Traffic Control Device Conspicuity

PUBLICATION NO. FHWA-HRT-13-044

AUGUST 2013

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

This report may be of use to traffic engineers and researchers who are concerned with the conspicuity of traffic signs.

The *Manual on Uniform Traffic Control Devices* advises that, "Signs should be placed on the right side of the roadway where they are easily recognized and understood by road users." Guidance is provided on the spacing and prioritization of signs, and in some conditions, additional steps may be needed to ensure that signs are conspicuous. Engineering judgment is required when locating signs. However, little additional information is available to engineers to assist in making such judgments. The research described in this report was intended to develop scientific support for additional guidance on traffic control device conspicuity. The report concludes with guidance on sign conspicuity enhancement for practitioners and provides suggestions for additional research to advance the overall state of knowledge on sign conspicuity.

Monique R. Evans
Director, Office of Safety
Research and Development

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA-HRT-13-044	2. Government Accession No.	3. Recipient’s Catalog No.

4. Title and Subtitle Traffic Control Device Conspicuity	5. Report Date August 2013
	6. Performing Organization Code:
7. Author(s) Vaughan W. Inman, Stacy A. Balk, William A. Perez	8. Performing Organization Report No.
9. Performing Organization Name and Address SAIC 6300 Georgetown Pike McLean, VA 22101-2296	10. Work Unit No.
	11. Contract or Grant No. DTFH61-08-C-00006
12. Sponsoring Agency Name and Address MUTCD Team Federal Highway Administration 1200 New Jersey Ave. S.E. Washington, DC 20590-9898	13. Type of Report and Period Covered Final Report. 10/1/2008–9/30/2011
	14. Sponsoring Agency Code HOP

15. Supplementary Notes

FHWA Contracting Officer’s Technical Representative (COTR) was Chris Monk (HRDS-30).

16. Abstract

The *conspicuity* of a traffic control device (TCD) is defined as the probability that the device will be noticed. However, there is no agreed-upon measure of what constitutes being noticed. Various measures have been suggested, including eye fixations, recall, and verbal reports. Four conspicuity studies are discussed in this report.

It has been observed that conspicuity is not solely a property of a TCD but must include consideration of the surrounding environment. The first of the studies described in this report used multidimensional scaling (MDS) to identify factors that characterize drivers’ perceptions of TCD environments. The MDS study revealed that two dimensions, clutter and predictability, characterized the roadway environments included in the study.

In the second study, drivers’ eye glances to TCDs were recorded on a 34-mi (55-km) drive. After passing selected TCDs, drivers’ recall of the TCD was assessed by asking them to identify it. That study showed that warning signs are seldom glanced at and only about half of them are recalled just 2 s after they are passed. About 20 percent of speed limit signs received glances, but drivers were aware of the posted speed limit about 80 percent of the time.

The third study examined drivers’ ability to detect speed limit and warning signs. The ability to detect speed limit signs, as measured by conspicuity angle, was degraded by cluttered backgrounds. However, the detectability of fluorescent yellow-green warning signs was not affected by background clutter.

The fourth study examined the effect of background environment on drivers’ ability to read TCDs. Background had no effect on speed limit sign readability and had a small effect on warning sign readability. Recommendations for enhancing the conspicuity of regulatory signs are proposed.

17. Key Words Conspicuity, Speed-limit sign, Warning sign, Sign detection, Sign recall, Eye tracking	18. Distribution Statement No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 66	22. Price N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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 yard	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 degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}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	35.314	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 degrees)		
^{o}C	Celsius	1.8C+32	Fahrenheit	^{o}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 March 2003)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

FHWA	Federal Highway Administration
GEE	Generalized estimating equations
MDS	Multidimensional scaling
MUTCD	*Manual on Uniform Traffic Control Devices*
ROI	Region of interest
ROW	Right-of-way
TCD	Traffic control device

EXECUTIVE SUMMARY

The objective of this project was to conduct studies on how driver behavior and performance are affected by messaging features within the right-of-way (ROW) in a variety of contexts and to use the new information in the development of evidence-based guidance that supports more effective communication to roadway users.

A review of literature on messaging in the ROW indicated that little is known about the interaction of traffic control device (TCD) messaging and the roadway environment. The review suggested several potential approaches for advancing understanding of this interaction and provided a basis for the series of experiments that followed.

An initial study used a multidimensional scaling (MDS) procedure to identify the factors that drivers consider when viewing roadway environments. Two factors were identified. The dominant factor was aesthetic pleasantness or degree of built structures and clutter. That is, areas with few built structures were judged aesthetically pleasing, and those with a lot of built structures were judged cluttered and less pleasant. A less dominant factor was the degree of organization in the scene. However, organization was correlated with aesthetic pleasantness—organized environments were judged more pleasing, even if built up. It is suggested that roadway classifications based on user judgments may be useful in organizing guidance on TCD design and placement. However, the present study, which examined only major arterials in one community, provides just a hint of the potential utility of such a system.

To communicate effectively, TCDs must be detected. Detection relies on both *visibility* and *conspicuity*. The factors that affect visibility are reasonably well understood. Conspicuity, the properties of a sign that make it likely to capture visual attention, is less well understood. Two common measures of conspicuity are sign recall and eye glances to signs. The present project used an eye tracker to record eye gaze location and queried participants on sign recall immediately after selected signs were passed. The most striking finding was that speed limit identification was good regardless of whether the speed limit signs received a gaze, whereas warning sign message identification was more dependent on the sign receiving a gaze. Speed limits were correctly identified about 80 percent of the time whether or not gazes to speed limit signs were detected. Warning sign messages that did not receive a gaze were recalled only 37 percent of the time. When gazed at, warning sign messages were correctly identified with about the same frequency as speed limits. Drivers who were unfamiliar with the roads were more likely to recall warning signs than drivers who were familiar with the roads. Drivers who were not asked to recall TCDs were somewhat less likely to glance at the signs than those who had been asked to recall TCDs. However, regardless of whether drivers were asked to recall signs or not, fewer than half of warning or speed limit signs received glances. The classification dimensions identified in the MDS study did not significantly correlate with either glance or recall performance.

It was concluded that neither glance nor recall data alone are sufficient to characterize the conspicuity of TCDs.

The ability to detect and identify signs with peripheral or near peripheral vision was also examined. In the laboratory, speed limit and warning signs were presented in various roadway scenes. Outdoors, the same signs were presented with two different background environments.

These experiments showed that drivers can detect the presence of signs in their far peripheral vision (20–70° from the point of gaze, depending on background conditions). Sign detection can be followed by a glance to the sign to read its message. However, the field experiment results suggested that drivers read some signs without looking directly at them. The final study in this project measured the critical angle at which warning and speed limit signs can be read in the absence of a direct look.

Five speed limit signs and five text-based warning signs served as target stimuli in a laboratory experiment to determine the peripheral angle at which the signs can be read. Each sign was presented in each of six roadway contexts. Each of the roadway contexts was a panoramic view that was included in the MDS study. A common psychometric technique, the method of limits, was used to measure the angle between the direction of gaze and the content on signs that could be identified.

Speed limit identification performance was superior to warning sign identification performance. Identification performance for both sign types decreased as the angle away from the fixation point increased. Speed limit signs were identified with over 80 percent accuracy at angles out to ±9° from gaze location. Warning signs were identified with above 80 percent accuracy with a 3° gaze offset, and identification remained above chance accuracy out to 15°.

The sign identification findings confirm that traffic sign messages can be recognized in the absence of foveal glances to them. Thus, failures to gaze at signs cannot be taken as evidence that drivers are unaware of sign content. Awareness of sign content, then, is a better measure of sign conspicuity than eye glances to a sign. This does not mean that glance data are not useful. In the laboratory, where the participant's only task is to identify signs, the probability of correctly reading a familiar sign without a direct glance is high. In an actual roadway environment, where the driver must attend to more than just signs, the probability of correctly reading a sign without a glance is probably lower. Furthermore, if gaze direction does not fall within 9° of a sign, it is unlikely that the content of the sign will be registered.

There is no generally accepted measure of the conspicuity of TCDs. Eye tracking has been used to assess whether TCDs receive glances, but the research reported here indicates that some TCD content was noticed and remembered even though the TCD did not receive a direct eye glance. In addition, about 20 percent of signs that received glances could not be recalled 2 s after they were passed. A field test that used an eye-tracking device and asked drivers to recall selected signs did not show a predictable effect of sign environment on glance probability or recall. However, two other psychophysical testing methods indicated that background environment influences sign detectability, especially regulatory sign detectability. With light colored or cluttered surrounds, speed limit signs were about half as detectable as they were with dark, uncluttered surrounds. Although further research is needed to develop empirically based guidance, the results of these studies suggest that guidelines for practitioners should be developed to suggest when TCD conspicuity enhancements are needed and which available enhancements are likely to be most effective in specific situations.

With the surrounds explored in these studies, warning sign detectability did not vary by predictable or practically significant amounts as a function of background. However, this should not be taken to mean that warning signs detectability would not be markedly degraded by more complex surrounds than were explored in these studies. In particular, the present results should not be used as support for posting more than one sign on a roadside support, as the literature suggests that crowding would reduce readability.

The final section of this report provides guidelines for ensuring the effectiveness of traffic control signs. These guidelines are based on an integration of the present findings with guidelines and recommendations from the *Manual on Uniform Traffic Control Devices* (MUTCD) and human factors principles from other resources.

INTRODUCTION

The immediate objective of this project was to conduct studies on how driver behavior and performance are affected by messaging features within the ROW in a variety of contexts. The ultimate objective was to develop evidence-based guidance that would support roadway designers and planners in more effectively communicating to roadway users.

In the first phase of this project, a literature review was conducted to identify what is known about how the roadway environment interacts with messaging features. A small study was conducted to identify environmental features that are important to motorists' perceptions. This study was followed by an on-road observational study in which drivers' glances to TCDs and recall of those TCDs were recorded. Because the literature on TCDs emphasizes the importance of visibility and conspicuity, a series of experiments were conducted to assess conspicuity of warning and speed limit signs as a function of the environment in which they are viewed. Based on the literature and the studies conducted as part of this project, recommendations for practitioners were developed and future research needs were identified.

A review of the literature on driver behavior suggested that little is known about the effects of the interaction of the roadway environment with roadway messaging features. Lay categorized sign use into four stages: (1) detection, (2) reading, (3) understanding, and (4) action. The present studies address factors that affect the first two stages, sign detection and reading.(1)

To ensure detection, a sign or marking must be visible and conspicuous. For visibility, a sign must be located in the driver's field of view, in a clear line of sight, and in adequate lighting. Conspicuity is generally defined in terms of the probability of an object being noticed. However, whether an object is noticed is not easily defined. For example, one measure of conspicuity used by Cole and Jenkins was whether participants fixated on an object.(2) However, Luoma found that despite a pedestrian warning sign being fixated on by 62 percent of drivers, only 8 percent of those drivers were aware of the warning when asked to identify the sign seconds after it was passed.(3) This suggests that eye fixations alone do not ensure that a sign has been attended to. Alternatively, there are cases in which stimuli can be perceived without a driver fixating on them. For instance, Luoma found that after drivers turned at an intersection, more than half reported being aware that the intersection lacked lane markings even though an eye tracker showed that they had not fixated on the areas of pavement where the lane markings would have been.(3) Eye tracking in dynamic environments is complex, and basic research in this area continues to evolve.(4–6) Therefore, terms such as *fixation*, *glance*, *gaze*, and *look* should be interpreted with caution. It should not be assumed that field data are measured with the same level of accuracy as laboratory data obtained when the observer's head is fixed, the lighting is optimized for measurement, the stimuli are static, and the sampling rate for eye position is equal to or greater than 240 Hz. For driving studies in which eye glances are reported, it can only be assumed that the evidence that an object was (or was not) brought into or near the center of gaze was adequate. As discussed in this report, observers can perceive objects without looking at or fixating on them. In a three-dimensional, dynamic world, it can be difficult to determine whether the 2° of foveal vision are focused on a large, near object or a small, far object that is juxtaposed with the near object in a two-dimensional plane. The approximately 2° cone of fine vision provided by the fovea of the eye describes a 17-ft (5.2-m) cone at a distance of 500 ft (153 m) from the observer. Many objects can fall within that cone of vision, and attention can be focused on any object within that cone as well as objects outside that cone if fine detail discrimination is not required.

Because recall and eye glance data do not appear to provide definitive measures of conspicuity, the inclusion of additional measures is desirable. Wertheim recently suggested a critical conspicuity distance, which is the lateral distance away from an object that a person can fixate on and still detect or identify the object.(7) This measure may be important when observers are primed to attend to certain targets. For example, drivers might be primed to attend to traffic signs. When signs are outside of this critical conspicuity distance, they are likely to go unnoticed. Variations on Wertheim's technique were used in two of the studies reported here.

Most investigators are in agreement that the environment around a sign is an important factor in determining its conspicuity. (See references 2 and 8–10.) However, there are few studies that investigate how to systematically characterize the roadway environment in ways that are relevant to TCD conspicuity. Typical engineering classifications are based on land use (e.g., rural or urban) or roadway function (e.g., feeder, minor arterial, or major arterial) rather than on drivers' perceptions or the appearance of the immediate surrounds of a TCD.

The first study reported here was conducted to assess one possible method of roadway classification that would be more sensitive to drivers' perceptions. The second study was a field study in which an instrumented vehicle was used to record drivers' eye glances to TCDs. After passing each selected TCD, the drivers were asked to identify the TCD so that eye glances could be related to TCD recall. The third study assessed TCD detection conspicuity, the largest angle away from a sign that a driver could gaze and still detect sign presence. The fourth study assessed TCD identification conspicuity, the largest angle away from a sign that a driver could gaze and still read a sign.

MDS CLASSIFICATION OF ROADWAYS

If perceptions of the roadway environment are important to the behavioral response to TCDs, then methods of identifying determinants of those perceptions are likewise important. There have been many attempts to accomplish this task and classify our visual environment in a meaningful way.(11,12) The Federal Highway Administration (FHWA) employs a functional-use system with the following classifications: interstates, other freeways, principal arterials, minor arterials, major collectors, minor collectors, and local roads.(13) This system relies on road functionality but ignores other environmental characteristics. For example, arterial roads in urban and rural areas can look vastly different. An arterial in a suburban or rural area may consist of two travel lanes and be surrounded by foliage and minimal signage. An arterial in an urban environment may contain six travel lanes and be surrounded by buildings and ample commercial signage, or with sufficient screening foliage, an urban arterial may look very much like a two-lane rural highway. Functional classes that do not reliably predict roadway appearance may not be a problem if the salient characteristics of roadway class determine driver responses to TCDs. However, alternative classification systems exist, and it is not known which classification systems best predict when drivers will notice and respond to TCDs.

Alternative roadway classification systems may rely on situational components—items that move freely to and from the area (e.g., pedestrians, vehicles). Items in a scene can also be classified as built, permanent components (e.g., grocery stores, trees). Whereas these types of functional use and component classification systems are quite useful in some respects (e.g., the implementation of speed limits, curbing, and sidewalks), they are unable to provide substantial objective information about environmental influences that may be vital to driver performance (e.g., detection of speed limit signs, stop signs, and construction zone warnings). Furthermore, these classifications fail to capture many driver-relevant perceptual differences between environments.

When performing a visual search task (looking for a specific target item among other items), the more non-target items present, the longer it takes to complete the task.(14–16) However, the exact manner for counting items is debatable. For instance, a person could be counted as a single item or as multiple items if shirt, shoes, pants, nose, fingers, etc. are considered separate elements. Further, the number of non-target items (set size) alone does not dictate the amount of time required to look at and identify a specific target object. In many cases the target item “pops out” (e.g., a red line among black lines).(17) People also have a tendency to direct attention toward items of relevance or guide attention to specific task-relevant areas of a visual environment.(18,19) For instance, drivers in countries that drive on the right look for signs on the right side of the road and may miss the same signs when they are placed on the left side of the road.(20)

Drivers tend to look at task-relevant signage. However, in visually complex environments, excessive clutter may increase the time required to identify, interpret, and respond to task-specific stimuli. This delay may lead to unsafe driving behavior.(15) It is easy to imagine that a driver might miss a relevant sign (e.g., lane ending) among a plethora of other signs and heavy traffic. As a result, the driver may be startled by a sudden change in the roadway or behave erratically.

It is obvious that the roadway environment is complex and it can be difficult to determine exactly what visual information degrades driver performance and what does not. It would be beneficial to increase the saliency of environmental components that improve driving performance. A first step toward accomplishing that goal is to better understand which items drivers attend to in a roadway environment. Such information could then be exploited in roadway design by directing drivers' attention to pertinent items and away from the non-essential. This study sought to increase the understanding of drivers' perceptions of the roadway environment and to use this understanding in the interpretation of data from subsequent studies that examined driver eye glance behavior and detection and identification of highway signs. Participants were asked to rate the similarity of various photographs of roadway environments. The analysis of observer perceptions of roadway environments utilized MDS, a somewhat novel methodology for the realm of transportation research.(21)

At the simplest level, MDS is a mathematical technique that recovers the spatial relationships between objects based on the distances between those objects. For example, Kruskal and Wish demonstrated that a map of the location of 10 major U.S. cities could be accurately reconstructed by submitting the distances between all pairs of those cities to an MDS.(22) Other methods exist for accomplishing this task when all paired distances are known and measured without error. MDS becomes useful when measurements cannot be made without error. That is, whereas the spatial distances between cities can be measured with great accuracy, subjective judgments of the similarity of objects, such as pictures of outdoor scenes, may reflect both inter- and intra-individual variability. Furthermore, if it is assumed that people perceive the similarity of objects based on multiple factors and that those factors can be conceived of in spatial relationships, then MDS can be used to tease out the factors that define the space. For instance, Wish asked students to make similarity judgments between pairs of nations constructed from a list of 12 nations. He identified two perceptual dimensions that predicted the spatial relationships extracted from MDS analysis: degree of industrialization (development) and communist/non-communist political orientation.(23) The latter dimension probably reflected the Cold War era during which Wish conducted his study.

MDS analyses might provide valuable clues as to the how drivers perceive roadway environments. When combined with the studies that follow, this type of information has the potential to extend understanding of the interactions between roadway sign placement, lane markings, and roadway geometry with other environmental factors that influence driver performance.

METHOD

Participants were asked to rate the similarity of roadway scenes. These similarity ratings were then used to infer a mental model of the scenes.

Stimuli

The roadway scenes were panoramic photographs of the environment surrounding the TCDs that served as the stimuli of interest in subsequent studies. The environments around 21 TCDs were photographed from a point 85 ft (26 m) upstream of the target TCD so as to present a driver's view as the TCD was approached. Each panorama consisted of three photographs that were stitched together to form a wide-angle panorama. All three photographs were shot from the right through lane of the roadway. The center photograph approximated a driver's view of the road and centered on the right lane at a point slightly beyond the target TCD. The left and right photographs bracketed the center photograph with approximately 30 percent overlap. From the original set of 21 panoramas, 14 were chosen for the similarity comparisons. The down selection was intended to maintain the widest range of roadway environments while limiting the number of paired comparisons needed.

Procedure

Participants were asked to rate the similarity of 91 unique pairs of the 14 panoramic roadway photographs (see figure 1 through figure 14). They rated the pairs on a scale from 1 (not at all similar) to 10 (very similar). Each panorama was presented on a laptop computer at approximately 960 (width) by 304 (height) pixels. Each panorama was presented as the upper or lower member of a pair an equal number of times.

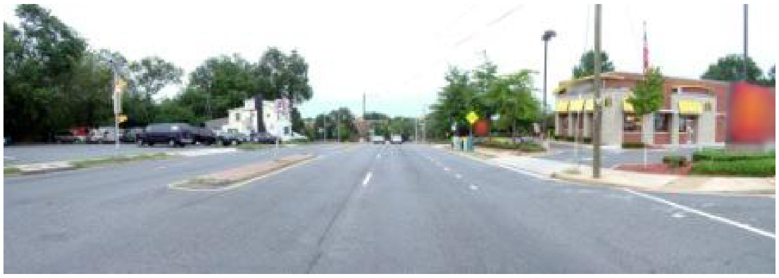


Figure 1. Photo. Panorama 1.

Figure 2. Photo. Panorama 2.

Figure 3. Photo. Panorama 3.

Figure 4. Photo. Panorama 4.

Figure 5. Photo. Panorama 5.

Figure 6. Photo. Panorama 6.

Figure 7. Photo. Panorama 7.

Figure 8. Photo. Panorama 8.

Figure 9. Photo. Panorama 9.

Figure 10. Photo. Panorama 10.

Figure 11. Photo. Panorama 11.

Figure 12. Photo. Panorama 12.

Figure 13. Photo. Panorama 13.

Figure 14. Photo. Panorama 14.

After rating the similarity of each of the pairs of photographs, participants were asked to rate each of the roadway photographs individually on five different descriptors: (1) built-up, (2) clutter, (3) openness, (4) aesthetically pleasing, and (5) organized/predictable. These ratings were on a 1–10 scale with 1 representing the high end of the scale and 10 representing the low end of the scale (e.g., 1 for "very built-up" and 10 for "not at all built-up"). These descriptors were derived from pilot testing in which colleagues were asked to generate a verbal description of the panoramic photographs. Participants were not provided definitions or examples for the descriptors but were left to interpret the terms on their own.

Participants

Thirteen people (7 males, 6 females) provided similarity ratings. All participants were recruited at a local community center, where they also completed the descriptor ratings. The mean age of participants was 39.8 years (range 24–63). All participants had a valid driver's license. MDS can be performed on similarity rating from as few as one individual. Unless individual differences are of interest, sample sizes in the range used for this study are generally adequate.

RESULTS

Table 1 shows the *x*, *y* coordinates of the MDS results for a two-dimensional solution.

Table 1. MDS coordinates of a two-dimensional solution for the panorama similarity ratings.

Panorama ID	Clutter/Built Dimension	Predictable Dimension
1	-1.438	0.457
2	1.712	-0.01
3	0.782	-1.189
4	-0.132	1.872
5	0.147	-1.266
6	-1.11	-1.183
7	-1.475	-0.416
8	-0.869	1.321
9	-0.529	0.014
10	-0.504	-1.121
11	0.37	1.09
12	0.486	0.363
13	1.217	0.863
14	1.342	-0.794

The MDS routine PROXSCAL was used to analyze the similarity ratings.(24) The data were treated as interval scale.(24) An examination of the scree plot suggested a two-dimensional solution (stress = 0.117). The two-dimensional MDS solution is shown in figure 15. The number beside each point in the plot refers to the panorama ID number. The labels on the axes are not MDS outputs; they have been supplied by the authors.

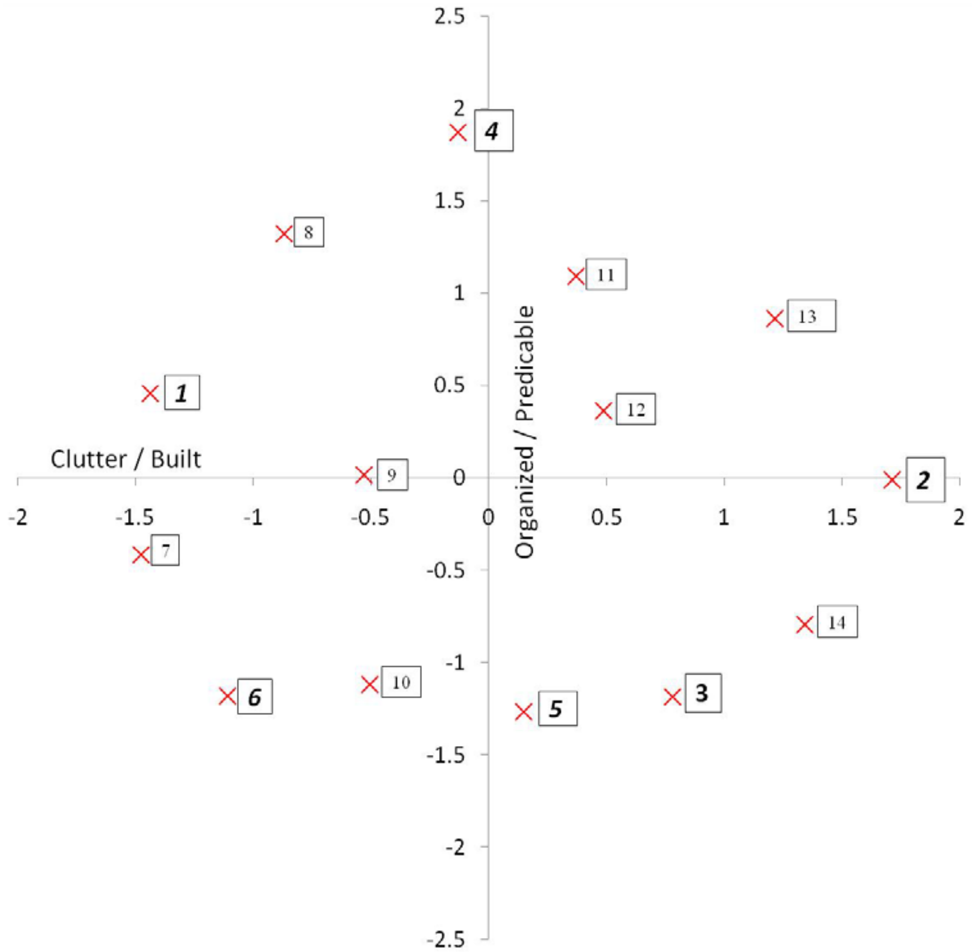


Figure 15. Graph. MDS solution for 14 panoramas along field study route.

The Pearson product-moment correlation between each of the five descriptor ratings of the panoramas and the MDS dimension scores of the panoramas was computed. As shown in table 2, each of the MDS dimensions correlated significantly with ratings of at least one of the preselected descriptors. The first MDS dimension significantly correlated with three descriptors: built-up ($r = 0.56$, $p < 0.05$), clutter ($r = 0.75$, $p < 0.01$), and aesthetically pleasing ($r = -0.66$, $p < 0.01$). The descriptor ratings built-up and clutter strongly positively correlated with one another ($r = 0.78$, $p < 0.01$). Thus, those environments with a high degree of manmade or built components were also judged to be cluttered. The first MDS dimension was also negatively correlated with aesthetically pleasing. Aesthetically pleasing was not significantly related to any of the other descriptors. Thus, it appears that dimension 1 may reflect the participants' perception of clutter; however, the possibility that the correlation is coincident with some factor that was not explored cannot be ruled out—MDS is an exploratory technique. If a scene is judged to be high on clutter, it is generally judged to be low with respect to being aesthetically pleasing. The inverse is also true.

The second dimension most closely correlated to the predictability or organization of the environment ($r = -0.55$, $p < 0.05$). Items that had high scores on the second MDS coordinate were judged to have low predictability or organization. Ratings of organization and predictability had a significant positive correlation with aesthetically pleasing ($r = 0.826$, $p < 0.01$).

Table 2. Matrix of correlations between each descriptor rating and each MDS dimension.

	Dimension 2	Built-Up	Clutter	Openness	Aesthetically Pleasing	Organized/ Predictable
Dimension 1	-0.010	0.559*	0.745**	-0.437	-0.664**	-0.472
Dimension 2		-0.391	-0.108	0.394	-0.485	-0.554*
Built-Up			0.779**	-0.756**	-0.128	-0.011
Clutter				-0.691**	-0.457	-0.369
Openness					0.074	0.125
Aesthetically Pleasing						0.826**

*Significant at 0.05.
**Significant at 0.01.

Discussion

This study used MDS to identify environmental factors that observers attended to when comparing roadway scenes. Two dimensions emerged that mapped well to previously suggested roadway environment descriptors. These factors provide insight into the types of characteristics that are salient to roadway users. It appears that participants attended to environmental components that have the potential to affect driving behavior. For example, an organized/predictable environment may allow drivers to better predict where vehicles are likely to turn or pedestrians are likely to cross.

The study utilized a range of roadway scenes that were present along the intended route for a field study of driver behavior. Because of constraints on the selection of TCDs to be included in that field study, the range of variability in the pictured environments may have limited the range of environmental factors that emerged from paired comparison ratings. It is important that subsequent research in this area include a wider variety of roadway environmental factors, such as traffic, nighttime scenes, greater variability in access control, a greater range of roadside advertising, and a greater range of pedestrian and bicycle activity. MDS relies on comparisons of nearly exhaustive pairings between items. As a result, the number of items compared generally needs to be limited to around 15 to avoid overwhelming participants. Nonetheless, MDS may prove to be a robust methodology for identifying aspects of an environment attended to by drivers. As a result, use of MDS in combination with other research tools has the potential to set the foundation for a driver-centric roadway classification system. For signing and marking applications, such an approach may be as or more useful in guiding practitioners than functional classification systems. Future studies may explore other methods of quantifying visual scenes, such as automated image analysis. Such methods combined with driver-centric techniques have the potential to greatly expand our understanding of the interaction between users and roadway environmental factors.

Each of the 14 panoramas used in the MDS analysis included a TCD that was a target for recall in the field study that followed. Each panoramic photograph was taken 85 ft (26 m) upstream of a TCD for which recall was requested after the driver passed the TCD. One question to be addressed in the analysis of the field study data is whether the MDS classifications predict either glances to or recall of the TCDs.

GLANCE BEHAVIOR AND SIGN RECALL

To fully address the effects of environmental factors on messaging in the ROW, the effects of environment on all four stages of processing identified by Lay (detection, reading, understanding, and action) must be addressed.(1) However, because each stage is dependent on the preceding stages, the present study focused on knowledge gaps regarding the first two stages: detection and reading.

As stated in the introduction, detection relies both on visibility and conspicuity. The factors that affect sign visibility are reasonably well understood.(1,25) However, the specific factors that affect the conspicuity of signs and other TCDs are less well understood. Conspicuity refers to the properties of an object that make it likely to capture visual attention (i.e., noticeable). However, there is no single agreed upon way of measuring visual attention or the factors that influence it. The following section reviews some of the methods that have been used to measure visual attention.

ASSESSING VISUAL ATTENTION

Modeling Approach

Itti and Koch discussed the development of computational models of visual attention that are based on physiological and psychophysical theories and are supported by robust empirical evidence.(26) The authors relate conspicuity to *perceptual saliency*, asserting that some objects are inherently salient in a given context (e.g., a red jacket among black tuxedos). They suggest that such saliency is the result of bottom-up visual processing—low-level automatic processing that is not influenced by higher cognitive processes or conscious attention. The authors posit that in a scene that has multiple salient objects a *saliency map* will determine which objects will be attended to first at the next higher level of processing (a still relatively low-level preattentive process). Itti and Koch acknowledge that experience and background properties can influence both of these processing stages. Both are bottom-up preattentive processes that are not subject to conscious control or top-down processing. A final preattentive process posited by the authors is *inhibition of return*, which prevents focus from returning to highly salient stimuli that have already been processed. Beyond these preattentive processes, top-down processes play a role in visual attention. These top-down processes involve relating memory, knowledge, expectation, and conscious control to making sense and use of the low-level visual information. Itti and Koch tested various computational models of visual attention for computing the time necessary to detect traffic signs. However, this basic research does not offer guidance that might be readily applied to highway design.

It has been suggested that conspicuous objects attract attention and that attention consists of both bottom-up processes and top-down processes. However, to understand the influence of conspicuity on messaging in the ROW, a methodology is needed to measure conspicuity in a way that is consistent and repeatable.

Verbal Reports

Verbal report methods have been used to assess both object conspicuity and which objects are attended to by drivers. Renge and Cole and Hughes asked drivers to talk aloud about what attracted their attention while watching films of scenes recorded from the driver’s perspective.(27,8) Renge asked participants to sit in a driving buck and mimic the steering and braking behavior presented in the driving scenario. Participants continuously verbalized what came to their attention while simulating the drive. Renge found that 79 percent of the verbal reports mentioned driving-related objects (e.g., other vehicles, TCDs, the road). About 11 percent of the reports were of non-driving-related objects (e.g., trees, advertising), and 9 percent were non-visual (e.g., how the vehicle was operating).

Cole and Hughes attempted to improve upon the instructions used by Renge. Participants were asked to only report objects and things to which they attended. Participants were required neither to maintain continuous verbalization nor to mimic driving through the film. Hughes and Cole had a group of participants drive the route shown on the film and verbalize objects that were attended to.(10) Overall, possibly as a result of the changes in instructions, participants in the Cole and Hughes study who watched the film reported a greater percentage of non-driving objects than participants in the Renge study. Further, when looking at both on-road and video-based reports, Hughes and Cole found that only about 50 percent of reports were driving-related (e.g., vehicles, pedestrians, TCDs) in residential areas, but the percentage of driving-related reports went up to about 65 percent in busy commercial areas. The percentage of driving-related reports was about 5–10 percent higher when participants drove the actual route than when they viewed the route on 16 mm film. Although there were somewhat more non-driving-related reports in the laboratory than in the field, the pattern of reporting was similar. Across three road classes, the percent difference in frequency of road-related to non-road-related remained about the same. Hughes and Cole concluded that laboratory studies of what drivers attend to could yield valid data for the prediction of real-world driver behavior. Thus, Hughes and Cole and Renge showed similar findings, but Hughes and Cole got more non-driving-related verbalizations.

In another variation of the verbalization method, Cole and Jenkins presented static roadway scenes to participants.(2) All photographs were taken from an Australian driver's viewpoint in the left lane and contained a target TCD 328 ft (100 m) ahead. A central fixation point was present prior to each tachistoscopic slide presentation. Each photograph was presented for 0.5 s, a duration that was assumed to allow participants only one saccade. As a result, the fixation that followed the saccade would be to the most conspicuous object. It was also assumed that the most conspicuous object would be reported first. Participants were instructed to report as many TCDs as possible in each of the photographs. After the 0.5-s viewing, a light was switched on so that participants could provide a written response. The numbers of both the identified target and non-target TCDs were recorded. On average, participants reported 1.24 objects per slide. Target stop signs were reported 62 percent of the time, but yield signs were reported only 1 percent of the time. Crossroads ahead warning signs were reported 91 percent of the time, and traffic signals were reported 51 percent of the time. When the experiment was replicated with the slide exposure time tripled to 1.5 s, the number of objects reported increased to an average of 1.68 objects per slide. Cole and Jenkins speculated that the reason the longer observation time did not result in a substantial increase in the number of TCDs reported, despite an average of four TCDs per slide, was that the TCDs were not sufficiently conspicuous to elicit foveal fixations and recognition. The authors did not discuss the possibility that 1.5 s might not be sufficient time to enable memory consolidation. That is, the act of providing written recall could have been sufficient to allow visual short-term memory to decay so that items not immediately recalled could not be rehearsed and thus would be unavailable for written recall. The authors also did not consider that the result might be related to the *perceptual blink* phenomenon reported by Shapiro.(28) In Shapiro's study, letter stimuli were presented one at a time at a rate of 10 letters per second. There were two target letters in the stream of letters. When the second target in the sequence was within half a second of the first, the second target was often not detected. Shapiro suggested that the sequential presentation of letter stimuli is analogous to perception of similar stimuli in a sequence of saccades. If this suggestion is correct, then the detection of a second TCD following the detection of a first TCD might be suppressed if the glance to the second TCD came immediately after the glance to the first TCD.

Verbal reports have the advantage of being relatively easy to obtain. If a driver reports attending to an object and that object is present, it is safe to say the driver attended to that object. The frequency of verbal reports of a TCD may be a valid way to assess the relative effectiveness of conspicuity treatments. However, it cannot be assumed that all objects attended to will be reported. Because drivers can shift visual focus about 3 times per second, it is unlikely that all objects that are viewed foveally could be verbally reported. Furthermore, the simple act of reporting one TCD may cause drivers to forget other objects. Especially for highly learned tasks, it is possible that much of what is viewed and acted upon may not be consciously processed, making it difficult to verbalize that information. For example, because lane maintenance is such an automatic process for experienced drivers, an effective lane marking conspicuity enhancement might not be noted by drivers even if driving performance is affected.

The verbal report method may be useful, and its application in a laboratory task may be efficient. However, it is not sufficient by itself to address all issues that relate conspicuity to the effect of roadway messaging on driver behavior. A method that is similar to the verbalization of attention method is to ask drivers to search for and report specific targets.

Target Search

Cole and Hughes compared the verbalization technique to directed search.(8) The authors refer to conspicuity measured using verbalization as *attention conspicuity*. Conspicuity measured by directed search, a technique in which drivers are instructed to report particular targets, is referred to as *search conspicuity*. The investigators placed 35 circular disks at locations along a 13.6-mi (21.9-km) route near Melbourne, Australia. Each disk was white, gray, or black. The white disks were in three diameters: 11.8, 19.7, and 27.6 inches (30, 50, and 70 cm). The gray and black disks were 19.7 inches (50 cm) in diameter. There were two groups of drivers. One group was given verbalization instructions; they were asked to report any objects that attracted their attention. The other group was given directed search instructions; they were asked to report all traffic signs and disk targets that they saw.

Only the proportion of disks reported was analyzed. In the attention conspicuity condition, 20 percent of the disks were reported. In the search conspicuity condition, 63 percent of disks were reported. Not surprisingly, in both reporting conditions, the proportion of disks reported increased with disk size. Disks tended to be reported when they were within 15° of the direction of travel and more than 160 ft (50 m) ahead. That is, the disks that were reported tended to be in areas where attentive drivers would be expected to look. The most striking finding was that the report rate was twice as high in residential areas, where search conspicuity was about 80 percent, than in commercial areas, where search conspicuity was about 40 percent. The researchers suggested that the lower conspicuity in commercial areas was the result of greater visual clutter, although the authors could not rule out differences in driving demands related to traffic and pedestrians as a cause of the differences in conspicuity.

Whether or not drivers look at signs may be related to conspicuity. Certainly, if a message is inconspicuous it can escape detection. If a message is important to the driver and it is conspicuous, highway engineers hope that it will be detected and looked at.

Eye Tracking

Eye trackers have been available for on-road research since the 1970s. In one study, drivers were given verbal instructions to follow a route with which they were not familiar.(29) Because of the nature of the navigation instructions, street names and other navigation signage were important to these drivers. As a result, drivers fixated on over 90 percent of traffic signals and about 80 percent of navigation signs. Drivers fixated less often on speed limit signs (about 60 percent) and even less on lane restriction and warning signs (about 50 percent). The investigators did not discuss the circumstances in which 10 percent of traffic signals were not fixated on by drivers or the criticality of the navigation signs that were not fixated on by drivers. Thus, it is not possible to determine from the report whether the signs that were not fixated on were deemed unimportant, missed because they were inconspicuous, or seen but not fixated on. Because no red-light violations were reported, one can likely infer that drivers are able to interpret some signs and signals without fixating on them or that drivers rely on other cues such as the behavior of other vehicles.

In a 1973 eye-tracking study reported by Bhise and Rockwell, drivers were instructed where to enter and exit a freeway but otherwise to drive as they normally would. Eye glance data were recorded while the participants drove on interstate highways.(30) The study focused on characterizing eye glances to navigation signs. The researchers reported that drivers moderated glance duration in a rational way. Signs with a lot of information received more glances but did not receive longer glances. Glance durations tended to be 1.5 s or less. The authors proposed a system for evaluating signs that takes into consideration legibility time-distance (based on individual driver visual acuity), first glance time-distance, and the distance at which the sign can no longer be read (based on rate of change in angle). According to this system, better signs use less of the total available time between first glance time and when the sign can no longer be read. The researchers pointed out that sign reading is shared with required driving tasks, so the time needed to read navigation signs must also accommodate traffic conditions, roadway geometry, and weather.

In a more recent study, Luoma used an eye tracker to examine driver glances to a limited selection of TCDs and advertising signs.(3) In the analysis, eye fixation data were combined with memory for the selected objects. Participants were asked to drive as they normally would on a 31-mi (50-km) route. They were not informed of what objects were of interest beforehand. After an object was passed, participants were queried to determine if they had perceived the object. *Perception* was defined as correctly recalling something about the specified object. The results of the eye-tracking and perception queries are presented in table 3, which shows whether an object was fixated on or not and whether it was correctly recalled or not. The mean fixation times for TCDs that were subsequently recalled ranged from 644 ms for a speed limit sign to 130 ms for the location where crosswalk lines were not painted. The mean fixation time on billboards for which the subject of the advertisement was correctly recalled was 2,310 ms. Mean fixation time for billboards for which advertisements were not recalled ranged from 185 ms to 444 ms. Perhaps the most important message from the Luoma study is that fixation on an object and awareness of that object are not interchangeable. TCDs that are not fixated on by drivers may be recalled and those that are fixated on may not be recalled even moments after the fixation. In the case of the pedestrian crossing warning sign that was fixated on by participants, the majority of drivers showed no verbal awareness of it. Thus, fixation may not be sufficient to ensure awareness of signs, at least when verbalization is the metric used to validate awareness.

Table 3. Percent fixated on and recalled for selected objects in Luoma study.(3)

Recall	TCD	Fixation	No Fixation
Recalled	Speed limit sign	100	0
	Game crossing sign	60	7
	Right-turn lane restriction marking	93	0
	Left-turn lane restriction marking	7	0
	No lane markings	38	54
	No crosswalk marking (at intersection)	47	33
	Pedestrian crossing ahead sign	8	0
	Pedestrian crossing sign	0	0
	Crosswalk marking	29	7
	Billboards	20	0
Not recalled	Speed limit sign	0	0
	Game crossing sign	0	33
	Right-turn lane restriction marking	7	0
	Left-turn lane restriction marking	0	93
	No lane markings	8	0
	No crosswalk marking (at intersection)	7	13
	Pedestrian crossing ahead sign	54	38
	Pedestrian crossing sign	21	79
	Crosswalk marking	50	14
	Billboards	23	57

Memory for Signs

Memory for signs has been used as a measure of conspicuity. The largest and most cited study of memory for traffic signs is by Johansson and Backlund.(31) In this Swedish study, more than 5,000 drivers were stopped soon after passing a traffic sign. Because of a curve in the road, the traffic blockade that required drivers to stop was not visible until after the sign had been passed. Six signs were tested at the same location: a speed limit sign and five different warning signs.

When drivers were stopped, they were asked, “What was the last road sign you passed?” If the first question was not answered, drivers were asked, “Do you remember if the last road sign you passed was [sign name]?” The authors estimated that 60–70 s elapsed between passing the sign and these questions. The percentages of correct responses (i.e., the answer to either the first or second question was correct) are shown in table 4.

Table 4. Percent correct recall of signs from Johansson and Backlund.(31)

Sign	Percent Correct
Speed limit	76
Police control	66
Broken pavement	55
Other danger	29
Pedestrian crossing	26
Animal warning	62

Based on these findings, the investigators drew the conclusion that the road sign system does not achieve its purpose—that highway signs often fail to communicate their message to drivers. However, the authors also proposed that the probability of a sign being "registered" with a driver is, in part, determined by its importance to the driver. That is, the investigators proposed that the speed limit sign and the presence of police controlling the road are registered because they are important to drivers, whereas drivers on rural highways do not view nonspecific warnings or warnings of a pedestrian crossing as important. The researchers asserted that pedestrians are rare in the environment where the test was conducted and that pedestrians in this environment typically yield to vehicles rather than the reverse. Such consideration might make a crosswalk warning sign irrelevant to most drivers. How drivers distinguish important and unimportant warning signs without noticing and evaluating them was not discussed. However, the investigators' analysis implies that "registering" a TCD occurs after a driver detects and analyzes the sign for its importance.

A similar motorist intercept study was reported by Shinar and Drory.(32) The study was conducted in Israel, and vehicles were stopped at an army checkpoint. The checkpoint was 56 mi (90 km) from the nearest town. Traffic in both directions was intercepted. The experimental signs were placed 658 ft (200 m) before the checkpoint, which became visible about the same time as the signs. Two experimental signs were used: a warning for an intersection ahead and a general warning. In addition, there were preexisting warning signs 1,300 ft (400 m) before the checkpoint, one on the northbound approach and one on the southbound approach. These were a stop ahead warning and a winding road warning. Drivers traveling in each direction were asked to recall the last two signs they had passed. It was hypothesized that the signs would be better recalled at night because during the day drivers could see the actual hazard at about the same time they could see the warning signs.

The investigators' prediction was confirmed: drivers recalled the warning signs 4.5 percent of the time during the day and 16.5 percent at night. However, it is unclear whether the effect of time of day was the result of the content carrying more weight at night or if the signs were simply more conspicuous. After all, roadway signs mostly consist of retroreflective material. When these signs are illuminated with headlights, a large contrast is created between the bright sign and the dark, visually stark environment. As a result, it is important to determine if the time of day effect is because many warning signs are more useful at night or because these signs are more conspicuous at night. Nonetheless, the Shinar and Drory study confirmed Johansson and Backlund's conclusion that warning signs are not well remembered by drivers.

Luoma compared the validity of the intercept/recall method of measuring conspicuity with the eye glance tracking method.(33) In the study, recall was tested following a minimum delay (about 2 s) and following a delay comparable to that earlier intercept studies (mean = 49 s). A speed limit sign and an animal crossing warning were used. All signs were fixated on an average of 2.9 times, with a mean duration of 484 ms for each fixation. Independent of immediate or delayed recall, 94 percent of participants recalled the speed limit sign. However, recall of the animal crossing sign was less: 71 percent with immediate recall and 31 percent with delayed recall. This result appears to support the findings of Johansson and Backlund that signs regarded as important by drivers are more likely to be recalled. However, the results also suggest that recall of signs may not be indicative of sign conspicuity or perception. Luoma also measured speed changes in proximity to the signs. The speed limit sign was associated with substantial speed reduction (about 6 mi/h (10 km/h)) whether or not the speed limit sign was recalled. A much smaller speed reduction occurred with the animal crossing warning (about 1.2 mi/h (2 km/h)) whether or not the sign was recalled. There was no speed reduction in the control condition (no sign) at the same location.

Luoma's study cast doubt on all measures of conspicuity discussed to this point. Drivers may fixate on signs multiple times but not recall them. Furthermore, signs may result in measurable driver control responses, suggesting they were perceived at some level, yet drivers may not be able to verbalize the stimulus that triggered the responses. Luoma did not assess how long drivers maintained the lower speed upon passing a sign that they could not recall. Nor was he able to assess whether drivers who slowed in response to the animal warning sign would be more likely to detect an animal presence. It is also unclear if increasing the conspicuity of these signs to the point where they would be recalled would increase their effectiveness. These unknowns are candidates for future research.

Some research shows that signs are more conspicuous in environments with less clutter (e.g., residential areas, rural roads) than in highly built areas (e.g., business districts and industrial areas).(8,34) Obviously, signs are necessary in both low- and high-clutter areas. As such, guidance is needed on how to maximize the conspicuity of individual signs and to ensure that necessary messages are communicated to drivers. Increased size, careful selection of sign location, and added visual cues are all potentially effective strategies that have been used in isolated instances. The literature reviewed suggests that measures such as eye glance fixation, recall, and verbalization are all related to conspicuity, but none of the measures unambiguously indicate whether a TCD is conspicuous and correctly influences driver behavior.

Like the Luoma study, the present study employed an eye tracker and asked participants to recall TCDs within seconds after they were passed. In addition, a small number of participants were not asked about the TCDs so that the effect of asking for recall could be evaluated. The focus of the present study was speed limit and warning signs. The objectives of the study were as follows:

- Replicate the Luoma studies in an urban/suburban setting in the United States. (The Luoma studies were conducted in rural Finland.)
- Assess the influence of recall requests on glance behavior, a factor Luoma did not address.
- Assess whether trends in glance and recall could be related to the environment in which the sign is located.

The demands for signing in urban areas are quite different from those in rural areas, which makes the extension of earlier study findings to urban areas of interest.(35,36) The assessment of the effects of prompting drivers to recall signs could influence the design of future studies in which eye glances to signs are measured. If environmental influences on TCD conspicuity can be identified, guidance on TCD design and placement could be more specific.

METHOD

Participants drove a 34-mi (55-km) route that consisted of arterial roadways. These included two-lane roads and four-lane divided and undivided roads. A small early portion of the route was rural in character. The remainder of the route included residential, commercial, urban, and suburban areas.

At 21 locations along the route, participants were queried about a recently passed TCD. Generally, the queries came within 2 s of passing the TCD. In the case of crosswalks, the query came after the crosswalk in question could no longer be viewed in the rearview or side-view mirrors. The participants' gaze direction was obtained with a dashboard-mounted eye-tracking system. This approach enabled the researchers to correlate gazes to TCDs with subsequent recall of those TCDs. In addition, an attempt was made to characterize the visual environment of each TCD.

Participants

Prior to participation in the study, volunteers provided consent for motor vehicle departments in their States of residence to release their driving records. Only drivers with no recent violations on their records were asked to participate further. Twenty-six licensed drivers from the Washington, DC, metropolitan area (Maryland, northern Virginia, and the District of Columbia) provided usable data. Seven other drivers were recruited but did not complete the study either because they could not be calibrated to the eye tracker or because of data loss during the drive. All volunteers had at least 20/30 vision in both eyes as assessed with a Snellen eye chart. Of the 26 drivers that provided usable data, 10 were male and 16 were female. The mean age of the male drivers was 38 years (range 23–67), and the mean age of the female drivers was 36 years (range 23–55).

Equipment

The route was driven in a 2007 Jeep Grand Cherokee equipped with a Smart Eye eye-tracking system.(37) The eye-tracking system is vehicle-mounted (not head-mounted) and non-invasive to the driver. The system uses two infrared light-flashers and three dash-mounted infrared cameras to detect head and eye position. Eye position was sampled at 60 Hz. The dashboard installation is shown in figure 16. Three additional forward-view cameras were mounted on the vehicle roof directly above the driver's head. The view from these cameras was digitally recorded so that the direction of the driver's gaze could be overlaid in postprocessing on a 76° view of the road ahead. The external cameras recorded at 25 Hz.

Figure 16. Photo. Eye-tracking system with three dash-mounted cameras and two infrared flashers.

Procedures

After informed consent was obtained and visual screening was completed, participants were shown a map of the route and asked to rate their familiarity with each of 10 route segments on a 5-point scale, with 1 indicating "not at all familiar" and 5 indicating "very familiar." Participants were also shown pictures of regulatory signs (black and white signs), warning signs (yellow diamond signs), navigation signs (green and blue signs) and informational signs (blue signs). They were told that the researchers were interested in what drivers looked at while driving and that they might be asked questions about regulatory, warning, navigation, and informational signage, among other things. All participants were given these instructions; however, 9 of the 26 participants were not subsequently asked to recall any TCDs. These nine participants served as a control group to enable assessment of the effect of the recall requests on glance behavior. The primary goal of this on-road study was to observe the relationship between glances to TCDs and recall of those TCDs. The possibility that the limited number of queries to TCDs would cause participants to pay more attention to all TCDs was of secondary interest; this is why recall was requested of the first 17 participants. After it was determined that adequate data were obtained for the comparison of glance behavior with recall behavior, nine participants were asked to drive the same route without requests for recall so that the possibility of a priming effect could be assessed. Nine participants were sufficient to show a significant priming effect.

Participants were seated in the research vehicle so that the eye-tracking system could be calibrated. Calibration took 15–30 min. If the calibration was successful, the drive began, and the participant was reminded of the overall route to be taken.

During the drive, a researcher in the front seat provided turn-by-turn route guidance and queried the participant at the 21 locations listed in table 5. There were two planned stops along the route where participants could stretch their legs and the eye tracker was recalibrated.

Table 5 lists the TCDs for which glances and recall were tabulated. The TCDs of primary interest were speed limit and warning signs. When recall of speed limit signs was requested from participants, they were asked, “What is the speed limit?” Speed limit signs were only queried at locations where the speed limit had changed or where the speed limit sign was the first to be encountered on the current road. This was done to reduce uncertainty as to whether correct recall was of the last sign passed or some previous speed limit sign that the driver may have thought was the last sign passed (participants were not told that the signs being queried had been passed in the preceding 2 s). The roadway locations where queries were made did not differ markedly from the immediately preceding roadways so that contextual cues to the change in speed limit would be minimized.

Table 5. TCDs for which recall was requested and glances were tabulated.

Order	TCD	TCD Category
1	Deer warning sign	Symbolic warning sign
2	Crosswalk	Unmarked crosswalk
3	30 mi/h	Speed limit
4	Bicycle crossing	Symbolic warning sign
5	Crosswalk	Longitudinal line crosswalk marking
6	25 mi/h	Speed limit
7	25 mi/h	Speed limit
8	Harvard St.	Street name on mast arm
9	Parked vehicle ahead	Text warning sign
10	35 mi/h	Speed limit
11	Bridge ices before road	Text warning sign
12	Health Department	Information
13	40 mi/h	Speed limit
14	Slippery when wet	Symbolic warning sign
15	35 mi/h	Speed limit
16	Crosswalk	Longitudinal line crosswalk marking
17	35 mi/h	Speed limit
18	Blind pedestrian	Text warning sign
19	Electric/Railroad	Street names on mast arm (Electric Ave. on left, Railroad on right)
20	Crosswalk	Unmarked crosswalk
21	Disabled pedestrian	Symbolic warning sign

The request for recall of warning signs was, “What was the last warning sign that you passed?” Any response that indicated the target sign was recalled was accepted. This criterion was particularly important with respect to the slippery when wet warning as most participants did not know the intended meaning of the sign and gave responses, scored as correct, such as “curvy road ahead” and “skidding vehicles.”

Crosswalks were queried to provide a comparison with the Luoma study in which stop lines were targets, as well as to reduce potential priming of recall for speed limit and warning signs by increasing the uncertainty as to which roadway elements might be queried.(33) The request for crosswalk identification was, “Was there a marked crosswalk at the previous intersection?” If the answer was affirmative, the driver was asked to describe the crosswalk. Responses were scored as correct if the type of lines (e.g., transverse, longitudinal, ladder) were correctly described.

Identification of two roadway name signs and the one informational sign with the location of a Health Department office were also requested. The request for street names was, “What was the name of the street just passed?” Responses were scored as correct if they approximated the correct street name. For example, “Hayward” was scored as correct identification of “Harvard.”

A researcher in the back seat of the vehicle monitored the quality of the eye tracking. On some occasions, the researcher would request that the driver find a safe place to stop so that the eye tracker could be recalibrated. Following the initial calibration, recalibration was a brief procedure that required only about 1 min.

Following completion of the drive, participants were debriefed and reimbursed for their time.

RESULTS

Eye-Tracking Data Reduction

The eye glance data were analyzed with MAPPS™ software.(38) With this software, an analyst marked regions of interest (ROIs) on the road-ahead video captured from the roof-mounted cameras. Each target TCD was marked with an ROI from a point 240 ft (72 m) upstream of the TCD until the TCD passed out of video view. The marking was done with a drawing tool on individual video frames. Only a small fraction of the video frames needed to be marked because the software interpolated the ROI area on intervening frames. The analyst then verified the interpolation and inserted corrections as necessary. The ROIs around signs were drawn such that they included an area the width of the sign on each sign side. An example of an ROI is shown in figure 17. At a distance of 85 ft (26 m), the ROI halo surrounding a TCD represented approximately 2° of visual angle. In a moving vehicle environment, the accuracy of the eye-tracking system is limited to a radius of about 2° of visual angle. Thus, ROIs were drawn so as to capture glances within this margin of error about the TCD. In the case of crosswalks, this approach was problematic because vehicles ahead often occluded large parts of the crosswalk. Therefore, visible areas of crosswalks or visible areas where a crosswalk would be marked were circumscribed without including an additional border. The center of the green circle in figure 17 indicates the calculated gaze location for that frame. The analysis software used 60-Hz data, and the green circle location was calculated at 25 Hz. The green circle was not used in the data reduction process.

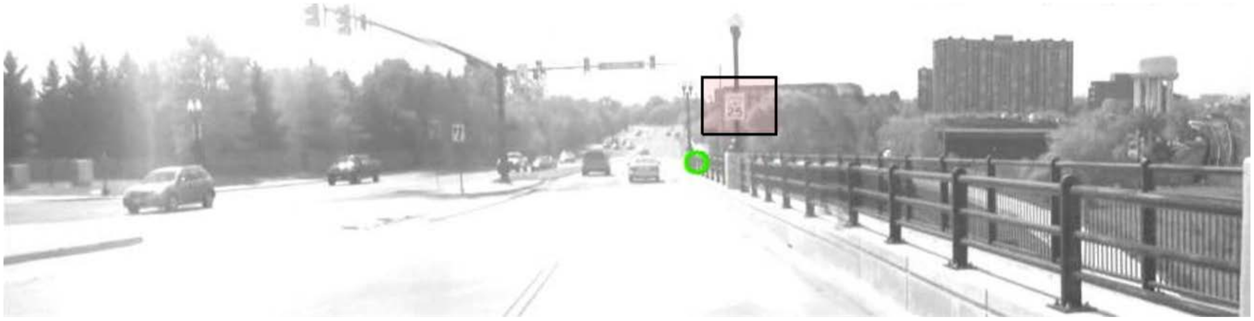


Figure 17. Photo. Analysis software ROI around a speed limit sign.

Because of the challenges of recording eye movements in a dynamic vehicle environment and because the eye tracker used in this study was limited to 60-Hz sampling, no attempt was made to identify eye fixations, saccades, or smooth pursuit movements. Rather, the location of direction of gaze in each 60-Hz sample was scored as either within or outside a marked ROI. If the sum of 60-Hz gazes (each frame representing 0.0167 s) on an ROI (whether continuous or not) exceeded 100 ms, then a *look* to the TCD within the ROI was recorded. Models of eye movement generally define five types of movement: saccades, microsaccades, fixations, smooth pursuits, and nystagmus. The many issues regarding the measurement of these movements are beyond the scope of the present report. Several books that deal with these issues are available, including one by Duchowski and another by Holmqvist et al.(39,40) The look or glance referred to in this report is the sum of the times between gaze-coordinate samples that fell within an ROI. This sum may have included portions of one or more fixations and the saccades between those fixations. As Holmqvist et al. point out, gaze locations represent points within a 0.0167-s interval, not the entire interval.(40) That is, any fixation may have started or ended any time within 0.0167 s. Most looks recorded in this study were the result of contiguous 0.0167-s intervals, and those that were not were separated by either missing data or coordinate locations that did not last more than two records (0.0334 s). Therefore, it is highly likely that these looks represented one or more physiological fixations. The minimum duration of fixations in visual tasks is open to some theoretical dispute and is likely task-related. Holmqvist et al. argue that the minimum duration is at least as small as 30 ms.(40)

Speed limit signs 6 and 7 in table 5 were actually a series of two signs. The ROIs for these signs moved from the first to the second sign as the first sign passed from view. In the case where a single ROI consisted of two signs, a look was recorded if the total of gazes to either or both signs exceeded the 100-ms criterion. Thus, these pairs of signs were treated as a single TCD in the glance and recall analyses. Figure 18 shows the ROI for the second speed limit sign that was paired with the sign depicted in figure 17. Speed limit sign 10 in table 5 also represents a series of two signs. However, the first of the pair was occluded by foliage so that it was not visible from 240 ft (73 m) upstream. Therefore, the upstream sign in that pair was marked as an ROI as soon as it became visible in the recorded video. Subsequent analysis revealed that this upstream sign never garnered a look. It was necessary to score these two pairs of signs as if they were one sign because the second sign of the pair was legible when the first sign was passed. Thus, the sign recall query would not represent a sign recall request until the second sign was out of view.

Figure 18. Photo. ROI shift from the first to the second sign in a sequence of speed limit signs.

TCD Recall

Initial analyses examined sign identification recall and included only those participants who were asked to identify the signs.

To enable easy comparison to the Luoma findings, table 6 shows the number of times that drivers correctly and incorrectly identified a TCD they had just passed as a function of whether the TCD had received a look.(33) Because some participants may have been familiar with some parts of the 34-mi (55-km) route, the sections that follow consider each TCD type as a function of familiarity as well as whether drivers looked at the TCD.

Table 6. Percent of TCDs of each type correctly and incorrectly identified as a function of whether drivers looked at them.

Recall	TCD Category	Look (percent)	No Look (percent)
Recalled	Symbolic warning	28	19
	Text warning	45	16
	Speed limit	43	38
	Unmarked crosswalk	38	18
	Longitudinal line crosswalk	39	12
	Street name	15	6
	Information	12	24
Not recalled	Symbolic warning	15	38
	Text warning	12	27
	Speed limit	8	10
	Unmarked crosswalk	21	24
	Longitudinal line crosswalk	33	15
	Street name	21	59
	Information	24	41

As in the Luoma study, there were a substantial number of cases of TCDs that were identified in the absence of looks as well as a substantial number of TCDs that were looked at but not correctly recalled only a few seconds later.(33) A *look* was defined as an eye glance dwelling on an ROI for a minimum of 100 ms. As discussed later in this report, it is possible to read TCD text and recognize symbols with near peripheral vision.(41) Therefore, it should not be assumed that TCDs that were not looked at by the current definition of a look were not seen or read. Of the 118 opportunities in the present study where warning and speed limit signs did not receive looks, 56 percent nonetheless resulted in correct sign identification. Of the 119 occasions where speed limit and warning signs received looks, 21 percent resulted in recall failure.

A generalized estimating equations (GEE) model was used to perform the statistical analyses discussed in the following sections. This type of model is appropriate for analysis of binomial data with repeated measures. Correct sign identification (0 or 1) was the binary response measure, and driver was the subject variable. For all analyses, the repeated measure was individual TCDs on the route. The Chi-square statistic is used to evaluate significance in GEE models.

Warning Signs

A preliminary analysis was conducted to determine whether there was a difference in warning sign recall as a function of sign type (i.e., a difference between text and symbol warning signs).

Variables in this preliminary analysis were whether the sign received a look, whether the drivers rated themselves familiar with the section of road where the sign was posted, and whether the sign contained text or a symbol. In this and all subsequent analyses, familiarity was reduced from five levels to two. Familiarity ratings of 1 or 2 were reclassified as unfamiliar (0) and ratings of 3, 4, or 5 were reclassified as familiar (1). Recall did not differ as a function of warning sign type, $\chi^2(1) = 0.01$, $p = 0.94$, nor were there any interactions with sign type. Therefore, the distinction between text and symbol warning signs was dropped in subsequent analyses.

Speed Limit and Warning Sign Recall

A GEE model was run in which the independent variables were sign type (speed limit or warning), whether the driver looked at the sign (yes or no), and whether the driver was familiar with the road segment on which the sign was located (yes or no). One of the 17 drivers was excluded from this analysis because familiarity ratings were not obtained from that driver. The statistical model was a full factorial (i.e., it included all three main effects and all interactions among the variables).

Warning signs were correctly identified about a third of the time when no looks to the signs were recorded. This was true despite the rather large area (about 2°) around each sign that was scored as a look to the sign.

The most striking finding was an interaction effect in which sign identification was good for speed limits regardless of whether the speed limit sign received a look, whereas warning sign recall was highly dependent on the sign receiving a look. This effect is shown in figure 19, where warning sign results are displayed in yellow and speed limit sign results are displayed in white. When drivers looked at the TCD, the identification difference between speed limit and warning signs was not significant ($p = 0.62$).

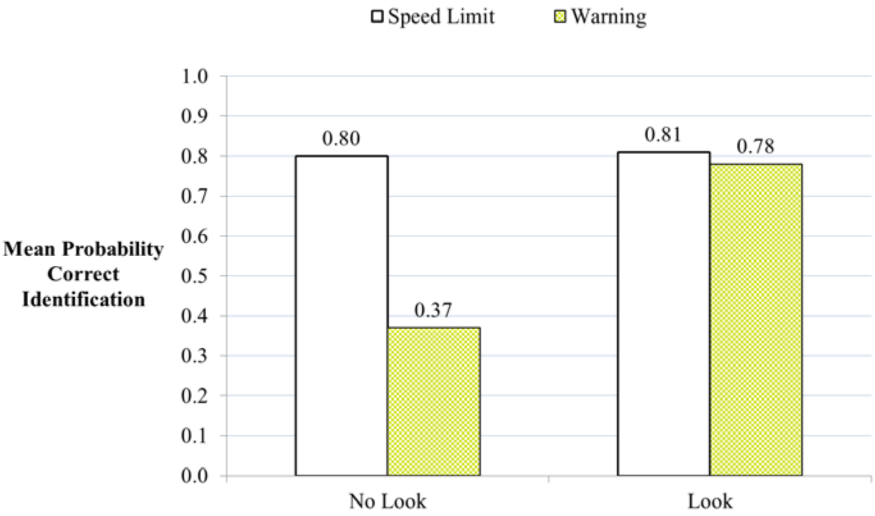


Figure 19. Graph. Probability of identification as a function of sign type and receiving a look.

Driver familiarity with the roadway segment had an interesting effect on sign recall. Recall of speed limit signs was reasonably high regardless of rated familiarity. However, recall of warning signs was better when drivers were unfamiliar with the roadway segment. This led to a two-way interaction between familiarity and sign type, $\chi^2(1) = 4.0$, $p = 0.046$, as shown in figure 20. This finding seems reasonable if drivers who are familiar with a roadway feel that they are familiar with the hazards and do not need to attend to warning signs. Drivers who are not familiar with the road may value hazard information more and therefore attend to these warning signs, thus facilitating later recall.

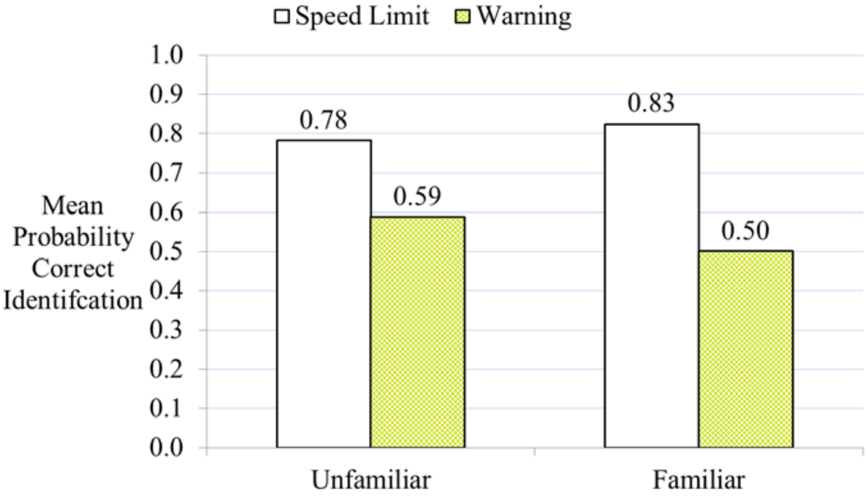


Figure 20. Graph. Probability of identification as a function of sign type and rated familiarity.

A notable finding not specifically related to conspicuity or glance behavior was that the slippery when wet sign, shown in figure 21, was not well comprehended by the participants. Of the 17 participants who were asked to identify this sign after it was passed, 12 "correctly" described it, but 8 of those 12 used descriptions such as "curvy road ahead" or "skidding vehicles ahead." Of the four participants who used the wording "slippery when wet," two were civil engineering interns who were likely to have had exposure to the sign in the course of their academic training. Table 7 summarizes identification response frequencies for the slippery when wet warning sign.

Figure 21. Illustration. Slippery when wet warning sign.

Table 7. Identification responses to the slippery when wet warning sign.

Response	Frequency
Curve, skid, etc.	8
Slippery when wet	4
Don't know	3
Other incorrect response	2

Probability of Look to Signs

Speed Limit and Warning Signs

Asking drivers to identify or recall a sign they just passed has the potential to prime drivers to search for highway signs. To assess the extent to which this type of priming affected glance behavior, nine participants drove the route but were not asked to identify signs. The probability of a glance to the target signs was then compared to the same probability from the 16 drivers that were asked to identify signs and had provided segment familiarity ratings.

Whether drivers were asked to identify signs (yes or no), familiarity with the road segment (yes or no), and the type of sign (warning or speed limit) were included as independent variables in a GEE analysis. The probability of a look to the sign as a function of the independent variables is shown in figure 22.

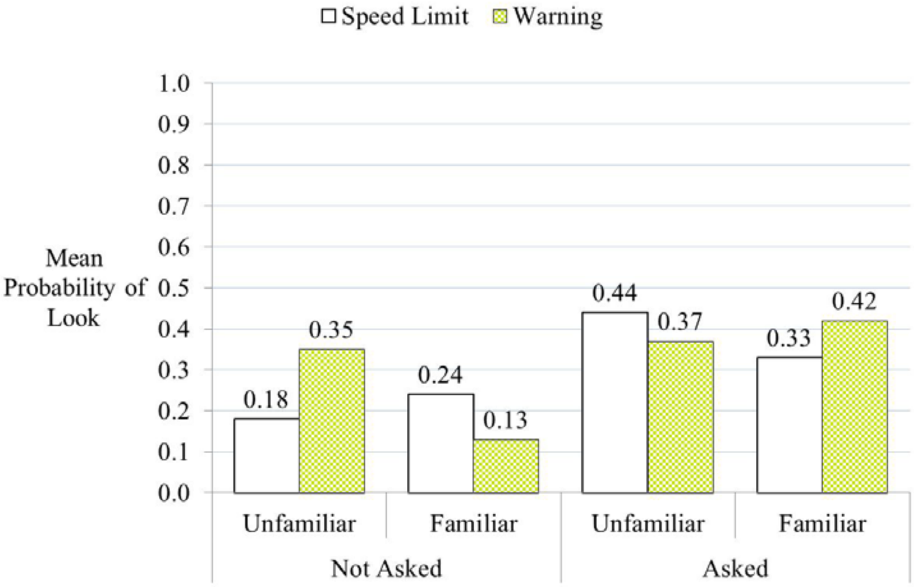


Figure 22. Graph. Probability of a look to a sign as a function of familiarity, sign type, and whether the driver was asked to identify signs.

There was a substantial and statistically significant priming effect, $\chi^2(1) = 8.2$, $p < 0.01$. Overall, participants were about twice as likely to look at a target sign when there was a possibility they might be asked to identify the sign. Nonetheless, the mean probability of looking at a target sign never exceeded 0.44. Priming was not consistent across conditions; there was a significant three-way interaction, $\chi^2(1) = 4.8$, $p = 0.03$. Drivers who were not being queried but were unfamiliar with a segment of road were about as likely to look at warning signs as drivers who were being queried. However, in the case of speed limit signs, a lack of familiarity was not associated with an increase in the probability of a look. Participants who were not asked to identify signs looked at about 20 percent of the speed limit signs.

When speed limits are reduced, many agencies repeat speed limit signs at relatively short distances, substantially less than the distance normally specified for separation where there is no change or an increase in speed limit.(42) The probability that the speed limit will be looked at and remembered was examined as a function of whether there was one speed limit sign or a sequence of two signs. In two areas where the 25-mi/h speed limit sign was repeated within 500 ft (153 m), the two signs were treated as one sign when scoring looks and recall; identification was requested after the second sign in the pair was passed. Looks and identification in those two areas were compared to two areas with 35-mi/h speed limit signs where looks and identification were scored for only one sign. The combined probability of a look to the speed limit increased when there were two signs, $\chi^2(1) = 7.1$, $p < 0.01$. With two signs, the probability of a look to at least one sign was 0.43, whereas with one sign, the probability of a look was 0.25. This is exactly the same result that would be obtained if the probability of a glance to either 25-mi/h sign was the same as the probability of a look to a 35-mi/h sign (i.e., $(0.25 + 0.25) - 0.25^2 = 0.437$). As in the previous analysis, the identification was high whether or not speed limit signs received looks. Mean probability of identification for the sign pair was 0.84 and for a single sign was 0.95. This difference was not significant ($p = 0.29$).

Crosswalks

The mean proportion of correct identification of whether crosswalks were marked or unmarked was 0.49. There were no significant differences in identification as a function of looks, marking type, or familiarity with the roadway segment.

Street Names

Because the street names that were queried were at cross streets where no navigation decisions were required, there was no explicit reason for drivers to attend to the street name signs. Correct identification of the street names varied only as a function of whether drivers looked at the sign, $\chi^2(1) = 4.4$, $p = 0.04$. If the sign received a look, identification probability was 0.42, whereas if the sign did not receive a look, identification probability was only 0.09.

DISCUSSION

There were numerous cases where drivers looked at TCDs yet failed to identify the TCD and many cases where TCDs were correctly identified in the absence of a look. This suggests that conspicuity measures that rely on either glance or recall alone are not adequate for evaluating the attention-getting qualities of TCDs.

Although 80 percent correct recall by drivers who glanced at speed limit and warning signs is impressive, unfamiliar drivers looked at only 35 percent of warning signs when not being queried and only slightly more when they might be asked to identify the signs. Overall, warning sign recall by both drivers familiar and unfamiliar with the roadway was about 50 percent. If it is assumed that recall of a warning sign reflects a driver’s need for the sign information, as argued by some researchers, then warning signs appear to have more perceived utility to drivers who are unfamiliar with roadway segments.(31,32)

The reason that warning signs were infrequently looked at or remembered cannot be determined from the present data. It could be that drivers were relying on other elements of roadway context and seldom felt the need to attend to warning signs. Alternatively, it could be that warning signs are difficult to attend to because of other demands on driver attention. This study cannot distinguish between these two circumstances or other explanations for failure to recall TCDs.

Drivers in the study were able to correctly identify the posted speed limit about 80 percent of the time regardless of whether the drivers looked at the speed limit sign or were familiar with the segment of roadway. There are at least two possibilities for this finding. One is that drivers do not need to fixate on speed limit signs to read them. Another possibility is that drivers are skilled at inferring speed limits from roadway context. The present research cannot distinguish between these two explanations. However, the sign identification conspicuity results presented later in this report suggest that speed limit signs can be read with 80 percent accuracy when the point of fixation is 9° away from the center of the sign and the sign subtends 2° of visual angle. Thus, there is evidence from a non-driving task that speed limits can be read in the absence of fixation.

Other studies have also reported that the slippery when wet warning sign is not well comprehended. Dewar, Kline, and Swanson found 44.6 percent recognition of this sign among drivers interviewed in Texas, Idaho, and Alberta, Canada.(43) Charlton reported similar comprehension difficulties with a similar international symbol sign.(44) A study conducted by the Texas Transportation Institute found only 62.5 percent comprehension of the slippery when wet sign among 747 participants who took a multiple-choice test.(45)

Participants in the present study were prompted to identify only a small proportion of signs along the 34-mi (55-km) route. This was done to minimize priming participants to pay special attention to signs. The selective sampling of signs for recall was not completely successful, as participants who were never prompted to identify signs were about half as likely to look at the target signs as participants who were prompted to identify signs. It is interesting that even when participants expected to be asked to identify signs, they glanced at less than half of the target TCDs. Although there were other demands on the driver's attention (e.g., other traffic, curves), the signs were visible to the driver for most or all of the last 240-ft (73.2-m) approach to the sign in all cases. In no case were the driving conditions such that safe opportunities to look at the signs were unavailable. If it is assumed that most, if not all, TCDs included in this study were intended to capture driver looks, then it might be concluded that these signs failed between 65 and 85 percent of the time. The present data do not warrant that conclusion. Only one of the warning signs indicated an existing hazard (i.e., parked vehicle ahead). The remaining warning signs were for occasional hazards that are usually not present (e.g., deer, ice on bridge). In these cases, the drivers may have realized that the warning was not intended for them and therefore elected not to look at or process the warning for future recall. Furthermore, Luoma has provided evidence that drivers respond to warnings by slowing even though the nature of the warning is not available for immediate recall.(33) The present data indicate that sign effectiveness evaluations need to go beyond glance and recall methodologies.

However, drivers in this study may have failed to look at TCDs because the TCDs lacked sufficient conspicuity to allow them to be reliably detected. The next study in this report specifically addresses the detectability of signs by measuring how far a person can focus his/her gaze away from a sign and still detect its presence.

SIGN DETECTION CONSPICUITY

Recently, Wertheim proposed a standardized and repeatable method of measuring conspicuity.(7) His method is based on the principle that conspicuity is not a property of the object but, rather, a property of the object and its environment. The measure combines the concepts of lateral masking and conspicuity, and it takes into account effects of environmental clutter on conspicuity. Wertheim's method, which expands on the work of Kooi and Toet, measures the extent to which individuals can divert their gaze from an object (i.e., the visual angle) and still detect the object or a property of the object.(46) For example, individuals might be asked to gradually move their fixation point away from a traffic signal until they can no longer detect its presence (detection method) or no longer identify the color of the signal indication (identification method).

Although Wertheim describes this method as standardized and repeatable and even suggests it could be used by agencies to regulate conspicuity, it is a psychophysical method that requires human observers as a critical instrument in the measurement procedure. Thus, the measurements are subject to individual differences in visual capabilities and may be subject to response bias. In addition, Wertheim describes three different implementations of the method that use different devices to measure the gaze diversion angle. While the results of each of these implementations are correlated, each yields significantly different conspicuity angles. Although the various methods yield different angles for the same stimulus, they all appear to yield results that are at least ordinal when ranking the conspicuity of different stimuli.

Wertheim has only applied his approach in a field setting, where conspicuity is assessed in the actual environments of the stimuli. Testing of TCD conspicuity in a laboratory environment is desirable because of the challenges involved in testing traffic signs in their natural environment. To use Wertheim's method to evaluate the conspicuity of a warning sign, observers would need to be positioned in a roadway traffic lane and gradually move their gaze away from the sign until it could not be detected. This would be a difficult and dangerous task in the presence of traffic. Therefore, a variation of the approach was developed that might be applied to TCDs in a laboratory setting and was validated by field observations that closely followed one of Wertheim's methods.

In the field, Wertheim's approach was implemented by asking participants to gradually shift their gaze away from actual signs in a daylight environment until they could no longer detect the presence of the signs. The laboratory approach used a staircase modification of the method of limits to approximate Wertheim's method with photographs of the TCD stimuli and environment.

In the modified laboratory application of Wertheim's methodology, panoramas 1 and 3 from the MDS classification were projected onto a screen for detection angle measurements (see figure 1 and figure 3). In addition, two panoramas of the environments used for the outdoor daylight assessments were used in the laboratory to enable direct comparison of the alternative approaches.

METHOD

Three signs served as detection targets in both the laboratory and outdoor environments: a speed limit sign (MUTCD, R2-1), a yellow pedestrian crossing warning sign (W11-2), and a fluorescent yellow-green pedestrian warning sign (W11-2).(36)

In the laboratory, the signs were presented against four backgrounds: an urban roadway scene (figure 1), a suburban background (figure 3), a copse (figure 23 and figure 24), and a parking lot (figure 25 and figure 26). In the outdoor environment, the actual copse and parking lot used in the laboratory projections served as backdrops for detection of physical signs.

Figure 23. Photo. Copse background without speed limit sign.

Figure 24. Photo. Copse background with speed limit sign.

Figure 25. Photo. Parking lot background without speed limit sign.

Figure 26. Photo. Parking lot background with speed limit sign.

Participants

The same 13 individuals participated in the outdoor and laboratory measurements. There were seven female participants (mean age 31 years, range 19–56) and six males participants (mean age 47 years, range 30–67). All participants were licensed drivers with corrected foveal visual-acuity in each eye of 20/30 or better. Seven participants completed the laboratory task first and six completed the outdoor task first.

Outdoor Procedure

A 36-inch (0.9-m)-tall speed limit sign and two 36-inch (0.9-m) pedestrian warning signs, one yellow and one fluorescent yellow-green, served as stimuli. Participants stood 85 ft (26 m) from a sign that was placed as shown in figure 24 and figure 26. Participants were instructed to point to the sign and then slowly point away, leftward, while gazing where they were pointing. They were to continue to move their gaze and point until they could no longer detect the sign in their peripheral vision. At that point, participants were asked to remember the location they were pointing when the sign was no longer detectable and rotate a compass pointer until it was aligned with that location. A researcher recorded the compass deflection angle and returned the pointer to zero. The procedure was then repeated two additional times with the same sign. This process was repeated with the other two signs for a total of nine trials.

Each participant completed the nine-trial procedure twice, once with the copse in the background and once with the parking lot in the background. The order of testing of signs and backgrounds was fully counterbalanced across 12 participants. However, one additional participant was tested and because no order effects were evident, the data for all 13 participants were included in the analyses.

Outdoor Stimuli

Photometric measurements were taken of the outdoor stimuli. The photometric measurements were made only once. Thus, because of varying times of participant testing and varying cloud cover, the measurements presented are intended only as estimates of the lighting conditions. These measurements also enable a rough comparison between the outdoor and laboratory lighting conditions. The laboratory measurements are reported in the next section. All measurements were taken from the location where participants stood when making conspicuity judgments.

Luminance measurements were made with a Konica Minolta CS-2000 Spectroradiometer. The white portion of the speed limit sign measured 555 fl (1,900 cd/m^2) and 849 fl (2,910 cd/m^2) with the copse and parking lot backgrounds, respectively. Average luminance of the areas to the right and left of the signs (0.2° aperture) measured 107 fl (366 cd/m^2) and 262 fl (899 cd/m^2) with copse and parking lot backgrounds, respectively. Although the speed limit sign had positive contrast with the parking lot background according to these measures, specular reflections from nearby car windows exceeded 84,067 fl (288,000 cd/m^2). As such, contrast ratios with the parking lot could vary greatly depending on cloud cover and slight adjustments in the photometer settings.

The yellow portion of the yellow pedestrian warning sign averaged 292 fl (999 cd/m^2) and 389 fl (1,331 cd/m^2) with the copse and parking lot backgrounds, respectively. The fluorescent yellow portion of the fluorescent yellow-green pedestrian warning sign averaged 813 fl (2,786 cd/m^2) and 1,186 fl (4,063 cd/m^2) with the copse and parking lot backgrounds, respectively. Readings to the left and right of the warning signs were similar to those for the speed limit sign.

Laboratory Procedure

Participants were seated in a driving simulator cab and viewed images projected on a cylindrical screen. In each trial, participants were presented with one of the four panoramic backgrounds. The TCDs in the original photographs had been removed from the panoramas. In half of the trials, a sign was present at the location where the target TCD had been in the original photographs. The background-alone image or background-plus-sign image was presented for 0.1 s. The participant's task was to indicate whether or not the sign was present. The difficulty of this discrimination was controlled by varying where the participant was instructed to look before each scene was projected.

The FHWA's Highway Driving Simulator was used to project the static stimuli. The simulator's screen is cylindrical, with a radius of 8.9 ft (2.7 m). Directly in front of the driver, the design eye point of the simulator is 9.5 ft (2.9 m) from the screen. The stimuli were projected onto the screen by five Barco projectors, each of which displays 2,048 horizontal by 1,536 vertical pixels. Because the projection system covered 240° and the panoramic stimuli covered only about 120°, the outside projectors displayed horizontally reversed images of the left and right images of the panoramas. The reversed images could only be viewed through the side windows of the vehicle cab.

A 3-ft (0.9-m)-wide sign at a distance of 85 ft (26 m) subtends a visual angle of approximately 2°. The speed limit signs in this experiment were 4 inches (10 cm) high when projected onto the screen, which yielded a sign that subtended 2° of visual angle from top to bottom. The speed limit numerals subtended the same visual angle as would 12-inch (30.5-cm)-high numerals viewed from a distance of 85 ft (26 m). The speed limit sign used the standard FHWA series E font.(47) Measured on the diagonal, the warning signs were 4.5 inches (11.4 cm) wide on the screen and subtended a visual angle of 2.3°. Letters on these signs subtended the same visual angle as would 4.7-inch (11.9-cm) letters when viewed from a distance of 85 ft (26 m). The warning signs used the standard FHWA series C font.(47)

The average luminance of the white portion of the speed limit sign measured with a 0.2° aperture was 2.3 fl (7.8 cd/m^2). The mean luminance of the black characters on the sign measured with a 0.1° aperture was 0.1 fl (0.5 cd/m^2). The mean luminance of the yellow areas on the yellow warning sign measured with a 0.2° aperture was 2 fl (6.8 cd/m^2), and the luminance of the black areas measured with a 0.1° aperture was 0.1 fl (0.5 cd/m^2). The luminance of areas immediately to the left and right of the signs ranged from 0.1 to 0.7 fl (0.5 to 2.4 cd/m^2) and averaged 0.4 fl (1.2 cd/m^2).

Method of Limits

Each trial consisted of a 1-s presentation of a fixation cross in a gray field followed by the presentation of a stimulus scene for 0.1 s. The stimulus scene was followed by a gray field that remained until the next trial was initiated. The gray fields filled the entire horizontal 240° of the projection screen. Each sign (speed limit, yellow warning, and yellow-green warning) was tested in separate sessions. Each session was about 12 min in duration. Within sessions, trials were in blocks of 16. Within blocks, each of the four backgrounds was presented four times, twice with the sign present and twice with the sign absent. Within each block, the presentation order of backgrounds was random, with the restriction that each background occurred four times. Participants pressed the right key on a remote control device to indicate that the sign was present or the left key to indicate that it was absent. A press of either key initiated the next trial.

A staircase variation of the method of limits was used to arrive at the critical conspicuity detection angle for each sign with each background.(48) At the end of each block of 16 trials, the offset of the fixation cross from the sign location was incremented up or down by 3°. For each background, the direction of the increment depended on participant performance in the preceding block. If the participant was correct concerning sign presence (or absence) on all four trials with a background, then the offset for that background was incremented by +3°. If an error was made on one or more trials (e.g., the participant indicated the sign was present when it was not or vice versa), then the offset for that background was incremented by -3°. Testing continued in this manner until the direction of the increment had reversed a minimum of five times with each background. The critical angle for detection of the sign in each background was then computed using values of offset angles when the direction of increments had been reversed. The first reversal was not included in the computation as it is more dependent than later trials on the angle at which testing began. Thus, for each background, the critical conspicuity angle for detection was based on at least four reversals. Because testing continued on all backgrounds until the criterion of five reversals was reached for all backgrounds, scores could be based on more than four reversals. The critical angle computation averaged the angle for which an error was made on trials following offset increases and the angle for which correct responses were made on trials following offset decreases. The staircase method provided an estimate of the angle at which a participant will be correct on four trials 50 percent of the time. Table 8 provides an example of how the critical conspicuity angle was computed for one sign-background combination, a fluorescent yellow-green warning sign in an urban background. In this example, there were six reversals rather than five because testing was done in blocks of 16 trials and the participant required more trials to reach five reversals with one of the other backgrounds. The purpose of continuing to test with backgrounds for which the criterion had been reached was to keep the background uncertainty constant and thereby maintain task difficulty.

Table 8. Example critical detection conspicuity angle computation for one participant.

Offset Angle	4 Correct Responses?	Score	Explanation
27	Yes		Start
30	No		First reversal excluded from scoring
27	No		
24	Yes	24	Reversal
27	Yes		
30	Yes		
33	No	33	Reversal
30	Yes	30	Reversal
33	No	33	Reversal
30	No		
27	No		
24	Yes	24	Reversal
Mean		**28.8**	

Blank cells indicate no score was recorded.

For two backgrounds, the offset angle for the first block of 16 trials was 27°. For the remaining two backgrounds, the starting offset angle was 45°. The starting angle for each background was counterbalanced across participants.

Laboratory Instructions

Participants were told that a fixation cross would appear on the screen before each trial. They were instructed to turn their head toward the cross and focus their eyes on it. They were told that the cross would be on the screen for about 1 s, after which a roadway scene would be presented for a fraction of a second. A picture of the sign was provided. If the sign was there, they were to press the right key on a small remote control. If they sign was not there, they were to press the left key. They were instructed to guess when unsure. They were told that the next trial would start shortly after a key was pressed. Participants were implored to "… always keep your gaze at the location of the fixation cross. Do not shift your gaze to the … sign. We are interested in finding how far away from people's gaze point a sign can be and still be detected. Shifting your gaze to the sign will defeat the purpose of this test. Therefore, keep your eyes fixated wherever the cross appears."

RESULTS

Outdoors

The mean offset detection angles from the outdoor procedure are shown in figure 27, where the error bars represent 95 percent confidence limits of the means. The sign-background interaction was significant, $F(2,11) = 9.9$, $p < 0.01$, $\eta_p^2 = 0.64$. The interaction was the result of the fluorescent yellow-green sign having a significantly greater detection angle than the yellow sign, regardless of background, $F(1,12) = 11.3$, $p < 0.01$, $\eta_p^2 = 0.48$, whereas the speed limit sign was only less conspicuous than the fluorescent yellow-green sign with the parking lot as a background, $F(1,12) = 8.1$, $p = 0.02$, $\eta_p^2 = 0.40$, but not with the copse background ($p = 0.15$). The main effect of background was not significant ($p = 0.08$). The main effect of sign was significant ($p = 0.04$).

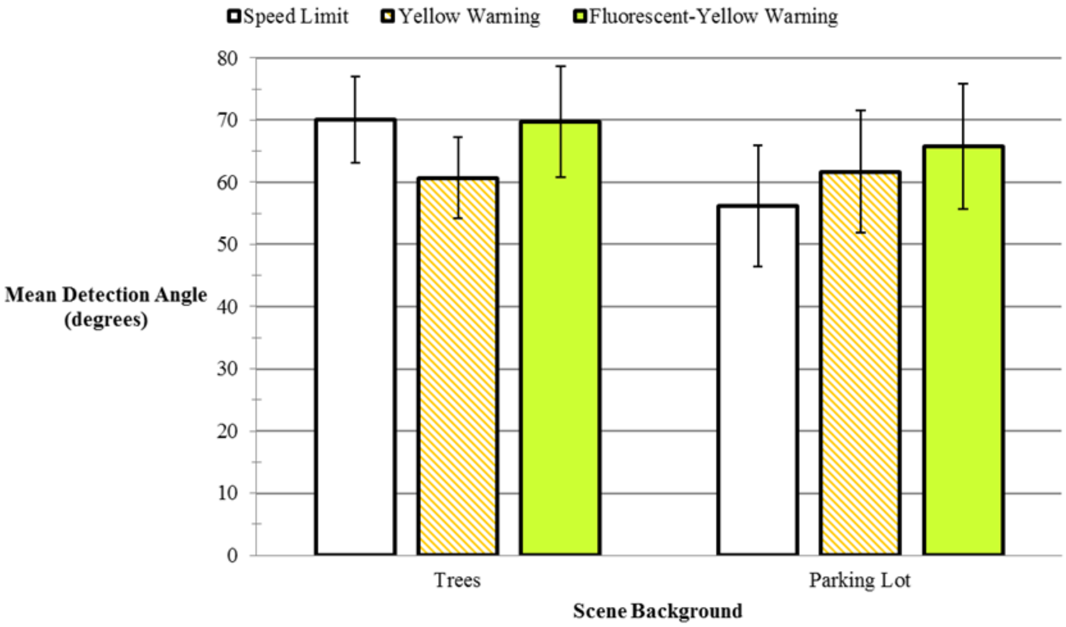
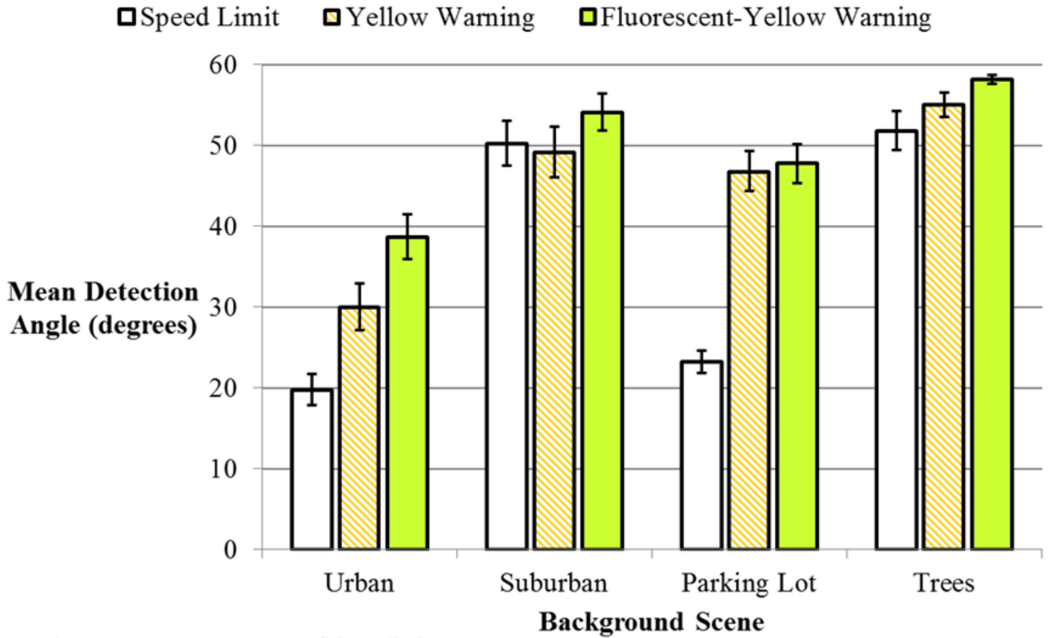


Figure 27. Graph. Mean detection offset angles measured outdoors.

Laboratory

The mean detection angles of the three signs with the four backgrounds are shown in figure 28. Error bars in the figure represent 95 percent confidence limits of the means. The maximum measureable angle was 60°. Beyond 60°, the A-pillar of the vehicle cab obstructed the screen. As a result, there was a ceiling effect that had the greatest influence on the conspicuity angle of the warning signs when presented with the suburban and copse backgrounds. In several cases, participants reached the 60° ceiling with few or no reversals. In such cases, the session was terminated before the criterion of five reversals was reached and the conspicuity angle was recorded as 60°. Despite this limitation, clear differences in detection conspicuity were obtained both for sign type and background. A reduction in standard error as a result of the ceiling is clearly shown in the confidence limits for the fluorescent yellow-green warning sign with the copse background.



Error bars represent 95 percent confidence limits.

Figure 28. Graph. Mean critical detection conspicuity angles measured in the laboratory.

Using repeated measures analysis of variance, the sign by background interaction was significant, $F(6,6) = 11.3$, $p < 0.005$, $\eta_p^2 = 0.92$, as were the main effects of sign type, $F(2,10) = 47.7$, $p < 0.001$, $\eta_p^2 = 0.91$, and background, $F(3,9) = 116.1$, $p < 0.001$, $\eta_p^2 = 0.98$. These effects are shown in figure 28. The mean detection angle with the copse background (54°) was significantly greater than those of the urban (29°) and parking lot (39°) backgrounds but was not significantly different from the mean detection angle with the suburban background (51°). The mean detection angle of the fluorescent yellow-green sign (50°) was significantly greater than that of the speed limit sign (36°), $F(1,11) = 74.5$, $p < 0.001$, $\eta_p^2 = 0.87$, and that of the yellow warning sign (45°), $F(1,11) = 5.2$, $p = 0.04$, $\eta_p^2 = 0.80$.

The interaction of sign and background can be traced to the comparison of the speed limit sign with the fluorescent yellow-green sign. In those comparisons, the interaction is significant when the urban environment is compared to the copse, $F(1,11) = 14.8$, $p < 0.01$, and when the parking lot is compared with the copse, $F(1,11) = 14.6$, $p < 0.01$, but not for the comparison of the suburban environment with the copse (*p* = 0.46). When yellow and fluorescent yellow-green comparisons are considered, all interactions with background are non-significant (*p* > 0.10). With the suburban and copse backgrounds, the differences in detection angle between sign types were not significant (*p* = 0.07), nor was there a significant difference in detection angle between those backgrounds (*p* = 0.09).

DISCUSSION

Signs must be detected before they are processed. This experiment showed that, in natural environments, speed limit and warning signs can be detected at angles of 60° or more from the point of gaze. In low contrast environments, such as those in the laboratory, the detection angles were still substantial—over 50° with an uncluttered background that provided reasonable color contrast. With busy or cluttered backgrounds and little contrasting color or luminance (e.g., speed limit sign with parking lot background), the detection angle is substantially reduced. Notably, Cole and Jenkins also reported that regulatory signs were less conspicuous than other colored signs used in their study.(2)

The 20° detection angle for the speed limit sign in the laboratory was obtained when participants were actively monitoring for sign presence. In a real-world context in which drivers are not actively searching for speed limits or warnings, it is reasonable to assume that detection angles would be considerably less than those observed. Nonetheless, the findings are relevant to real-world signing. If a warning or speed limit message is important to communicate, then consideration of factors that maximize the probability of detection are also important. The present findings suggest that the environment around signs affects their detection conspicuity. The speed limit sign stood out against backgrounds of leafy green trees but was much less conspicuous against a background of cars, pavement, advertising signs, and other objects. With light-colored surrounds, strong consideration should be given to making speed limit signs, and perhaps other regulatory signs, more conspicuous. The results do not suggest how this should be done, but two common approaches are to make the signs larger or to use a conspicuous contrasting border. Given the superior detection conspicuity of fluorescent yellow-green signs, perhaps fluorescent yellow should be considered as a candidate for enhancing speed limit sign conspicuity. The 2009 MUTCD provides for a yellow notice plaque (W16-18P) that might increase speed limit sign conspicuity.(36) Given the study's results, it would seem that this plaque should be seriously considered wherever the surrounding environment provides poor contrast with the speed limit sign.

The fluorescent yellow-green warning sign was less sensitive to background clutter perhaps because its color contrasted with all the backgrounds used. Had nearby elements in the scenes been similar to the yellow-green color, the sign may have suffered detection degradation. It should be noted that because they fluoresce in natural light, fluorescent yellow-green signs have greater luminance than standard yellow signs. This may have contributed to the slight advantage the fluorescent sign had in the outdoor detection test. However, in the laboratory the detection test, fluorescence was not a factor. Nonetheless, the yellow-green color was 14 percent greater in luminance than the standard yellow color.

Color is an important visual property, even in peripheral vision. Although it has been reported that color perception is absent beyond 40°, more recent research has shown that, for relatively large targets, opponent cone color perception is retained to at least 50°.(49,50)

This study demonstrated that the angle away from the point of gaze is an important consideration in the detection of signs, especially black-on-white regulatory signs in light-colored and cluttered background environments. This has important implications for the placement of these signs. On wide roadways, such as 8- or 10-lane interstates, speed limit signs 12 ft (3.7 m) or more to the right of the travel way may not attract drivers' attention. Near intersections, a common placement for speed limit signs and roadside regulatory signs may be far from the gaze point of drivers making turning movements. In the case of wide roadways, conspicuity enhancement should be considered. In the case of intersections, consideration should be given to midblock placement of speed limit signs and conspicuity enhancement should be considered for turn restriction signage.

The specific objectives of the conspicuity detection experiment were to determine how close to the direction of gaze signs need to be for their presence to be detected and whether laboratory methods are sufficient for assessing conspicuity angles. The results suggest when the observer's only task is to detect sign presence, speed limit and warning signs are detectable at any angle a driver is likely to encounter them. The exceptions to this may be signs placed at intersections or other locations where the driver's focus of attention is more than 20–40° away from the location of the sign and where other the demands on attention are high. The results also suggest that Wertheim's conspicuity angle measurement techniques can be adapted to the laboratory and provide interpretable results even when the contrast ratio between signs and surrounds is orders of magnitude less than in a natural environment.(7) Shape and color of backgrounds, rather than the magnitude of contrast ratios, seem to be determining factors in TCD detectability, at least with the ranges of contrast examined in this study.

It was found that signs are detectable at large angles of offset from the direction of gaze. However, in the on-road field study, drivers were reporting the content of signs that glance data indicated they had not looked at directly. To confirm that drivers can read signs they do not look at directly, the laboratory experiment reported next was performed. In the following experiment, the off-axis angle at which signs can be read was explored.

SIGN IDENTIFICATION CONSPICUITY

In the glance behavior and sign recall study, drivers were asked to identify speed limit and warning signs about 2 s after the signs were passed. It was found that 24.3 percent of the time drivers could not identify signs that they had just gazed at but correctly identified 53.3 percent of the signs they had not looked at directly. It is possible that some signs that had not received looks were guessed from the roadway context. However, the selection of signs queried was biased toward signs for which contextual cues would be minimal. For instance, the most common warning sign, the pedestrian crossing sign, was not included, and non-standard warning signs (e.g., parked vehicle ahead) were included. Speed limit signs were only queried after a change in speed limit or on a new road, so recall of previous speed limit signs was probably not a factor in speed limit recall. Reduced speed ahead signs did not precede any of the targeted speed limit signs. In most cases, there were no marked changes in roadway environment in proximity to the speed limit signs.

Only the central 2° of vision, foveal vision, provide resolution sharp enough for reading or recognizing fine detail.(41) Useful information for reading can be extracted from parafoveal vision, which encompasses the central 10° of vision.(41) Rayner et al. suggest that foveal vision encompasses 6–8 characters of normal-size printed text.(41) They presented sentences to participants and used an eye tracker to move a mask and hide the portion of the sentence around the participant’s fixation point. When the mask covered the width of 17 characters of text, participants were still able to read text at the edges of the mask, albeit at a rate of only about 10 words per minute. The text not hidden by the mask was in the participants’ peripheral vision. Thus, drivers might be able to read traffic signs, which generally have large symbols or letters, without fixing their gaze on them. As with sign detection, the surrounding environment may affect the ability to read the sign. The objective of the present study was to measure off-axis sign-reading ability in the context of various surrounds. The fixation point offset from the signs was varied from 0 to 15° in the context of five backgrounds used in the MDS classification study.

In a Finnish study, peripheral perception of traffic signs was examined for offsets from a fixation point of 10–80°.(51) Perception of sign color and shape was examined in addition to sign identification. Color and shape perception was accurate to about 50°. Sign identification was relatively accurate at 20°, but most of the signs used were easily distinguished from each other based on shape or color differences. Discrimination at 20° was essentially chance when the identification relied on reading text or distinguishing between symbols on otherwise identical signs. The study did not assess whether drivers could distinguish speed limits or text warnings in parafoveal or peripheral vision.

For signs that subtended 4° of visual angle, Karttunen and Hakkinen found no effect of background scene on peripheral sign perception.(51) However, the authors did find that the inclusion of signs above and below the target sign diminished correct perception of the target sign. This suggests that similar signs located close to a target reduce identifiability. Such an effect is known as *crowding*.(52) Crowding was not the focus of the present study, which instead focused on the effect of the broader environment in which signs are located rather that the local effects of clutter in the immediate surrounds.

In the experiment reported here, signs embedded in various roadway backgrounds were projected onto a screen. The visual angle between the signs and the participant's fixation point was varied. The dependent measure was identification of the signs' messages. Speed limit and text-based warning signs were used. Given the results of the glance behavior and sign recall study, it was hypothesized that both types of messages would be readable at substantial off-axis angles. The findings of Rayner et al. suggested that sign reading may occur with glance offset up to 10°.(41)

METHOD

The same driving simulator was used in the same manner as in the sign detection conspicuity study.

Stimuli

The following TCDs were used:

- Five speed limit signs (R2-1) with limits of 25, 30, 35, 40, and 45 mi/h.
- Five text-based warning signs: loose gravel (W8-7), rough road (W8-8), low shoulder (W8-9), uneven lanes (W8-11), and fallen rocks (W8-14).

Each TCD was presented in each of six roadway contexts. These contexts or scenes served as an independent variable. The scenes were the six panoramas shown in figure 1 through figure 6. Each scene was composed of three photographs stitched together to form a panorama of about 120°. The center photograph in the panorama was always aligned with the roadway and centered on a point in the right through lane somewhat beyond the TCD location. In some locations, there was an acceleration or deceleration lane to the right of the through lane.

Sign stimuli used in this experiment were presented within the panoramic highway scenes at locations on the right side of the road, where such signs might be expected and where an actual TCD 85 ft (26 m) from of the camera had been present in the original photographs.

Procedures

Speed limit and warning sign identification was tested in separate blocks of 240 trials. The order of blocks was counterbalanced across participants. Each trial began with the presentation of a fixation cross that subtended 2° of visual angle on a gray background. The fixation cross was displayed for 1 s. The cross was followed by a panoramic scene that was displayed for 0.15 s. The panoramic scene was followed by a gray background.

The fixation cross was vertically aligned with the target sign in the subsequent scene. The horizontal offset of the fixation cross from the location of the target TCD was varied randomly from trial to trial. Each participant received a different random order of scenes, offsets, and signs. Offsets of -9, -6, 0, 3, 6, 9, 12, and 15° were used. The target signs were all on the right side of the road, and the photographs were centered on the roadway at a point beyond the signs. Scene factors such as lane width and horizontal and vertical curvature resulted in shifts in screen location of signs as a function of scene. Figure 29 provides an example of where the fixation cross was positioned relative to a target sign. The horizontal line illustrates the vertical positioning of the fixation cross. Five of the eight offset angles are labeled in the figure.

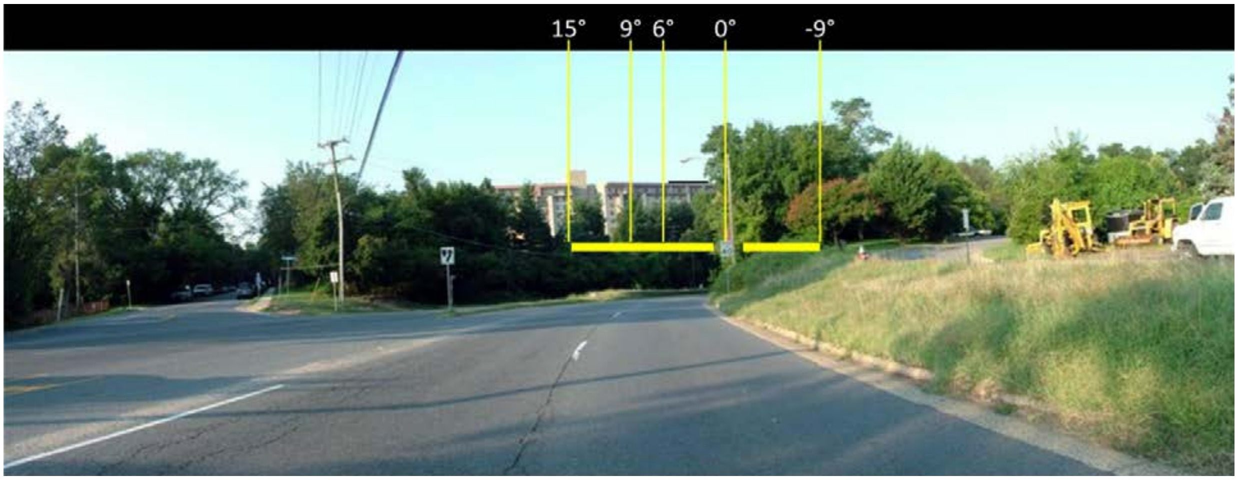


Figure 29. Photo. Illustration of the locations of fixation crosses relative to a target sign.

Participants were provided short breaks every 80 trials. Five practice trials preceded each block of 240 trials, one practice trial with each sign. The practice trials all had a 0° offset. The background scene for the practice trials was not one of the six scenes used on test trials but was created in the same manner as those scenes.

Participants

Twelve individuals were tested. Nine were male, and three were female. The mean participant age was 35 years (range 27–50). All participants were licensed drivers and had 20/30 or better foveal visual acuity (with correction if necessary) in each eye.

Instructions

Participants were instructed, "We are interested in how far a sign can be from the point of gaze and still be read." They were asked to turn their head and gaze toward the fixation cross and to keep their gaze at the cross's location even when the roadway scene appeared. Participants were urged, "Remember, always keep your eyes fixed on the location of the cross. Do not shift your gaze to the sign." Participants were informed of the type of signs to be presented in the upcoming block (i.e., speed limit or warning signs) and shown an array of pictures of the five signs in that block. They were asked to call out the speed limit or text on the sign as soon as possible after the sign appeared.

RESULTS

The proportion of correct sign identifications was analyzed as a function of sign type (speed limits or warnings), background scene (six scenes), and degree of offset of the fixation point from the signs (eight offsets). A 2 (sign type) by 6 (scene) by 8 (offset) repeated measures analysis of variance was used. The proportion correct for speed limit signs was computed by averaging 1 (correct) and 0 (error) values over the five speed limit signs. Likewise, the proportion correct for warning signs was computed by averaging 1 and 0 values for the five warnings. Thus, each participant provided 48 data points. An arcsine transformation was performed on the proportion correct before performing the analysis of variance.(53) This transformation resulted in a distribution of scores that better met the analysis of variance normality assumption. Partial eta squared values were calculated to indicate effect size.

As shown in figure 30, speed limit identification performance was superior to warning sign identification performance, $F(1,11) = 221.2$, $p < 0.001$, $\eta_p^2 = 0.95$. Identification performance for both sign types decreased as the angle away from the fixation point increased, $F(1,11) = 35.8$, $p < 0.001$, $\eta_p^2 = 0.77$.

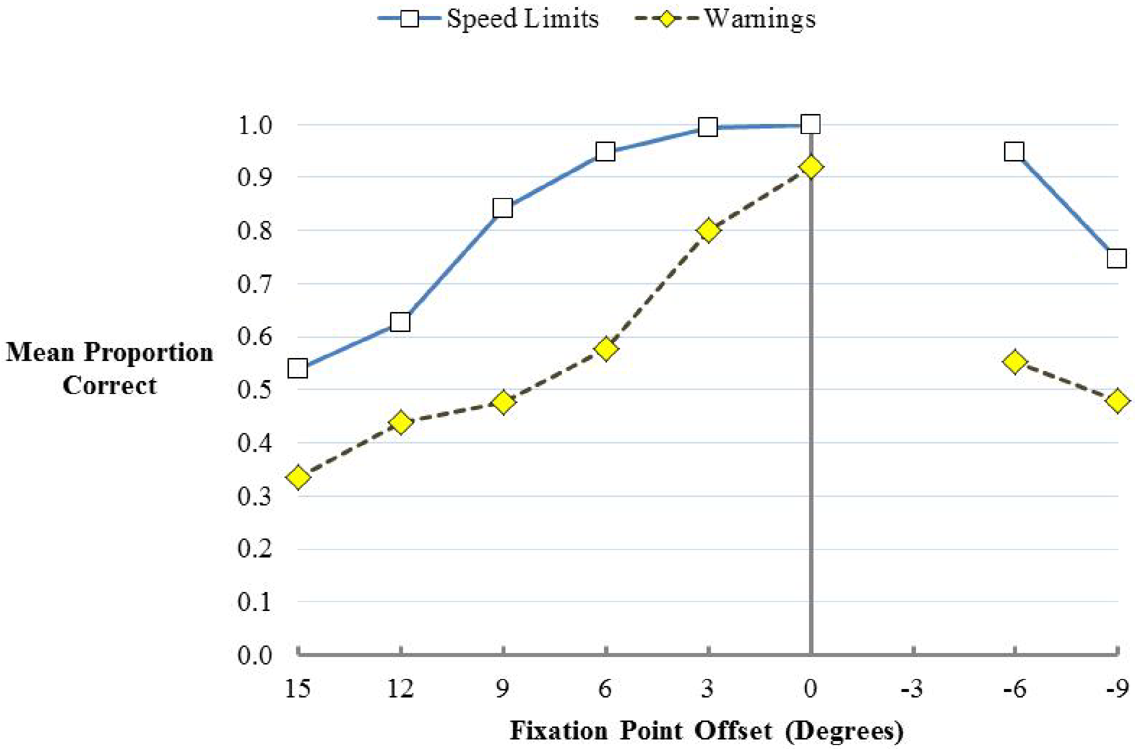


Figure 30. Graph. Proportion of correct sign identification responses as a function of fixation point offset and sign type.

There was an interaction between sign type and scene background, $F(5,55) = 2.9$, $p = 0.04$, $\eta_p^2 = 0.21$, that resulted because background scene had a significant effect on warning sign identification, $F(5,55) = 2.9$, $p = 0.03$, $\eta_p^2 = 0.24$, but not on speed limit sign identification ($p = 0.11$). These effects are shown in figure 31, where error bars represent standard errors. Post-hoc paired comparisons showed that warning sign identification with scene 3 was significantly better than with scenes 2 and 4 ($p < 0.01$) and that performance with scene 5 was marginally superior to that in scene 4 ($p = 0.04$). No other paired comparisons yielded statistically significant performance differences.

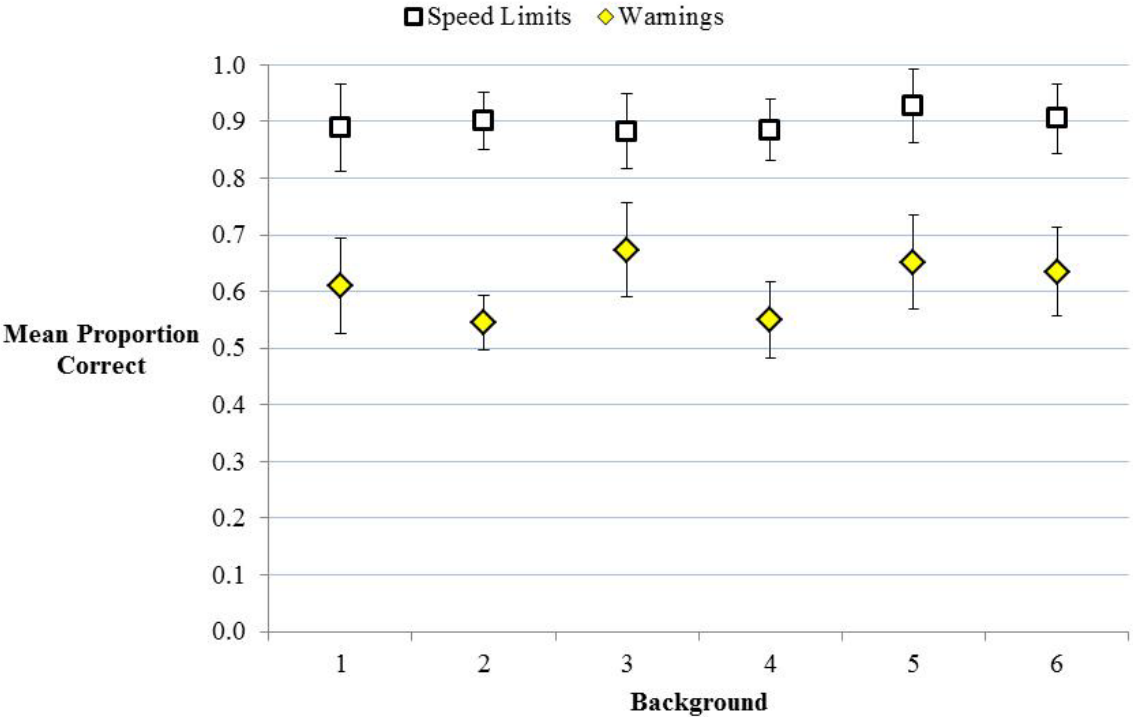


Figure 31. Graph. Proportion of correct sign identification responses as a function of background scene and sign type.

DISCUSSION

With five signs to select from, chance sign identification performance was 20 percent. Even with a 15° offset, average performance remained above chance. This confirms that traffic sign messages can be recognized in the absence of a fixation. Thus, failures to look at signs cannot be taken as evidence that drivers are unaware of signs. Awareness of sign content, then, is a better measure of sign conspicuity than fixation on a sign. This does not mean that glance data are not useful. When glances do not fall within 9° of a sign, the probability of understanding the sign is markedly reduced. This effect is likely to be more pronounced in an actual roadway environment than in a laboratory environment where the participant's only task is to identify signs from a small known set of alternatives.

The difference in performance between speed limit and warning signs is likely the result of the size of the characters. The speed limit numbers were scaled to be equivalent to 12 inches (31 cm) high, whereas the warning sign letters were scaled to be equivalent to 4.5 inches (11 cm) high. The speed limit numbers were scaled to be typical of those on posted on arterial roadways. The warning sign letters were somewhat smaller than typical because the warning diamonds were mistakenly scaled to be 36 inches (91 cm) on the diagonal rather than on the edge. Therefore, the results probably underestimate the off-axis readability of text-based warning signs.

Although some roadway scene environments resulted in significant differences in warning sign identification, these differences were not large. The correlation between sign identification and the background scene dimensions identified in the MDS analysis was examined. No relationship was apparent between sign identification performance and the MDS dimensionality of the scenes. The best warning sign identification occurred with scene 3, which was low in both clutter and predictability. The worst warning sign identification performance was with scene 2, which was lowest on the clutter dimension and neutral on the predictability dimension. Low warning sign identification performance also occurred on scene 4, which was highest on the predictability dimension and neutral with respect to clutter. Scene 5, which yielded slightly better warning sign identification performance than scene 4, was also neutral with respect to clutter but was at the low end of the predictability dimension. Thus, within the range of scene environments explored in this study, environment had little obvious systematic influence on the ability to distinguish between warnings or speed limits.

The failure to find an interpretable effect of background scene on sign identification performance replicates the findings of Karttunen and Hakkinen, whose background scenes varied over a greater range of environments than those in the present study.(51) However, the traffic signs used in the Karttunen and Hakkinen study were larger and differed more from each other. Schnell, Aktan, and Li also found a lack of background effect on sign identification, but in their study, the sign always appeared in the same location and there was no attempt to limit the signs to peripheral vision.(54) Although background clutter would seem, intuitively, to affect perception of a sign's message, such an influence is difficult to demonstrate. Karttunen and Hakkinen showed a decrement in sign identification performance when they juxtaposed other traffic signs with the target signs, so there is evidence to show that background matters in sign identification.(51) However, there is insufficient research to provide guidance on how to enhance or prevent degradation to sign identification performance.

It is possible that some participants shifted their gaze to the signs on some trials despite the instruction to keep their gaze at the fixation cross location. Indeed, this was likely the case for two participants who missed very few identifications and whose performance did not appear to vary with offset. However, even when the data of these two participants are excluded, mean performance at the 15° offset remained above the chance level of 0.2, and the performance curves remained similar in shape to those in figure 30. Limiting sign and scene exposure to 0.15 s was intended to reduce the ability of participants to shift their gaze from the fixation cross location to the anticipated sign location. However, gaze can be shifted by a saccade in about 0.02 s, and useful information can begin to be extracted about 0.02 s after a saccade has been completed.(41) Thus, participants who shifted their attention when the scenes were first displayed, either knowingly or unknowingly, could have had up to 0.11 s to fixate and read the signs. An eye-tracking device would be necessary to rule out such shifts in fixation. Nonetheless, the drop-off in performance as a function of offset and the fairly symmetrical drop-off between equal negative and positive offsets suggest that most participants were compliant on most trails and that the present data are interpretable even if they may somewhat overestimate legibility as a function of gaze offset.

The signs in this study were located at or near the edge of the pictured travelled way, which is typical of urban signing practice.(35) To provide a measure of safety to run-off-road vehicles, the MUTCD recommends a 12-ft (3.7-m) lateral offset from the edge of the travelled way or an 8-ft (2.4-m) offset from the edge of an 8-ft (2.4-m) shoulder.(36) From a distance of 85 ft (26 m), a 12-ft (3.7-m) offset would put the sign about 15° to the right of the driver's forward gaze. From longer distances, the angle would be less. The present results suggest that the likelihood that signs will be read in the absence of direct fixations on them would increase if offsets less than 12 ft (3.7 m) were used or if warning signs were larger than current recommendations, which are 36 inches (110 cm) for conventional roads and 48 inches (146 cm) for freeways.

SUMMARY

There is no generally accepted measure of the conspicuity of TCDs. Eye tracking has been used to assess whether TCDs receive glances, but the research presented in this report indicates that some TCDs were noticed and remembered even though they did not receive an eye glance. In addition, about 20 percent of signs that received glances could not be recalled 2 s after they were passed. A field test that used an eye-tracking device and asked drivers to recall selected signs did not show a predictable effect of sign environment on glance probability or recall. However, two other psychophysical testing methods showed that background environment does influence sign detectability, especially regulatory sign detectability. With light-colored or cluttered surrounds, speed limit signs were about half as detectable as they were with dark, uncluttered surrounds. With the surrounds explored in these studies, warning sign detectability did not vary by predictable or practically significant amounts as a function of background. However, this should not be taken to mean that warning sign detectability would not be markedly degraded by more complex surrounds than those explored in these studies. In particular, the present results should not be used as support for posting more than one sign on a roadside support, as the literature suggests that crowding would reduce readability in that situation.

CONCLUSIONS AND RECOMMENDATIONS

Before drivers can behaviorally respond to signs, they must detect them. The sign detection angle appears to be a good measure of detectability. In these studies, the sign background affected detectability angle, but it was not clear whether the effects of background were the result of the general background or the part of the background that was immediately around the signs (e.g., within 2° of visual angle). Studies using the method of limits and the laboratory techniques used here should be useful in clarifying this issue. These studies should also assess the effectiveness of various conspicuity enhancements in mitigating the degrading effects of cluttered background scenes. Mitigation strategies that should be evaluated include increasing sign size and adding yellow plaques to regulatory signs.

This research suggests that in low-workload situations drivers can read speed limit signs that are 9° away from their gaze direction. Figure 32 shows that at 85 ft (26 m) a speed limit sign with 12-inch (30 cm) numerals that is located 12 ft (3.7 m) from the edge of the traveled way can be read without a glance away from the forward roadway. At distances closer to the sign than 85 ft (26 m), a glance away from the forward roadway would be necessary. At 255 ft (77.8 m), the sign would fall within 3°, or forward gaze, and would be legible while gazing at the forward roadway.

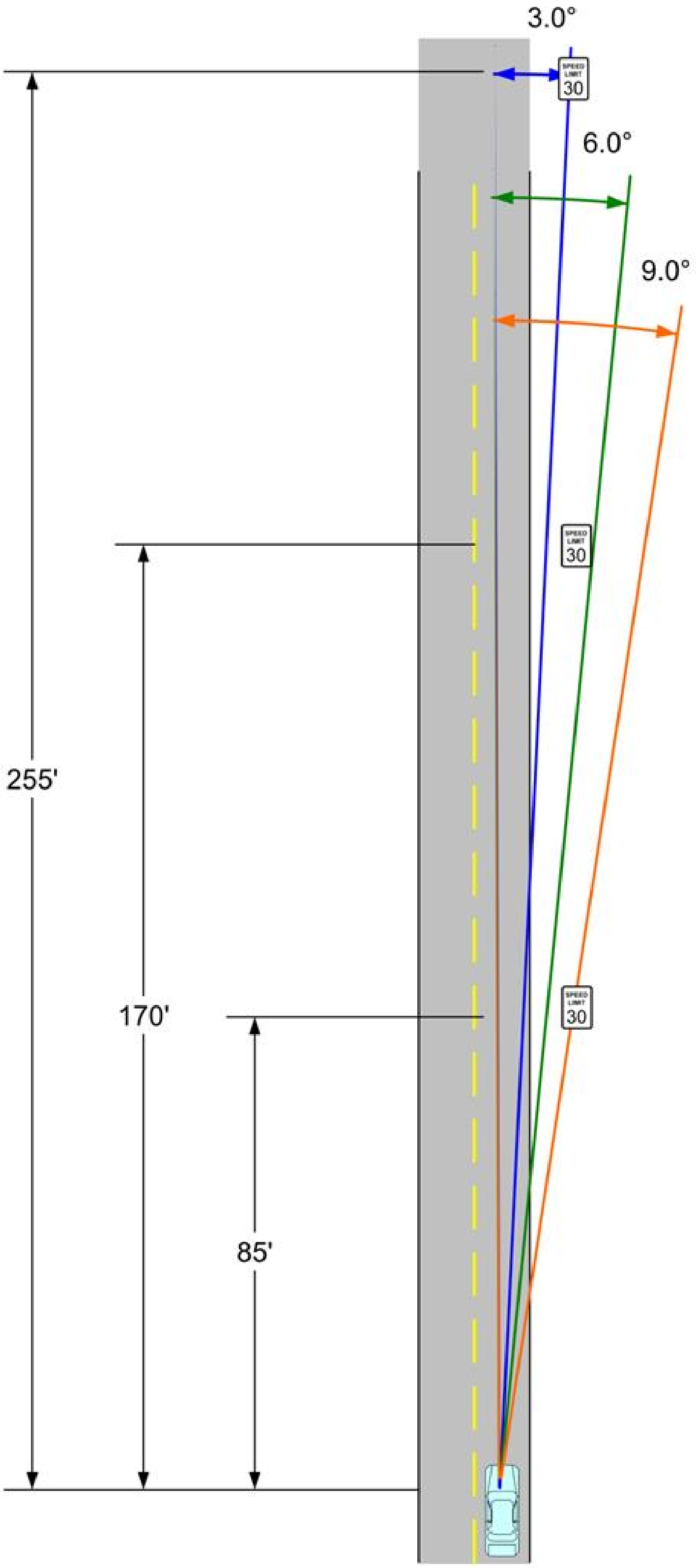


Figure 32. Illustration. Relationship of viewing distance and visual angle offset from the driver's forward view of the roadway.

Legibility is a function of several factors. Within 3° of forward vision, high-contrast letters should be legible to most drivers with the MUTCD-recommended 1 inch (3 cm) of character height for every 30 ft (9 m) of viewing distance. Thus, a warning sign with 6-inch (15-cm) letters should become legible at 180 ft (55 m) and may be read without a glance directly to the sign at that distance. However, at a distance of 85 ft, a warning sign with 3-inch (8-cm) letters would require a glance away from the forward roadway to place the sign within foveal vision.

The MUTCD suggests that TCDs should be in the road user's view and that location and legibility should provide adequate time for response.(36) The results of this study suggest that the field of view for sign detection exceeds 60° under favorable conditions (i.e., low-clutter background that contrasts with sign color). Attention should be given to ensuring that signs stand out from their background. The study used the speed limit sign as an exemplar of regulatory signs. Intersections are a common location for black-on-white regulatory signs such as lane and turn restrictions. The need to place these signs on mast arms or posts in the immediate intersection environment often dictates the use of smaller signs and limits the ability to control the background and proximity to other signs. In these cases, strong consideration should be given to increasing the conspicuity of safety-critical signs (e.g., no U-turn and no turn on red). Many intersections present drivers with challenging visual environments comparable to the parking lot background used in this study's sign detection experiment. Unlike the observers in the sign detection experiment, drivers have multiple visual tasks to perform and will often lack the spare capacity to detect small signs or read those signs in their peripheral vision. To ensure that drivers look at and read safety-critical signs, every effort should be made to make the signs as large as possible and, if necessary, to add conspicuity enhancements such as the yellow notice plaque (W16-18P).

MUTCD section 2A.04 cautions against the excessive use of signs.(36) Warning sign prevalence may detract from warning sign effectiveness. To be effective, warning signs should specify a specific appropriate response that drivers can identify. The glance and recall findings in this study may be the result of overuse of occasional hazard signs for which no appropriate response is apparent and for which the actual hazard is rarely present (e.g., blind pedestrian, disabled pedestrian). One warning sign on the data collection route (not used as a target) was a curve warning sign with a speed advisory placard for 35 mi/h. Less than 85 ft (26 m) downstream from this sign and before the curve hazard was a 45-mi/h speed limit sign, an increase from the preceding 35-mi/h limit. At a minimum, increases in speed limits should not be placed upstream of curves where the speed advisory is less than the upwardly revised speed limit. Further down that same road, on a long tangent, was the slippery when wet warning sign that was comprehended by only 25 percent of the drivers who could recall it. That sign could benefit from a placard to explain its meaning and the expected driver response, such as an advisory speed for wet road conditions. It was not clear whether the area beyond the sign was extraordinarily slippery when wet or whether the sign was intended as a general reminder. In any case, signs such as these are likely to result in less than desirable attention to other warnings.

Regulatory signs of a general nature (e.g., littering prohibited) should be used very conservatively. One large sign at a town entrance is likely to be more effective than many small signs placed at intersections.

MUTCD section 2A.06 allows the use of word messages not included in the manual and does not require experimentation for word messages.(36) The present research suggests that the appropriate use of such warnings is effective. The parked vehicle ahead warning was particularly effective. That sign was on a two-lane road, upstream of where the road widened slightly and on-street parking was allowed. All five of the drivers who rated themselves unfamiliar with that stretch of road scored a glance to that sign and recalled it. Of the 11 drivers who rated themselves as familiar with the stretch of road, only 4 did not correctly recall the sign, although 3 of those 4 scored a look to it. This contrasts, for instance, with the deer warning symbol sign that was looked at by only 4 of 26 participants and recalled by only 4 of 16 who were asked to identify it. Immediate hazard signs, even text signs, appear to capture attention better than occasional warning signs. This does not imply that occasional warning signs should not be used, but rather, that they be used judiciously.

MUTCD table 2C-4 provides suggested distances upstream of a hazard where the warning sign for the hazard should be placed.(36) Placement further upstream than suggested is strongly discouraged because drivers' memories are short. Where the subject of the warning (e.g., intersection, crosswalk) is not visible 2 s upstream of the warning sign, a distance placard is strongly recommended. As noted previously, warnings for which no response is apparent are quickly forgotten.

Additional research is needed to characterize the influence of environment in TCD detection and awareness. MDS may be a useful tool in that effort. However, other methods of characterizing the TCD environment are also needed.

ACKNOWLEDGEMENTS

Thanks to Pascal Beuse, Dana Duke, and Jason Kennedy for their efforts in conducting the eye glance and recall field study. Thanks to Mike Baumgartner, Ryan Cartwright, Peter Chou, and Jason Williams for their efforts in enabling the laboratory detection and identification studies. Thanks again to Dana Duke for his creative contributions to the outdoor data collection effort.

REFERENCES

1. Lay, M.G. (2004). Design of traffic signs. In C. Castro and T. Horberry (Eds.), *The human factors of transport signs* (pp. 25–48). Boca Raton, FL: CRC Press.

2. Cole, B.L. and Jenkins, S.E. (1982). Conspicuity of traffic control devices. *Australian Road Research*, *12*, 223–238.

3. Luoma, J. (1988). Drivers' eye fixations and perceptions. In A.G. Gale, M.H. Freeman, C.M. Haslegrave, P. Smith, and S.P. Taylor (Eds.), *Vision in vehicles II* (pp. 231–237). Amsterdam, Netherlands: Elsevier.

4. Munn, S.M. and Pelz, J.B. (2009). Fixtag: An algorithm for identifying and tagging fixations to simplify the analysis of data collected by portable eye trackers. *ACM Transactions on Applied Perception*, *6*, 1–25.

5. Pelz, J.B. and Canosa, R. (2001). Oculomotor behavior and perceptual strategies in complex tasks. *Vision Research*, *41*, 3587–3596.

6. Reimer, B. and Sodhi, M. (2006). Detecting eye movements in dynamic environments. *Behavior Research Methods*, *38*, 667–682.

7. Wertheim, A.H. (2010). Visual conspicuity: A new simple standard, its reliability, validity and applicability. *Ergonomics*, *53*, 421–442.

8. Cole, B.L. and Hughes, P.K. (1984). A field trial of attention and search conspicuity. *Human Factors*, *26*, 299–313.

9. Jenkins, S.E. and Cole, B.L. (1986). Daytime conspicuity of road traffic control devices. *Transportation Research Record*, *1093*, 74–80.

10. Hughes, P.K. and Cole, B.L. (1986). What attracts attention when driving? *Ergonomics*, *29*, 377–391.

11. Gibson, J.J. (1979). *The ecological approach to visual perception.* Boston, MA: Houghton Mifflin.

12. Li, L., Socher, R., and Fei-Fei, L. (2009). Towards total scene understanding: Classification, annotation and segmentation in an automatic framework. In *IEEE conference on computer vision and pattern recognition, 2009* (pp. 2036–2043). New York, NY: Institute of Electrical and Electronics Engineers.

13. Federal Highway Administration. (1989). *FHWA functional classification guidelines*. Washington, DC: Author. Retrieved June 21, 2011, from http://www.fhwa.dot.gov/planning/fctoc.htm

14. Treisman, A. (1986). Features and objects in visual processing. *Scientific American*, *255*, 114–125.

15. McPhee, L.C., Scialfa, C.T., Dennis, W.M., Ho, G., and Caird, J.K. (2004). Age differences in visual search for traffic signs during a simulated conversation. *Human Factors*, *46*, 674–685.

16. Bravo, M.J. and Farid, H. (2004). Search for a category target in clutter. *Perception*, *33*, 643–652.

17. Johnson, A. and Proctor, R.W. (2004). *Attention: Theory and practice*. Thousand Oaks, CA: Sage Publications.

18. Treisman, A. (1982). Perceptual grouping and attention in visual search for features and for objects. *Journal of Experimental Psychology: Human Perception and Performance, 8*(2), 194–214.

19. Wolfe, J.M. (1994). Guided search 2.0: A revised model of visual search. *Psychonomic Bulletin & Review*, *1*, 202–238.

20. Borowsky, A., Shinar, D., and Parmet, Y. (2008). Sign location, sign recognition, and driver expectancies. *Transportation Research Part F*, *11*, 459–465.

21. Young, F.W. (1984). Scaling. *Annual Review of Psychology*, *35*, 55–81.

22. Kruskal, J.B. and Wish, M. (1978). *Multidimensional scaling*. Thousand Oaks, CA: Sage Publications.

23. Wish, M. (1971). Individual differences in perceptions of preferences among nations. In C.W. King and D. Tigert (Eds.), *Attitude research reaches new heights* (pp. 312–328). Chicago, IL: American Marketing Association.

24. IBM. (2011). *PROXSCAL*. Armonk, NY: Author. Retreived June 3, 2012, from http://publib.boulder.ibm.com/infocenter/spssstat/v20r0m0/index.jsp?topic=%2Fcom.ibm.spss.statistics.help%2Fidh_prxs.htm

25. American Association of State Highway and Transportation Officials. (2004). *A policy on geometric design of highways and streets*. Washington, DC: Author.

26. Itti, L. and Koch, C. (2001). Computational modelling of visual attention. *Nature Reviews Neuroscience*, *2*, 194–203.

27. Renge, K. (1980). The effects of driving experience on a driver's visual attention. *IATSS Research*, *4*, 95–106.

28. Shapiro, K.L. (1994). The attentional blink: The brain's 'eyeblink.' *Current Directions in Psychological Science*, *3*, 86–89.

29. Sprenger, A., Schneider, W., and Derkum, H. (1999). Traffic signs, visibility and recognition. In A.G. Gale, I.D. Brown, C.M. Haslegrave, and S.P. Taylor (Eds.), *Vision in vehicles VII* (pp. 421–425). Amsterdam, Netherlands: Elsevier.

30. Bhise, V.D. and Rockwell, T.H. (1973). *Development of a methodology for evaluating road signs* (Report No. OHIO-DOT-01-73). Columbus, OH: Ohio State University.

31. Johansson, G. and Backlund, F. (1970). Drivers and road signs. *Ergonomics, 13*, 749–759.

32. Shinar, D. and Drory, A. (1983). Sign registration in daytime and nighttime driving. *Human Factors*, *25*, 117–122.

33. Luoma, J. (1991). *Evaluations of validity of two research methods for studying perception of road signs* (Report No. UMTRI-91-15). Ann Arbor, MI: University of Michigan Transportation Research Institute.

34. Edquist, J. (2009). *The effects of visual clutter on driving performance*. Doctoral dissertation, Accident Research Centre, Monash University.

35. Sparks, J.W. (1997). Unique urban signing considerations. In *Traffic signing handbook*, (pp. 89–102). Washington, DC: Institute of Transportation Engineers.

36. Federal Highway Administration. (2009). *Manual on uniform traffic control devices for streets and highways* (2009 ed.). Washington, DC: U.S. Government Printing Office.

37. Smart Eye AB. (2010). *Smart Eye Pro 2-8 Cameras*. Göteborg, Sweden: Author. Retreived June 23, 2011, from http://www.smarteye.se/productseye-trackers/smart-eye-pro-2-6-cameras

38. EyesDX. (2011). *MAPPS*. Coralville, IA: Author. Retreived February 8, 2011, from http://www.eyesdx.com/products/mapps

39. Duchowski, A.T. (2007). *Eye tracking methodology: Theory and practice* (2nd ed.). London, UK: Springer.

40. Holmqvist, K., Nystrom, M., Andersson, R., Dewhurst, R., Jarodzka, H., and Van de Weijer, J. (2011). *Eye tracking: A comprehensive guide to methods and measures.* New York, NY: Oxford University Press.

41. Rayner, K., Inhoff, A.W., Morrison, R.E., Slowiaczek, M.L., and Bertera, J.H. (1981). Masking of foveal and parafoveal vision during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance*, *7*, 167–179.

42. Eastern Roads. (2010). *Setting the limit: NYSDOT manual of traffic control devices—Rules on speed limits*. Forest Hills, NY: Author. Retreived June 17, 2011, from http://www.nycroads.com/history/speed_MUTCD

43. Dewar, R.E., Kline, D.W., and Swanson, H.A. (1994). Age differences in comprehension of traffic sign symbols. *Transportation Research Record, 1994*, 1–10.

44. Charlton, S.G. (2006). Conspicuity, memorability, comprehension, and priming in road hazard warning signs. *Accident Analysis & Prevention, 38*, 496–506.

45. Picha, D.L., Hawkins, H.G., and Womack, K.N. (1995). *Motorist understanding of alternative designs for traffic signs* (Report No. FHWA/TX-96/1261-5F). College Station, TX: Texas Transportation Institute.

46. Kooi, F.L. and Toet, A. (1999). Conspicuity: An effect alternative for search time. In A.G. Gale, I.D. Brown, C.M. Haslegrave, and S.P. Taylor (Eds.), *Vision in vehicles VII* (pp. 451–462). Amsterdam, Netherlands: Elsevier.

47. Federal Highway Administration. (2004). *Standard highway signs*. Washington, DC: U.S. Government Printing Office.

48. Trygg, E. (1971). Psychophysics. In J.W. Kling and L.A. Riggs (Eds.), *Woodworth and Schlosberg's experimental psychology* (3rd ed.). New York, NY: Holt, Rinehart and Winston.

49. Moreland, J.D. and Cruz, A. (1959). Colour perception with the peripheral retina. *Optica Acta, 6*, 117–151.

50. Hansen, T., Pracejus, L., and Gegenfurtner, K.R. (2009). Color perception in the intermediate periphery of the visual field. *Journal of Vision, 9*(4):26, 1–12.

51. Karttunen, R. and Hakkinen, S. (1982). *Discrimination of traffic signs in the peripheral areas of the field of vision*. Helsinki, Finland: Central Organization for Traffic Safety.

52. Levi, D.M. (2008). Crowding—An essential bottleneck for object recognition: A mini-review. *Vision Research*, *48*(5), 635–654.

53. McDonald, J.H. (2009). *Handbook of biological statistics* (2nd ed.). Baltimore, MD: Sparky House Publishing.

54. Schnell, T., Aktan, F., and Li, C. (2004). Traffic sign luminance requirements of nighttime drivers for symbolic signs. *Transportation Research Record, 1862*, 24–35.