should be installed so that daytime legibility is maintained and the luminance requirements are realistic.

Under nighttime conditions, several things happen that may make it desirable to maintain brightness and contrast below their optimum levels so that legibility is not sacrificed. Excessive contrast (or luminance on partially retroreflectorized signs) is more likely to degrade legibility for older drivers.[9] At night, drivers are exposed to darker surrounding luminance, which raises their contrast sensitivity. Increasing sign luminance increases conspicuity and legibility up to a point, after which irradiation may degrade legibility. When contrast is maintained within reasonable levels, irradiation should not be a problem; therefore one would expect that the luminance of fully retroreflectorized signs may be increased without degrading legibility. This assumption needed to be verified, especially with respect to the new higher intensity materials.

A report from the University of Michigan states that with partially retroreflectorized signs, irradiation is particularly serious for older drivers.[10] They recommend that at high levels of luminance, the stroke width of white letters on dark backgrounds should be decreased and the stroke width of black letters on retroreflective backgrounds should be increased to offset the effects of irradiation.

The problems that the present study needed to address were primarily concerned with the effects of size and brightness on legibility distance, the economic result of tradeoffs between them, and how these and other factors effect the LI for younger and older drivers. Although the literature could not provide any definitive answers because of the absence of older drivers in most studies and the recent availability of new and brighter materials, the relevant literature was reviewed for assistance in designing the experiments, choosing levels of relevant variables and forming hypotheses.

PREVIOUS RESEARCH

Legibility Studies

Size, reflectance, and internal contrast are the dimensions generally considered in attempts to improve sign legibility because the other dimensions are more strictly controlled by the *Manual on Uniform Traffic Control Devices* (MUTCD). In practice, size is established by the MUTCD and adjusted in response to level of service and design speed, not MRVD requirements. Because color is the major determinant of daytime internal sign brightness and contrast, daytime legibility is primarily manipulated by size. For a specified color, nighttime contrast is determined by the retroreflectivity of the materials chosen.

Some research on sign legibility has drawn attention to the variability in recommended luminance levels.[(11,12)] Research on luminance requirements of traffic signs has focused on establishing both minimum and optimum levels for legibility. When a sign is fully retroreflectorized, the luminance requirements are described in terms of both the brightness and contrast of the brightest component (typically the letters) against the background. Signs with only one retroreflectorized component are measured with respect to the luminance of the retroreflectorized material. According to other relevant reviews, for a given contrast and luminance, the highest LI will be achieved when the strokes and spacing of the letter E are equal.[1] This analysis also suggested that not all letters will be equally visible.[(13,14)]

Other research has provided optimum and replacement values for partially retroreflectorized signs on dark surroundings on the basis of a literature review.[(15)] The optimum value of 75 cd/m^2, provided by a University of Michigan Transportation Research Institute report, is the geometric mean of six studies with recommendations ranging from 24 to 343 cd/m^2.[(15)] The optimum value is primarily relevant to the goal of increasing sign brightness to enhance conspicuity. This same study suggests 2.4 cd/m^2 as the 50th percentile legibility requirement that might be appropriate for a minimum or replacement value. This value represents ideal conditions and requires adjustment for the effects of age, glare, and so forth. Also, 2.4 cd/m^2 is not adequate for conspicuity at high levels of background complexity, and it is questionable that it is representative of the needs of older drivers for legibility.[(15)]

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[1] This is not a characteristic of Standard Highway Series Letters.

For fully retroreflective signs, based upon a review of the literature, a 1988 report suggested a contrast ratio range of 4:1 to 15:1 as appropriate for most conditions.[16] For example, if the luminance of the green background is 5 cd/m^2, the luminance of the legend should be at least 20 cd/m^2. Lower contrast is not acceptable, and contrast as high as 50:1 is typically not considered to be a problem.

With regard to the effect of driver age on legibility, the following generalizations were noted:[10]

- Older drivers require more contrast between the message and the background of a sign than younger drivers to achieve the same level of comprehension.

- Legibility losses with age are greater at low levels of background luminance. A reduction in legibility distance of 10 to 20 percent should be assumed when signs are not fully reflectorized.

- Higher surrounding luminance improved the legibility of signs more for older drivers and reduced the negative effects of excessive contrast.

- Signs are more likely to suffer a loss in legibility for older drivers when luminance is increased beyond the optimum level on a partially reflectorized sign.

Increasing luminance increases legibility up to a maximum point where overglow or irradiation begins to degrade legibility. The loss of legibility is difficult to document. Some researchers report the loss to be quite small and only to occur at very high levels of luminance.[17] Others have shown irradiation to be more of a problem, particularly for older drivers.[18]

The problem of irradiation effects caused by Virginia's widespread use of high intensity sheeting has been addressed in an FHWA report.[14] The report also reviewed additional evidence that the way to increase legibility with brighter materials is to increase the stroke width. This is thought to be particularly effective with black legends on bright backgrounds and that for white legends, stroke width may have to be decreased. The only empirical research on this that we are aware of is a 1992 Transportation Research Board report.[19] This research concluded that widening the stroke width did not improve the legibility of black-on-orange signs.

One research group used subjects with an 85th percentile corrected acuity of 20/20 and found night visibility distances to be 15 percent to 20 percent shorter than daytime visibility distances.[20] The 85th percentile LI for series E was 55 ft/in (6.6 m/cm) in the daytime and 44 ft/in (5.28 m/cm) at night. Another research group, using subjects with normal vision to read three-letter nonsense syllables at night, found that legibility distance increased with letter width.[17] The maximum values were 45 ft/in (5.4 m/cm) for series A, 58 ft/in (6.9 m/cm) for series C, and 90 ft/in (10.8 m/cm) for series F.

A 1979 Human Factors report suggests that older drivers should not be expected to achieve an LI of 50 ft/in (6 m/cm) under most nighttime circumstances.[21] The data provided by this report gives some expectation that 40 ft/in (4.8 m/cm) is a reasonable goal under most conditions. Their data compare young and old drivers on luminance and contrast requirements for different legibility criteria, different colors, background, and surrounding luminance. A 40-ft/in (4.8-m/cm) standard can generally be achieved by older drivers with contrast ratios greater than 5:1 (slightly higher for guide signs) and luminance greater than 10 cd/m^2 for partially retroreflectorized signs.

Recommendations in the literature for the optimization of inter-letter spacing are limited to daytime situations. In general, legibility improves with increased spacing, but at some point reaches an optimal level beyond which further increases in spacing reduces visibility.[22] Some authors have recommended letter spacing equal to 50 to 100 percent of letter width.[23,24] Also, the distance threshold of recognition (DTR) for closely spaced words, has been found to be 20 percent less than letters tested in isolation.

With regard to capitalization, three findings from one research study seemed most applicable to the interests of this research.[25]

- When capital letter height is equal, uppercase words have a 20-percent greater legibility distance than mixed-case words.
- When mixed-case loop height is equal to uppercase letter height, lowercase words are more legible than uppercase words.
- When upper and mixed-case words subtend the same area on a sign, there is little advantage to choosing one style over the other.

Conspicuity Studies

The issue of sign conspicuity has been addressed by several authors. A conspicuous object has been operationally defined as an object that will, for a given background, be seen with certainty (greater than 90 percent probability of detection) within a short observation time (250 ms) regardless of its location in the visual field.[26] Other authors have suggested that driver motivation and expectancy should also be considered in any definition of a conspicuous object.[6] This distinction allows for manipulation of conspicuity by changing the driver's "set" so that changes in a sign or its location are not always necessary. Guide signs are more conspicuous to drivers looking for them (i.e., motivated) and stop signs following a STOP AHEAD sign are more conspicuous to everyone (i.e., high expectancy). Conspicuity may, therefore, be aided by multiple or advance signing as well as changes in size, luminance, and placement.

The luminance requirements for legibility and those for conspicuity are not always in agreement. A verbal sign with small critical detail may require more luminance for its legibility than for its conspicuity. However, a symbol sign with large critical detail, may require very little luminance for its legibility.

To satisfy the need for conspicuity, detection should not be confused with visual thresholds. Threshold detection for typical traffic signs is over 3000 ft (914 m).[27] Although detectable, traffic control devices at this distance are not conspicuous.

The role of visual complexity in the conspicuity of traffic signs has been studied in nighttime scenes and in daytime scenes.[6,16,28] Both studies found scene complexity to be a significant determinant of sign detection. In general, rural scenes may be thought of as low complexity and urban scenes as high complexity; however, the results from two separate reports show that scene complexity is not one-dimensional and that simple measures such as visual clutter are poor predictors of detection performance.[6,22] Specifically, complex nighttime scenes are those with high demands on driving (i.e., multiple lanes, other traffic, signals, etc.) and a significant amount of detail in the entire scene, not just in the area searched for signs.[6] Similar measures for daytime complexity were not available.

Additional research has determined that during daylight hours, size and visual complexity of the scene are more important determinants of conspicuity than target brightness.[26,29] Many authors have shown the importance of contrast to sign conspicuity, but the effect of contrast diminishes at high levels of visual complexity.[6]

Under real-world driving conditions, a shoulder-mounted 30-in (76.2-cm) yellow diamond was recognized anywhere from 600 ft (182.8 m) (14 arc minutes) to 1400 ft (426.7 m) (6 arc minutes) depending upon its luminance and the visual complexity of the surroundings.[6] Signs measuring as little as 1.5 cd/m^2 provided detection distances greater than 500 ft (152.4 m) for 30-in (76.2-cm) signs when visual complexity was low. When visual complexity was high, signs with luminance of 4.3 cd/m^2 or greater were inadequate to provide 500-ft (152.4-m) detection distances.

OVERVIEW OF TECHNICAL APPROACH

The goals of this research were pursued through the implementation of four field studies plus an economic analysis of tradeoffs in size and sheeting reflectance. Each study was designed to investigate a number of signing parameters and utilized one of three methodological techniques. Two static invehicle studies (#1 and #4) measured legibility from within a vehicle so that the variability of sign luminance was simulated as a function of retroreflective properties of materials and headlamp beam patterns. The dynamic field study (#2) measured legibility and conspicuity from a moving vehicle as the vehicle was driven through complex visual surroundings.[27] A static walking daytime study (#3) was implemented in the study where nighttime measurements and headlighting were not of interest.[30]

SUBJECT CHARACTERISTICS

Subjects over 65 years of age (older) were recruited through local chapters of the American Association of Retired Persons (AARP). Subjects under 40 years of age (younger) were recruited through advertisements placed in local newspapers or by word of mouth. All subjects were paid based on the number of experiments in which they participated.

All subjects participated in a battery of tests to determine their performance on tasks believed to be related to driving. These tests assessed visual acuity and contrast sensitivity and cognitive and motor skills. Each of the performance measures is discussed below and the average performance by age group is shown in table 1.

Table 1. Average performance on subject screening.

	Age	Acuity	Contrast Sensitivity	Reaction Time (seconds)	Stroop (seconds)
Younger Subjects	27	20	1.98	0.39	100
Older Subjects	72	26	1.80	0.83	162

Visual Performance was measured by tests of acuity, contrast sensitivity, and color vision. The latter performance measure was tested using the Dvorine pseudo-isochromatic plates, and resulted in two male subjects being excluded from our sample.

Visual acuity was used as the primary screening device because of its use in driver licensing and the availability of true age-specific normative data. In comparing our subjects to the U.S. population, we referred to the document *Monocular-Binocular Visual Acuity of Adults, United States 1960-1962.*[31] This document shows that individuals under 44 years of age have a 50th percentile acuity of approximately 20/15, and that almost 99 percent of these individuals have acuity scores of 20/40 or better. By contrast, the median acuity of persons greater than 65 years old is reported at almost 20/28, while only 77 percent have acuities better than 20/40. One subject was excluded from our sample because of vision below 20/40 in both eyes.

Contrast sensitivity was measured using a Pelli-Robson test chart.[32] To date, there are no normative or age-representative data describing performance on this test chart. Descriptive statistics that characterize the performance of our subject sample are presented for comparison to future normative analyses.

Cognitive Performance was assessed by means of a modified Stroop test, the development of which was inspired by a *Journal of Genetic Psychology* report.[33] In the most important portion of this test, the subject is shown a card with 100 words printed on the surface. The words are color-words (e.g., red, blue) and are printed in a color other than that depicted by the word (e.g., the word "red" is printed with blue ink). The subject is required to name the color of the ink used to print each of the 100 words as fast as possible. In the words of Comalli et al. "*...the test involves interference between color naming and word reading....Thus, a highly automatized activity (reading color-words) conflicts with the naming of a perceptual property (color).*"[33] Forty-eight individuals between the ages of 17 and 44, and 15 individuals from 65 to 80 years of age were tested.[33] The mean score for the younger subjects was 106 seconds; the mean score for the older subjects was 165 seconds.

Psychomotor Performance combines the use of motor and cognitive processes to initiate an act. Standard tests of psychomotor abilities attempt to minimize the cognitive aspect. The most straight forward method employs a simple reaction-time (RT) task. A measure of this ability was included in the battery of tests. A computer was located in front of the seated subject. The subjects placed their dominant hand on the table between themselves and the computer. At random time intervals, the computer emitted a simultaneous auditory and visual cue. The subjects were required to tap any key on the computer keyboard as soon as they either heard the "beep" or saw the monitor change. The purpose of using dual-sensory stimuli was to address the loss in both vision and hearing in the older population. Practice trials were administered until each subject achieved a stable level of performance. This avoided the problem of older subjects needing more trials in order to reach peak performance than their younger counterparts.[26] All subjects were then tested five times, the median of which was their recorded reaction time threshold. Although there has been a great deal of research on the topic, there is no consensus on age-related changes in simple reaction time. Review of relevant literature, however, suggests some small increase in RT with age, particularly when motion is involved. While age norms are not available, a comparison of older and younger performance is shown in table 1.

STUDY 1: EFFECT OF RETROREFLECTIVITY AND STROKE WIDTH ON SIGN LEGIBILITY

The purpose of this study was to test the effects of retroreflectivity and stroke width on the nighttime LI for letters of different sizes or letter series. Both negative-contrast partially retroreflective (black-on-orange or white) and positive-contrast fully retroreflective (white-on-green) signs were tested. However, letter size was not evaluated on partially retroreflective signs, and letter series was not evaluated on fully retroreflective signs. A second purpose of this study was to determine the optimum stroke width for each combination of retroreflective sheeting, color, and letter size. Similar hypotheses were tested for daytime legibility except that differences in material reflectance were assumed to be nonexistent.

EXPERIMENTAL PROCEDURE

This study used a static letter legibility methodology.[34] Subjects were seated in the front seat of a stationary car with low-beam headlights on, and they viewed signs at a number of fixed distances. Each sign was exposed for 10 s. Unlike the study that tested one sign at a time, numerous trials were completed with a variety of signs at one location before moving the sign location. This eliminated variation of sign luminance among signs of the same color and material at the same distance, a variation that could have resulted from differences in the car's position if only one sign at a time were tested at different distances.

Testing began at a distance slightly beyond the predicted threshold for the subjects being tested. Signs with the letters B, K, and E in three stroke widths on four materials were shown at decreasing distances until identification of the K and the E was correct on two consecutive trials. Correct identification of the B proved to be too difficult for some older subjects. To create uncertainty concerning the details of the stimulus, the position (left, center, and right) and orientation of the letters (forward and backward) were varied. Because the pilot study found a response bias towards correctly oriented letters even when all letters and orientations were equally probable, the orientation of the sign was reversed on successive presentations. This resulted in every letter being shown backwards and forwards in every two consecutive trials. The change in distance from one trial to the next resulted in a 10-percent increase in the visual angle of the target. Two subjects (seated in a 1989 Oldsmobile Delta 88) were tested at a time by having subjects make their responses in private using a cloth partition. The experimenter in the rear seat entered their responses into a computer.

INDEPENDENT VARIABLES

Sign Color and Materials

Three colors of sign background were tested: orange, white, and green. All sign panels were retroreflective. The black letters on the orange background (B/O) and black letters on the white background (B/W) resulted in a partially retroreflectorized sign with negative contrast. White letters on the green background (W/G) resulted in a fully retroreflectorized sign with positive contrast.

The negative-contrast signs of white and orange background used sheeting now on the market or available in the near future. The materials with ASTM-type numbers in parenthesis were:

- Avery's engineering-grade sheeting (I).
- Seibulite's super-engineering-grade sheeting (II).
- Stimsonite's cube-corner, high-performance sheeting (IV).
- 3M Company's diamond-grade sheeting (referred to as type VII in this report, although it has not yet been assigned an official ASTM type).

The R(a) values for both B/W and B/O are shown in figures 1 and 2 across a range of observation angles. These figures also show the LI associated with various observation angles, assuming 8-in (20.3-cm) letters and the car position and sign offset used in the static field studies. These LI estimates were calculated by dividing the distance producing the associated observation angle by the letter height. These calculations suggest, for example, that if the legibility index for any observer of any sign with 8-in (20.3-cm) letters was 35 ft/in (4.2 m/cm), the observation angle at the distance of 280 ft (85.3 m) would have been 0.4.

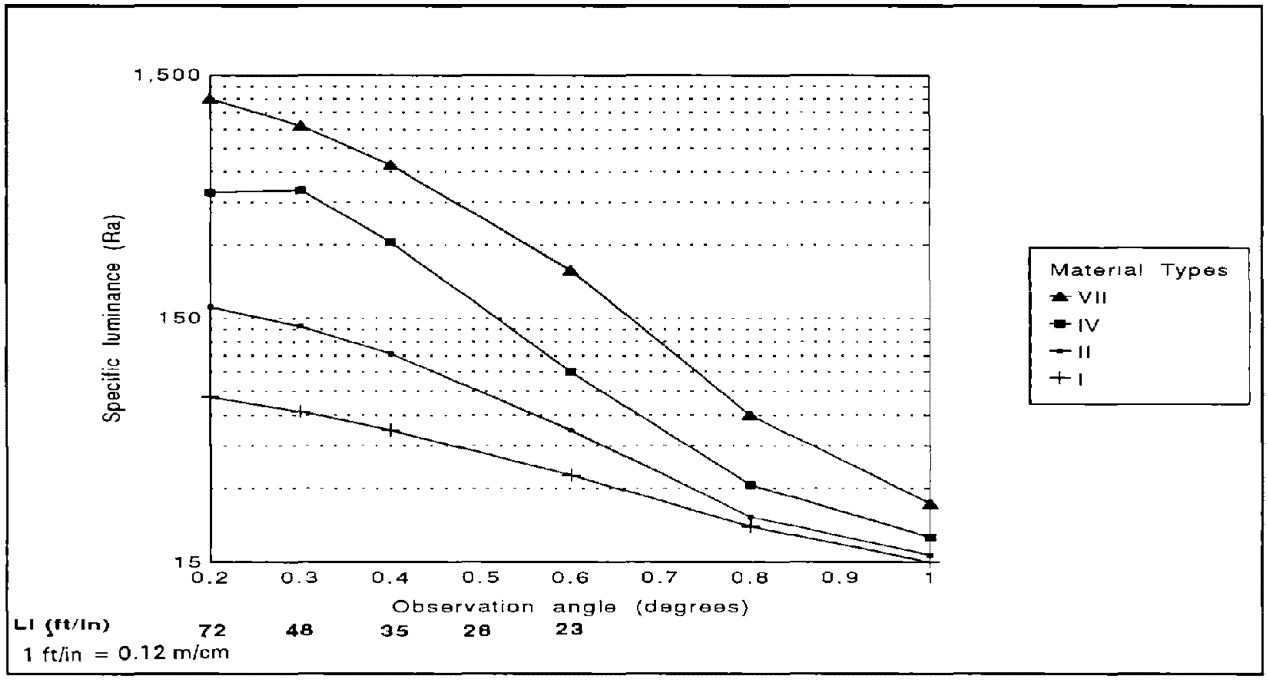


Figure 1. R(a) of white materials.
(entrance angle = -4 degrees)

For the testing of positive-contrast guide signs (i.e., green background and white legend), four combinations of sheeting types were evaluated. The selection of these combinations was based on a survey of State practices in 1988 and the desire to evaluate a range of legend-to-background contrast. These combinations used the same types I, II, and VII materials from which the negative-contrast signs were constructed, but also included 3M Company's glass bead high-intensity (type III) in place of the type IV cube-corner material.

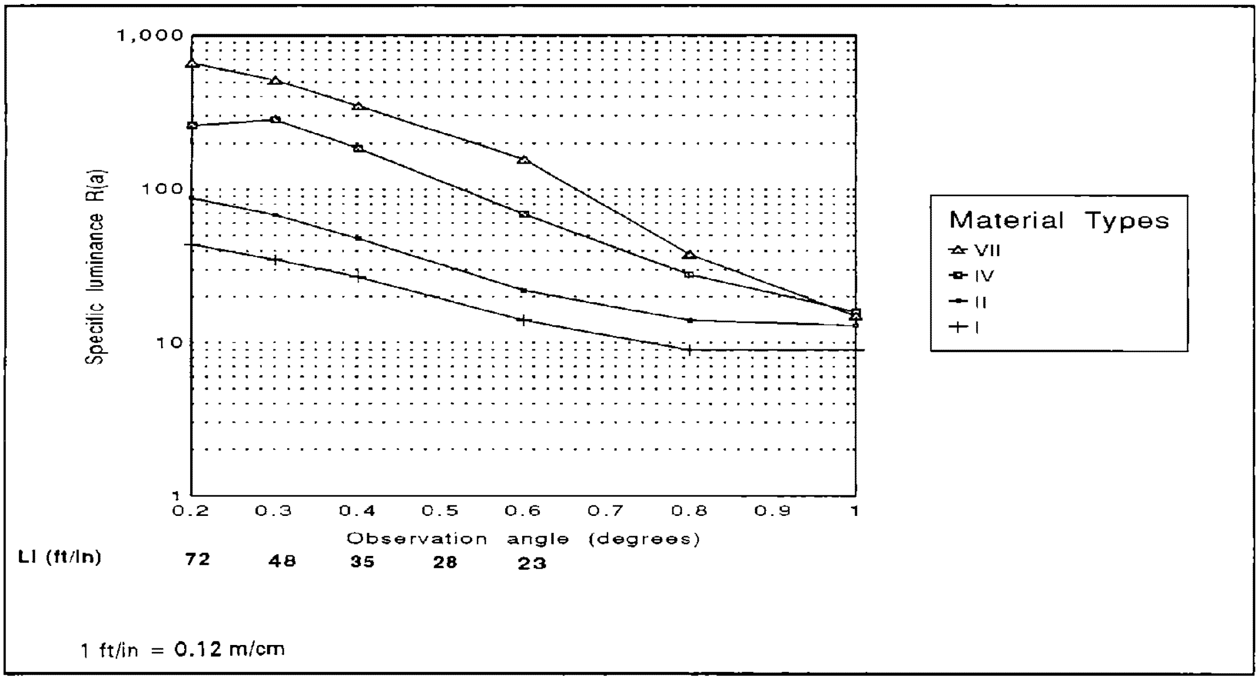


Figure 2. R(a) of orange materials.
(**entrance angle = -4 degrees**)

The following four combinations were tested:

- Type III on type I.
- Type VII on type III.
- Type VII on type VII.
- Type VII on type I.

The contrast ratios for each of these combinations are shown in figure 3, again with the distances and LI's noted.

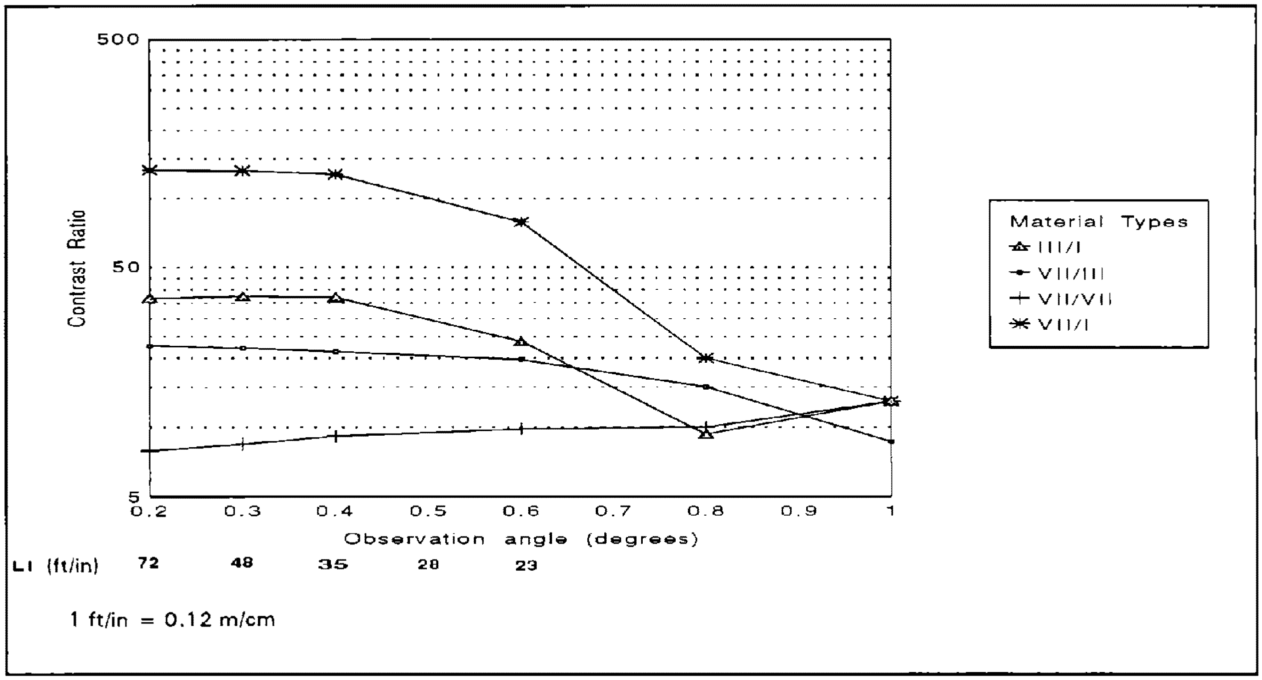


Figure 3. Contrast of white-on-green, retroreflective signs. (entrance angle = -4 degrees)

Letter Height

The range of letter heights for B/W letter-only signs found on today's roadways is from 1 in to 12 in (2.5 cm to 30.4 cm). The range in letter heights for B/O letter-only signs is from 4 in to 8 in (10.1 cm to 20.3 cm). Letters 4 in (10.1 cm) in height were considered too small to study because at distances under about 160 ft (48.7 m) (where older drivers read them), the different materials do not result in brightness differences because of the large observation angle.

The 8-in (20.3-cm) letter height was chosen for both the B/W and the B/O signs to represent the whole range of letter heights. Larger letter heights were studied on negative contrast signs in study 4. The standard letter heights for retroreflective-white-on-retroreflective-green (W/G) signs range from 4 in (10.1 cm) on street name signs to more than 12 in (30.4 cm) on overhead guide signs. The 8-in (20.3-cm) letter was chosen for comparability to the other colors. The 12-in (30.4-cm) letter was also included to represent those letters used on expressway and freeway signs and to determine the effect of size on the LI.

Stroke Width and Letter Series

Irradiation has the effect of increasing the perceived stroke width of retroreflective letters mounted on lower or non-retroreflective backgrounds (i.e., positive contrast) and decreasing the perceived stroke width of non-retroreflective letters that are mounted on a retroreflective background (i.e., negative contrast). The manipulation of stroke width in this study was an attempt to control these effects. All letters were shown at a standard stroke width determined by each of the standard highway series that were evaluated. Series C and D letters were included with negative contrast signs and series E(M) was the only letter series tested with positive contrast signs. Stroke width was either increased (for negative contrast) or decreased (for positive contrast) from the standard in discrete steps. When stroke width was altered, it was accomplished on the interior of letters, to maintain constant letter width as well as position relative to sign edges.

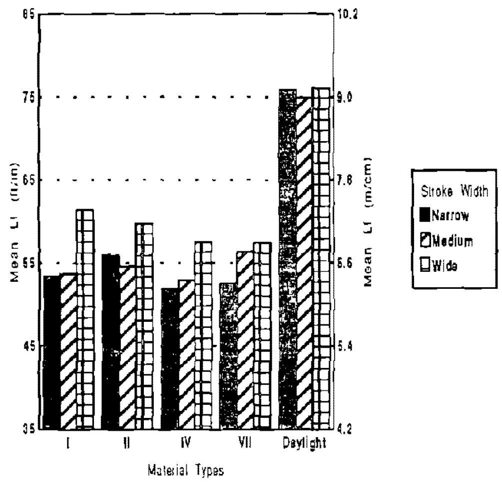
The stroke widths evaluated included an amalgamation of the results of several studies. (See references 32 through 36.) Positive-contrast signs (W/G) used a stroke-width-to-height (SW/H) ratio of 0.2 (that of series E(M) letters); then the stroke width was decreased by 25 percent and 62.5 percent, respectively. The 62.5-percent reduction (0.075 SW/H ratio) is based upon a research study and represented the largest change recommended in the literature.[35] The SW/H ratios for negative-contrast signs (B/W, B/O) were increased by 25 percent and 35 percent, respectively.

SUBJECTS

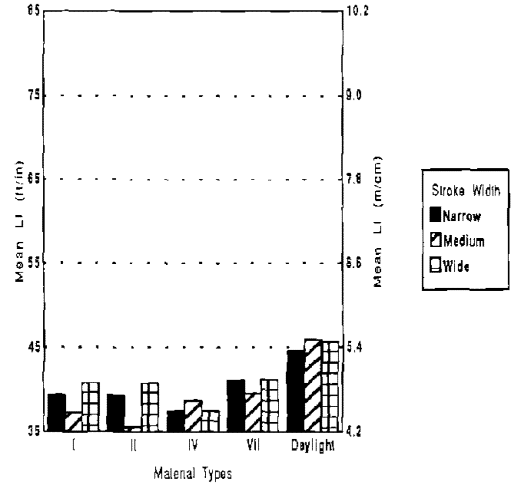
Sixty subjects participated in the daytime study. At night, 1 group of 15 younger and 15 older subjects evaluated B/W signs, while another group of 15 younger and 15 older subjects evaluated B/O signs. Approximately half of each group was randomly selected to provide a similar group of 15 younger and 15 older subjects to evaluate the 8-in (20.3-cm) W/G signs, while the remaining half evaluated the 12-in (30.4-cm) W/G signs. All groups of young drivers were evenly matched in acuity. The average acuity of older subjects evaluating B/W signs was 20/25 and the average acuity of subjects in the B/O group was 20/29. This was not a significant problem since direct comparisons of sign color were not anticipated.

RESULTS

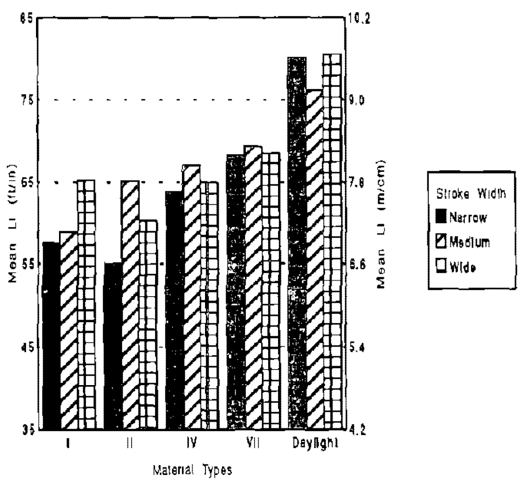
The legibility distance was converted to an LI in feet per inch of letter height to facilitate comparison among letter sizes and with other data reported in the literature. All results, except those regarding stroke width on partially retroreflectorized signs, were consistent with expectations based upon prior research. The data for partially retroreflectorized signs are summarized in figures 4 and 5.



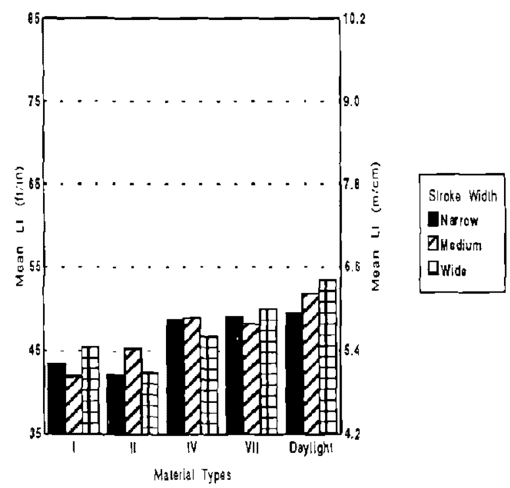
(a) Young Drivers: 8-in (20.32-cm), series C letters E & K in three stroke widths on four materials at night and daytime.



(b) Older Drivers: 8-in (20.32-cm), series C letters E & K in three stroke widths on four materials at night and daytime.

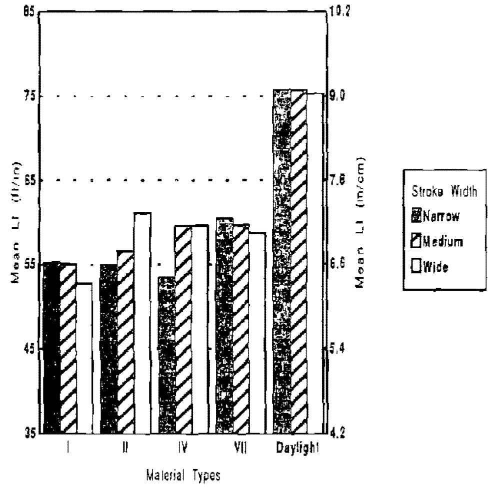


(c) Young Drivers: 8-in (20.32-cm), series D letters E & K in three stroke widths on four materials at night and daytime.

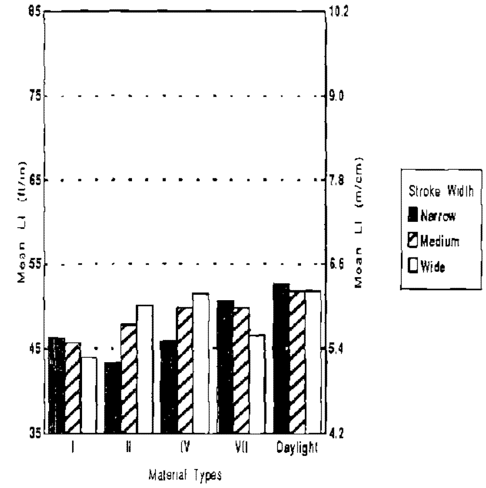


(d) Older Drivers: 8-in (20.32-cm), series D letters E & K in three stroke widths on four materials at night and daytime.

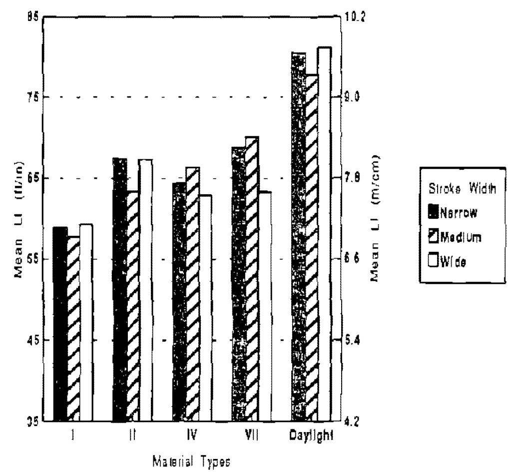
Figure 4. Legibility index for black-on-orange signs.



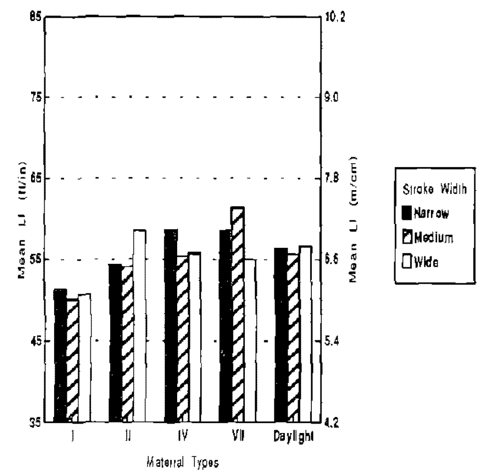
(a) Young Drivers: 8-in (20.32-cm), series C letters E & K in three stroke widths on four materials at night and daytime.



(b) Older Drivers: 8-in (20.32-cm), series C letters E & K in three stroke widths on four materials at night and daytime.



(c) Young Drivers: 8-in (20.32-cm), series D letters E & K in three stroke widths on four materials at night and daytime.



(d) Older Drivers: 8-in (20.32-cm), series D letters E & K in three stroke widths on four materials at night and daytime.

Figure 5. Legibility index for black-on-white signs.

A wider stroke width increased the legibility of B/O signs at night more for the less bright material and only for younger drivers. Stroke width was not significant for B/W signs and there were no stroke width effects for B/W or B/O during daylight.

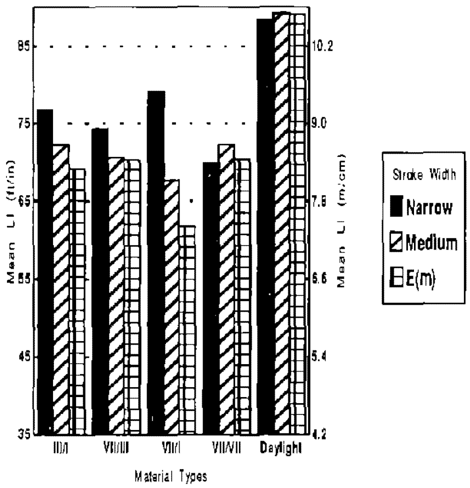
The magnitude of improvement in LI from brighter B/W materials is generally equivalent to the improvement of series D over series C. Series D gives an LI of 7 or 8 ft/in (0.84 or 0.96 m/cm) greater than series C. Type VII material typically results in an LI of 5 to 8 ft/in (0.6 to 0.96 m/cm) greater for series C and D letters, respectively, than that for type I material. A sign with type VII material and series C letters provides an LI of 54.3 ft/in (6.5 m/cm) similar to a sign of type I material with an LI of 54.7 ft/in (6.56 m/cm) on series D letters. With the data for stroke widths combined, types II and IV materials performed about as well as type VII with both series C and D letters.

With series C letters, type VII material did not provide as much legibility for older drivers [LI=50.6 ft/in (6.1 m/cm)] as type I material with younger drivers [LI=55.3 ft/in (6.6 m/cm)]. Using series D letters on type VII material provided legibility for older drivers [LI=58.5 ft/in (7 m/cm)] equal to that of younger drivers with type I material [LI=58.9 ft/in (7.06 m/cm)].

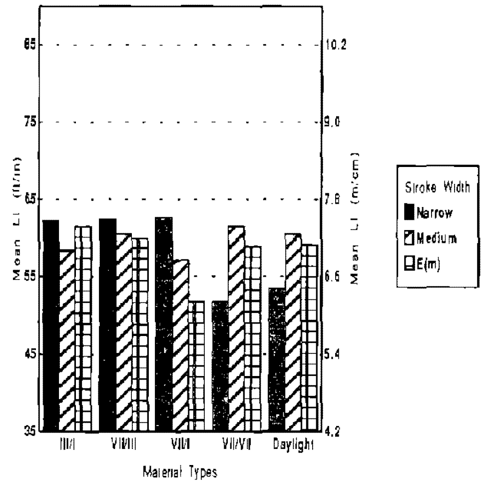
With B/O signs and series C letters, there was no significant difference among any of the materials. With series D letters, both types IV and VII materials resulted in approximately a 5-ft/in (0.6-m/cm) increase in LI over types I and II materials.

Data for fully retroreflectorized signs are summarized in figure 6. The LI of 8-in (20.3-cm) letters was generally about 15 to 20 ft/in (1.8 to 2.4 m/cm) greater than the LI of 12-in (30.4-cm) letters. Except for the high-contrast combination of type VII on type I, which was about 7 ft/in (0.84 m/cm) lower than other materials tested, there were no significant differences observed. While nighttime legibility with the high-contrast sign was significantly improved with a narrow stroke width, the wider normal stroke width was needed to optimize daytime legibility for older subjects. Since all other materials maintained maximum legibility for older subjects with the same normal stroke width that was best in daytime, it is clear that high-contrast combinations of materials should be avoided.

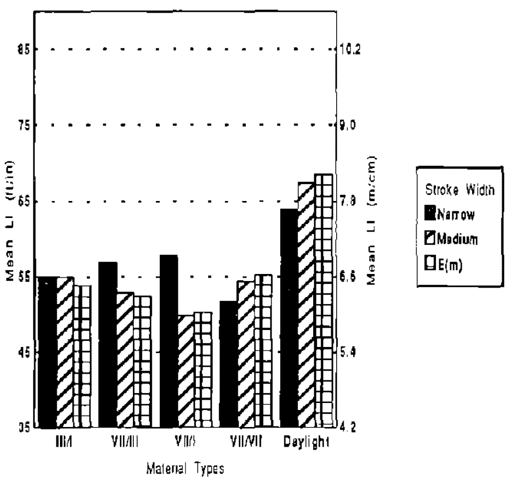
Analyses of percentile data indicated that the LI that accommodates 85 to 90 percent of younger drivers will accommodate about 50 percent of older drivers. If the LI is chosen to accommodate 85 percent of older drivers, almost all younger drivers will be accommodated. An exception is the 8-in (20.3-cm) letters on W/G signs, for which the LI required for 50 percent of older drivers will satisfy almost all younger drivers. Specific recommendations concerning these LI's are given in the summary and conclusion.



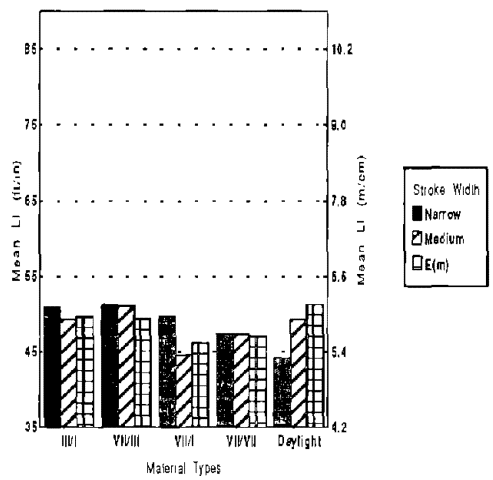
(a) Young Drivers: 8-in (20.32-cm), series E letters E & K in three stroke widths on four materials at night and daytime.



(b) Older Drivers: 8-in (20.32-cm), series E letters E & K in three stroke widths on four materials at night and daytime.



(c) Young Drivers: 12-in (30.48-cm), series E letters E & K in three stroke widths on four materials at night and daytime.



(d) Older Drivers: 12-in (30.48-cm), series E letters E & K in three stroke widths on four materials at night and daytime.

Figure 6. Legibility index for white-on-green signs.

STUDY 2: RELATIVE NIGHTTIME CONSPICUITY

The primary objective of this study was to determine the *relative* nighttime conspicuity of signs that were made of differing sizes and retroreflective materials. Since the methodology allowed legibility data to be obtained without added expense, a secondary objective was to verify conclusions concerning stroke width obtained in study 1 and to explore the effects of a different font on legibility. The study was implemented night and day using a dynamic field study method.

EXPERIMENTAL PROCEDURE

The test route for the conspicuity experiment was about 20 mi (32 km) long and contained 17 sites of which 14 were used for the daytime study, 12 for the W/G nighttime study, 9 for the B/W nighttime study, and 10 for the B/O nighttime study. All but one sign location provided at least a 1,000-ft (305-m) line of sight, and all were free of competing signs except for the B/W condition. The test sites were relatively homogeneous in design and had a posted speed of 35 mi/h (56 km/h). Signs were mounted on posts located at a height and offset consistent with other signing in the area.

The methodology was similar to that used in a 1982 FHWA report.[36] For reasons of safety, particularly where older drivers were concerned, an experimenter drove the test route with a single subject in the front seat of a 1989 Oldsmobile Delta 88. Subjects were told to report traffic signs mounted on the right shoulder when they matched the color indicated in their instructions. In addition, they were told to report when the sign was legible by reading the word on the sign. The experimenter recorded both reports with a digital measuring instrument (DMI). Threshold detection was defined as the distance from the sign at which the sign was recognized as a traffic sign of a given color. Threshold legibility was defined as the distance from the sign that the driver correctly recognized the word on a sign (the top word on signs with two words).

In order to ensure that subjects did not overemphasize eye scanning on the right side of the road, they were given a monetary incentive to report special X's constructed from 3M fluorescent orange type VII material that were placed at sign height throughout the route along the left side of the road.

INDEPENDENT VARIABLES

Sign Variables

Signs using the three colors and three of the four materials discussed in study 1 were made in sizes of 24-in and 36-in (0.61-m and 0.91-m) squares. Half of the 36-in (0.91-m) B/W signs had two words, the other half had one word.

Letter Variables

All signs were tested with one letter height of 8 in (20 cm). In addition to color and material type, the study included an evaluation of the effects of stroke width and font. Words on B/O and B/W signs were displayed using two stroke widths, standard series C and series C increased by 35 percent. W/G signs served to compare the highway standard series E(M) font to the Clarendon font used by the National Park Service.

Sign copy consisted of simple words analytically selected to be of approximately equal legibility. Six words were chosen for each sign size to reduce the likelihood of subjects' guessing the correct answer. All six words in each group were of the same length and began with the same letter in order to avoid subjects responding solely to word length or first letter recognition.

Site Characteristics

Nighttime complexity was scaled for 13 sites using the procedure developed in a 1982 report.[36] Four of the five sites lowest in complexity were classified as low complexity for the purpose of the experimental design. In these sites, sign size was not manipulated; only the smaller 24-in (0.61-m) signs were used. The other nine sites varied from low to high complexity and were used in testing both 24-in and 36-in (0.61-m and 0.91-m) signs.

Daytime complexity was determined using the method suggested by a report presented to the Australian Road Research Board.[29] The 14 sites used during the daytime study were ordered by having 72 subjects compare photographs of 13 sites to a photo of 1 site chosen as a reference. A 5-point ranking, from "much less complex" to "much more complex," was used. The data were analyzed separately for each of three age groups. The average complexity score was computed for each photograph with the reference photograph being given a 3.0. The photographs were then given ranked scores, and the ranks in the three age groups were averaged because they were highly intercorrelated.

SUBJECTS

Fifty-three subjects were recruited to complete this study. Twenty-seven of these subjects were 40 years old or less, and 26 were 65 years or older.

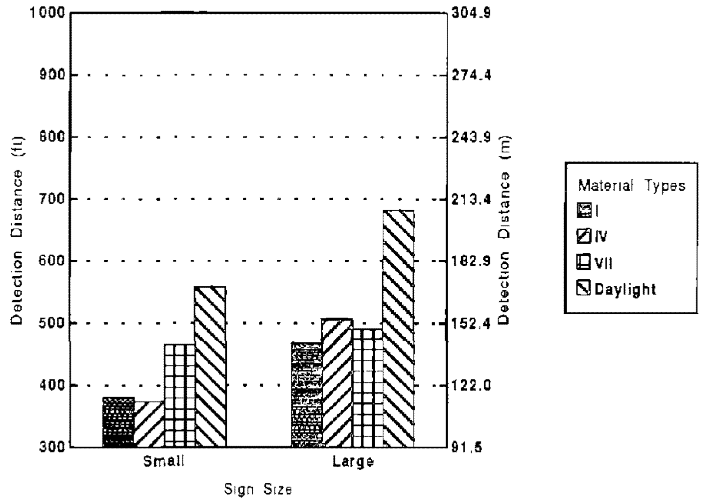
RESULTS

Contrary to the results from the static legibility studies, neither sign material or stroke width had a significant effect on dynamic legibility for B/W or B/O signs, although the effect for B/O approached significance (p=0.08). The absence of a material effect is probably the result of greater variability resulting from the dynamic testing procedure. For positive-contrast signs, the lower contrast type VII on type VII produced about a 5-ft/in (0.6-m/cm) advantage over the high-contrast type III on type I signs. The Clarendon font produced an improvement in legibility for both young and elderly drivers that approached statistical significance.

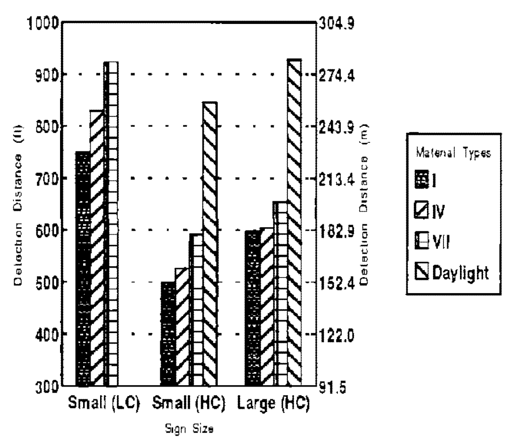
Surprisingly, sign material had similar effects on detection as it did on legibility. The B/O signs also had much greater conspicuity than the B/W signs. This finding is consistent with a hypothesis found in a 1988 report, namely that B/W signs may be confused with numerous point light sources that exist at many sites.[16] Therefore, increasing the brightness of B/W signs is not as likely to improve conspicuity as with B/O signs (figure 7).

The data suggest that sign size had a significant effect with all sign colors. With B/O signs, size may be used as an alternative to sign brightness for the purpose of maintaining conspicuity or brightness may be used as an alternative for size. Small 24-in (0.61-m), type VII B/O signs were seen almost as far away as large 36-in (0.91-m), type I signs. Also, 24-in (0.61-m), type VII on type VII W/G signs were seen farther away than larger 36-in (0.91-m) signs using less bright materials. Variation in visual complexity or other site parameters does affect sign conspicuity. Sites characterized as low complexity tend to be more homogeneous and their site parameters do not have a significant effect on conspicuity.

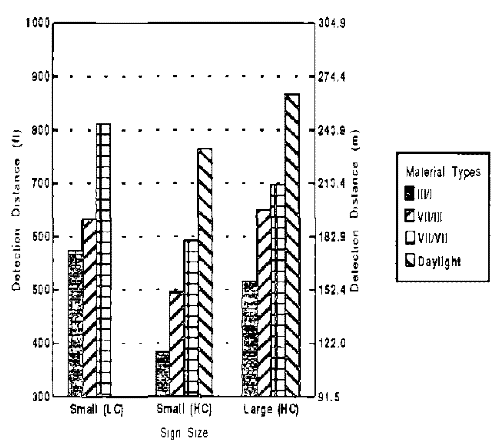
The daylight results indicated that stroke width and font did not affect legibility. Although larger signs were more conspicuous, the small signs were seen farther away during daylight than any of the materials on large signs at night. There was no difference in the detection distances with one or two words on B/W signs at night or during daylight. Although the effects of material were not significant at the $p=0.05$ level for all negative contrast signs; among B/O signs, material approached significance with $p=0.069$.



(a) Black-on-white signs: 2 sizes in daylight and 3 materials at high-complexity (HC) sites at night with all drivers.



(b) Black-on-orange signs: 2 sizes in daylight and 3 materials at low (LC) and high (HC) complexity sites at night.



(c) White-on-green signs: 2 sizes in daylight and 3 materials at low (LC) and high (HC) complexity sites at night.

Figure 7. Average nighttime threshold detection distance of signs.

STUDY 3: CHANGE IN LI ACROSS LETTER SIZE

Visual acuity is measured by assessing the minimum target size resolvable, and is expressed in terms of visual angle. The concept behind describing the size of a stimulus in visual angle is predicated on the notion that distance and size are interchangeable. The acuity model for legibility states that when all else is equal (contrast, luminance, etc.) legibility distance is determined by the size of a character's critical detail. This implies that as long as the size of the critical detail (in visual angle subtended) is maintained, the legibility of that character will be the same, regardless of the distance from the observer. For example, if a 4-in (10-cm) letter A of a particular font has a threshold legibility distance of 200 ft (61 m), a 12-in (30.4-cm) letter A of the same font, viewed by the same observer, will have a threshold of 600 ft (183 m).

The purpose of this research was to determine the change in LI across a range in letter heights. The assumption underlying the validity of LI is that a change in the size of a stimulus is accompanied by a proportionate change in the distance threshold. The LI has been used for more than 50 years as a means of comparing the legibility of different fonts and stroke widths and as a method of generalizing results obtained with one letter size (generally small letters in laboratory settings) to other letter sizes (generally larger letters required in field situations). This study was conducted in daytime only, when illumination is thought to be invariant with distance.

EXPERIMENTAL PROCEDURE

All sessions were held in the daytime with sun overhead or behind the observers. Legibility thresholds were measured in a manner similar to that used in a 1939 Highway Research Board study.[37] Subjects (in groups of three or four) began viewing signs at a distance determined to be the threshold for the subject having the best acuity in the group. At that distance, subjects recorded the letters that they could see (and the orientation of the Lazy E) on an answer form that contained a spatial representation of the sign-panel layout. The entire set of 21 stimuli letters was displayed simultaneously on three signs, each corresponding to a different letter series or contrast direction. Each subject had a stack of answer sheets attached to a clipboard, and they entered the distance at which they were viewing the signs and their answers to as many letters as they could read. When the subjects were finished filling in the form, the signs were turned so that they could not be viewed, and the subjects walked a fixed distance toward the signs that increased the visual angle 10 percent. This procedure was repeated at each distance. When they reached a distance where everyone in the group could clearly read all the letters, the procedure ended. Threshold legibility for each letter was recorded as the greater of two consecutive distances at which the correct responses were recorded.

INDEPENDENT VARIABLES

Two groups of black-on-retroreflective-white stimuli were evaluated: one used the highway standard series C font and the other used the series D font. The positive contrast white-on-green signs were evaluated only in the series E(M) font. Within each series, sign copy consisted of five characters: four alphabetic characters and a Lazy E visual acuity optotype. The alphabetic characters under series C and series E were: B, G, M, and X. Under series D, the letters C, K, S, and Z were used. These letters were chosen for two principal reasons: to represent both the curved and angular letters of the alphabet, and to introduce confusion between letters to ensure that each response was based on more than global letter form alone. Five letter heights were employed: 6, 8, 10, 12, and 16 in (15, 20, 25, 30, and 41 cm).

SUBJECTS

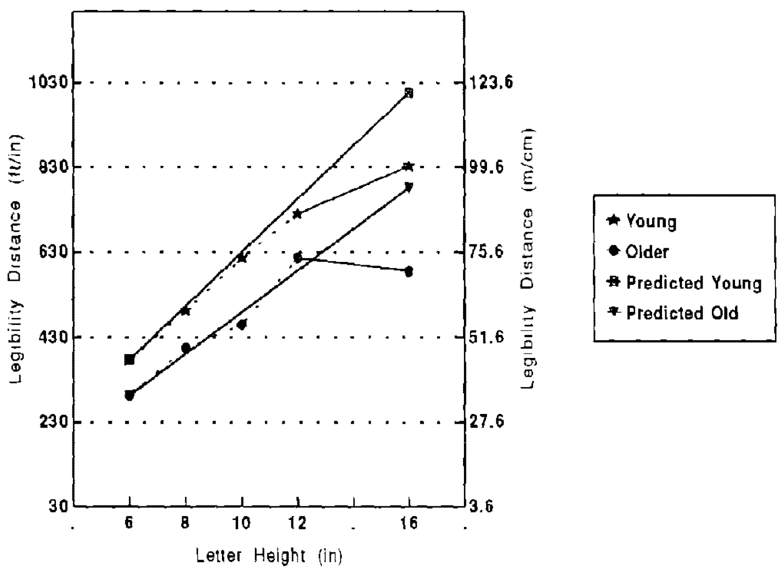
Subjects consisted of 15 young (16 to 40 years old) and 15 old (65 years and older) individuals.

RESULTS

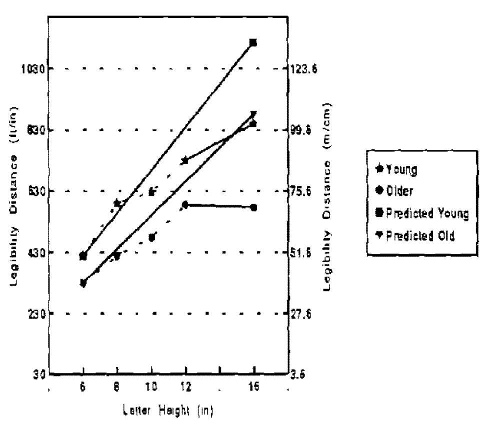
With regard to the difference between the Lazy E and letters, younger drivers found the Lazy E to be more legible, particularly at closer distances in the 6-in (15-cm) size. Older drivers found the Lazy E to be less legible, particularly at greater distances in the 12-in (30-cm) size. The Lazy E might be expected, based on critical detail, to be more legible than random letters. The result that older drivers found lazy E's to be less legible may be due to the task being more abstract and perhaps not well-comprehended. The analysis of variance of random letters showed that letter height and series were significant for both age groups and that there were no height-by-series interactions.

Although the height-by-series interaction was not significant ($p=0.085$), the effect of increased height on LI was greater for series D and E than for series C (see figure 8). The LI appears to remain fairly constant for older drivers up to the 12-in (30-cm) letter height, but then drops dramatically for the 16-in (41-cm) letters. While this may be the result of the difficulty they had with the Lazy E, the fact that there is some decrease in performance between 8-in and 12-in (20-cm and 30-cm) letters for both series D and E suggests that, to some extent, this decline is the result of visual factors and not difficulty with the task. Younger drivers showed a steady decline in their LI for letter heights 8 in (20 cm) and larger with series D and E letters. With series C letters, the decline does not begin until 12-in (30-cm) letters are used.

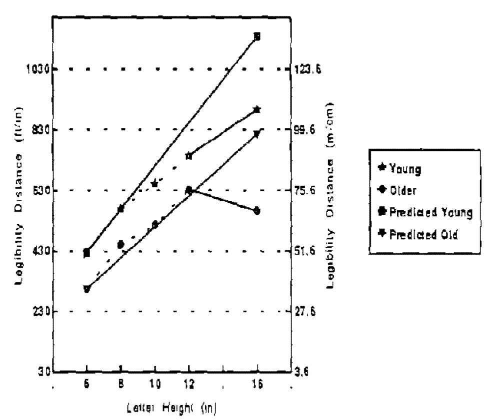
The data suggest that it is around 600 ft (183 m) where the increases in legibility distance cease to be proportional to increases in letter height. For younger drivers, the 600-ft (183-m) mark is reached with 8-in or 10-in (20-cm or 25-cm) letters. The loss in legibility may not be apparent for older observers, as these individuals do not approach 600 ft (183 m)



(a) Black-on-white, series C, daytime legibility.



(b) Black-on-white, series D, daytime legibility.



(c) White-on-green, series E, daytime legibility.

1 in = 2.5 cm

Figure 8. Average daytime threshold legibility distance.

of legibility with letter heights below 12 in (30 cm). This observation also explains why letter height had less of an effect with series C letters. Since the legibility of the series C letter is less than series D and E, the 600-ft (183-m) legibility distance is not reached until a 10-in (25-cm) letter is used.

Since the decrease in LI that accompanies the increase in letter size is less for older drivers and signs with short legibility distances, it may be that LI is still a useful indicator to compare signs and to determine the letter size required to satisfy the MRVD.

STUDY 4: LETTER SPACING

The purpose of this study was to determine whether increasing inter-letter spacing (140 or 200 percent of standard spacing) would affect the nighttime legibility of a word and whether this would hold true for different retroreflective materials, letter series, and heights on negative-contrast signs. A second purpose concerned the manipulation of letter case and whether words composed of lowercase letters (initial letter capitalized) would have legibility equal to the same words composed of all capital letters, either when letter height of lowercase words was manipulated such that the width of the lowercase words and uppercase words was equal, or when loop height of lowercase letters was adjusted to the height of uppercase letters. These questions were addressed with both low-contrast and high-contrast combinations of white-on-green retroreflective materials.

EXPERIMENTAL PROCEDURE

The procedure for obtaining legibility was nearly identical to that described for study 1. Two subjects were seated in the front seat of the test vehicle. Signs were shown, one at a time, at an initial distance determined to be slightly beyond the subjects' legibility threshold. The subjects, who were separated by a cloth partition, responded to the signs by writing their response on an illuminated magnetic pad and holding the pad up for the experimenter (located in the back seat) to see. The experimenter then entered the responses into a laptop computer where the data were scored. This permitted signs to be removed from the stimulus set once both subjects responded correctly at two consecutive distances. The signs were then displayed at a closer distance representing an increase in visual angle of 10 percent.

For one-third of the subjects, the largest signs were shown first. At later distances, sequences containing the middle-size signs were introduced. At the final distances, the smallest signs were added to the stimulus set. This displaying and moving of the signs was repeated until the subject correctly identified all of the signs at two consecutive distances; the farthest of the two distances was recorded as being the threshold. To reduce the time of this procedure, as soon as the subject reached the threshold on a particular sign, that sign was dropped from the presentation. In this way, the experimental session progressed until all signs had been removed from the set. The remaining subjects were divided equally into two groups. One of these groups saw the smallest signs first, then the largest, and then the intermediate size; the other group saw the intermediate signs first, then the smallest, and finally the largest. This was done to balance out the effects of learning and fatigue across the size variable.

INDEPENDENT VARIABLES

Letter Series, Height, and Capitalization

The B/W and B/O signs were tested with words created using 6-, 8-, and 10-in (15-, 20-, and 25-cm) uppercase letters. These signs used both highway standard series C and series D letters. One-half of the W/G signs used words with lowercase letters and an initial capital letter, while the other half used uppercase letters only.

All W/G signs used series E(M) letters. Two letter heights were used with the capital/lower (mixed) case words: 8-in (20-cm) capital letter with 6-in (15-cm) lowercase letters, and 13.3-in (33.8-cm) capital letter with 10-in (25-cm) lowercase letters. The uppercase-only W/G signs used letter heights of 7, 10, and 12 in (18, 25, and 30 cm). The heights of the uppercase-only letters were selected so that two of the sizes [7 and 12 in (18 and 30 cm)] would result in words being nominally the same widths as words of the mixed-case letters, and the 10-in (25-cm) letter would match the loop height of the 10-in (25-cm) lowercase letter.

Inter-Letter Spacing

B/W signs in series D were shown with two spacings: standard and 140 percent of standard. In addition, six signs with spacing equal to letter stroke width (resulting in a reduction in spacing from the standard) were included. Series C letters were shown with standard, 140 percent, and 200 percent of standard spacing. B/O signs in series C were shown with two spacings: standard and 200 percent of standard. The series D signs consisted of words with inter-word spacings equal to stroke width, standard spacing, and 200 percent of standard. All W/G signs used series E(M) letters and were shown with three spacings: standard, 140 percent, and 200 percent of standard.

Sign Copy

Copy for all signs consisted of simple three-letter words analytically selected to approximate equivalent legibility distance. All words per color began with the same letter. These two measures were taken to avoid subjects responding solely to word length or first letter recognition.

Materials

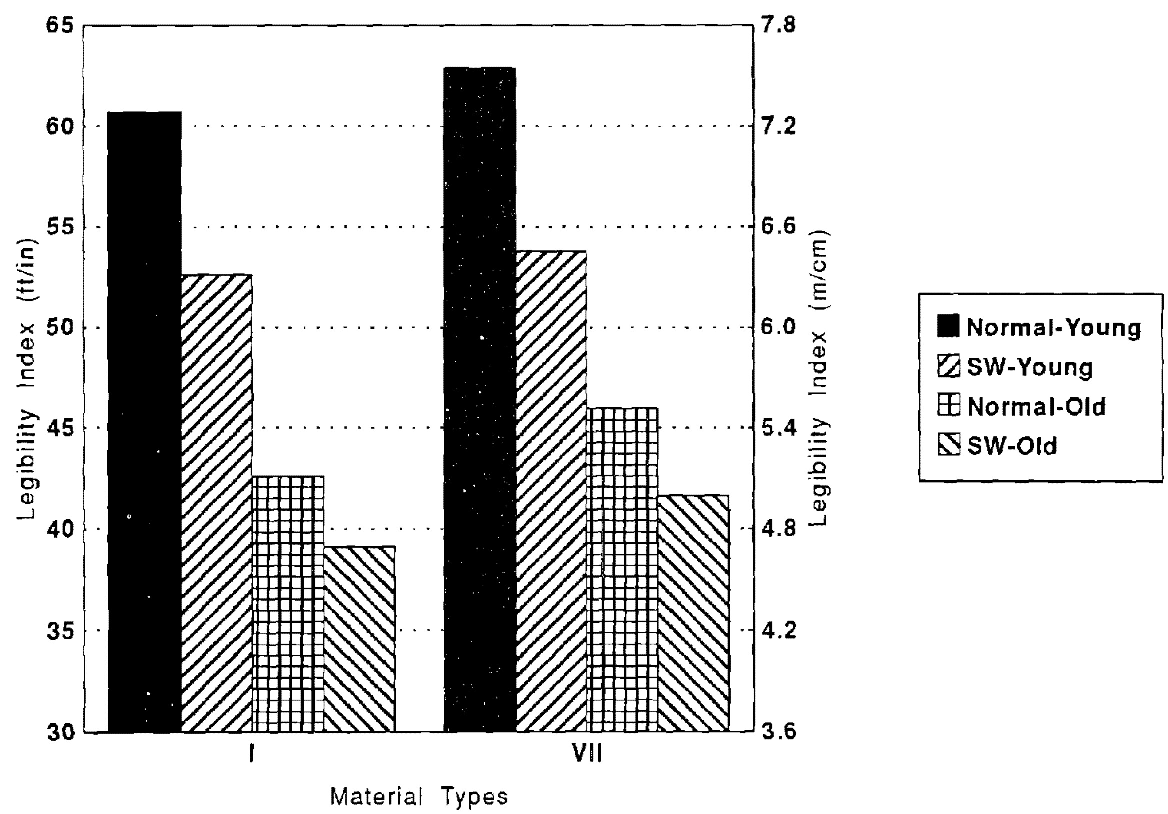
The B/W and B/O signs consisted of black vinyl letters on either type I or type VII sheeting. The W/G signs were constructed of either white type III material on a green type I background (high contrast), or white type VII letters on a green type VII background (low contrast).

SUBJECTS

The B/W signs were tested with 22 young and 21 older subjects. Both the B/O and W/G signs were tested with 18 older subjects only.

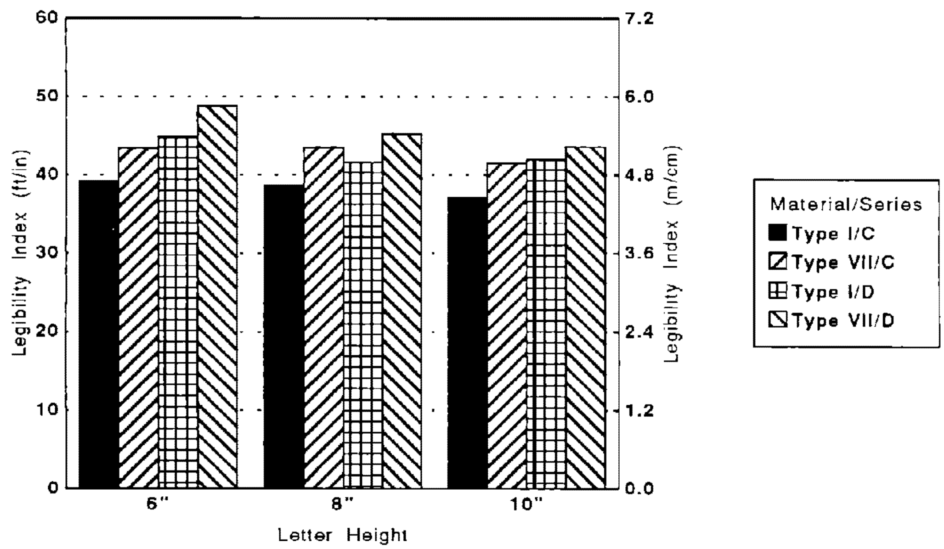
RESULTS

Similar results were observed for both B/W and B/O materials. Increasing inter-letter spacing did not improve legibility; however, a significant decrease in performance was observed when spacing was reduced from standard to a value equivalent to the letter stroke width (see figure 9). Type VII material resulted in performance increases of about 5 ft/in (0.6 m/cm) with the series C font on both B/O and B/W signs (see figure 10). However, with the series D font, the improvement was only about 2 to 3 ft/in (0.24 to 0.36 m/cm).



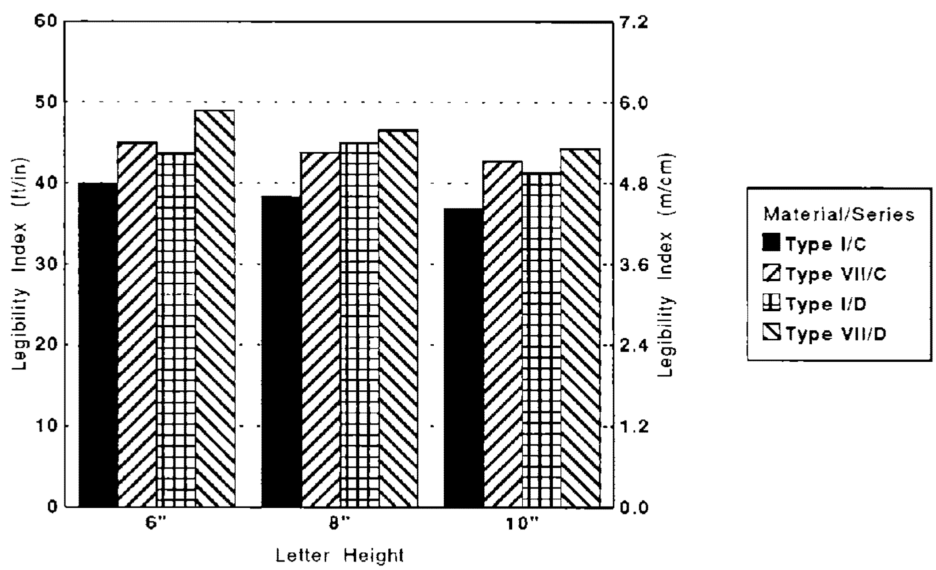
8-in (20-cm), series D letters, black-on-white signs, all drivers.

Figure 9. Legibility index—narrow (SW) vs. normal spacing.



(a) Black-on-white signs.

1 in = 2.54 cm



(b) Black-on-orange signs.

1 in = 2.54 cm

Figure 10. Average nighttime legibility index for older drivers.

Letter height was significant for series D letters with both B/W and B/O materials, however, these effects were not significant with series C letters. The largest effect of letter height was seen among series D letters on type VII materials where the decrease in LI was between 4 and 5 ft/in (0.48 and 0.6 m/cm) for both colors.

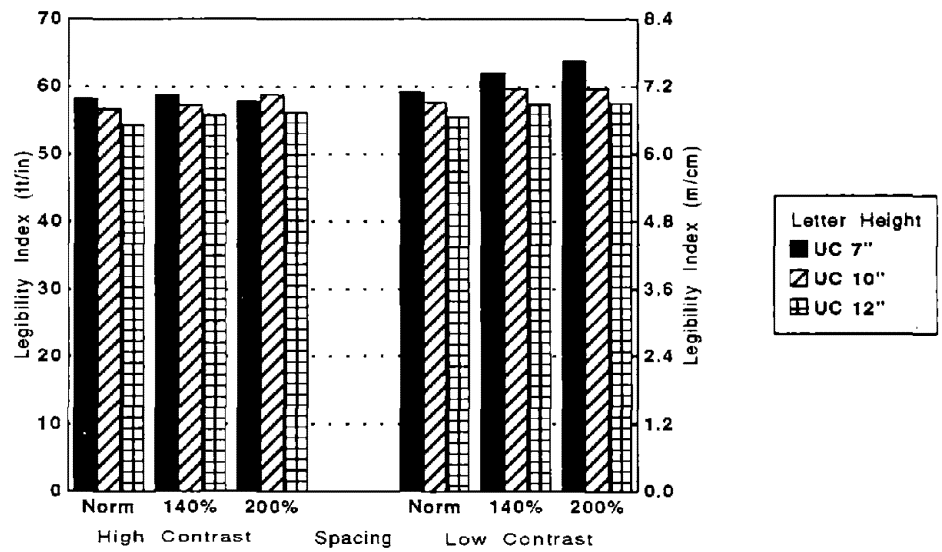
The least legible sign in either color was one of the series C letters on type I material. Upgrading the sign to either series D letters or to type VII material improved the LI by about 4 or 5 ft/in (0.48 or 0.6 m/cm), less for larger letters. Upgrading the sign again to include both series D letters and type VII material improved the LI by 4 or 5 ft/in (0.48 or 0.6 m/cm) again. The total increase in LI by upgrading from series C on type I material to series D on type VII was about 8 or 9 ft/in (0.96 or 1.08 m/cm).

The effect of various signing parameters on W/G signs was less dramatic than the effects on B/W and B/O signs (see figure 11). Low-contrast, type VII on type VII materials had an LI only 2 ft/in (0.24 m/cm) greater than the high-contrast, type I on type III materials with uppercase letters; however, contrast had no effect with lowercase letters. Spacing increased the LI, but again, only by about 2 ft/in (0.24 m/cm). Comparisons of the legibility of mixed and uppercase letters seem to agree with the findings of earlier research (see figure 12). When letter height was controlled so that the loop height of the lowercase letter matched the height of the uppercase letter, mixed case provided greater legibility. The improvements were small, particularly for low-contrast materials. Given that the mixed-case sign would be wider and more costly, the improvement would not seem justified on the basis of legibility. The comparison of mixed and uppercase letters when word width was held constant indicated no difference in legibility when the capitals were 10 in (25 cm) high, but a superiority of uppercase letters when 12-in (30-cm) capital letters were used.

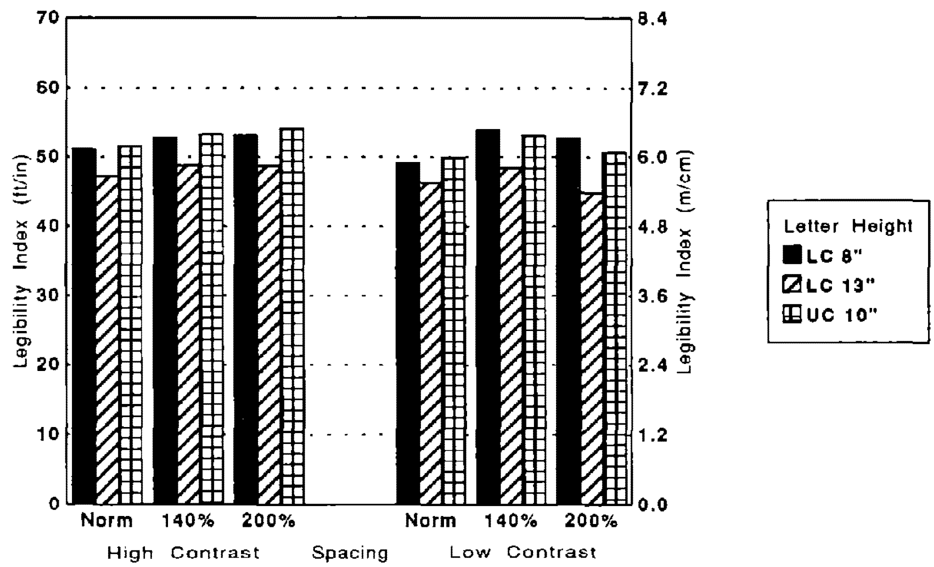
ECONOMIC ANALYSIS OF TRADEOFF IN SIGN SIZE AND BRIGHTNESS

Both letter height and letter series affect the size of a sign, and, of course, larger signs are more expensive than smaller signs. Materials of higher reflectance often improve visibility, but cost more than the basic engineering grade type I material. Since both increases in sign size and material reflectance increase the cost of a sign, any attempt to increase sign legibility requires a tradeoff between size and material.

Tradeoffs are necessary, however, only when there is a need to increase legibility. The MRVD software reveals that most signs offer adequate legibility, even for an older driver with the least retroreflective type I material.[7] The reason for this is that most signs provide an excessive amount of what we call "supply of critical detail." The supply of critical detail is the visual angle subtended by the smallest detail that the eye must resolve at the distance where a sign should be legible. All of the signs with bold symbols; those with short words that have larger [e.g., 8-in (20-cm)] and/or series D letters; and many signs with smaller letters that have short required legibility distances, have ample critical detail even for older drivers.



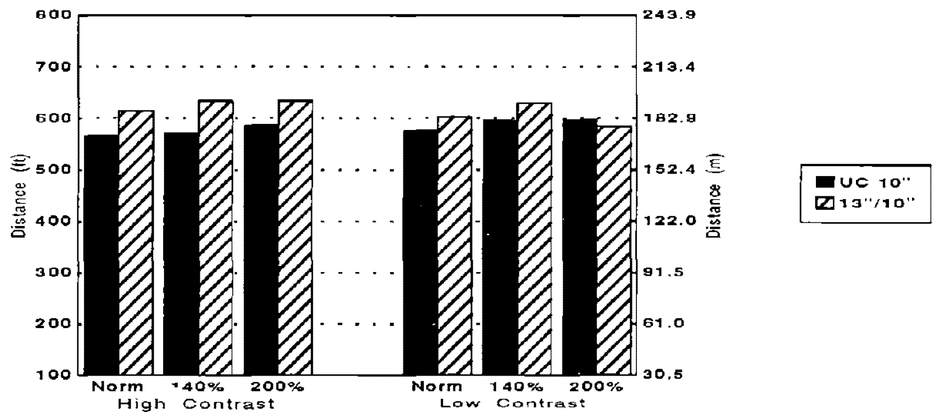
(a) **White-on-green, E(M), uppercase letters.**



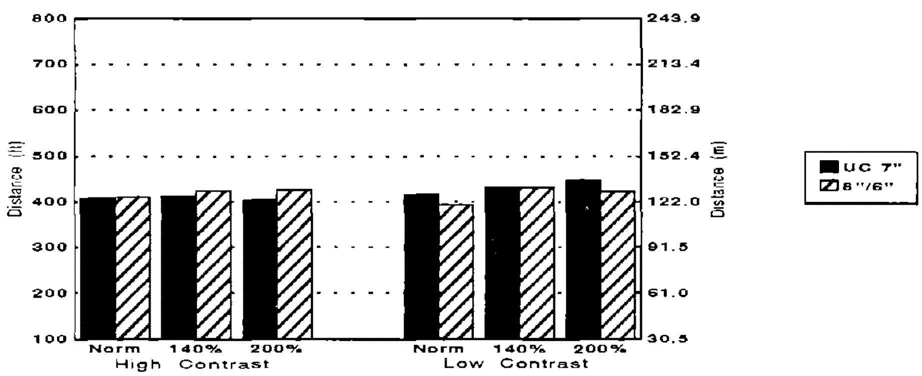
(b) **White-on-green, E(M), lowercase letters.**

1 in = 2.5 cm

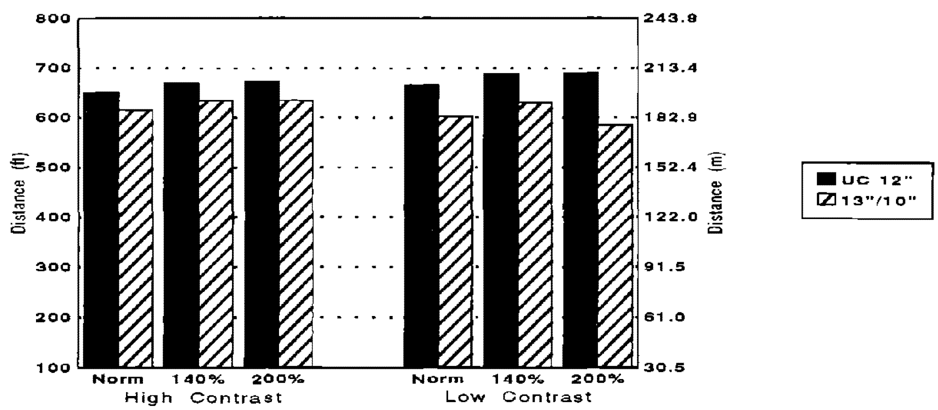
Figure 11. Comparison of letter heights for all drivers.



(a) 10-in (25-cm) upper- and 13-in/10-in (33-cm/25-cm) mixed-case letters.



(b) 7-in (18-cm) upper- and 8-in/6-in (20-cm/15-cm) mixed-case letters.



(c) 12-in (30-cm) upper- and 13-in/10-in (33-cm/25-cm) mixed-case letters.

1 in = 2.5 cm

Figure 12. Comparison of upper- and mixed-case letter heights for all drivers.

Signs with long legibility distance requirements and signs with small letters and dense messages often do not supply adequate critical detail; and increasing brightness may not be adequate to provide legibility at MRVD. In some cases, only an increase in letter height (and subsequent sign size) will provide the legibility needed. When only small increases in legibility are required, however, the possibility exists for achieving legibility through either an increase in letter height, changing to a wider font (i.e., letter series), or increasing the material's reflectance.

RESEARCH APPROACH

The dimensions of the sign-legend and sign-panel of three illustrative signs were evaluated to identify the economic implications of the alternative application scenarios. Empirically derived legibility indices were applied to analytically derived minimum required legibility distances for specific signs with orange or white background colors. These calculations provided minimum letter heights for each sheeting color, sheeting type, and letter series being tested. Larger letter heights sometimes caused the overall sign-panel dimensions to increase. The legibility distance provided by each application alternative was compared to the analytically derived minimum required legibility distances. The amount of marginal legibility distance was used to assist in identifying the most advantageous sheeting and sign-size alternatives.

This approach was not appropriate for evaluating alternatives for conspicuity. These evaluations had to be made in terms of relative performance of different signs and not the empirically derived detection distances that different signs provided. Therefore, a comparison of brighter 24-in (0.61-m) signs vs. less bright 36-in (0.91-m) signs was appropriate.

The research results, with regard to the effects of materials upon legibility, were not always consistent or statistically significant. The results and the literature both suggest that with fully retroreflectorized signs of reasonable contrast, the materials do not affect legibility. With regard to negative-contrast signs, the effects of material type were variable and changed with color and letter series. Because of this variability and the large number of statistical tests conducted, there is a clear need to cross-validate these results before they are used to make cost comparisons of the legibility performance of different materials. The analysis performed is, therefore, illustrative of a cost tradeoff that might be made if these results are ever validated.

RESULTS

In order to compare the alternatives in terms of the legibility distance provided and the material costs, the relationship between legibility and cost was expressed in terms of dollars per additional foot of legibility. For this comparison, the incremental material cost was based on the legibility distance provided by the base alternative, which was a standard-size sign with type I sheeting. An analysis of these data for negative-contrast signs suggests that larger signs with type I sheeting are generally more cost efficient than smaller signs with either type IV or type VII material.

The tradeoff of size and material for conspicuity was evaluated by comparing the cost of a 24-in (0.61-m) sign with type VII sheeting and a 36-in (0.91-m) sign with type I sheeting. This comparison was appropriate because the research results indicated that these two signs had approximately equal detection distances for each of the three sign colors. The tradeoff analysis suggested that the 36-in (0.91-m) negative-contrast signs with type I material were 4 percent (B/W) to 13 percent (B/O) less expensive than the 24-in (0.61-m) sign with type VII material. With positive-contrast signs, the small 24-in (0.61-m) sign with type VII material cost less than the 36-in (0.91-m) sign with type III on type I materials.

It should be noted, however, that the cost evaluations presented did not consider the service-life differences between the sheeting materials. Equivalent uniform annual costs (EUAC) analysis should be considered in future economic evaluations. The EUAC analysis might result with the higher sheeting grades being more cost-effective as these grades typically have longer service lives, and that costs for storage and handling of larger signs should be considered in future economic assessments.

The limitations of brighter materials must also be kept in mind. In general, the research findings indicate the improvement in the LI of type VII over type I materials to be about 5 ft/in (0.6 m/cm). Even if, based upon life-cycle costs, it were less expensive to do this than to increase the letter height 1 to 2 in (2.5 to 5 cm) to attain the same increase in legibility, this improvement will only net 40 or 50 ft (12 or 15 m) with an 8-in or 10-in (20-cm or 25-cm) letter. If more legibility is needed, it will have to be achieved with an increase in letter height.

SUMMARY AND CONCLUSIONS

LEGIBILITY

This research resulted in a number of findings (summarized in table 2) which are relevant to optimizing sign legibility. With regard to older drivers, the studies resulted in two findings that were generally unexpected. First, sign legibility is not a bigger problem for older drivers at night than it is during daylight. The LI for older drivers is very low both day and night. One likely explanation for this is that the farthest distance at which the older drivers are capable of discerning the critical detail of the signs is within the limits of the headlamp/retroreflective system. That is, visual resolution, not the lighting system (sunlight or headlamps) is the delimiting factor for older observers. This is not the case for younger drivers who are reading 8-in (20-cm) letters in the daylight at distances in excess of 600 ft (183 m), a distance that at night results in a significant reduction in luminance.

Table 2. Summary of results.

INDEPENDENT VARIABLES	RESULTS
Driver Age	LI of younger drivers is 5 to 20 ft/in > older drivers at night and 20 to 30 ft/in > older drivers during the day. The LI of older drivers is the same during the day or night.
Color	W/G E(M) is 5 to 10 ft/in > negative-contrast sign day and night. B/W is more legible than B/O.
Material	Positive high-contrast (type I on type VII) gave poor results. The LI with negative-contrast type VII is about 5 ft/in > type I with series C or D letters.
Letter Series	LI of series D is 5 to 8 ft/in > series C.
Letter Height	Legibility distance is less than proportional to letter height, particularly for younger drivers and signs legible at longer distances, e.g., with series D letters or type VII material.
Stroke Width	Avoid high positive-contrast signs so that normal stroke width may be effective day and night. Use normal stroke width on negative-contrast signs.
Letter Spacing	Wider spacing produced some improvement with positive-contrast signs. The narrow spacing equal to stroke width reduced the LI by 8 to 14 percent. Font
No significant difference between Clarendon and Highway font.	

1 ft/in = 0.12 m/cm

The second finding regarding older drivers is that increasing letter size is more likely to produce a proportionate increase in legibility distance among older drivers than among younger drivers up to about 12-in (30-cm) letters. This was observed during both daytime and nighttime conditions. At night, the reduction of sign luminance at distances beyond 600 ft (183 m) would explain this discrepancy between old and young drivers; however, another explanation is needed for the daytime results. The flattening of the legibility distance curves between 12-in (30-cm) and 16-in (41-cm) letters for both young and old drivers suggests that further increases in letter height beyond 16 in (41 cm) might not produce the expected increases in legibility distance.

Although the legibility of signs for older drivers is almost as poor in daylight as at night, the fact that it is no worse during the day suggests that for the purpose of establishing the letter size required for any MRVD, only nighttime performance needs to be considered.

The data collected in this study seem to suggest that there is no strong basis to argue to change the stroke width of the series C, D, or E letters. Although a narrower stroke width improves legibility for high-contrast combinations of positive-contrast materials, the results suggest that the nominative series E(M) font is best as long as high-contrast combinations of materials are avoided.

With the exception of high-contrast signs using type VII on type I material, the range of contrast tested had little impact on legibility, suggesting that the materials used on positive-contrast signs may be chosen based upon the needs for conspicuity and cost factors. On the basis of legibility alone, the data would suggest the use of uppercase letters; although with letters smaller than 12 in (30 cm), there was no performance difference. Whether or not lowercase aided the search for place name information was not investigated.

With negative-contrast signs, type VII material consistently provided—with the exception of B/O with series C letters—greater legibility than type I material. With B/W signs, types II and IV materials resulted in legibility similar to type VII material.

Standard highway letter spacing should be maintained unless sufficient space exists on the sign to increase spacing without increasing the size of the sign. Spacing less than standard should be avoided. Type VII material should be used when other factors, such as letter series or sign size, tend to reduce the legibility distance.

The nominative LI of 50 ft/in (6 m/cm) of letter height corresponds to a visual acuity of 20/25 (1.25 minutes of arc), which has been estimated to exceed the visual ability of 40 percent of the drivers over age 65. This reflects the fact that the data from which the 50-ft/in (5-m/cm) standard was derived, were obtained using young subjects with better-than-average vision. A most conservative standard would provide drivers with 2 minutes of arc, which corresponds to 20/40 vision and a 30-ft/in (3.6-m/cm) LI. On the basis of the findings of this research, and without consideration of the cost trade-offs involved with making larger signs or choosing brighter materials, we would recommend the following guidelines that, while being more practical than the most conservative standard, will, in general, provide the letter size needed to accommodate 75 to 85 percent of older drivers and 95 percent or more of younger drivers.

- For B/W and B/O signs, assume an LI of 30 ft/in (3.6 m/cm) with series C letters on any retroreflective material, and with series D letters on Type I or II sheeting. With series D letters on Type III or Type IV sheeting, assume an LI of 40 ft/in (4.8 m/cm).

- For W/G signs, assume an LI of 45 ft/in (5.4 m/cm) with 8-in (20-cm) letters, and an LI of 40 ft/in (4.8 m/cm) with 12-in (30-cm) letters.

CONSPICUITY

With regard to the conspicuity of B/W signs, the results of this research suggest that there is probably no advantage to using brighter materials, although there may be an advantage with smaller signs. A 36-in (0.91-m) sign with type I sheeting was noticed at about the same distance as the same size sign with type VII sheeting. Among B/O and W/G signs, type VII material increased detection distances by 100 to 200 ft (30.5 to 61 m) for both 24- and 36-in (0.61- and 0.91-m) signs and in low- and high-complexity situations. The brighter materials on 24-in (0.61-m) signs resulted in similar detection distances as the type I material on 36-in (0.91-m) signs, and the combination of increased size and brightness resulted in even greater detection distances for younger, but not older, observers.

TRADEOFFS IN MATERIALS AND SIZE

Because of a lack of consistency in the effect of materials with negative-contrast signs, the tradeoff analysis is only illustrative and should not influence policy decisions. There is a clear need to conduct a study to validate the effect of materials on nighttime legibility before any firm policy guidelines can be offered for negative-contrast signs. The results for positive-contrast signs were more consistent, and clearly the only tradeoff is with regard to conspicuity.

The results of the tradeoff analysis with regard to the legibility of negative-contrast signs suggested that increasing letter size with type I sheeting was, in general, more cost-effective than using type VII material with smaller letters, when both were equated to provide the same legibility distance. With regard to conspicuity, the 36-in (0.91-m) sign with type I material is 4 percent to 13 percent less expensive than the equally detectable 24-in (0.61-m) sign with type VII material. The legibility results may be generalized for letter sizes up to 12 in (30.5 cm), however, the conspicuity results may not be generalized beyond the sizes tested.

A tradeoff analysis for the legibility of positive-contrast signs was not performed because there were not any practical differences among different material combinations. It was recommended that the high-contrast type VII on type I be avoided since it performed so poorly and type III on type I would have greater legibility at less cost. Type VII on type VII offered slightly better legibility than type III on type I, but only with wider letter spacing that would necessitate a larger sign. Furthermore, larger or wider letters would offer more improvement than the increased spacing. With regard to conspicuity, the 24-in (0.61-m) type VII sign costs about 7 percent less than the 36-in (0.91-m) type III on type I sign, which provided a similar detection distance.

It should also be recognized that the improvement in legibility distance attainable from brighter sheeting is limited to only 50 or 100 ft (15.2 or 30.5 m), depending on the letter series and size. In general, the use of type VII material increases legibility distance only by the same amount as an increase of 1 or 2 in (2.5 or 5 cm) in letter height. Further improvements in legibility must come from increasing letter size. Also, the benefits of the larger size are available 24 h/d, whereas increasing retroreflectivity only helps after dark. The fact that sign reflectance degrades with age and that there is variability in the light intensity provided by different vehicles, suggest the importance of installing signs of adequate size so that luminance requirements are kept realistic.

Developing a comprehensive formula for tradeoffs in size and material proved to be elusive. The complexities of sign design and the absence of proportionality between letter size and legibility distance made this most difficult. Since larger signs require larger increases in letter height to offset the gain from brighter materials, the tradeoff in size and reflectance for 12-in (30.5-cm) letters and larger is unknown.

FINDINGS RELATED TO RESEARCH METHODOLOGY

The results of study 3 suggest that scale models of visual targets may not give valid predictions of visual performance with larger visual targets. The generalization of research results to stimulus sizes not tested should, therefore, be exercised with care.

Although the studies were not designed with the intent to make comparisons among colors, it appeared that color had no effect. The average LI of B/W and B/O signs for each combination of letter series and material within study 4 and for younger drivers in study 1, were within 5 percent of each other. Although the mean performance for B/O signs for older drivers in study 1 was between 10 and 20 percent less than B/W signs, the mean acuity of the B/O group (20/29) was much less than the mean acuity of the B/W group (20/25). Therefore, it appears that when acuity is accounted for and luminance is at relatively high levels, the LI is not affected by color.

The legibility data collected in the two static field studies, one with random letters (study 1) and the other using three-letter words (study 4), was remarkably similar for younger drivers. With older drivers, the difference between the two studies suggested that older drivers appeared to have more difficulty with the abstract random letters.

A rough comparison of the LI's observed in studies 1 and 2 suggest that the differences between the static and dynamic study of legibility are not very large. As expected, the averages are generally a little lower in the dynamic study. The fact that size was the only independent variable that had a significant effect on LI is probably a reflection of the larger variances observed in the dynamic studies.

ADDITIONAL RESEARCH NEEDED

As usual, further research seems warranted. Because of the large number of variables considered in this research, some questions had to go unanswered.

As mentioned earlier, an additional study is needed to cross-validate the results of this research with regard to the effects of retroreflective materials on nighttime legibility. This study should focus on negative-contrast signs, and series C and D letters with an 8-in (20-cm), a 12-in (30.5-cm), and, preferably, a larger letter.

Additional studies of letter spacing should be done using multiple and longer words. A study is also needed to determine how much the legibility curve flattens with increases in letter size beyond the 16-in (40.6-cm) letters tested in this study. Such a study under retroreflective nighttime conditions is imperative, not only to refine the tradeoff analysis for retroreflective materials and large letters, but also to know the limits of legibility for a single sign.

With regard to conspicuity, there is also a need to study signs in larger sizes. The results of this study cannot be generalized to any sizes smaller or larger than the 24- and 36-in (0.61- and 0.91-m) signs tested.

Since most of the results of this research are defined in terms of the LI, it is necessary for practitioners to have some idea of the MRVD before they can effectively apply the results. A research study aimed at identifying the MRVD and minimum size requirements for classes of signs and driving situations would be most useful in the determination of sign size and material.

COMPARISON WITH PREVIOUS RESEARCH

The most important findings from earlier research, taken from the background section of the introduction, are summarized below, together with a conclusion concerning their validity based upon the results of the studies reported here.

1. Not all letters are equally legible.

This finding was confirmed in study 1 by the fact that the subjects could not reach the threshold level on the letter *B*.

2. **Contrast should be 4:1 to 15:1 for fully retroreflective positive-contrast signs, although ratios as high as 50:1 may not be a problem. Luminance may be increased as long as a reasonable contrast is maintained.**

This observation was clearly confirmed, even with the brightest of the new materials. There were no differences in the legibility of signs with ratios from about 10:1 to 40:1, including the brightest type VII on type VII sign. The only bad combination was type VII on type I with a contrast ratio of well over 100.

3. **The legibility of negative-contrast signs requires a minimum of 2.4 cd/m^2 for the 50th percentile younger driver. Optimum luminance is 75 cd/m^2.**

This hypothesis is difficult to evaluate from the findings of this research because there was very little control of luminance, i.e., both R(a) and headlamp intensity were allowed to vary with viewing distance. With new retroreflective materials, sample measurements suggest that in the static field studies, the luminance of orange type I sheeting varied from 6 or 7 to 30 cd/m^2 between 240 and 480 ft (73 and 146 m). These distances, which encompass the range of most of our respondents, correspond to an LI of 30 to 60 ft/in (3.6 to 7.2 m/cm) with an 8-in (20-cm) letter. With type III or type VII sheeting, luminances were always greater than 40 cd/m^2. The fact that the luminance of the least bright material was at least 10 times the minimum and one-half the optimum value suggested in the literature, probably explains why the effects of different materials were so small.

4. **Older drivers require more contrast.**

Within the range of contrast tested, older drivers did not need more contrast. It may well be that this result would have been confirmed if we had tested contrast ratios less than 5:1.

5. **The legibility distance of negative-contrast signs will be 10 to 20 percent less than positive-contrast signs.**

This hypothesis was confirmed by the legibility results from studies 1, 2, and 4.

6. **Night visibility distances are 15 percent to 20 percent shorter than daytime.**

This hypothesis was confirmed for younger drivers. However, for older drivers, there was no difference between day and night for positive-contrast signs and for negative-contrast signs, the reduction at night was closer to 10 percent.

7. **Increasing luminance increases legibility up to a point where irradiation results in decreases in legibility.**

With negative-contrast signs, the level of luminance obtained with type VII material did not result in any detrimental irradiation effects. With positive-contrast signs, increases in luminance were not detrimental to legibility as long as contrast was not excessive as with the type VII on type I combination.

8. **Increases in surrounding luminance improves legibility of signs for older drivers more than for younger drivers.**

This hypothesis was not tested.

9. **Older drivers are more likely to suffer a loss in LI when luminance is increased beyond the optimum level.**

This hypothesis was not confirmed within the range of luminances tested.

10. **The 85th percentile daytime LI of series B is 33 ft/in (3.96 m/cm), series D is 50 ft/in (6.0 m/cm), and series E is 55 ft/in (6.6 m/cm).**

The results of studies 1, 2, and 4 suggest that these values may be reasonable averages for older drivers, but not for the younger drivers from whom they were derived. The daytime LI for young drivers for series C, D, and E was approximately 75, 80, and 90 ft/in (9.0, 9.6, and 1.08 m/cm), respectively. For older drivers, the average LI was 47, 52, and 60 ft/in (5.6, 6.2, and 7.2 m/cm).

11. **The legibility of closely spaced words is 20 percent less than letters tested in isolation.**

The results of study 4 suggest a 13- or 14-percent reduction for younger drivers and an 8- or 9-percent reduction for older drivers with words a stroke width apart, compared to highway standard spacing.

12. **Uppercase words have better legibility than mixed-case words when their height is equal to the uppercase letter in the mixed-case word. When the loop height of the lowercase word is equal to the height of the uppercase word, the mixed-case word has better legibility.**

This finding was confirmed with type I and type VII sheeting in study 4.

REFERENCES

1. Staplin, L.K., "Age-Related Diminished Capabilities and Driver Performance," Working Paper, FHWA, January 1985.

2. Solomon, D., "The Older Driver and Highway Design." Malfetti, J.L. (ed.). *Needs and Problems of Older Drivers: Survey Results and Recommendations. Proceedings of the Older Driver Colloquium*, AAA Foundation for Traffic Safety, February 1985.

3. Committee for Study on Improving Mobility and Safety for Older Persons, "The Safety Risks Faced by Older Drivers and Pedestrians and Potential Improvements," TRB-NRC, 1986.

4. Yee, D., "A Survey of the Traffic Safety Needs and Problems of Drivers Age 55 and Over," *Needs and Problems of Older Drivers: Survey Results and Recommendations*, AAA Foundation for Traffic Safety, Falls Church, VA, February 1985.

5. Gittings, G.L., "Tort Liability in the Pennsylvania Department of Transportation," *Proceedings of the Conference on the Effectiveness of Highway Safety Improvements*, Nashville, TN, March 1985.

6. Mace, D.J.; Hostetter, R.S.; Pollack, L.E.; and Zweig, W.P., *Minimal Luminance Requirement for Official Highway Signs*, FHWA/RD-86-151, May 1986.

7. Mace, D.J. and Gabel, R., "Modeling Highway Visibility: Minimum Required Visibility Distance," *TRB 72nd Annual Meeting*, Washington, DC, 1992.

8. Forbes, T.W. and Holmes, R.S., "Legibility Distances of Highway Destination Signs in Relation to Letter Height, Width, and Reflectorization," *Proceedings, Highway Research Board Bulletin*, Vol. 19, 1939, pp. 321-326.

9. Forbes, T.W.; Moskowitz, K.; and Morgan, G., "A Comparison of Lowercase and Capital Letters for Highway Signs," *Proceedings, Highway Research Board*, Vol. 30, 1950, pp. 355-373.

10. Olson, P.L.; Sivak, M.; and Egan, J.C., *Variables Influencing the Nighttime Legibility of Highway Signs*, Ann Arbor, Michigan: University of Michigan Transportation Institute, Report No. UMTRI-83-36, June 1983.

11. Sivak, M. and Olson, P.L., "Optical and Minimal Luminance Characteristics for Retroreflective Highway Signs," *Transportation Research Record*, 1985, 1027, pp. 53-57.

12. Mace, D.J.; Hostetter, R.S.; Pollack, L.E.; and Zweig, W.P., "Minimal Luminance Requirement for Official Highway Signs," Report No. FHWA/RD-86-151, May 1986.

13. Howett, G.L., *Size of Letters Required for Visibility as a Function of Viewing Distance and Observer Visual Acuity*, National Bureau of Standards, Technical Note 1180, 1983.

14. Shepard, F.D., *Sign Legibility for Modified Messages*, Final Report No. FHWA/VA/R33, 1987.

15. Olson, P.L.; Sivak, M.; and Egan, J.C., *Variables Influencing the Nighttime Legibility of Highway Signs*, University of Michigan Transportation Research Institute, Final Report No. UMTRI-83-36, 1987.

16. Mace, D.J., "Sign Legibility and Conspicuity," *Transportation in an Aging Society Improving Mobility and Safety for Older Persons*, Vol. 2, 1988, pp. 270-293.

17. Allen, T.M. and Straub, A.L., *Sign Brightness and Legibility*, Hwy. Res. Bd. Bull. #127, pp. 1-14.

18. Forbes, T.W. and Holmes, R.S., "Legibility Distances of Highway Destination Signs in Relation to Letter Height, Letter Width, and Reflectorization," *Traffic and Safety*, 1940, pp. 321-335.

19. Kuemmel, D.A., "Maximum Legibility of Traffic Signs in Construction Zones," *Transportation Research Board, 71st Annual Meeting*, 1992.

20. Forbes, T.W.; Moskowitz, K.; and Morgan, G., "A Comparison of Lowercase and Capital Letters for Highway Signs," *Proceedings of the 13th Annual Meeting of the Highway Research Board*, 1950, pp. 355-373.

21. Olson, P.L. and Bernstein, A., "The Nighttime Legibility of Highway Signs as a Function of Their Luminance Characteristics," *Human Factors*, Vol. 21, 1979, pp. 145-160.

22. Solomon, D., *Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle*, U.S. Dept. of Commerce, Traffic Systems Research Division, 1964, pp. 1-44.

23. Lauer, A.R., "Certain Structural Components of Letters for Improving the Efficiency of the Stop Sign," *Highway Research Board Proceedings*, Vol. 27, 1947, pp. 360-371.

24. Hodge, D.C., "Legibility of a Uniform Stroke-Width Alphabet: I. Relative Legibility of Upper- and Lowercase Letters," *Journal of Engineering Psychology*, Vol. 1, 1962, pp. 34-46.

25. Johnston, A.W., *An Investigation of Some Factors Which Impede the Acquisition of Visually Displayed Information*, Ph.D. Dissertation, University of Melbourne, Australia, 1974.

26. Cole, B.L. and Jenkins, S.E., *Conspicuity of Traffic Control Devices*, Australian Road Research Report No. 12, 1983, pp. 223-228.

27. Mace, D.J. and Pollack, L., "Visual Complexity and Sign Brightness in Detection and Recognition of Traffic Signs," *Transportation Research Record*, No. 904, 1983, pp. 33-41.

28. Jenkins, S.E., "Consideration of the Effects of Background on Sign Conspicuity," *11th ARRB Conf.*, Vol. II, 1981.

29. Cole, B.L. and Jenkins, S.E., *The Effect of Size and Luminance on Visual Conspicuity in the Road Traffic Environment*, Australian Road Research Board, Internal Report No. AIR 218-3, 1979.

30. Forbes, T.W.; Fry, J.P.; Joyce, R.P.; and Pain, R.F., "Color and Brightness Factors in Simulated and Full-Scale Traffic Sign Visibility," *Highway Res. Record*, 1968.

31. Roberts, J., "Monocular-Binocular Visual Acuity of Adults," *Vital and Health Statistics*, Series 11, 1968, pp. 1-30.

32. Pelli, D.G.; Robson, J.G.; and Wilkins, A.J., "The Design of a New Letter Chart for Measuring Contrast Sensitivity," *Clin. Vision Sci.*, Vol. 2, No. 3, 1988, pp. 187-199.

33. Comalli, P.E. Jr.; Wapner, S.; and Werner, H., "Interference Effects of Stroop Color-Word Test in Childhood, Adulthood, and Aging," *The Journal of Genetic Psychology*, No. 100, 1962, pp. 47-53.

34. Perchonok, K. and Pollack, L., *Luminous Requirements for Traffic Signs: A Comparison of Sign Performance and Requirements*, Federal Highway Administration, Interim Report F, 1981, pp. 1-37.

35. Berger, Curt, "Stroke Width, Form, and Horizontal Spacing of Numerals as Determinants of the Threshold of Recognition," *Journal of Applied Psychology*, 1943, pp. 208-231.

36. Mace, D.J.; Perchonok, K.; and Pollack, L., *Traffic Signs in Complex Visual Environments*, FHWA Final Report No. FHWA/RD-82/102, 1982.

37. Forbes, T.W. and Holmes, R.S., "Legibility Distances of Highway Destination Signs in Relation to Letter Height, Width, and Reflectorization," *HRB Proc.*, Vol. 19, 1939, pp. 321-326.