Use of Color Changeable Message Signs – Human Factors Study

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16. Abstract

The report presents the results of laboratory and field research related to the use of colors and symbols in the design of messages displayed on changeable message signs (CMSs). The research was performed to address gaps in information identified through a literature review of existing published information and discussions with the Traffic Management Center (TMC) Pooled Fund Study (PFS) members. The laboratory study evaluated comprehension, reaction time, and legibility for various designs of messages that might be considered for display on a color changeable message sign (CMS). The research team developed and tested a total of 117 unique messages that included various combinations of colors, legends, and symbols. A closed-course field study was conducted to gather information on the legibility of messages displayed on a portable CMS. The testing focused specifically on the effects of font and color on legibility, and also investigated participant preferences for different design elements (symbol placement, border presence, and use of color-coding) included in the design of messages displayed. This report presents the results of the testing conducted with different types of messages displayed on color CMSs, along with the limitations of the research and how the approach to the study may have impacted the results.

Messages displayed on CMSs within roadway or highway rights-of-way are required to follow the provisions in the Manual on Uniform Traffic Control Devices for Streets and Highway (MUTCD, Federal Highway Administration, 2009, Revision Numbers 1 and 2). The provisions of the MUTCD are to be followed in the design and display of messages on and use of CMSs. Chapter 2L of the MUTCD provides standards and guidance on the use of CMSs.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square 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)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°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)		
°C	Celsius	1.8C+32	Fahrenheit	°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

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LIST OF ACRONYMS

AIC	Akaike Information Criterion
CI	Confidence interval
CMS	Changeable message sign
ET	Eastern Time
FHWA	Federal Highway Administration
GIF	Graphics Interchange Format
HOV	High-occupancy vehicle
IQR	Inter-quartile range
JPEG	Joint Photographic Experts Group
KDOT	Kansas Department of Transportation
LED	Light-emitting diode
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
PFS	Pooled Fund Study
PNG	Portable network graphics
RGB	Red Green Blue
SHS	Standard Highway Signs and Markings Book
SI	International System of Units
TMC	Traffic Management Center
VA	Virginia
VSL	Variable speed limit

EXECUTIVE SUMMARY

Two overarching objectives of the Traffic Management Center (TMC) Pooled Fund Study's (PFS) and Federal Highway Administration's (FHWA) Use of Color Changeable Message Signs (CMSs) project were to understand the current practices regarding the use of CMSs and display of messages on CMSs. As a part of the project, the research team conducted laboratory and field human factors studies to gain insights into how the use of color, symbols, and message design may assist with communicating information to drivers. The results of these studies and their findings are not intended to be incorporated directly into the design and use of messages displayed on CMSs. Rather, the intent is to advance the general understanding of how the capabilities (e.g., color, graphics) of modern CMSs may positively or negatively impact approaching drivers on different roadways and in different environments or conditions.

Messages displayed on CMSs within roadway or highway rights-of-way are required to follow the provisions in the Manual on Uniform Traffic Control Devices for Streets and Highway (MUTCD, Federal Highway Administration, 2009, Revision Numbers 1 and 2). The provisions of the MUTCD are to be followed in the design and display of messages used on CMSs. Chapter 2L of the MUTCD provides standards and guidance specific to the use of CMSs, while provisions from other parts and chapters of the Manual also apply. Messages should be developed by engineers well versed in the MUTCD and traffic control principles.

Advances in CMS technology allow for the ability to display color, full-matrix text, and images that were not previously available or affordable to transportation agencies. This research project conducted and evaluated participant understanding of, and reactions to, a variety of messages displayed on color, full-matrix CMSs. More specifically, the research team assessed the potential implications for motorists that displaying messages with color and symbolic elements may have, including: the ability of motorists to notice the symbols and messages, the ability to comprehend the symbols and messages, and the amount of time it takes the driver to read and comprehend a message displayed on a CMS. Messages used a variety of text, symbol, and color combinations. These messages were evaluated using a combination of computer-based (laboratory) testing and field testing.

The laboratory study portion of the research evaluated comprehension, reaction time, and legibility for various types of messages that might be displayed on CMSs. Thirteen message categories (e.g., Road Work Ahead, Speed Limit) were evaluated across five different sign classifications (Regulatory, Warning, Guide, Toll/Managed Lanes, and Miscellaneous). Different legend designs for these messages were evaluated within each sign category. The message alternatives varied based on symbol placement, legend (text) color, background color, and border presence. The research team developed and evaluated a total of 117 unique messages.

The focus of the closed-course field study was to gather information on the effects of font and color on legibility of messages displayed on a CMS. The field study was organized into two parts. The first part investigated sign legibility for three different fonts (Series D, Series E, and LED-style font) and for eight different color combinations in the signs' text and background.

Participants viewed signs from six different pre-determined distances from a 4x8-foot high-resolution, full-color CMS.

The second part of the field study investigated participant preferences of different message elements (symbol placement, border presence, and use of color-coding) and sign brightness. For both parts of the field study, participants viewed signs in daytime and nighttime conditions.

Results are presented in this report separately for the laboratory and field studies by category of messages (symbol use and placement, use of color, border presence, font style, and considerations for use of CMSs in daytime versus nighttime).

Based on the results of the research, the symbols examined in this study did not influence the comprehension of messages displayed on the CMS. Comprehension rates were typically between 90-100 percent for all message categories, with only two categories' comprehension rates falling below 90 percent. The only symbol that influenced reaction time was the route shield on the Ramp Closed signs. The message alternatives with the route shield within the text were associated with a faster reaction time than average, and alternatives with the route shield placed to the left of the text were associated with a slower reaction time than average.

Similarly, a message depicting a static Speed Limit sign also resulted in faster reaction times than the text-only alternatives. In theory, the exclusive shape and extensive use of the route shield and Speed Limit signs create an instant recognition and comprehension of meaning, whereas the alternative word versions of these messages require reading the entire text to fully comprehend the meaning. Given that other comparisons of symbols to equivalent word messages did not show a similar benefit of faster reaction times, results suggest that symbolic messages or message elements are not universally better than word messages.

The legibility findings indicated that signs with symbols to the left or right of text typically performed equally well as the text-only signs. These findings, however, were influenced by the use of easy-to-recognize symbols. If a symbol is not legible or easy to recognize before the text version of the message is legible, a symbol will have the same legibility as a text only message, as the participants would be reading the text of the message before the symbol.

The use of color did not influence comprehension of messages, and only influenced reaction times in one instance. For the HOV message category, black text on white backgrounds was associated with a faster reaction time than white text on black backgrounds. However, this observation was not the case for any other message categories that evaluated these color combinations.

Additionally, findings suggest that motorists may not fully understand the meaning behind the use of certain colors (e.g., pink for incident management, white for regulatory) in messages displayed on CMSs. Both the laboratory and field testing examined the effect of color on message legibility. The laboratory legibility findings indicated that negative contrast colors (e.g., black-on-white) used in messages tended to have a shorter legibility distance (the distance the message first becomes legible) than positive contrast colors (e.g., white-on-black) in most cases, resulting in less time for road users to read and react to the message.

The field legibility testing indicated that the black-on-orange messages resulted in the longest average legibility distance, which was significantly longer than all other messages except for the white-on-black and black-on-yellow messages. Green-on-black messages had the shortest legibility distance, followed by white-on-green messages. The field study yielded no statistically significant differences between the white-on-black, yellow-on-black, black-on-white, and black-on-yellow messages. However, the evaluation methods were different for the laboratory and field legibility testing, therefore limiting any conclusions that can be drawn from a comparison.

Border presence did not result in significant differences in comprehension, reaction time, or participant ratings. Interestingly, in 4 out of 5 cases (83 percent) where black-on-white messages were evaluated with and without a border in the laboratory testing, there was an effect of border presence on legibility distance. However, these findings were split between borders being associated with longer and shorter legibility distances.. In the field study, participant preference ratings for the Road Work Ahead messages were significantly higher for messages with a border than without a border.

Legibility distances of the messages displayed in the field study did not vary significantly in the daytime versus nighttime, except for yellow-on-black messages, where legibility distance was significantly longer during the daytime than during nighttime. Participant ratings of messages with varying design elements (border presence, color-coding, symbol placement) were typically not affected by light (daytime vs. nighttime). Participants were shown four different legend/background color combinations (black-on-white, black-on-yellow, red-on-black, and white-on-black) for a text-only message and provided feedback on the brightness of each message. Overall, the messages evaluated during the night were rated as brighter than those evaluated during the day. However, the statistical significance of this difference disappears when examining each sign individually.

Font style was only examined in the field study. The findings indicated that Series E had the longest average legibility distance, which was significantly longer than Series D and the LED-style font.

CHAPTER 1. INTRODUCTION

BACKGROUND AND MOTIVATION

The objectives of this Traffic Management Center (TMC) Pooled Fund Study's (PFS) and Federal Highway Administration's (FHWA's) Use of Color Changeable Message Signs (CMSs) project was to understand the current practices regarding the use of and display of messages on color changeable message signs. As a part of the project, laboratory and field human factors studies were conducted to gain insights into how the use of color, symbols, and message design may assist with communicating information to drivers. The results of these studies and their findings are not intended to be incorporated directly into the design of and use of messages displayed on CMSs. Rather, the intent is to advance the general understanding of how the capabilities (e.g., color, graphics) of modern CMSs may positively or negatively impact approaching drivers on different roadways in different environments or conditions.

The provisions of the Manual on Uniform Traffic Control Devices for Streets and Highway (MUTCD) are to be followed when designing and displaying messages on and operating or using CMSs. Chapter 2L of the MUTCD provides standards and guidance specific to the use of CMSs (Federal Highway Administration, 2009, Revision Numbers 1 and 2). Nonetheless, provisions from other parts and chapters of the MUTCD also apply, therefore messages should be developed by engineers well versed in the entire MUTCD and traffic control principles.

Advances in technology allow for color and full-matrix text and images to be displayed on CMSs that were not previously available or affordable to transportation agencies. A review of chapter 2L of the MUTCD and published literature, along with discussions with the TMC Pooled Fund Study members, identified a desire in the transportation community for more information to assist transportation agencies with displaying messages with color on full-matrix CMSs.

Transportation agencies need information on the implications of using different colors and color combinations in messages and how these messages may be displayed on CMSs. Research can indicate when colors might be effective in helping to convey a message, what types of messages might benefit from the use of colors, and what colors or color combinations might improve or detract from a message display. In addition, agencies need information on the potential benefits of using a symbol or graphic in a message displayed on a CMS.

The FHWA conducted a literature review identifying existing research and current practices regarding the use of yellow/amber for letter color and symbols. The few States that have developed guidance suggest the CMS display a single graphic on the left-hand side with a worded message on the right-hand side. The literature review identified a gap in research related to the effects of colors and symbols in messages displayed on full-matrix CMSs. Most of the existing research on color and symbols displayed on CMSs was conducted before full-matrix CMSs became available. This lack of information on the use of color in messages displayed on full-matrix CMSs is a major challenge for practitioners. As the cost of full-matrix color CMS equipment has decreased, agencies have started using color in the messages displayed on these signs. However, there is a lack of empirical data to support this practice. Through the literature

review, only six documents were found that provide information on designing a CMS message which includes any combination of text, symbols, and colors.

This final report presents the results of laboratory and field testing of prioritized questions resulting from the discussions with the TMC PFS members.

RESEARCH OBJECTIVES

The objective of this research project was to experimentally evaluate motorists' understanding of, and reactions to, a variety of messages displayed on color, full-matrix CMSs. More specifically, the research team assessed the impacts that using color and symbols on CMSs may have on motorists, including:

- Drivers' ability to notice symbols and messages.
- Drivers' ability to comprehend symbols and messages.
- The amount of time it takes the driver to read and comprehend a message displayed on a CMS.

RESEARCH APPROACH

Common messages typically displayed on CMSs were created using a variety of text, symbol, and color combinations. As different research questions require different approaches, the research team conducted a combination of computer-based testing and closed-course field testing using a portable CMS to accomplish the research objectives.

Table 1 describes the purpose of the different testing methods used in this study.

Table 1. Purpose of Different Testing Methods Used to Study Changeable Message Sign (CMS) Messages

Utility	Computer-Based Comprehension Testing	Computer-Based Legibility Testing	Field Legibility Testing and Subjective Feedback
Justification for Testing Methods	• Useful in determining whether symbols and/or text-based messages are easily understood • Provides examples of signs in context • Useful in determining driver legibility among similar sign message alternatives	• Useful in determining the distance required to accurately read the sign message • Provides a controlled environment where the focus is on reading messages as opposed to other items in roadway environment	• Allowed for testing of a full-matrix color CMS in a controlled environment • Allowed for adequate testing in daytime and nighttime conditions where computer-based simulation cannot accurately portray each environment • Useful in gathering participant comprehension of messages on an actual CMS
Research Questions Addressed	• Is there an optimal placement of symbols on messages? • Which symbols are well understood, and which are not on color full matrix CMSs? • Does the use of color help to convey messages more easily? • When replicating a static sign in a message displayed on a CMS, are borders required?	• Is there an optimal placement of symbols on messages? • Does the use of color help to convey messages more easily? • When should symbols be used instead of text in messages displayed on color full-matrix CMSs?	• Do text and background colors influence legibility? • Does font influence legibility? • What are considerations for displaying messages in daytime versus nighttime on CMSs? • What are participant preferences for various sign design features, and do these design features affect subjective ratings? - Are borders helpful on messages on CMSs? - Is there an optimal placement of symbols on messages on CMSs? - Does the use of color (i.e., color-coding) help to convey messages more easily? • Does color influence participant feedback on message brightness?

CHAPTER 2. COMPUTER-BASED (LABORATORY) TESTING

METHOD

Objective

The laboratory study was used to evaluate comprehension, reaction time, and legibility for various messages displayed on a CMS. The message design features of interest included symbol placement, symbol understanding, and the use of color. The computer-based testing was organized into two parts: (1) comprehension data collection and (2) legibility data collection. The research questions for the comprehension testing and legibility testing will be identified in their respective sections in this chapter.

Stimulus Development

The research team developed 117 unique messages using a vector graphics editor, using the FHWA color specifications chart and various highway-style fonts. These messages were then exported for use with the experimental software. At least two different messages (e.g., Road Work Ahead) were selected for each of five different sign classifications. The message alternatives varied based on symbol placement, legend (text) color, background color, and border presence. Not every message design feature was applied to each sign category. Table 2 provides an overview of the message design features applied. Table 3 shows the message categories used and example alternatives developed for each category.

Table 2. Message Design Features Applied to Laboratory Test

Message Design Feature	Design Feature Options
Symbol Placement	• Text only • Symbol only • Symbol aligned left with text centered right • Symbol centered top with text centered bottom • Text centered left with symbol aligned right
Text Color	• Black • White • Yellow • Red • Multi-colored (including green, blue and/or red)
Background Color	• Black • White • Yellow • Orange • Green • Fluorescent Pink

Message Design Feature	Design Feature Options
Border Presence	• With border • Without border

Table 3. Message Categories Included in Laboratory Study

Sign Classification	Message/Sign Category	Example Test Messages
Regulatory	No Trucks	
Regulatory	Speed Limit	
Warning	Slippery When Wet	
Warning	Road Work Ahead	
Warning	Road Closed Ahead	
Guide	Travel Time	
Guide	Ramp Closed	
Guide	Special Event	
Toll/ Managed Lanes	Toll Costs	
Toll/ Managed Lanes	HOV 2+	
Miscellaneous	Fasten Seatbelt	
Miscellaneous	Don't Text and Drive	
Miscellaneous	Wipers On, Headlights On	

HOV=High Occupancy Vehicle

Selection of Message / Sign Categories

At least two different messages were selected to represent the Regulatory, Warning, Guide, and Tolls and Managed Lanes sign classifications. Three miscellaneous messages were also selected. The following sections discuss the message or sign categories that were selected for the laboratory testing.

Regulatory Signs

The No Trucks sign category was selected because this is a common sign with a message that could be presented as symbol-only, text-only, and using both text and symbol. The MUTCD only provides the symbol option of R5-2 (No Trucks), but the 2004 Edition of the Standard Highway Signs and Markings Book (SHS) provides a text only option titled R5-2a, which provides text

that could be used for the five different sign designs depicted in figure 1. Any symbols (such as R5-2) that were used in the laboratory study using a computer-simulated CMS maintained the proportions provided in the MUTCD, but were scaled to fit the computer screen.

Figure 1. Graphic. MUTCD Signs R5-2 and R5-2a.
Source: *Federal Highway Administration*

Similarly, the research maintained the proportions of the text in R5-2a as recommended by the Standard Highway Signs and Markings Book (SHS), but scaled the text to fit the simulated CMS and computer screen. The R2-5 sign was selected for testing as it was identified by the research team as a commonly used message displayed on a CMS, which has approved uses for both symbol only or text only. Message alternatives for the No Trucks sign category varied based on text color (yellow or white) and symbol placement (symbol-only, symbol left, symbol right, symbol top center, and text-only). See Appendix B for message alternatives for each sign category.

The R2-1 (Speed Limit) sign, as shown in figure 2, was also tested. The design of this type of sign varied from the No Trucks sign because R2-1 does not have a symbol. This is also a sign that is very familiar to motorists. Therefore, testing this sign with and without the border on a CMS (as it is depicted in the MUTCD and as it is seen on the roadway) is necessary to replicate a static sign. The testing of this sign using different color combinations such as white text on black background (the inverted from the MUTCD) or yellow text on black background was conducted to determine if variations in color or border presence influenced participants' perception of the sign (e.g., if they interpreted it as an advisory speed limit). Alternative messages to test on a CMS for the Speed Limit sign category varied based on text/background color combination (black-on-white, white-on-black, yellow-on-black) and border presence. A sign resembling a static speed limit sign (depicting R2-1) was also included, as shown in table 3.

Figure 2. Graphic. MUTCD Sign R2-1.
Source: *Federal Highway Administration*

Warning Signs

The Warning sign categories were selected to include messages that are typically depicted on CMSs and have either text-only or text with symbols on a sign. Although the MUTCD only provides a symbol option for Slippery When Wet (W8-5), the 2012 Supplement to the SHS provides a text-only plaque option (W8-10P) which provided the text for the study. Figure 3 depicts W8-5 and W8-10P.

The MUTCD provides both text-only (W20-1) and symbol (W21-1) options (see figure 4) for work zone warnings. The "Road Work Ahead" (W21-1) sign serves as a general warning of obstructions or restrictions. The W21-1 sign is only used to depict workers actually in or near the roadway and is typically only in short duration work zones and when workers are present. These are two different signs used to convey two distinctively different meanings.

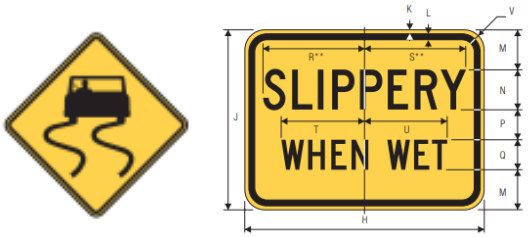


Figure 4. Graphic. MUTCD Signs W8-5 and W8-10P
Source: *Federal Highway Administration*

Figure 3. Graphic. MUTCD Signs W20-1 and W21-1
Source: *Federal Highway Administration*

Message alternatives developed to test the Slippery When Wet sign category varied based on text/background color (e.g., yellow-on-black, black-on-yellow) and symbol placement (e.g., symbol-only, symbol right, symbol left, symbol top center, and text-only). Alternative messages developed to test the Road Work Ahead sign category varied based on text/background color (e.g., yellow-on-black, black-on-orange, white-on-black) and the alternatives for symbol placement representing workers present (symbol-only, symbol right, symbol left, symbol top center, and text-only). The text-only messages were also developed with and without a border.

The Road Closed Ahead sign category was included in the laboratory testing in response to a request made by the TMC PFS members to evaluate messages using the fluorescent pink background color identified in the MUTCD for incident management signs. Messages were developed and tested using four text/background color combinations to determine if color influences perceptions of the meaning of the sign and/or urgency of the sign message. The message alternatives for the Road Closed Ahead sign category varied only based on text/background color (black-on-pink, black-on-yellow, yellow-on-black, red-on-black).

Figure 5. Photo. Example Travel Time Signs.
Sources: New Jersey Department of Transportation (top); Georgia Department of Transportation (bottom)

Guide Signs

The messages to test for the Travel Time sign category were developed based on examples provided by the TMC PFS members, shown in figure 5, which are used in New Jersey (top) and Georgia (bottom). The TMC PFS also requested testing the concept of using color-coding to convey additional information about travel times. Therefore, these messages also evaluated color-coded travel times, where green was used to depict

travel times at low volumes, amber to depict travel times at medium/high volumes, and red to depict travel times at heavily congested volumes. The testing of these message variations allowed for an assessment of whether color-coding travel times changed participants' comprehension or increased reaction times. The message alternatives for the Travel Time sign category varied based on text/background color (yellow-on-black, white-on-green), color-coding, and border presence (for white-on-green signs).

The Ramp Closed sign category was selected for testing based on examples of messages used on CMSs in Wisconsin (figure 6), where the route shield symbol is provided to the left of the text indicating that the ramp is closed. Though not depicted in figure 6, there was also discussion with the TMC PFS members about including the route shield within the text (i.e., as part of the sentence) to see if this design affected driver comprehension or legibility. The message alternatives for the Ramp Closed sign category varied based on text/background color (yellow-on-black, white-on-black, white-on-green) and symbol (route shield) placement (text-only, symbol left, symbol within text).

Figure 6. Photo. Example of Ramp Closed Messages on a Changeable Message Sign
Source: Wisconsin Department of Transportation

The Special Event sign was included in the laboratory testing as a text-only sign that could be used to test various text/background color combinations, as well as some less conventional color combinations such as green, red, or blue text on black backgrounds, to determine how these colors influenced legibility. The message alternatives for the Special Event sign category varied based on text/background color combination (white-on-black, black-on-white, white-on-green, yellow-on-black) and border presence. The research team also developed message alternatives (black background) to include other colors (green, blue, red) in addition to the primary text colors (white, yellow).

Toll / Managed Lanes Signs

In the Toll/Managed Lane sign category, the study developed and tested the use of messages to display information similar to a Priced Managed Lane Toll Rate sign (R3-48 in the MUTCD, shown in figure 7) on a CMS. The Toll Cost sign category also evaluated the use of color-coded text for the toll costs, with green text used to depict normal tolls , amber used to depict slightly higher-than-normal tolls, and red used to depict significantly higher-than-normal tolls. Alternative messages with no color-coding were also studied. The testing of these alternatives will allow an assessment of whether the use of color coding for the cost of tolls changes drivers' comprehension or perceptions of the messages displayed.

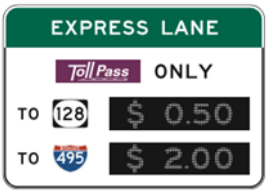


Figure 7. Graphic. MUTCD Sign R3-48
Source: *Federal Highway Administration*

The HOV 2+ sign category was selected to develop and test messages with information similar to the R3-13 sign in the MUTCD (figure 8). The alternative messages tested for the HOV 2+ sign category varied based on text/background color (white-on-black, black-on-white), symbol placement (symbol left, symbol right, symbol top center, text-only) and border presence (for text-only signs).

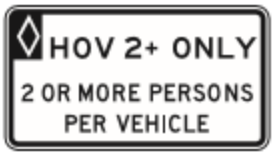


Figure 8. Graphic. MUTCD Sign R3-13
Source: *Federal Highway Administration*

Miscellaneous Signs

The miscellaneous sign categories were included as additional opportunities to test the different elements of interest in color messages displayed on a CMS.

The Wipers On, Headlights On sign category was included in the laboratory testing to represent a general safety message. The electronic messages developed and tested alternatives for the Wipers On, Headlights On sign category varied based on text/background color (white-on-black, black-on-white, yellow-on-black, black-on-yellow) and border presence.

The Fasten Seat Belt sign category was selected for laboratory testing. The message to be tested originated from an example of a two-phase sign message used by the Kansas Department of Transportation (KDOT) (figure 9). The messages developed and tested conveyed "fasten your seat belt," with "State law" above the "fasten seat belt" text to see if the additional text could be included without negatively influencing legibility. Alternative messages were also developed and tested for the Fasten Seat Belt sign category with varying text/background color (white-on-black, black-on-white) and symbol placement.

Figure 9. Photo. Example Seat Belts Message
Source: Kansas Department of Transportation

The Don't Text and Drive sign category was tested to determine if certain colors are more likely to convey legality of a message. For example, the intent of the Don't Text and Drive message is to convey the message that it is illegal to text and drive. Messages were developed to test the use of colors associated with regulatory signs (white, black) or colors associated with warning signs (yellow, black), influence how participants interpret the sign (e.g., as a general warning, or as conveying a law). Alternative messages were developed and tested for the Don't Text and Drive sign category based on text/background color (white-on-black, black-on-white, yellow-on-black, black-on-yellow) and border presence.

Development of Alternatives Messages to Test within Different Sign Categories

It is impractical to examine each design element (e.g., border presence, color, symbol placement) for every sign category, as this would result in an excessive number of sign alternatives. Additionally, it was not necessary to test every variable of interest for each sign category.

The study team developed 117 unique messages across the 13 different sign categories. Additionally, 8 practice signs (for use before beginning the laboratory study) and 12 distractor signs (for use in the legibility testing) were developed using different messages than those developed for the study. Appendix A provides a full list of all 117 tested messages and describes the features unique to displaying each message on the CMS. Appendix B provides images of every message tested, the practice messages, and distractor signs developed for the laboratory study.

Apparatus

Introduction

This section details the hardware and software used for the computer-based testing.

Hardware

The display used for the legibility testing had a height of 31.5 inches. It was mounted to the wall of a room with no windows in order to keep the room dark during the legibility testing. The comprehension testing was conducted both on this display and on several laptop computers, so that comprehension data could be collected at various geographical locations.

Software

The signs were developed using a vector graphics editor, using the FHWA color specifications chart and various highway-style fonts. These signs were then exported in JPEG file format for use with the experimental software. The comprehension testing and the legibility testing was conducted using a non-proprietary sign simulation application. The function of the legibility software is described in the Computer-Based Legibility Data Collection section of this report.

Participants

A total of 146 people participated in the comprehension testing for the laboratory study, and 47 of those same participants also participated in the legibility testing. Due to the research design, fewer participants were required for the legibility testing. Additionally, because the legibility testing required a more controlled and darker environment (see Computer-Based Legibility Data Collection), the legibility testing occurred in one location: Gainesville, Virginia. A total of 47 participants completed both the legibility and comprehension testing in Gainesville, VA. The comprehension testing allowed for more flexibility in terms of the data collection environment and required more participants, due to the research design (see Computer-Based Comprehension Data Collection). Therefore, an additional 99 participants completed only the comprehension testing, for a total of 146 participants. Comprehension testing was conducted in a variety of locations, including Gainesville, Virginia; Arlington, Virginia; Chesterfield, Virginia; Fredericksburg, Virginia; Morganton, North Carolina; and Lewisberry, Pennsylvania. There was not an even distribution of participants within each of these locations; however, at least 10 participants were run in each location. There was an approximately-even distribution between male and female participants, and participants ranged in age from 18 to 74 years. Table 4 and table 5 show the participant distribution by age and sex for the comprehension testing and legibility testing, respectively.

Table 4. Participant Distribution by Age Group and Sex, Comprehension Testing

Age	Female	Male	SUM
Older	35	35	70
Younger	39	37	76
SUM	74	72	**146**

Age groups: “Younger” = ages 18-40; “Older” = ages 41+

Table 5. Participant Distribution by Age Group and Sex, Legibility Testing

Age	Female	Male	SUM
Older	10	12	22
Younger	13	12	25

Age	Female	Male	SUM
SUM	23	24	**47**

Age groups: "Younger" = ages 18-40; "Older" = ages 41+

Participants were recruited through an online advertisement and through word-of-mouth. The advertisement provided general information about the study with a link to an online form that people could complete to submit their interest to the research team. The information in the advertisement included the purpose of the study, who was sponsoring the research, the amount of time to participate, compensation details, and how to sign up to participate. Interested individuals were directed to a Participant Intake Form, which included fields to collect the following information: name, gender, age, phone number, and email address.

A designated member of the research team would contact prospective participants by phone to review the details about the study and answer any questions. If the prospect was still interested in participating, the researcher would schedule an appointment and send a confirmation email to the participant with the date and time of their appointment and instructions for where to meet the experimenter. Confirmation emails also provided contact information for the research team and included other pertinent instructions (e.g., to bring any corrective lenses used while driving, to call and reschedule if the participant was feeling any flu or cold-like symptoms). Reminder emails were sent to participants the day before their scheduled appointment.

Computer-Based Comprehension Data Collection

The first portion of the laboratory study evaluated driver comprehension of and preference for sign alternatives in the different sign categories. The computer-based comprehension testing addressed the following research questions :

1. Is there an optimal placement of symbols on full-matrix CMS messages?
2. Which symbols are well understood, and which symbols are not well understood when displayed on a full-matrix color CMS?
3. Does the use of color help to convey messages more easily?
4. When replicating a static sign in a message, are borders required on CMSs?

Participants were assigned to one of eight different comprehension conditions, with approximately equal numbers of participants in each of the eight conditions. Each comprehension condition consisted of the same 13 sign categories presented in table 3:

- No Trucks.
- Speed Limit 50.
- Slippery When Wet.
- Road Work Ahead.
- Ramp Closed to I-95 North.
- Concert Traffic.
- Wipers On, Headlights On.
- Don't Text and Drive.

- High Occupancy Vehicles Only.
- Fasten Seatbelt.
- Toll Costs.
- Travel Time.
- Road Closed Ahead.

The comprehension test for each sign category consisted of an initial open-ended question to assess each participants' comprehension and reaction times. The participants were then asked a variety of follow-up questions, which varied depending on the sign category. The participants answered all questions for a single sign category before moving on to the next sign category and repeating the process for each of the 13 sign categories.

For the initial comprehension and reaction time question, participants were only exposed to one message alternative within each sign category. The eight participant conditions varied based on the message alternative that was presented within each sign category for the initial comprehension question, as well as the order in which the sign categories were presented. Participants were pre-assigned to a single condition file. Participants were evenly distributed by age group and sex, to each of the eight conditions.

For every follow-up question, participants were exposed to the same message alternatives, regardless of their participant conditions. A description of the different types of questions, with examples, are provided below.

Participant Intake

Prior to beginning the computer-based comprehension testing, participants were asked to read a Briefing Statement (Appendix D) which provided information about the study. The experimenter answered any questions that the participants may have had, and then confirmed if the participants wanted to continue participation in the study. If the participants wished to participate, the experimenter then read them the instructions for the comprehension testing out loud. Participants had the opportunity to ask any additional questions before beginning the study and were also given the opportunity to familiarize themselves with the controls (i.e., keyboard keys) that they would be using during the comprehension portion of the study.

Open-Ended Comprehension and Reaction Time

Each sign category (e.g., No Trucks) began with an open-ended question to assess comprehension of the sign. Participants were shown an image of a sign on a simple roadway background (see Figure 10) and were instructed to press a button as soon as they knew the meaning of the sign. The exact wording of the question varied slightly depending on which sign category the participants were viewing. When the participants pressed the button, the sign disappeared, and they described aloud what they thought the sign meant. The experimenter recorded the participant responses, which the research team later coded as correct, incorrect, or partially correct. The time from when the sign appeared on the screen to when the button was pressed were the participant's reaction times, which were automatically recorded by the software. Therefore, this question measured both comprehension (whether they understood the

intended meaning of the sign) and reaction time. The reaction times were used to determine if participants take more or less time to react (comprehend) to certain sign alternatives compared to others within a sign category. Participants were only exposed to one sign alternative within each sign group for this question.

Figure 10. Graphic. Example of an image shown to participants for the initial open-ended comprehension question.
Source: *Federal Highway Administration*

Follow-up Questions

After the initial open-ended comprehension question, participants were asked follow-up questions to further assess their understanding and interpretation of different messages. These follow-up questions included additional open-ended questions, ranking (to rank-order sign alternatives), and/or rating questions (to rate how well they thought each sign alternative would work to convey the intended message). These questions varied by sign category. For example, after answering the initial comprehension question for the No Trucks sign category, participants were shown each No Trucks sign alternative, told the intended meaning of the sign, and asked to rate each sign on how well they thought it would work to convey the intended meaning. Participants were given a rating scale from 1-5 where 1 means "would not work at all," 3 means "might work," and 5 means "would work very well." Figure 11 provides an example of the image and instructions provided to participants for this question. The participants repeated this process for each of the seven No Trucks sign alternatives shown in figure 11.

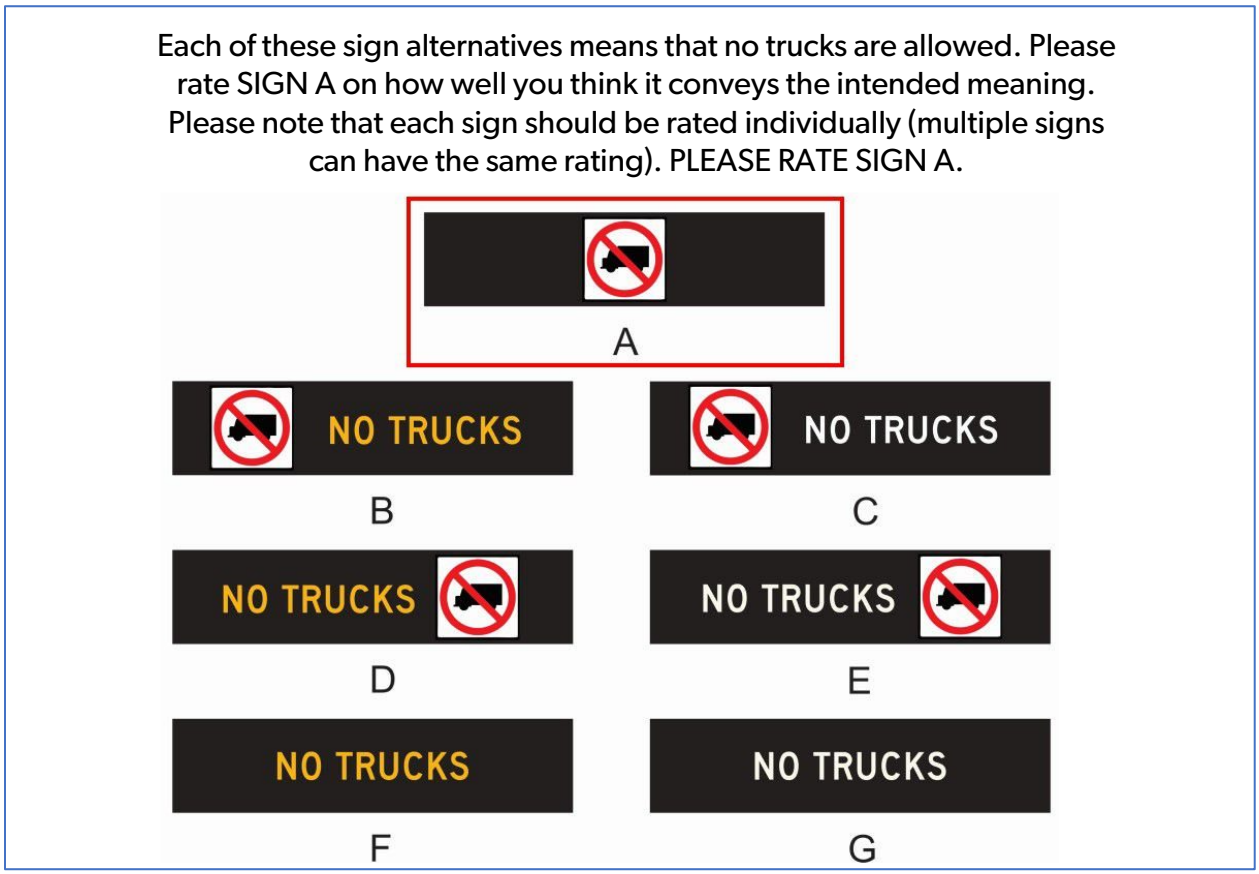


Figure 11. Graphic. Example rating question for No Trucks message category.
Source: Federal Highway Administration

After providing ratings for the No Trucks sign alternatives, participants were shown two No Trucks sign alternatives, displayed in figure 12, and were asked, "Do you think there is any difference in the meaning of these two signs?" Participants provided open-ended responses. The intent of this question was to determine if the different text colors (yellow vs. white) conveyed any difference in meaning to participants.

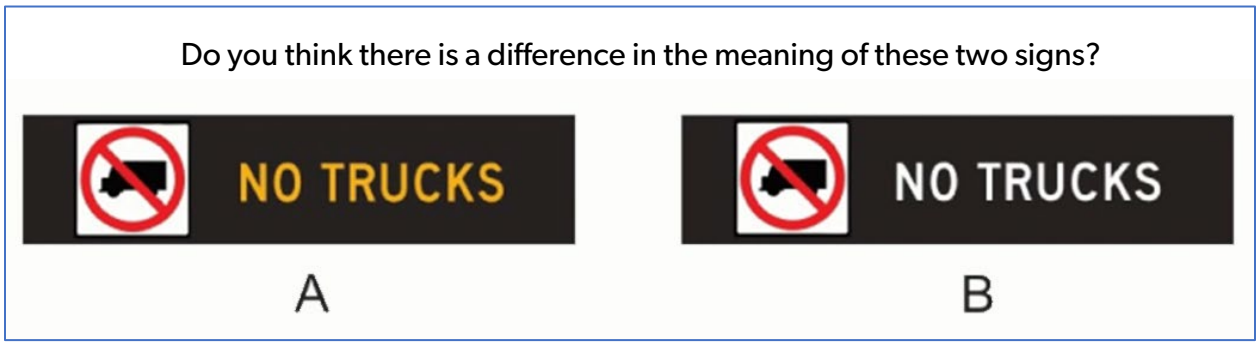


Figure 12. Graphic. Example follow-up question for No Trucks message category.
Source: Federal Highway Administration

The follow-up questions varied for each sign category depending on the type of information being gathered for that particular sign category. Table 6 lists the different questions asked for each sign category. Each question, along with relevant sign alternatives, are discussed in more detail in the Results section of this chapter.

Table 6. Type of Questions Asked for Each Sign Category

Sign Category	Comprehension / Reaction Time	First Follow-up Question	Second Follow-up Question	Third Follow-up Question	Fourth Follow-up Question
No Trucks	Open-Ended	Rating	Open-Ended	-	-
Speed Limit	Open-Ended	Rating	-	-	-
Slippery When Wet	Open-Ended	Open-ended	Rating	-	-
Road Work Ahead	Open-Ended	Rating	-	-	-
Ramp Closed	Open-Ended	Ranking	-	-	-
Concert Traffic	Open-Ended	-	-	-	-
Wipers On, Headlights On	Open-Ended	Rating	-	-	-
Don't Text and Drive	Open-Ended	Rating	-	-	-
HOV 2+	Open-Ended	Rating	-	-	-
Fasten Seat Belt	Open-Ended	Rating	-	-	-
Toll Costs	Open-Ended	Open-Ended	Open-Ended	Open-Ended	-
Travel Time	Open-Ended	Open-Ended	Open-Ended	Open-Ended	Rating
Road Closed Ahead	Open-Ended	Open-Ended	Open-Ended	Ranking	-

The open-ended questions that provided objective findings (e.g., comprehension, reaction time, legibility) were the primary measures used in determining the effectiveness of different message alternatives. Alternatively, the rating and ranking questions provided subjective findings, (i.e., based on personal opinion) and were therefore used as supplementary information to the objective findings. Ratings and rankings of message alternatives can often provide additional information (e.g., participant preference for one color over another) when two message alternatives are otherwise the same and/or perform the same for all other measures.

The comprehension testing took approximately 20 minutes to complete. Following the comprehension test, participants either continued to the legibility testing or were finished with the study depending on the testing location. Once participants completed the study, they were required to read a Debriefing Statement (Appendix E) and were able to ask any additional questions that they had about the study. Participants were then asked to sign a Payment Receipt Form (Appendix F) prior to receiving payment for participating.

Computer-Based Legibility Data Collection

The second portion of the laboratory study evaluated the legibility of different message alternatives in the different sign categories. The following research questions were addressed through the computer-based legibility testing:

- Is there an optimal placement of symbols in a message displayed on a color full-matrix CMS?
- Does the use of color help to convey messages more easily?
- When should symbols be used instead of text on color full-matrix CMSs?

The legibility testing occurred immediately following the completion of the comprehension testing for those participants who partook in the study at the Gainesville, VA location.

The legibility testing was conducted in dark conditions to minimize glare. Participants were seated approximately 4.5 feet away from the display and were asked to place their hand on a keyboard in front of them. The experimenter read the instructions for the legibility test out loud and gave participants the opportunity to ask questions. Once the participants fully understood the instructions, the experimenter initiated a practice test. The practice test consisted of eight practice signs that were different from the experimental messages to be displayed on the CMS. However, the procedure was the same. After the completion of the practice test, the experimenter answered any additional questions before initiating the legibility test.

The legibility testing was conducted using software that displayed one message on a CMS at a time on a plain black background. The sign started at a small size, to simulate a distance of 1000 feet away from the sign. The message gradually increased in size, at a simulated speed of 55 mph, as if the participants were driving toward the CMS. Participants were instructed to press the space bar on the keyboard as soon as the message being displayed became legible to them. The press of the space bar marked the legibility distance. As soon as the participants pressed the space bar, the sign disappeared from the screen and they were asked to describe what they saw on the sign. Participants were instructed to press the space bar as soon as they could make out the text and/or symbolic elements on the message; it did not matter if they knew the meaning of the message. If the participant's response indicated that the message on the CMS was legible to them, the experimenter proceeded to the next message. If their response indicated that the message displayed on the CMS was not fully legible to them, the message reappeared on the screen where it was previously stopped and continued to increase in size until the participant pressed the space bar again. This process was repeated for the display of approximately 130 messages.

Following the completion of the computer-based legibility test, participants were given a debriefing statement and were asked to sign a payment receipt form prior to receiving payment for participating in the experiment. The Debriefing Statement and the Receipt for Payment Form are included in Appendix E and Appendix F, respectively.

RESULTS

Computer-Based Comprehension Results

For each sign category, comprehension scores, reaction times, coded responses to open-ended follow-up questions, ratings, and rankings were analyzed with generalized linear models.

The laboratory comprehension results are presented in this section by sign category. A summary of the laboratory study findings by research question is provided in the Summary of Results section of this chapter.

No Trucks

The No Trucks messages garnered 100 percent correct interpretations (comprehension) by participants. There were no significant differences in reaction times by message alternatives. In giving their responses, 15 percent of participants also mentioned that these messages applied to a specific type of truck. However, this did not vary significantly by message alternative.

When asked if they thought there was a difference in the meaning of the two messages shown in figure 13, only 13 percent of participants perceived a difference in meaning between the two alternatives. The majority of those 13 percent mentioned that yellow text (Sign A) conveys more caution than the white text (Sign B). Participants tended to indicate that white text is more general or "normal" information, whereas yellow conveys a warning. One participant interpreted the yellow text (Sign A) as a warning and the white text (Sign B) as being "illegal" (i.e., regulatory).

Figure 13. Graphic. Image used for No Trucks comprehension testing
Source: Federal Highway Administration

Speed Limit

The Speed Limit messages garnered 99 percent comprehension by participants. Analysis of reaction times indicated that showing a depiction of the actual message (rather than text-only) was associated with 0.4s faster reaction time than average (p=.01), as shown in figure 14. This could be due to high familiarity with Speed Limit signs. Because of this, participants may recognize the message, see the number 50, and quickly know what the message is telling them, whereas the text-only messages may require slightly more time to read. Overall reaction time by message alternative is shown in figure 15.

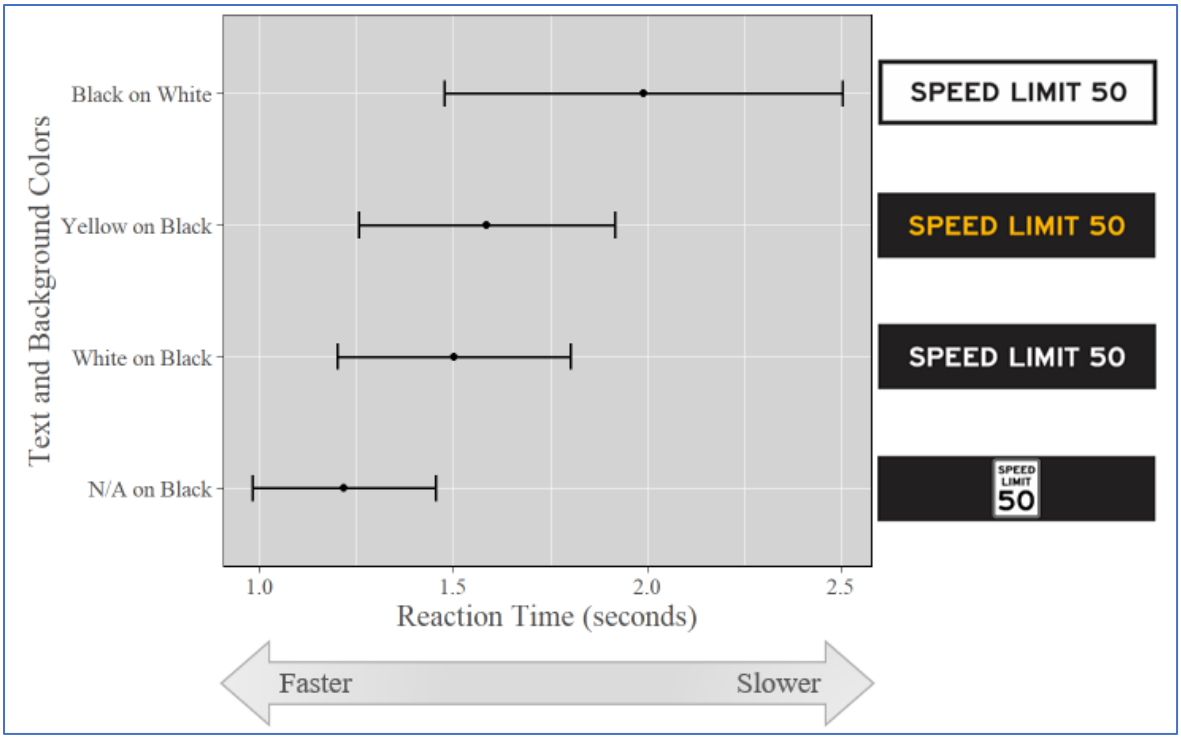


Figure 14. Graph. Speed Limit sign reaction times by text color.
Source: Federal Highway Administration

Marginal means show the average reaction time for each message alternative, averaged over levels of other variables, represented by black dots. Black bars represent 95 percent confidence intervals.

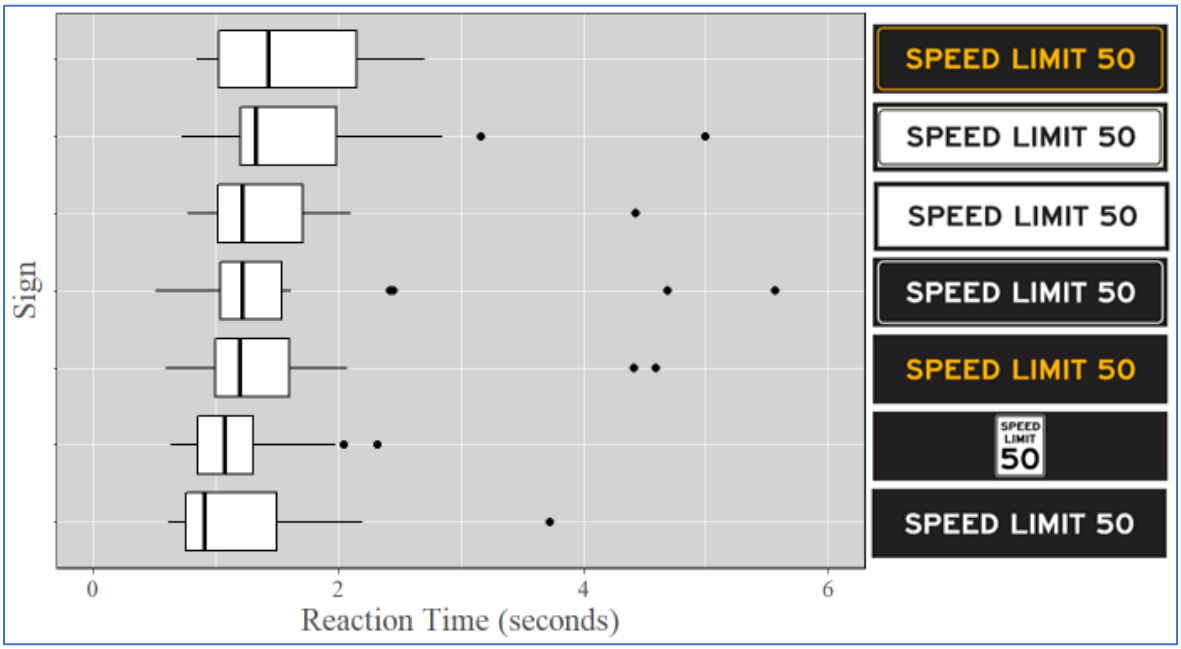


Figure 15. Graph. Reaction times for Speed Limit message comprehension.
Source: Federal Highway Administration

In figure 15, this box-and-whisker plot shows the 25th and 75th percentiles (outer edges of box) and median (vertical line in center of box) for reaction times for each message alternative. The horizontal lines extending from the boxes extend to 1.5 times the inter-quartile range (IQR) above and below the 75th and 25th percentile values, respectively. Black dots represent outliers as defined by the 1.5*IQR rule. (Note: One outlier is not shown in the graph above, an 11.7s reaction time for sign SL2).

When asked to rate each message alternative on how well they thought it would work to convey the intended meaning (to indicate the speed limit), participants also tended to rate the depiction/ image of the speed limit message higher than all other alternatives, as shown in figure 16. For the text-only alternatives, participants did not seem to have a clear preference for text/background colors.

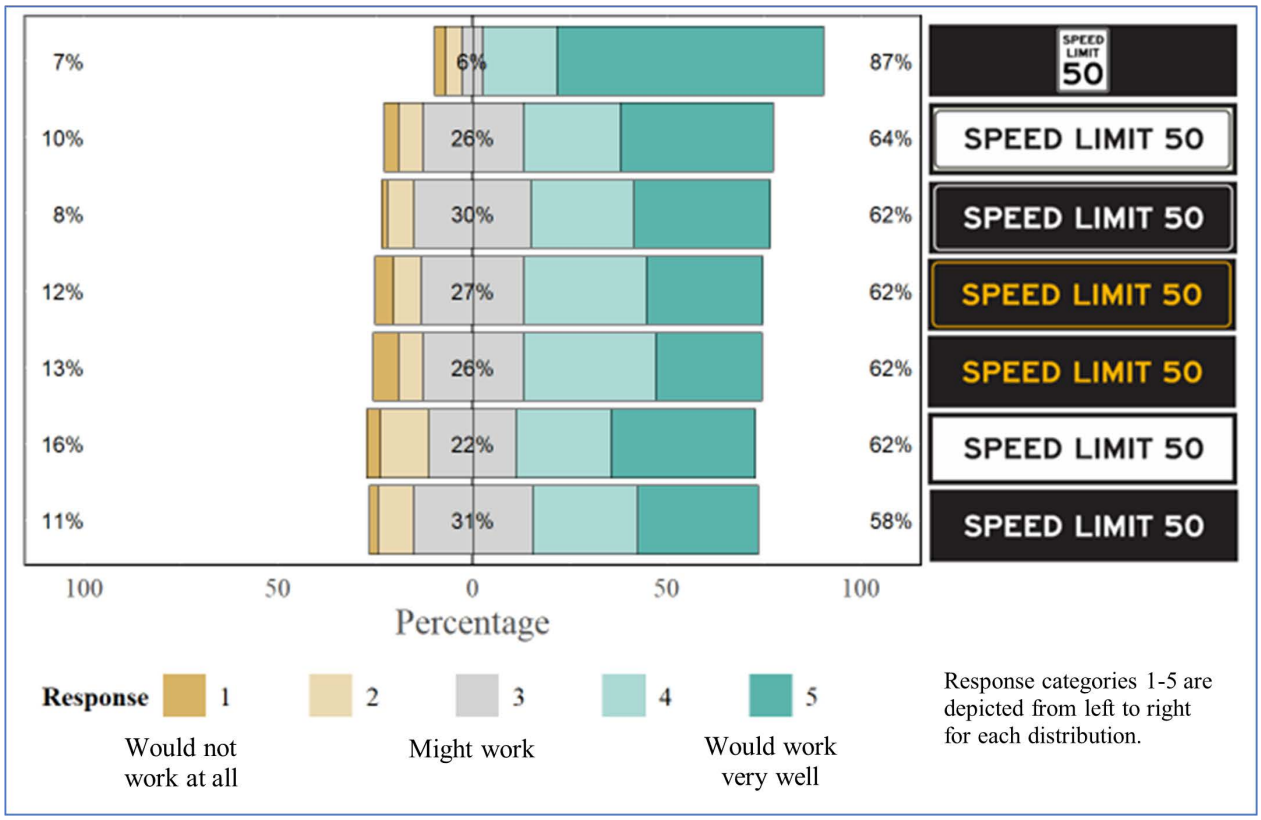


Figure 16. Graph. Participant ratings for Speed Limit message alternatives
***Source: Federal** Highway Administration*

Slippery When Wet

The Slippery When Wet messages garnered 95 percent correct interpretations by participants. There were no significant differences in correctness by each alternative, and no significant difference for reaction time. The correct interpretations were categorized by the specific wording that was used by participants. As shown in figure 17, there was more variation in the specific wording of correct responses for the symbol-only messages.

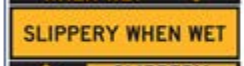
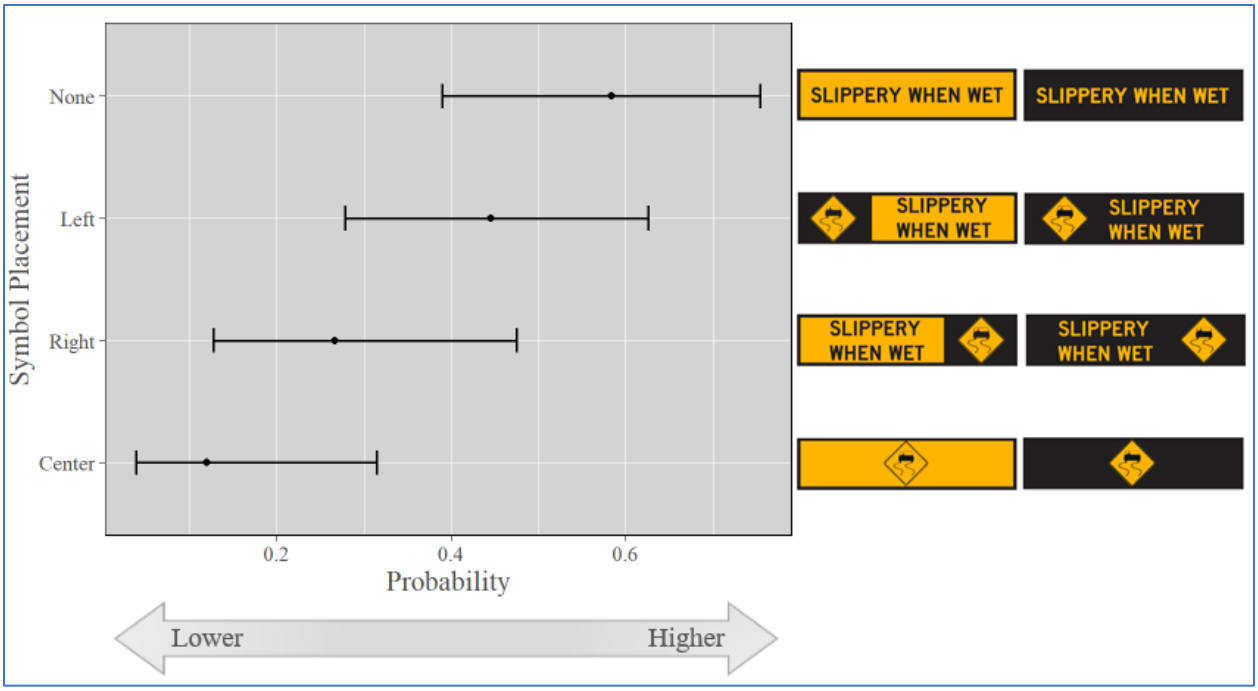
Correct Responses	"Road is slippery when wet"	"Road is slippery" OR "Slick roads ahead" (without specifying why)	Did not specify slippery, but identified wet or icy conditions	"Road is slippery OR wet"
	25%	50%	12.5%	12.5%
	100%	-	-	-
	95%	5%	-	-
	100%	-	-	-
	94%	6%	-	-
	31%	62%	-	8%
	100%	-	-	-
	100%	-	-	-

Figure 17. Chart. Specific wording for Slippery When Wet message correct comprehension responses
Source: Federal Highway Administration

The participants (5 percent) who provided incorrect responses viewed the symbol-only messages; however, correctness did not vary significantly by alternative. Incorrect participants either thought that the message meant "curvy roads ahead" or "possible swerving/hazards ahead."

Following the initial comprehension question, participants were then asked, "What action, if any, would you take if you saw this message displayed while driving?" The majority of participants (65 percent) indicated that they would slow down or be cautious, and 35 percent of participants indicated that they would act (e.g., slow down) depending on the weather or road conditions. For example, these participants were likely to say something like "I would slow down, *if* it was raining" or "I would be more cautious *if* the roads were wet." As shown in figure 18, the probability of indicating that they would act **and** mentioning weather/road conditions varies by sign alternative, with the symbol-only signs resulting in the lowest probability of participants mentioning weather or road conditions. This doesn't necessarily indicate that these participants didn't understand why they should slow down or be cautious, but rather that they were less likely to comment on the weather or road conditions.



Scale of probability ranges from 0 to 1, where 0 = will not indicate and 1 = will indicate.

Figure 18. Graph. Probability of participants indicating they would act based on displayed message mentioning weather/road conditions.

Source: Federal Highway Administration

Participants were then shown each message alternative, told the meaning (the roadway may be slippery when it's wet), and asked to rate each message on how well they think it would work to convey that meaning. As shown in figure 19, subjective ratings were higher for the message alternatives that included both the symbol and text, and ratings were slightly higher for messages displayed using black text (on yellow background) than for the messages displayed using yellow text (on black background).

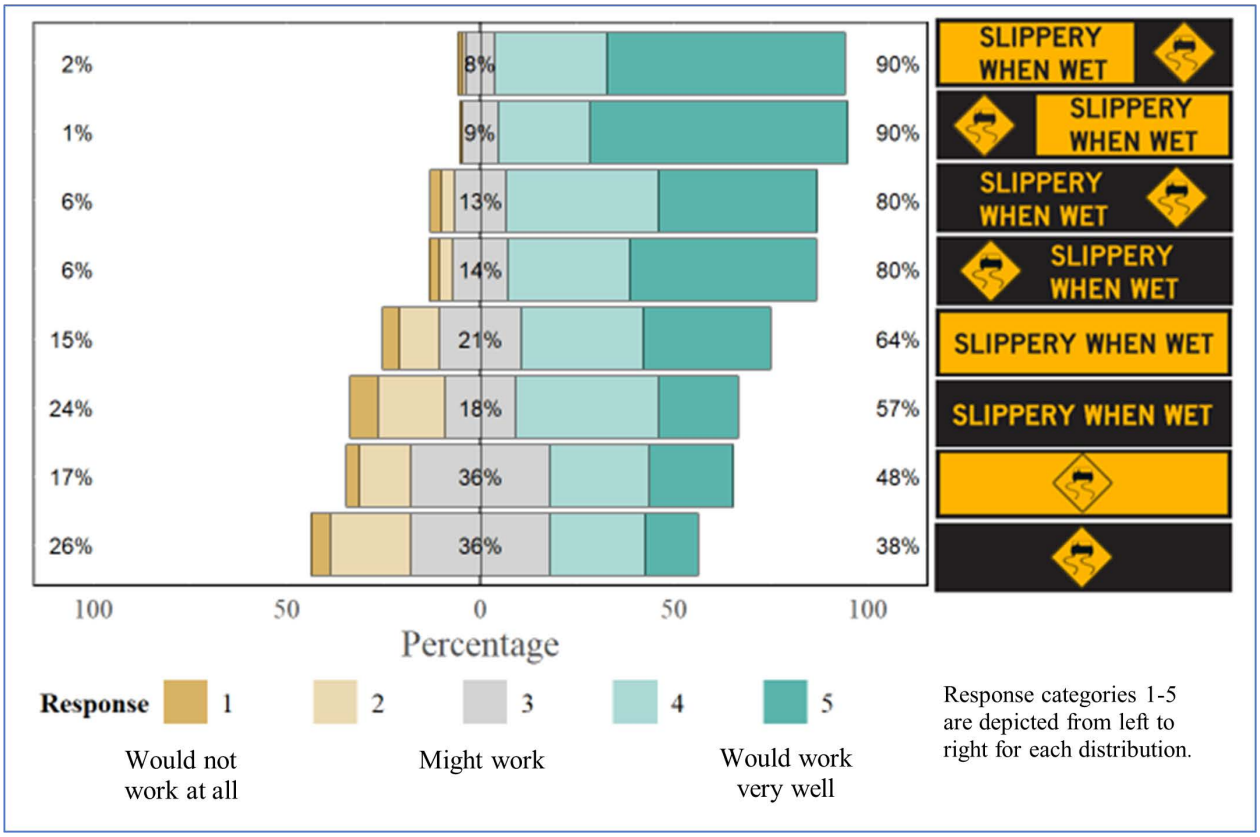


Figure 19. Graph. Participant ratings for Slippery When Wet message alternatives
Source: *Federal Highway Administration*

Road Work Ahead

The Road Work Ahead signs garnered 99 percent correct interpretations by participants. There were no significant differences in reaction time by message alternative.

Following the initial comprehension question, participants were shown each Road Work Ahead alternative, told the intended meaning of the message (there is road work ahead), and asked to rate each message alternative on how well they think it would work to convey that meaning. As shown in figure 20, subjective ratings were higher for the message alternatives that included both the symbol and text, and ratings were also slightly higher for the black-on-orange than for the white-on-black alternatives.

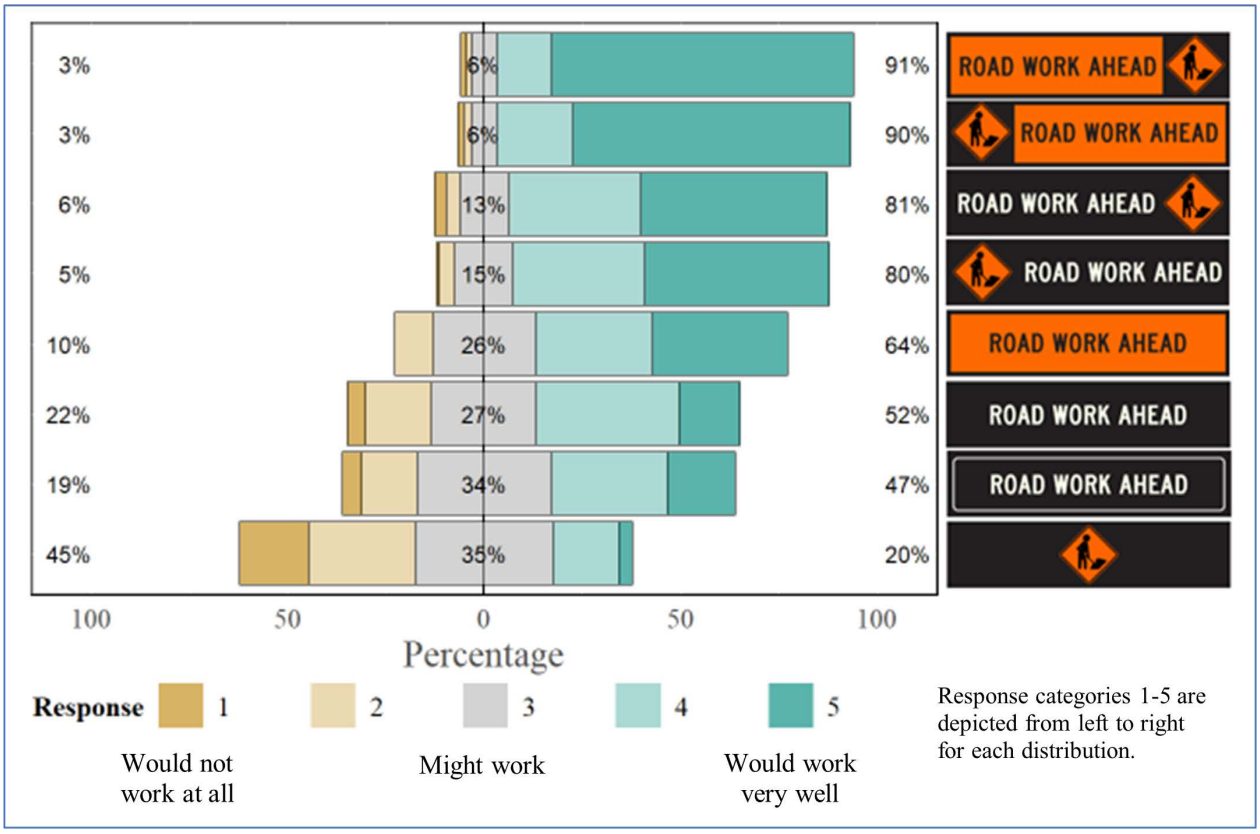


Figure 20. Graph. Participant ratings for Road Work Ahead message alternatives.
Source: Federal Highway Administration

Ramp Closed

For the Ramp Closed messages, participants were rated as incorrect (10 percent), partially correct (44 percent), or fully correct (46 percent) for the first comprehension question. Participants were considered fully correct if they indicated that the ramp to I-95 North was closed, and partially correct of they indicated that a ramp was closed but did not specify I-95 North. For example, these participants may have said "the ramp is closed" or "the ramp to I-95 South was closed." Figure 21 shows the level of correctness for each Ramp Closed sign alternative.

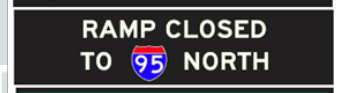
INCORRECT	PARTIALLY CORRECT (Ramp closed, but did not specify 95N)	CORRECT (Ramp to I-95 North is closed)	
11%	63%	26%	
11%	22%	67%	
5%	40%	55%	
3%	44%	53%	
15%	55%	30%	
18%	18%	64%	

Figure 21. Chart. Level of correctness for Ramp Closed message alternatives.
Source: Federal Highway Administration

There were statistically significant differences in the probability of being fully correct (versus partially correct) due to symbol placement in the message. As shown in figure 22, for the messages with black backgrounds, the probability of being fully correct was significantly higher when the route shield was placed to the left of the text (0.77) than when no route shield was used (0.29, $p < 0.05$). For messages with green backgrounds, the probability of being fully correct was significantly higher when the route shield was placed center (0.79), i.e., within the text, rather than when the route shield was placed to the left of the text (0.34, $p < 0.05$). There is no clear indication as to why these findings would differ based on background color, though it is possible that participants are simply more familiar with seeing guidance information on signs with green backgrounds, and thus this influenced their responses in some way.

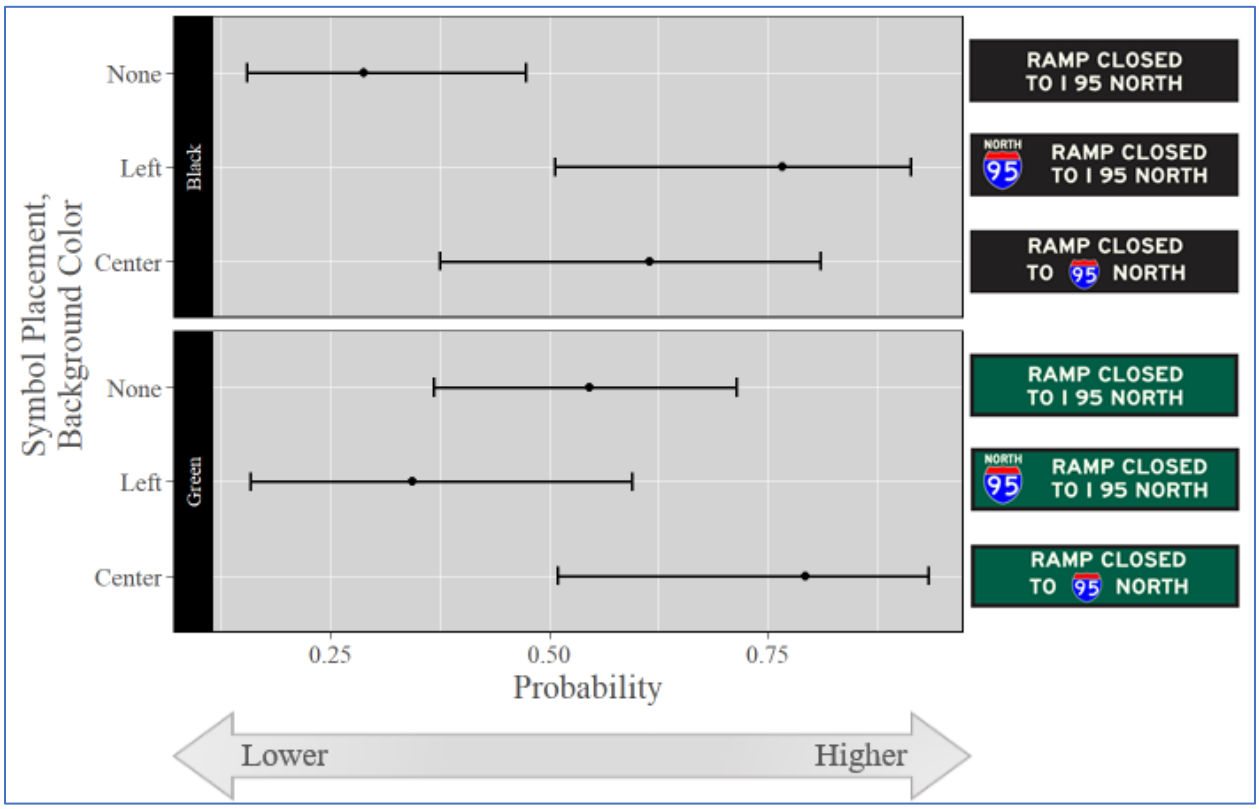


Figure 22. Graph. Probability of being fully correct by Ramp Closed message alternative.
Source: Federal Highway Administration

There were also significant differences in reaction times due to symbol placement, regardless of background color. The message alternatives with center symbol placement were associated with a 0.4 seconds faster reaction time than average ($p<0.01$), and message alternatives with left symbol placement were associated with a 0.6 seconds slower reaction time than average ($p<0.01$). The reaction times for all message alternatives are shown in figure 23, and reaction times by symbol placement (i.e., averaged across background color) are shown in figure 24.

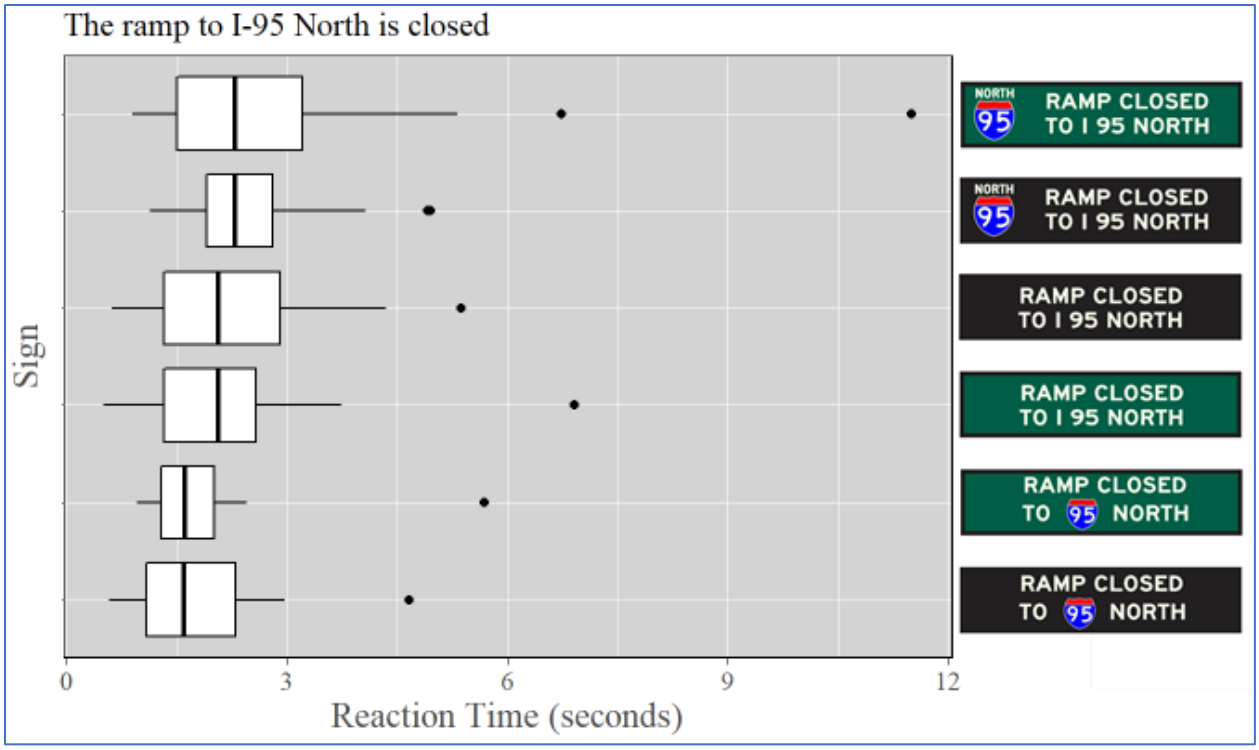


Figure 23. Graph. Reaction times for Ramp Closed message alternatives.
Source: Federal Highway Administration

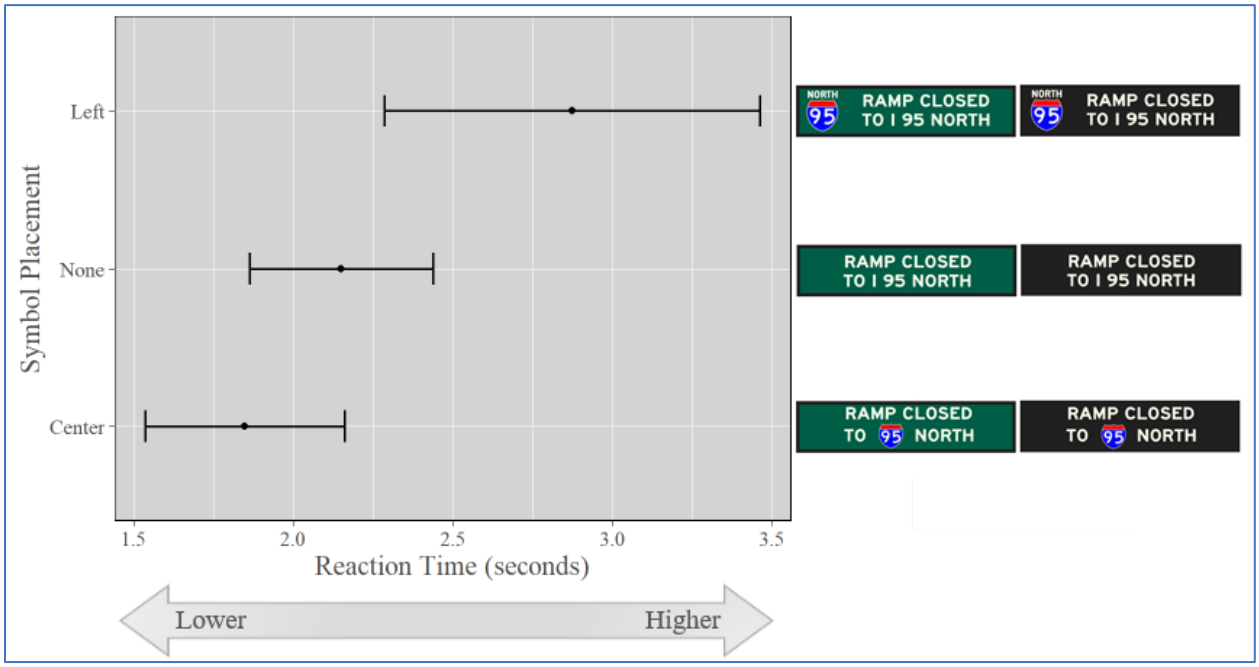


Figure 24. Graph. Ramp Closed reaction times by symbol placement.
Source: Federal Highway Administration

For the Ramp Closed messages, participants were shown three text-only messages, in three different text/background color combinations, and were asked to rank-order the messages based on their preference for each. Participants could use a mouse to drag and drop messages into their preferred order, placing the preferred message (best) on the top, followed by the message they preferred next, and so on until they had the messages ordered with the design they preferred best at the top and the message they preferred least at the bottom. Message rankings were recoded to numerical values between 1 and 3, with 1 indicating the highest ranking (preferred most), 2 indicating the next highest preferred second), and 3 indicating the lowest ranking (preferred least). As shown in figure 25, participant preference was similar for the white-on-green and yellow-on-black messages, which they preferred more (ranked higher) than the white-on-black messages.

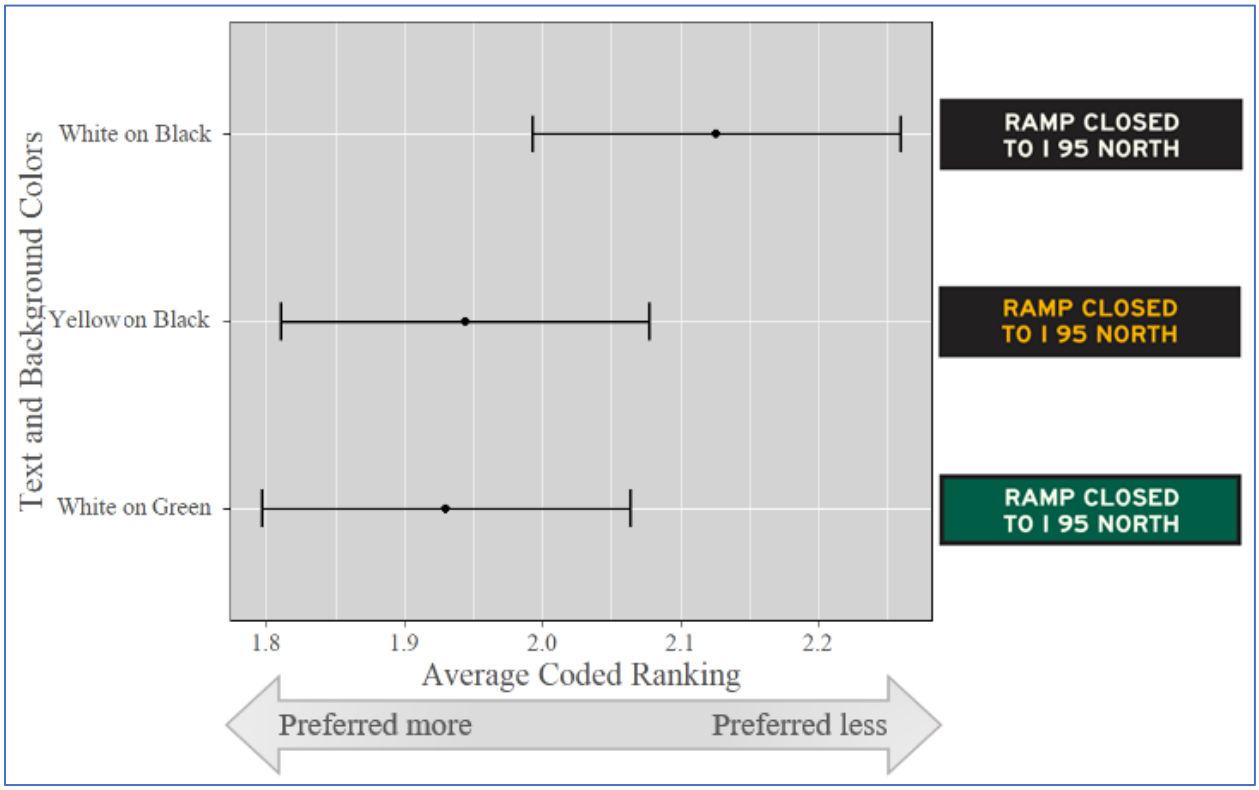


Figure 25. Graph. Participant preference (rankings) for Ramp Closed message design (color)

Source: Federal Highway Administration

Participants were then shown three white-on-green message alternatives using each of the three different symbol placements (text-only, symbol left, and symbol center) and were asked to rank-order their preferences for the design of the messages. Message rankings were recoded to numerical values between 1 and 3, with 1 indicating the highest ranking (preferred most), 2 indicating the next highest preferred second), and 3 indicating the lowest ranking (preferred least). As shown in figure 26, participant preference was similar for the symbol-left and symbol-center message alternatives, which they preferred more (ranked higher) than the text-only message alternative.

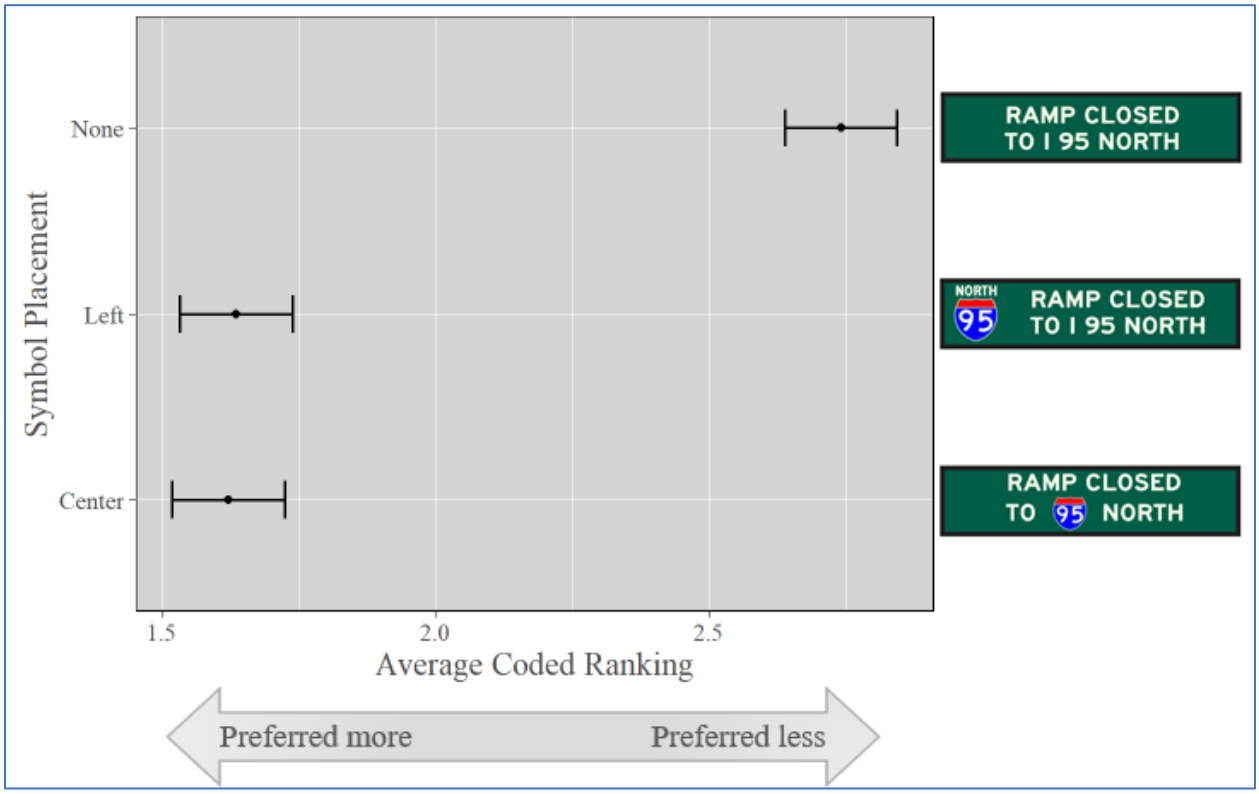


Figure 26. Graph. Participant preference (rankings) for Ramp Closed message design (symbol placement)

Source: Federal Highway Administration

Special Event

The Special Event messages signs garnered 69 percent correct interpretations (comprehension). Of the 31 percent of participants who were incorrect:

- Forty percent thought the message was telling them there would be traffic and they should use Exit 15 to bypass the traffic.
- Thirty-three percent thought the message was telling them to be aware that there would be congestion due to a concert.
- Twenty-seven percent were wrong for other reasons.

For the correct responses, there were no significant differences in reaction time by message alternative. Following the initial comprehension question, participants were shown each Special Event message alternative, told its intended meaning (vehicles going to the concert should use exit 15 to reach their destination), and asked to rate each message alternative on how well they thought it would work to convey that meaning. As shown in figure 27, there was very little variation in subjective ratings by message alternative, suggesting that participant preference was not influenced by text/background color or border presence.

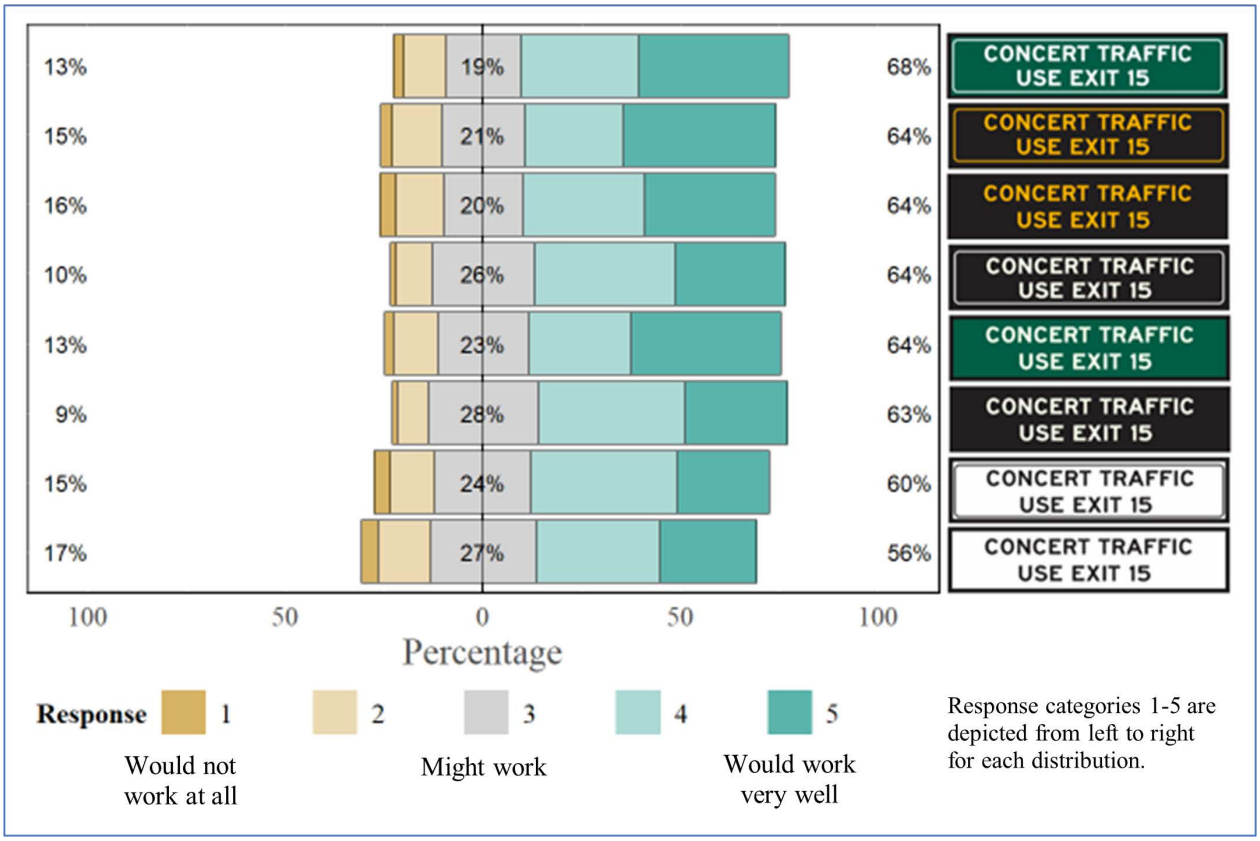


Figure 27. Graph. Participant ratings of Special Event (Concert Traffic) messages
Source: Federal Highway Administration

Wipers On, Headlights On

The Wipers On, Headlights On safety informational messages garnered 99 percent correct interpretations by participants. There were no significant differences in reaction time by alternative messages. Although this safety informational message is intended to indicate that if a driver's wipers are on, their headlights are encouraged to be turned on, the assessment of the test results determined the message would be achieving the intended goal if drivers turned on their headlights. Therefore, the correct interpretations were categorized by the specific wording that participants used in order to gain a better understanding of how participants interpreted the message. As shown in table 7, 43 percent of participants interpreted the exact meaning of the message: if your wipers are on, then your headlights should also be on. Forty percent of participants thought the message was telling them to turn on their wipers AND headlights, and

39 percent simply repeated the text in the message: "wipers on, headlights on." There were no significant differences in the interpretations of these alternative messages.

Table 7. Participant Interpretations of Wipers On, Headlights On Messages

Wipers AND Headlights On (Correct)	If Wipers Are On, Headlights Should Also Be On (Correct)	Wipers On, Headlights On (Correct)	It's Raining / Road Conditions (Incorrect)
40%	43%	39%	1%

As stated previously, if participants understood, in some form, that their headlights should be turned on, then the message ultimately achieved its goal. However, even if motorists understand the *meaning* of this safety information message, some motorists may not understand its *purpose*. For example, one participant was considered correct because they indicated that "I should turn my wipers and my headlights on," but continued that statement by saying "…maybe I'm driving through a dark tunnel that is leaking water." In a case like this, the ultimate goal (of turning the headlights on) may have been achieved, but the motorist may not have understood *why* they were doing this. In their responses, only 16 percent of participants mentioned rain and/or weather. However, it should be noted that these findings may be different if motorists are viewing the message in inclement weather conditions.

Don't Text and Drive

The Don't Text and Drive messages garnered 99 percent correct interpretations by participants. The test responses were assumed to be correct responses if participants interpreted that it was "illegal to text and drive" from the messages. Of the correct respondents, 99 percent did not mention the practice associated with the message was illegal. There were no significant differences in reaction time of participants with different message alternatives.

Following the initial comprehension question, participants were shown each Don't Text and Drive message alternative, were told the intended meaning of the message (it is illegal to text and drive), and were asked to rate each alternative on how well they thought it conveyed that meaning. As shown in figure 28, the black-on-yellow message (with and without border) were rated slightly higher than the other alternatives. After being told the intended meaning of the sign (i.e., it is *illegal* to text and drive), participants still had a slight preference for the black-on-yellow message design. This suggests motorists may not recognize the difference between something being a rule/law (regulatory) and a warning message displayed on a CMS based on color alone.

Perez, et al. (2016) found similar results when examining the use of regulatory versus advisory speed limit signs for active traffic management. The researchers indicated that participants misinterpreted advisory variable speed limit (VSL) signs as regulatory speed limit signs. The majority of participants correctly interpreted the white (regulatory) speed limit signs as a speed limit. However, the majority of participants also interpreted the yellow (advisory) speed limit signs as a regulatory speed limit as well.

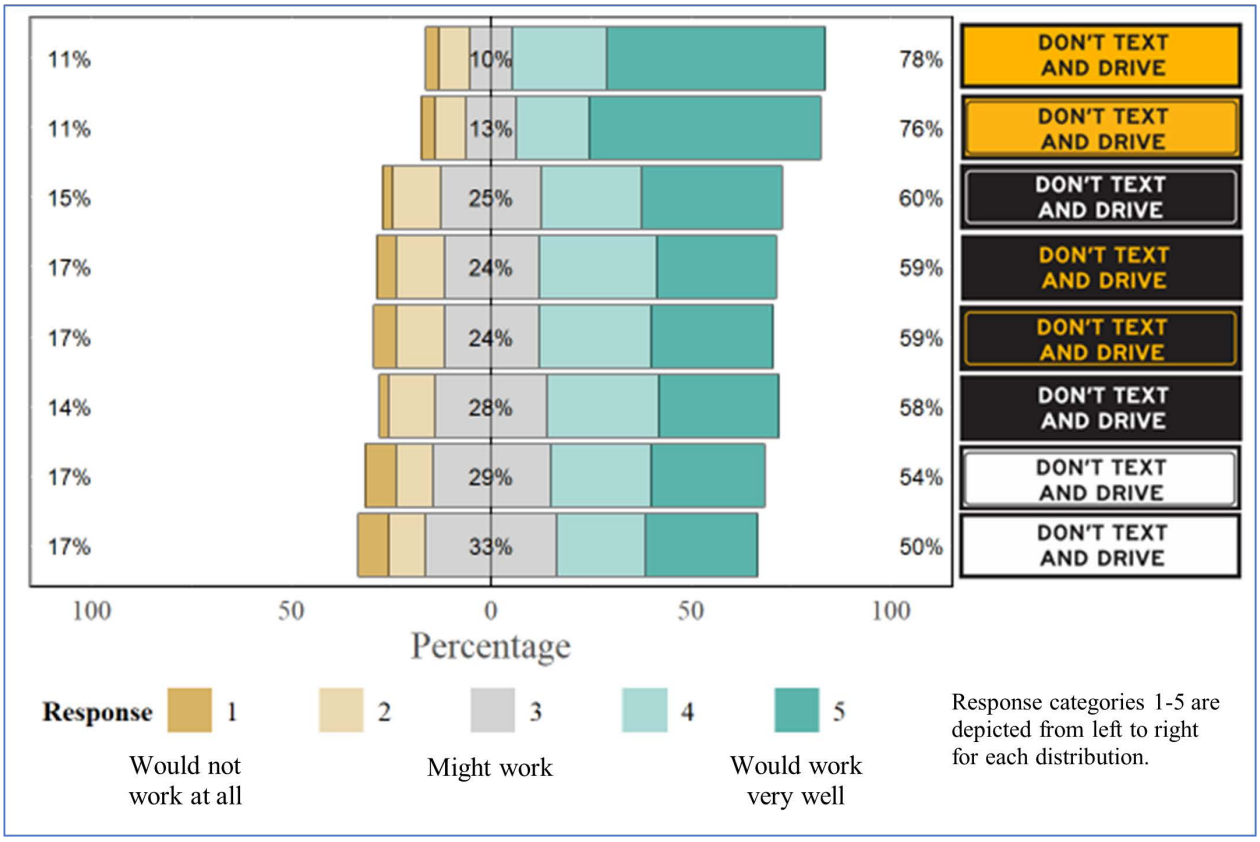


Figure 28. Graph. Participant ratings of Don't Text and Drive message alternatives.
Source: Federal Highway Administration

HOV 2+

For the HOV messages, participants' responses were rated as incorrect (3 percent), partially correct (7 percent), or fully correct (90 percent) for the first comprehension question. Participants' responses were considered fully correct if they mentioned the HOV component as well as the specific vehicle occupancy requirements (i.e., need 2 or more people to use the facility). Participants' responses were considered partially correct if they mentioned HOV, but did not mention the 2+ requirements, or got the occupancy requirements wrong. There were no significant differences in the participants' responses to how the occupancy requirement was included in the different messages.

There were significant differences in reaction times due to background color, regardless of message layout (symbol placement). The black-on-white (white background) message alternatives were associated with a 0.6 second faster reaction time than the white-on-black (black background) messages (p=0.01). These findings are depicted in figure 29 and figure 30. The messages in figure 30 represent the text/background colors only (regardless of message design).

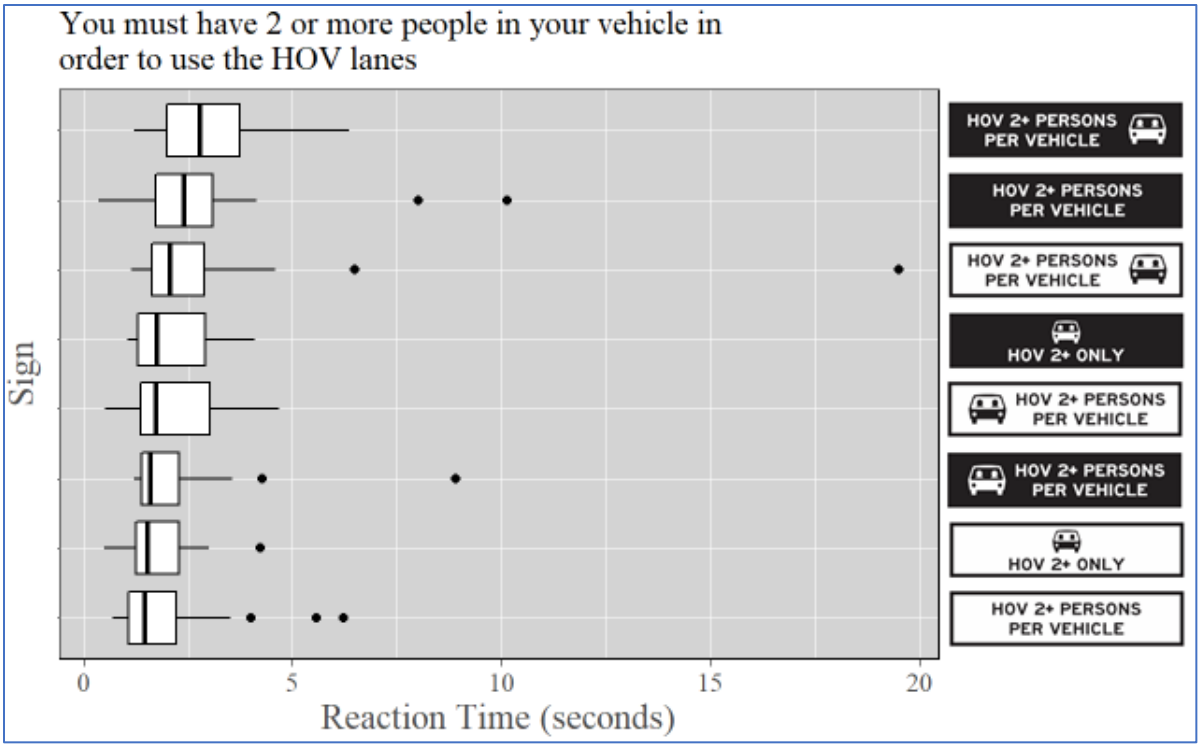


Figure 29. Graph. Reaction times for HOV 2+ messages.
Source: Federal Highway Administration

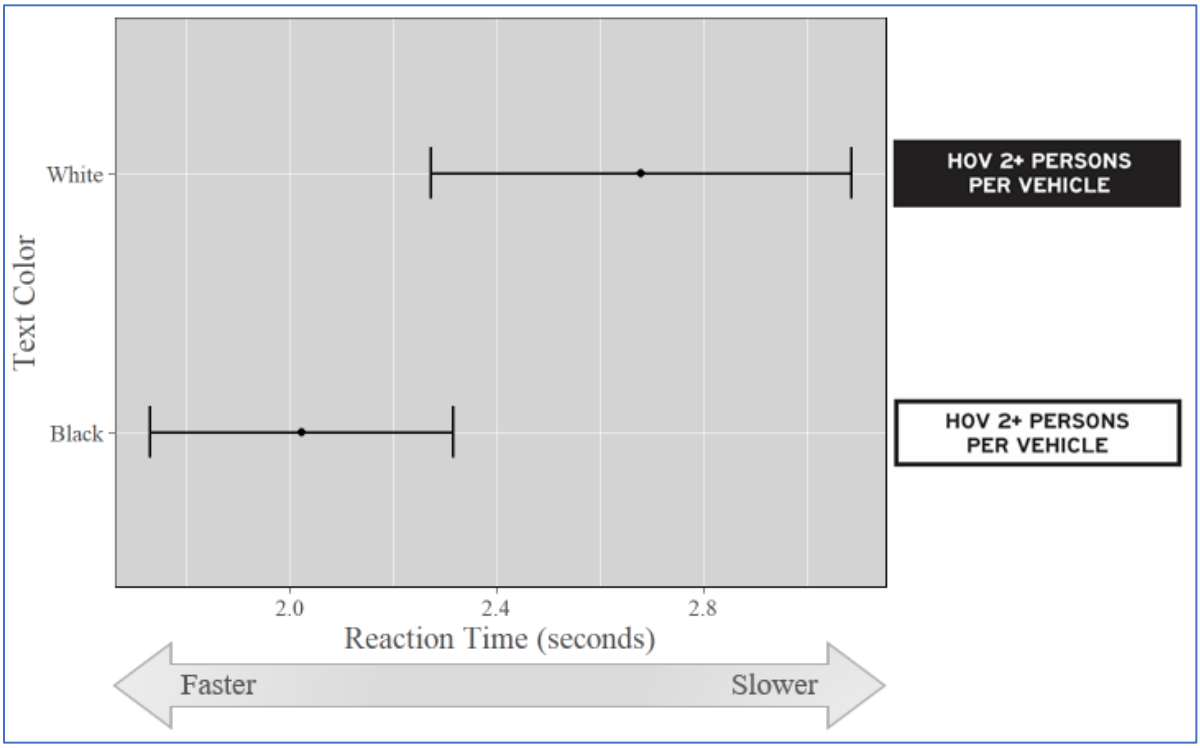


Figure 30. Graph. HOV 2+ reaction times by message color.
Source: Federal Highway Administration

Following the initial comprehension question, participants were shown each HOV message alternative, told the intended meaning (you must have 2 or more people in your vehicle in order to use the HOV lanes), and asked to rate each alternative on how well they think it would work to convey that meaning. As shown in figure 31, the message alternatives that included both text and symbols were rated higher than the text-only messages, regardless of text/background color combination.

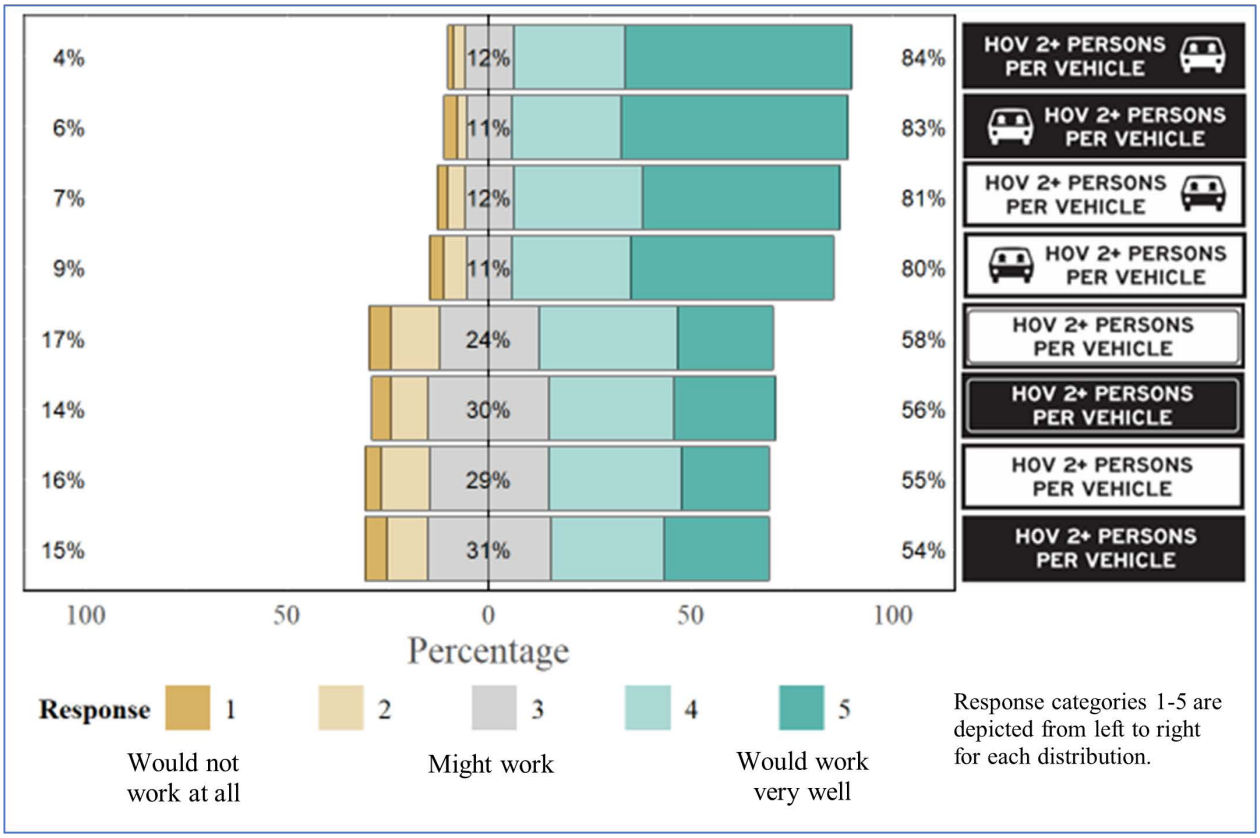


Figure 31. Graph. Participant ratings of HOV 2+ message alternatives.
Source: Federal Highway Administration

Fasten Seat Belt

The Fasten Seat Belt messages garnered 99 percent correct interpretations by participants. The research team reviewed correct responses to see if participants mentioned anything about it being illegal to drive without wearing your seat belt. Of the correct respondents, only 5 percent mentioned the requirement to drive wearing a seat belt. The mention of this requirement did not vary significantly by message alternative. There were also no significant differences in reaction time by message alternative.

Following the initial comprehension question, participants were shown each Fasten Seat Belt message alternative, told the intended meaning of each message, and asked to rate each alternative on how well they think it conveyed that meaning. As shown in figure 32, the message alternatives that included both text and symbols were rated higher than the text-only messages, regardless of text/background color combination.

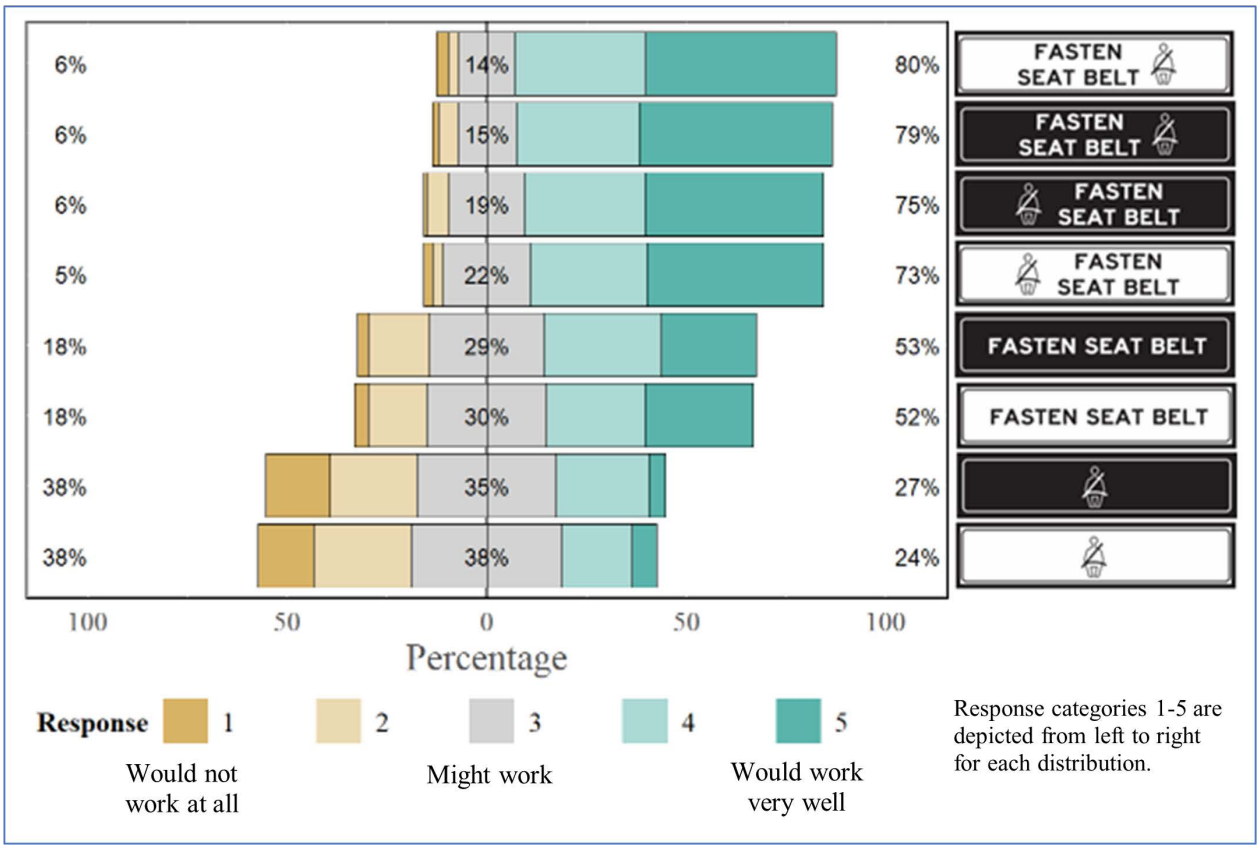


Figure 32. Graph. Participant ratings of Fasten Seat Belt message alternatives.
Source: Federal Highway Administration

Toll Cost

For the Toll Cost sign comprehension question, participants were told that they would see a message on a CMS that tells them the current toll cost to get to Washington. They were instructed to press the button as soon as they could determine the toll. The Toll Cost messages garnered 92 percent correct responses (comprehension). The white-on-green message alternatives were associated with higher rates of correct responses (see figure 33), though these differences were not statistically significant. There were no significant differences in reaction times by message alternative.

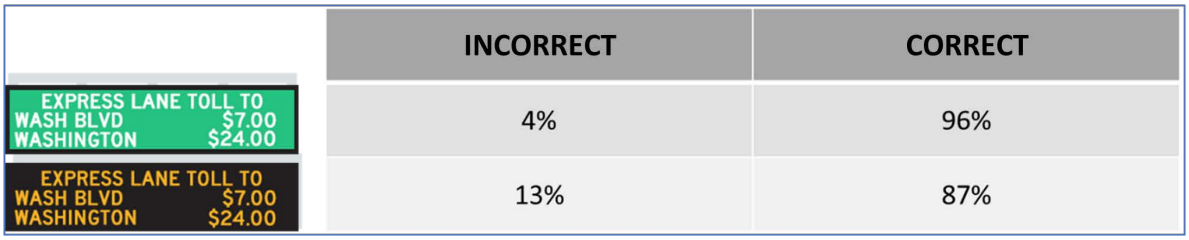


Figure 33. Chart. Toll Cost comprehension by text/background color.
Source: Federal Highway Administration

Following the initial comprehension question, participants were shown two messages (figure 34) and asked "Do you notice a difference between these two messages? If so, please describe any differences that you see." As shown in Table 8, only 4 percent of correct respondents mentioned something about the meaning of the color-coding.

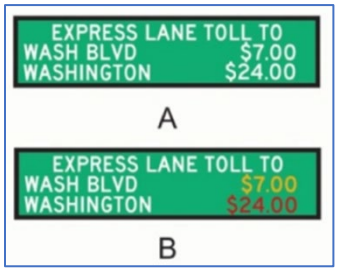


Figure 34. Graphic. Participants' responses when asked the question "Do you notice a difference between these two messages?" (Toll Cost)
Source: Federal Highway Administration

Table 8. Participant Response to "Do you notice a difference between these two messages?" (Toll Cost)

Yes, with general description of differences	Yes, and mentioned meaning of colors	Reported no differences
95%	4%	1%

Participants were then asked directly "What do you think the colors are telling you?" As shown in table 9, 43 percent of participants responded that there is no particular meaning to the colors and/or that they are just being used to distinguish between the two different prices. Younger participants were 2.5 times more likely to report a meaning to the colors than older participants. Overall, approximately half (54 percent) of participants provided responses that correctly reflected an understanding of the intended meaning of the color-coding, as indicated by columns two and three.

Table 9. Participant responses to "What do you think the colors are telling you?" (Toll Cost)

No Difference / Nothing / Distinguishing Between Prices / Unsure	Amount of Traffic	Relative to Normal Toll Cost / Cheap vs. Expensive	Distance / Farther Away vs. Closer	Other
43%	18%	35%	1%	3%

Travel Time

For the Travel Time message comprehension, participants were told that they would see a message that tells them how long it will take to get to Springfield. They were instructed to press the button as soon as they knew how long it would take to travel to Springfield. The Travel Time messages garnered 95 percent correct responses. There were no significant differences in reaction time by message alternative.

Following the initial comprehension question, participants were shown two messages (figure 35) and asked "Do you notice a difference between these two messages? If so, please describe any differences that you see." As shown in table 10, only 12 percent of correct respondents mentioned something about the meaning of the color-coding.

Figure 35. Graphic. Messages shown to participants when asked "Do you notice a difference between these two messages?" (Travel Time)
Source: Federal Highway Administration

Table 10. Participant responses to "Do you notice a difference between these two messages?" (Travel Time)

Yes, with general description of differences	Yes, and mentioned meaning of colors	Reported no differences
88%	12%	-

Participants were then asked directly "What do you think the colors are telling you?" As shown in table 11, 22 percent of participants responded that there is no particular meaning to the colors and/or that they are just being used to distinguish between the two different times. Overall, the majority of participants (71 percent) indicated an understanding of the meaning of the color-coding.

Table 11. Participant responses to "What do you think the colors are telling you?" (Travel Time)

No Difference / Nothing / Distinguishing Between Times / Unsure	Amount of Traffic	Relative to Normal Travel Time	Distance / Farther Away vs. Closer	Other
22%	38%	33%	4%	3%

Road Closed Ahead

The Road Closed Ahead messages garnered 97 percent correct interpretations. There were no significant differences in reaction time by message alternative.

Following the initial comprehension question, participants were shown each Road Closed Ahead message alternative, told the intended meaning of the message (the road that they are currently driving on is closed ahead), and asked to rate each alternative on how well they think it would work to convey that meaning. As shown in figure 36, the black-on-yellow message alternative received the highest subjective ratings, followed by the yellow-on-black alternative.

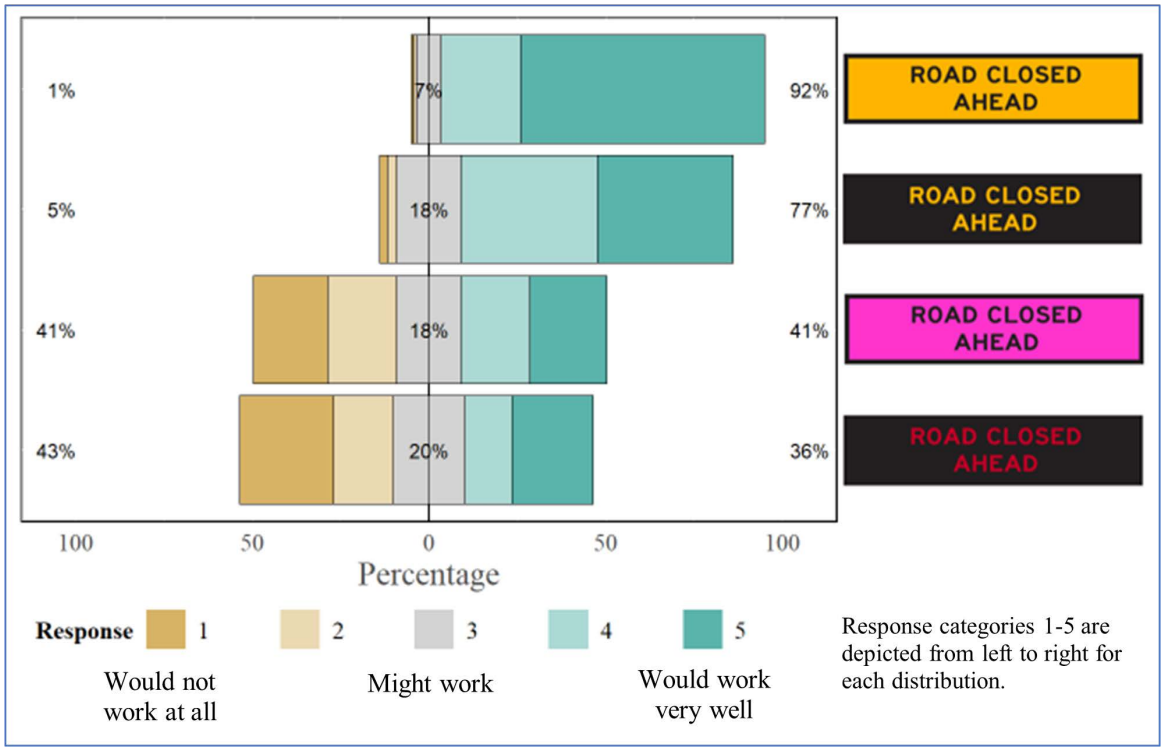


Figure 36. Graph. Participant ratings for Road Closed Ahead Messages
Source: Federal Highway Administration

Following the initial comprehension question, participants were shown all four message alternatives (figure 37) and asked "Do you think there is any difference in the meaning of these 4 signs?" The majority (83 percent) of participants indicated that there was no difference in the meaning of the four messages. Participants were then asked, "What do you think the different sign colors are telling you?" As shown in table 12, 46 percent of participants indicated the colors weren't telling them anything, or they didn't know what the colors were supposed to be telling them. Alternatively, 54% percent of participants thought the different colors conveyed different meanings and/or were used to attract attention.

Figure 37. Graphic. Messages shown to participants for "Do you think there is any difference in the meaning of these four signs?" question (Road Closed Ahead)
Source: Federal Highway Administration

Table 12. Participant responses to "Do you think there is any difference in the meaning of these four signs?" (Road Closed Ahead)

Don't Know / Nothing	Condition / Reason it's Closed	Don't think it's telling anything (or don't know), but colors are to attract attention	Certain colors telling you to be more cautious or alert (some more serious, hazardous, or urgent than others)
46%	10%	11%	33%

Of the participants (10 percent) who thought the colors were telling them the conditions or reason the road is closed, 47 percent thought that the yellow (Message D) meant that there was road work or construction, and 27 percent thought the pink (Message B) meant something "not normal" or temporary (e.g., crash or special event).

The participants (11 percent) who thought the colors were used to attract attention tended to say that the pink (Message B) and yellow (Message D) signs stood out more than the others. Participants mentioned that the pink stands out because it is a color rarely used in road signs. One participant mentioned that Messages B and D draw more attention to the background, whereas Messages A and C draw attention to the words. Multiple participants mentioned that the red text (Message C) is hard to read.

Of the 33 percent of participants who thought certain colors were telling motorists to be more cautious or alert (or that some were more hazardous, serious, or urgent than others), people tended to interpret the color yellow (Messages A & D) as conveying caution. Further, participants tended to think that the yellow background (Message D) conveyed more caution than yellow text (Message A).

Although most participants indicated that the red text (Message C) was hard to read, they tended to interpret the color red as being a stronger warning than the color yellow. Some examples of this include:

- Red is stronger warning than yellow.
- Yellow is caution, red is extreme caution.
- Yellow means detour, red means turn around.
- Yellow – road closed ahead, red – road closed right in front of you.
- Yellow means caution, red means danger or stop.

In general, participants did not know what the pink sign (Message B) was supposed to mean. Several participants described it as "weird" and/or stated that they didn't think it should be used.

Participants were then asked to rank-order the Road Closed Ahead message based on how urgent they perceived the message to be. Participants were instructed to drag and drop the sign alternatives in order so the message they thought was the most urgent was on the top and the least urgent was on the bottom. Rankings were recoded to numerical values between 1 and 4 with 1 indicating the highest ranking (most urgent) and 4 indicating the lowest ranking (least urgent). As shown in Figure 38, the black-on-yellow message was ranked as conveying the most urgency, and the black-on-pink ranked as conveying the least urgency.

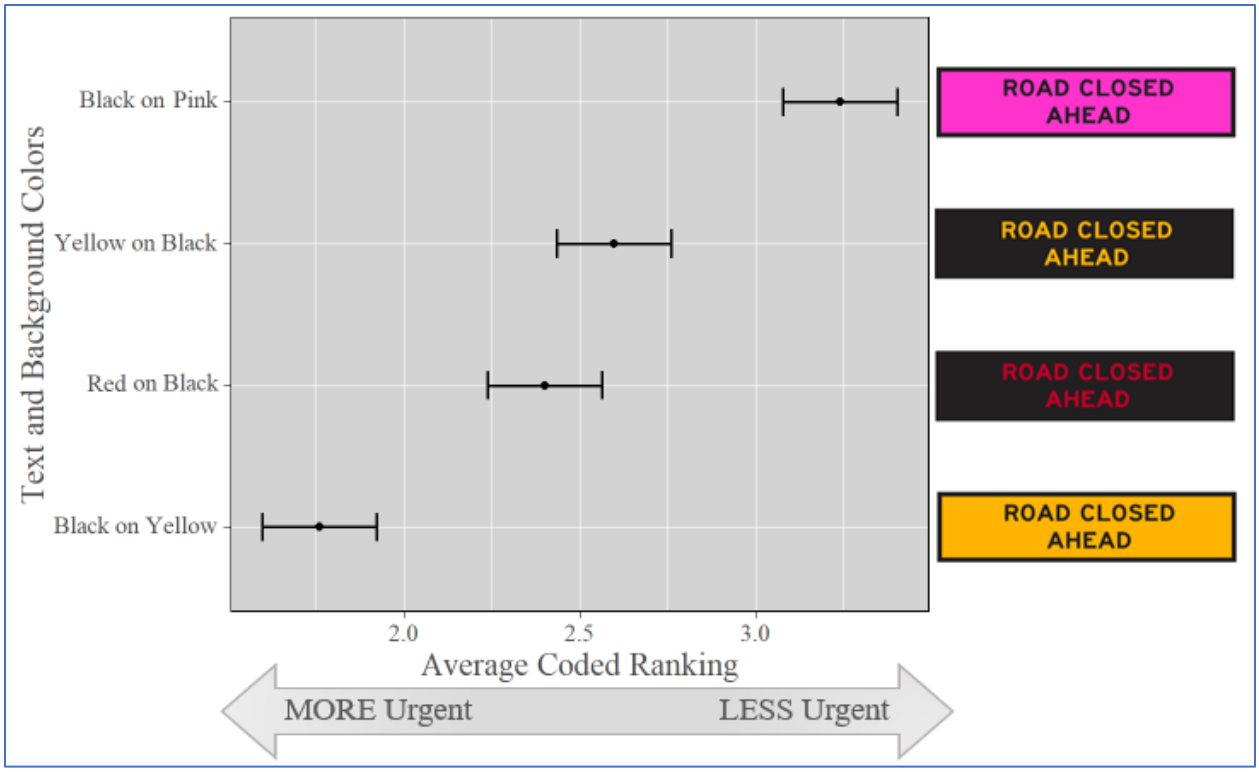


Figure 38. Graph. Participant ranking of Road Closed Ahead message by conveyed urgency

Source: Federal Highway Administration

Computer-Based Legibility Results

For each message category, data were analyzed using a mixed-effects linear model to estimate legibility distance as a function of different message variables (e.g., text/background color combination, symbol placement, border presence). Color (text, background), symbol placement, and border presence were used as fixed effects, participant vision score as random effects, with participant-specific intercepts.

The laboratory legibility results are presented in this section by sign category. A summary of the laboratory study findings by research question is provided in the Summary of Results section of this chapter.

No Trucks

When examining legibility distance as a function of symbol placement (i.e., averaging over level of text color), legibility distances were significantly shorter (mean=530ft) when viewing symbol-only messages compared to when viewing messages with a symbol on the left (m=617ft, p<.0001), messages with a symbol on the right (m=613ft, p<.0001), text-only messages(m=609ft, p<.0001), and messages with a symbol in the top center (m=569ft, p<.0001). The message alternatives that had the symbol in the top center (i.e., above the text) also had significantly shorter legibility distances than the message alternatives with symbol to the left

(p<.0001), symbol to the right (p<.0001), and text-only messages (p<.0001). These findings are depicted in figure 39.

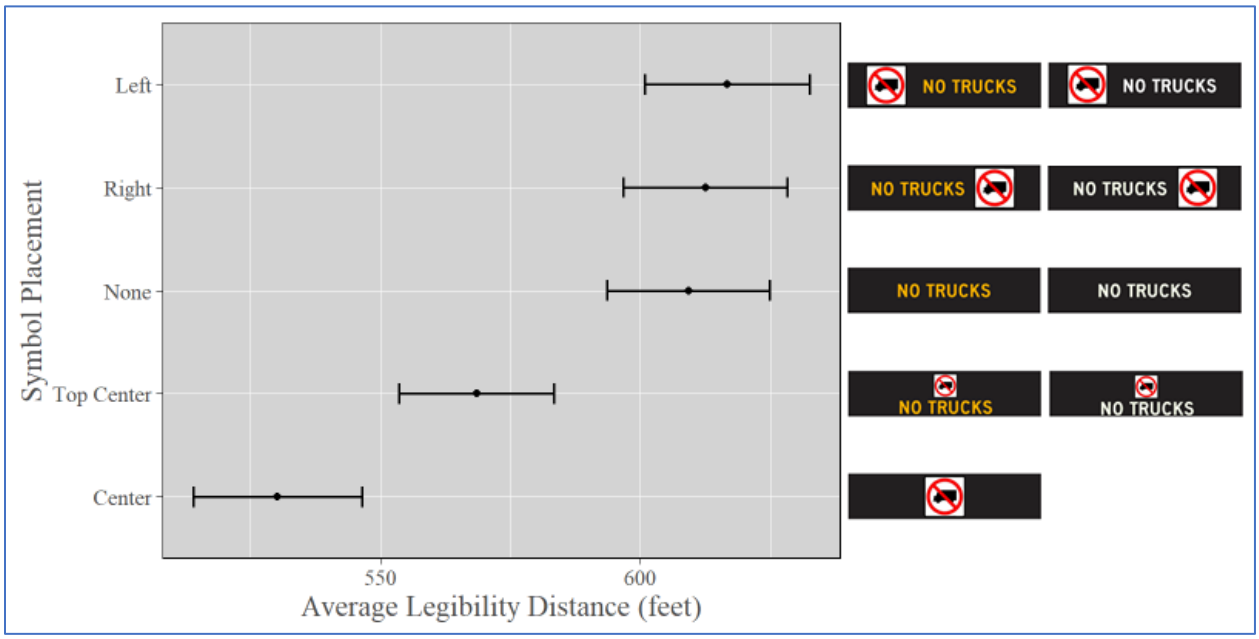


Figure 39. Graph. Average legibility distance of No Trucks message by symbol placement
Source: Federal Highway Administration

When exploring symbol placement by text color, there was a significant difference in legibility distances when the symbol was to the right of the text. In this case, the white text had longer legibility distances than the yellow text (p=.04).

Speed Limit

When estimating legibility distance as a function of text color (i.e., averaging over level of border presence), legibility distances were significantly shorter (m=531ft) for the message alternative depicting the speed limit sign image than they were for the other alternatives including white text (m=624ft, p<.0001), black text (m=615ft, p<.0001), and yellow text (m=613ft, p<.0001). There were no significant differences between the three text colors. These findings are depicted in figure 40.

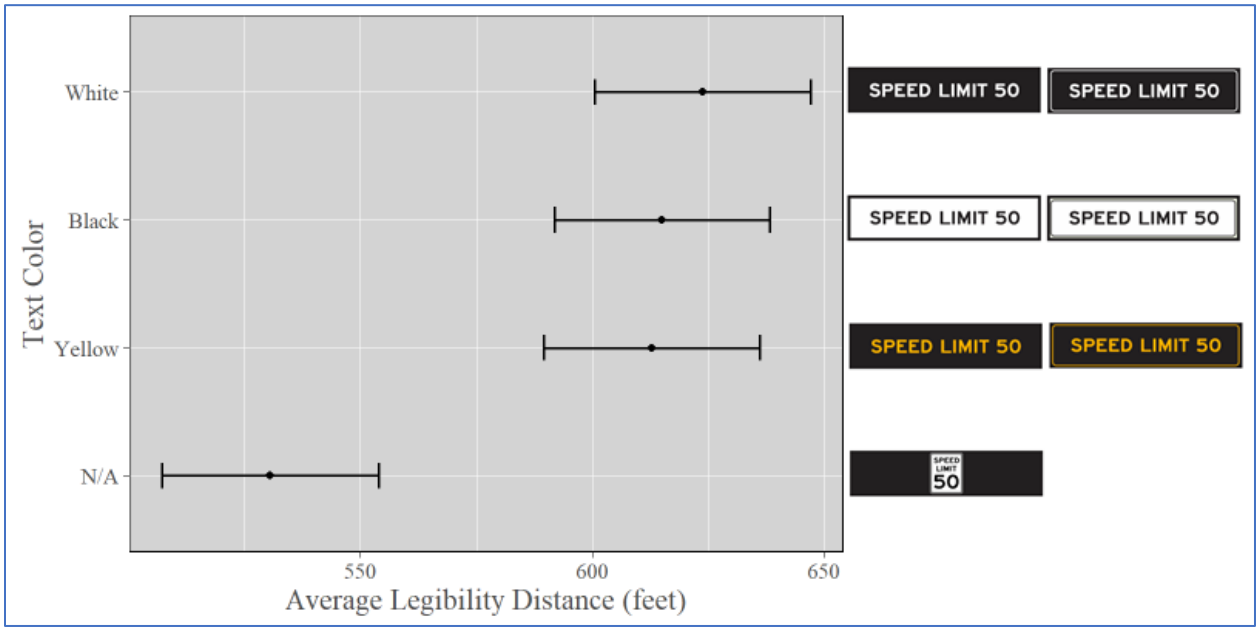


Figure 40. Graph. Legibility distance for Speed Limit message by text color.
Source: Federal Highway Administration

When examining border presence within each text color, there was a significant difference in legibility distances for the black-on-white message alternatives. The black-on-white message without a border had significantly longer legibility distances than those with a border (p<.0001).

Slippery When Wet

When estimating legibility distance as a function of symbol placement (i.e., averaging over level of text color), legibility distances were significantly shorter (mean=339ft) when viewing symbol-only message alternatives compared to when viewing the other message alternatives including text-only (m=580ft, P<.0001), symbol right (m=573ft, P<.0001), symbol left (m=565ft, P<.0001), and symbol top center (m=543ft, P<.0001). These findings are depicted in figure 41

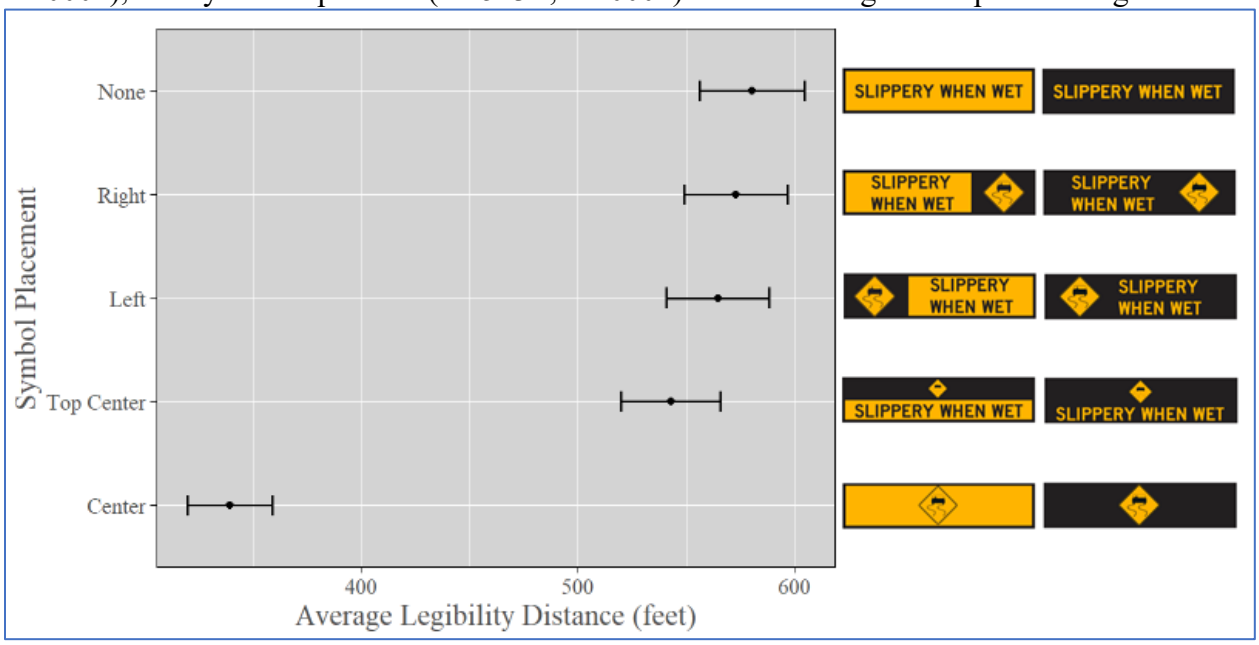


Figure 41. Graph. Legibility distance of Slippery When Wet messages by symbol placement.

Source: Federal Highway Administration

When exploring differences between text color (yellow or black) within each level of symbol placement (left, right, top center, text-only), there were no significant differences by text color, except for the text-only message. For the text-only alternatives, the average legibility distance for the message alternative with yellow text on a black background (m=598ft) was significantly longer than with black text on a yellow background (m=563ft, p<.05). These findings are depicted in figure 42.

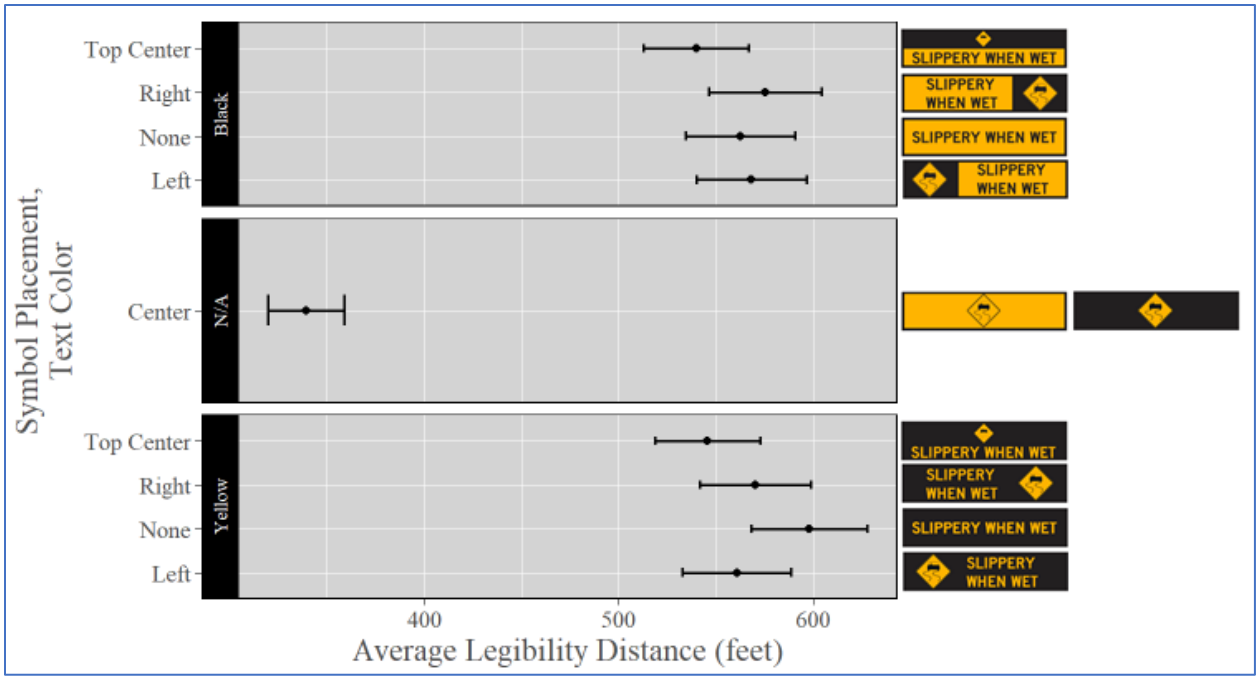


Figure 42. Graph. Legibility distance for Slippery When Wet messages by symbol placement and text color.
Source: Federal Highway Administration

Road Work Ahead

When estimating legibility distance as a function of symbol placement (i.e., averaging over level of text color and border presence), legibility distances were significantly shorter (mean (m)=452ft) for the symbol-only message alternative than for all other alternatives, including text-only (m=566ft, P<.0001), symbol right (m=566ft, P<.0001) and symbol left (m=573ft, P<.0001). These findings are shown in figure 42. The message examples included in figure 43 represent the variable of symbol placement only (i.e., averaged across all levels of text/background color).

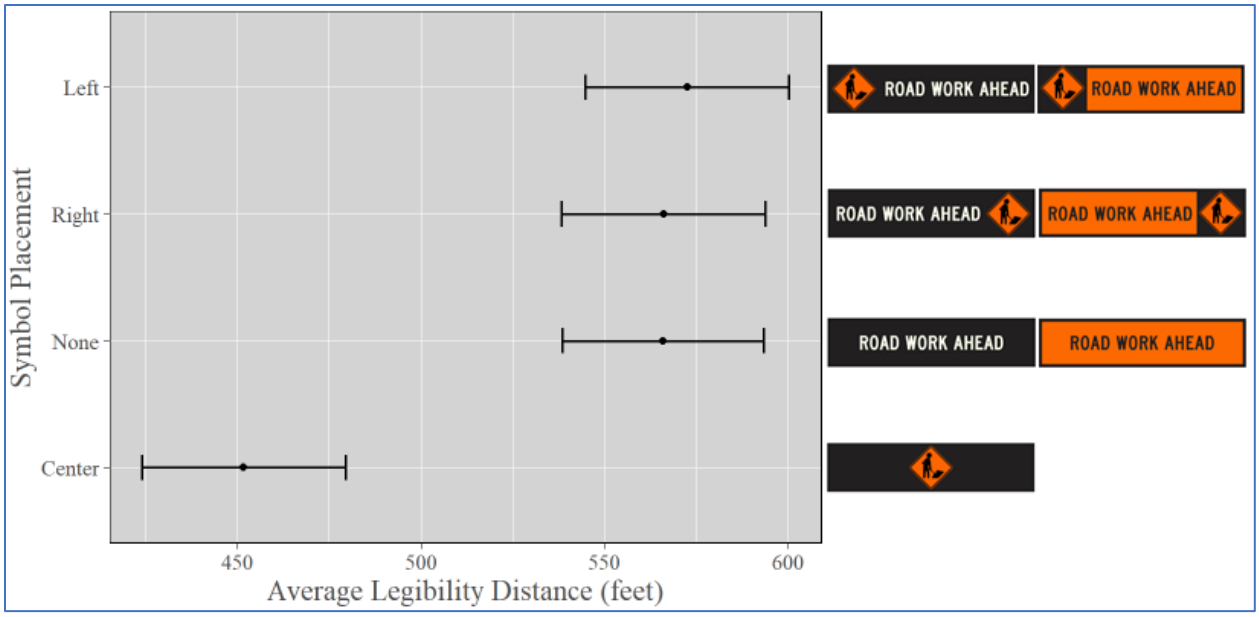


Figure 43. Graph. Legibility distance for Road Work Ahead message by symbol placement.
Source: Federal Highway Administration

When estimating legibility distance as a function of text/background color (i.e., averaging over level of symbol placement and border presence), the black-on-orange message had significantly shorter legibility distances (m=552) than both the white-on-black messages (m=570, p<.001) and the yellow-on-black messages (m=570, p<.001).

When estimating legibility distance as a function of symbol placement and text color (i.e., averaging over level of border presence), the symbol-only message had significantly shorter legibility distances than all other alternatives (p<.0001). For message alternatives with white text, the message with the symbol on the left had significantly longer legibility distances than the text-only message (p<.001). For the text-only message, the sign alternative with yellow text had significantly longer legibility distances than the message with the white text (p<.005).

Only two message alternatives in this category included a border. There were no significant differences in legibility due to border presence.

Ramp Closed

When estimating legibility distances as a function of symbol placement (i.e., averaging over level of text/background color combination), there were no significant differences between the message alternatives with no symbol (text-only), the symbol (route shield) to the left of the text, and the symbol (route shield) within the text.

When exploring legibility distance as a function of symbol placement by text/background color combination, there were no significant differences in legibility distance by symbol placement for the white-on-black or the white-on-green messages. However, for the yellow-on-black messages, the average legibility distance for the alternative with the symbol (route shield) within the text was significantly longer than the legibility distance for the alternative with no symbol (text-only). This finding is depicted in figure 44.

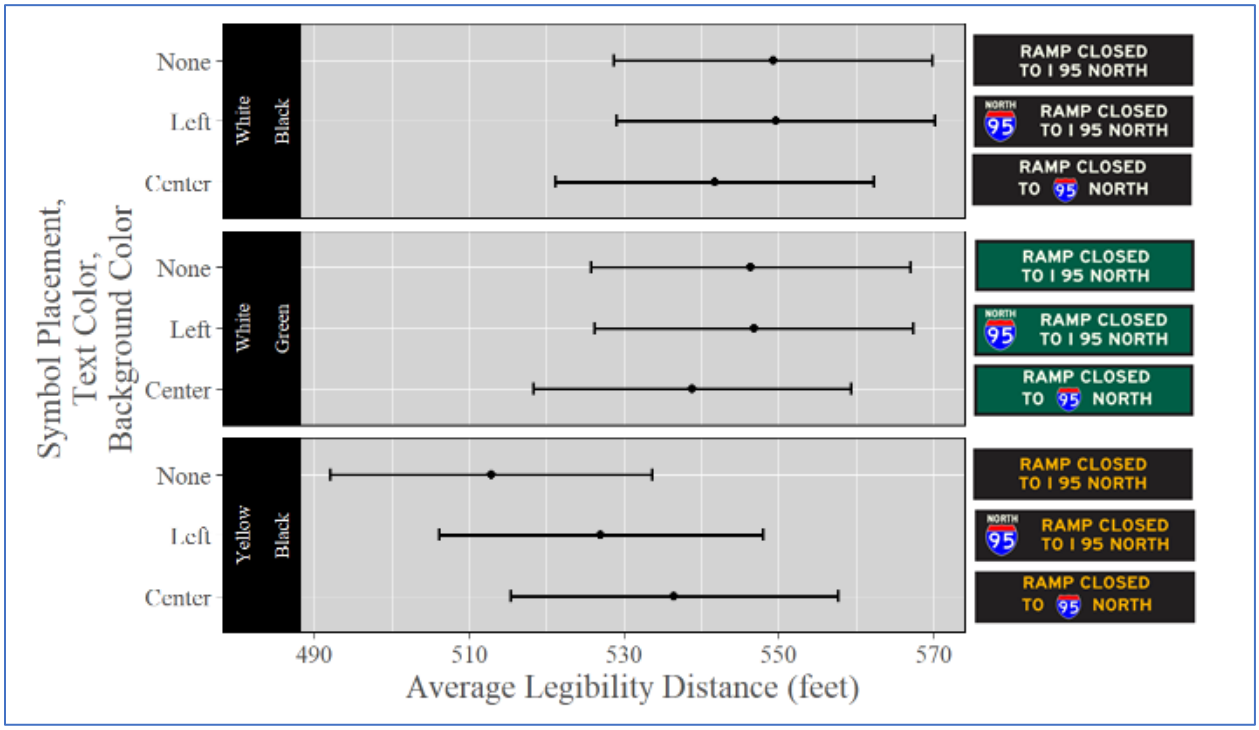


Figure 44. Graph. Legibility distance for Ramp Closed message by text/background color combination and symbol placement.
Source: Federal Highway Administration

Special Event (Concert Traffic)

When estimating legibility distances as a function of text/background color combination (i.e., averaging over border presence), the white-on-black option had significantly longer legibility distances than all other color combinations (p<.0001), as shown in figure 45.

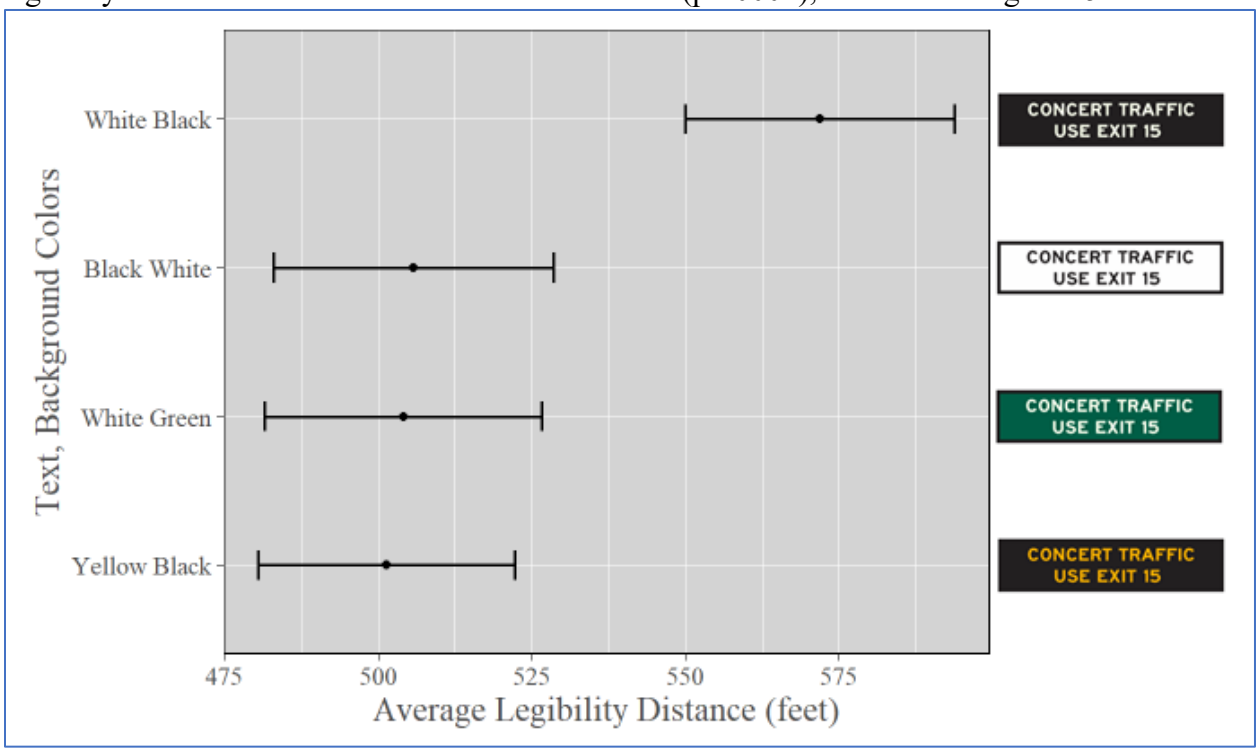


Figure 45. Graph. Legibility distance for Special Event (Concert Traffic) messages by text/background color combination.
Source: Federal Highway Administration

When examining legibility distance by border presence and text/background color, the black-on-white messages had significantly longer legibility with the border (m=519ft) than without the border (m=492ft, p<.05). The yellow-on-black messages also had significantly longer legibility with the border (m=535ft) than without the border (m=468ft, p<.0001). There was no significant difference by border presence for the white-on-black messages (p=.058) or the white-on-green messages (p=.058). These findings are depicted in figure 46.

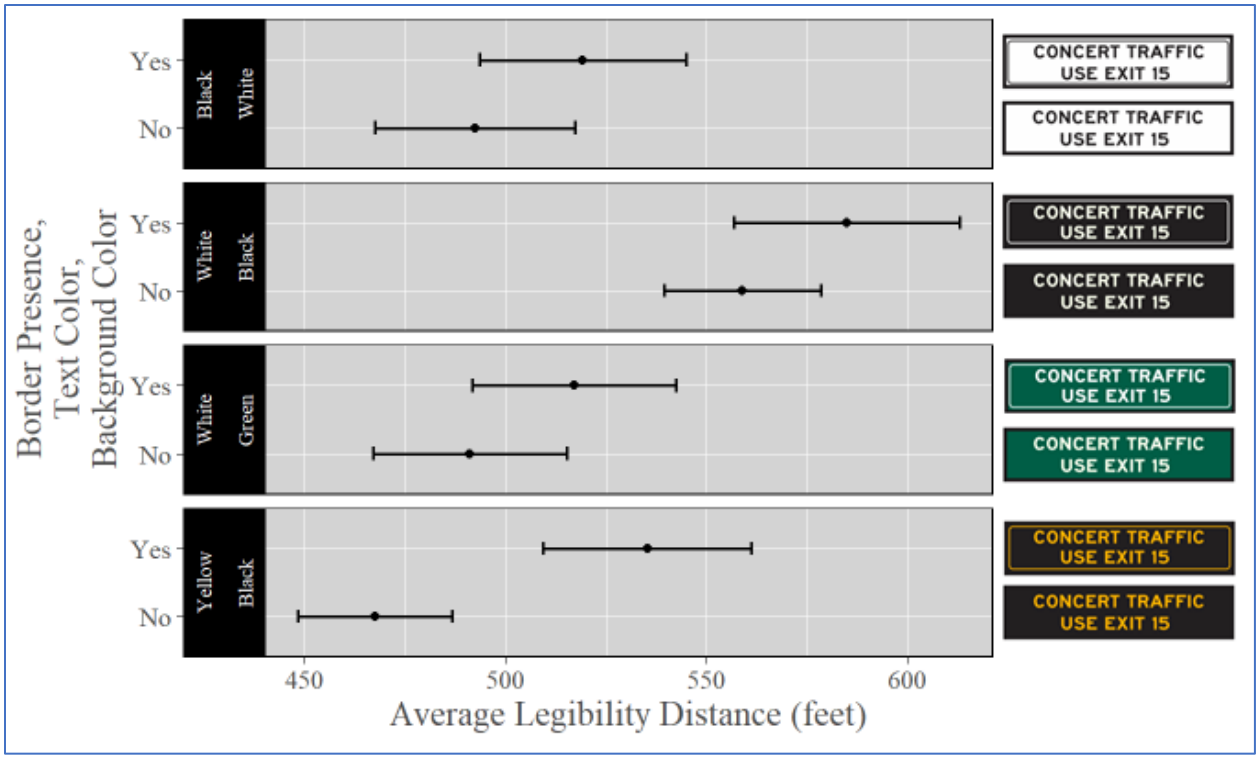


Figure 46. Graph. Legibility distance for Special Event (Concert Traffic) messages by text/background color and border presence.
Source: Federal Highway Administration

When considering the inclusion of other colors (red, blue, green), regardless of the primary text color of the messages, the addition of blue text (mean=402ft) resulted in significantly shorter legibility distances then messages that did not include any additional colors (mean=544ft, p<.0001), messages that included red text (mean= 531ft, p<.0001), and messages that included green text (mean=574ft, p<.0001). This is not surprising, as visual acuity is typically poorer for the color blue. On the contrary, the inclusion of green text on the message (mean=574ft) resulted in longer legibility than messages that did not include any additional colors (mean=544ft, p<.001), messages with red text (mean=531ft, p<.0001), and messages with blue text (mean=402ft, P<.0001).

Wipers On, Headlights On

When estimating legibility distance as a function of text/background color combination (i.e., averaging over level of border presence), legibility distances were significantly shorter (mean=488ft) for black-on-yellow messages than they were for all other messages, including black-on-white signs (mean=527ft, p<.0001), yellow-on-black (mean=541ft, p<.0001), and white-on-black messages (mean=553ft, p<.0001). The white-on-black messages also had significantly longer legibility distances than the yellow-on-black (p<.0001) and the black-on-white (p<.0001). The yellow-on-black messages also had significantly longer legibility distances than the black-on-white (p<.05) and the black-on-yellow messages (p<.0001). These findings are depicted in figure 47.

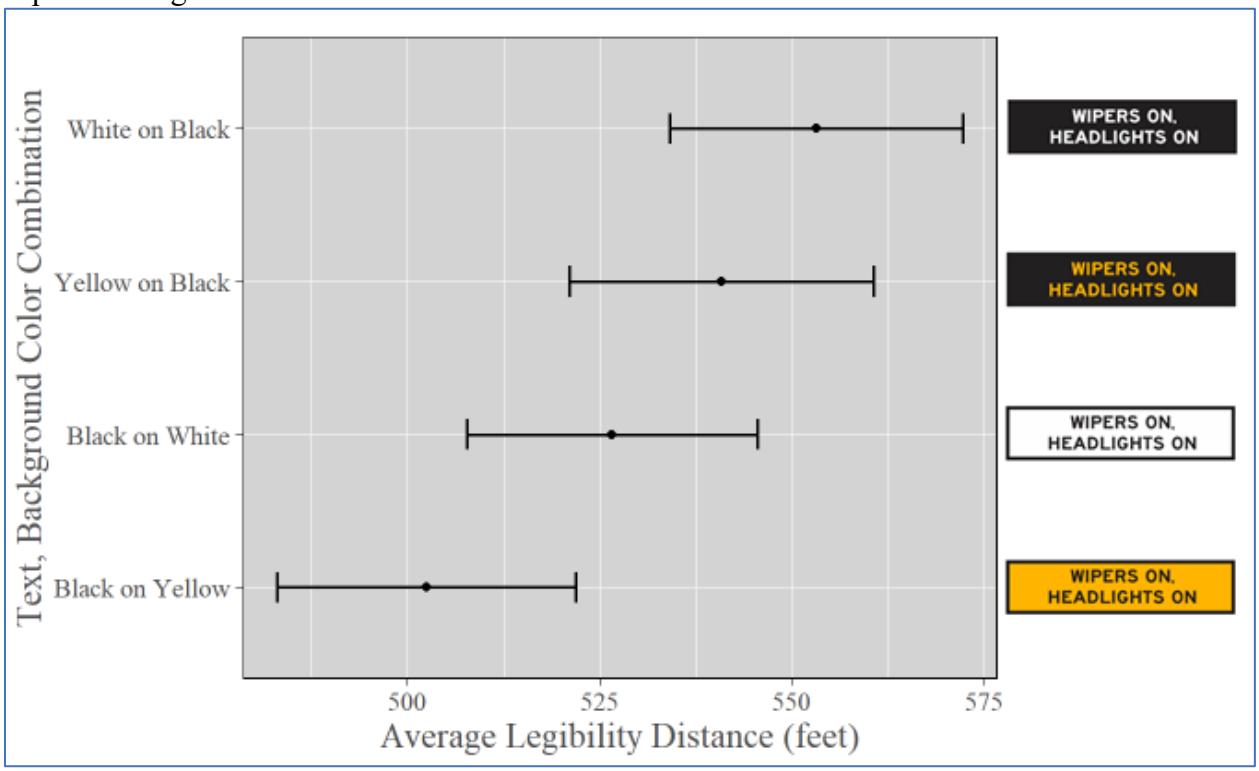


Figure 47. Graph. Legibility distance for Wipers On, Headlights On messages by text/background color combination.
Source: Federal Highway Administration

Don’t Text and Drive

When estimating legibility distance as a function of text/background color combination (i.e., averaging over level of border presence), legibility distances were significantly shorter for the negative contrast messages (black-on-yellow and black-on-white) than for positive contrast messages (yellow-on-black and white-on-black). More specifically, there was no significant difference between the average legibility distances of yellow-on-black and white-on-black messages (p=0.35), and there was no significant difference between the average legibility distances of black-on-yellow and black-on-white messages (p=0.92). However, the legibility distances for white-on-black messages were significantly longer than those for both black-on-white (p<.0001) and black-on-yellow (p<.0001) messages. Additionally, the legibility distances for yellow-on-black messages were also significantly longer than those for both black-on-white (p<.0001) and black-on-yellow (p<.0001) messages. These findings are shown in figure 48.

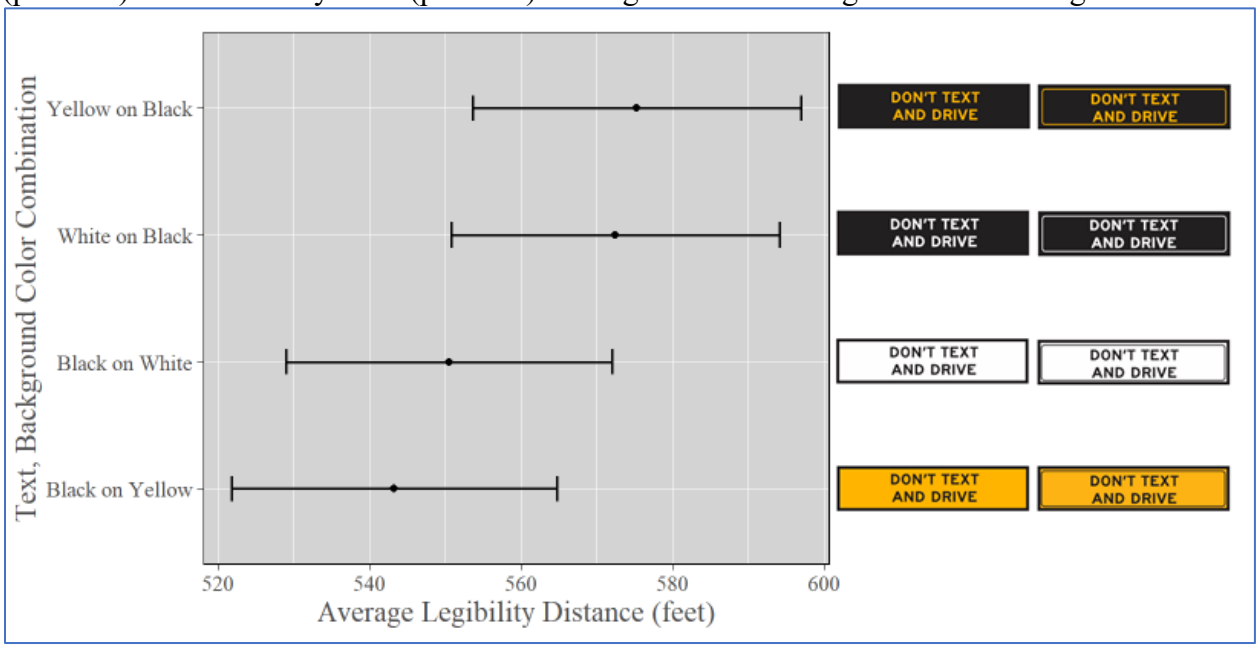


Figure 48. Graph. Legibility distances for Don't Text and Drive messages by text/background color combination.
Source: Federal Highway Administration

When examining mean legibility distance by both border presence and text/background color combination, there were no significant differences due to border presence for the white-on-black messages (p=.22) or for the yellow-on-black messages (p=.68). However, for the black-on-white messages, legibility distances were significantly longer for the message with a border (mean=560ft) than for the message without a border (mean=541ft, p=.0016). For the black-on-yellow message, legibility distances were also longer for the sign with a border (mean=551ft) than for the message without a border (mean=536ft, p<.05). These findings are depicted in figure 49.

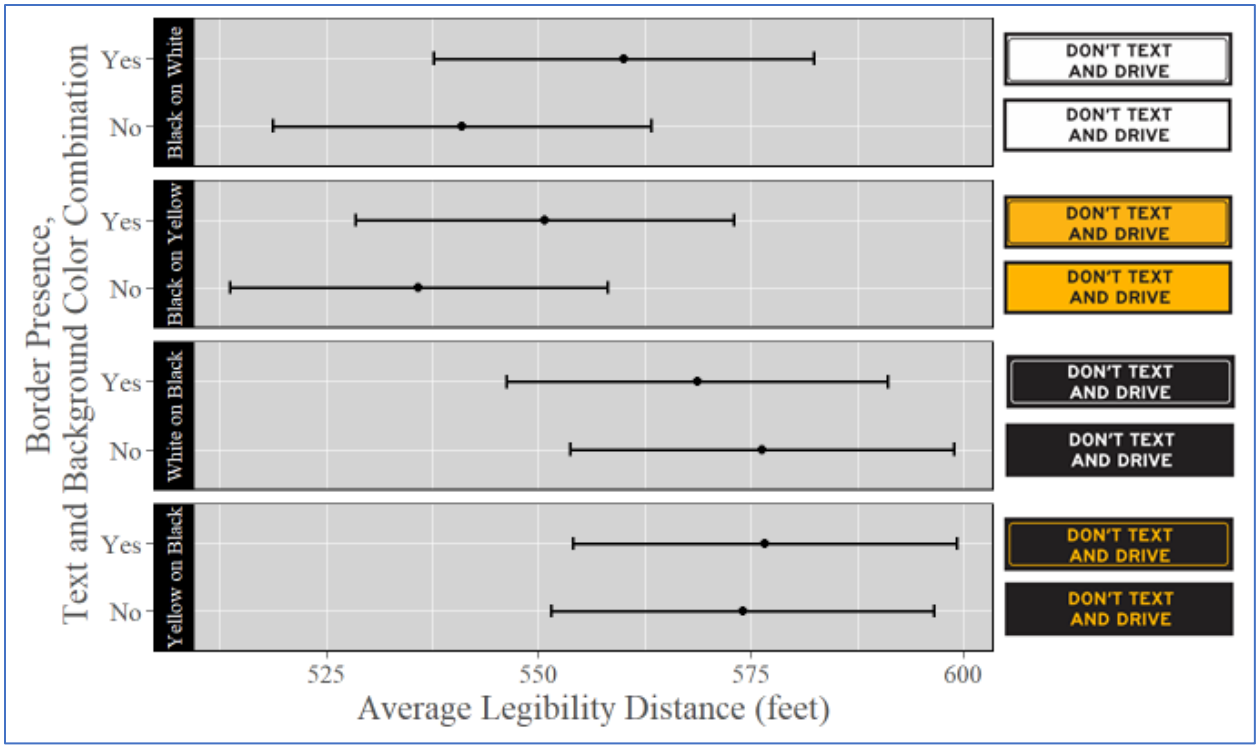


Figure 49. Graph. Legibility distances for Don't Text and Drive messages by text/background color combination and border presence.
Source: Federal Highway Administration

HOV 2+

When examining legibility distance as a function of text color (i.e., averaging over level of symbol placement and border presence), legibility distances were significantly longer for the white-on-black messages (mean=532ft) than for the black-on-white messages (m=510ft, p<.0001). These findings are depicted in figure 50.

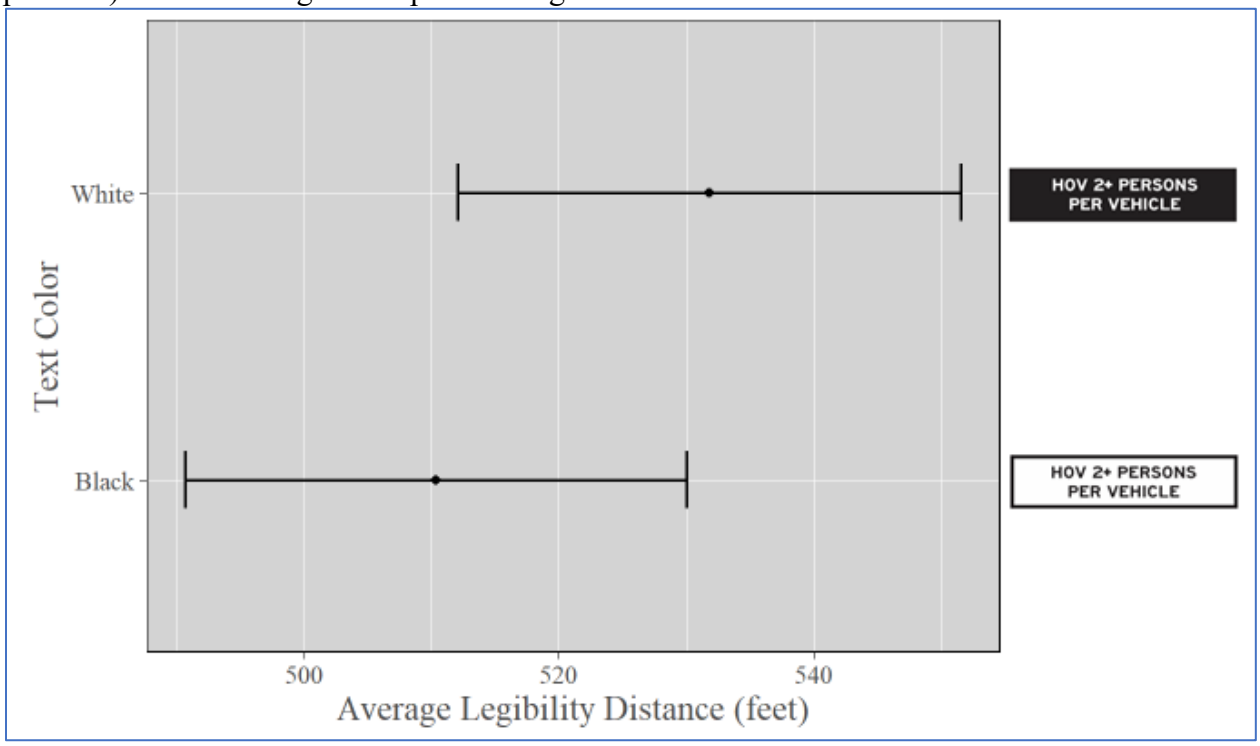


Figure 50. Graph. Legibility distances for HOV 2+ messages by text color.
Source: Federal Highway Administration

When examining symbol placement (i.e., averaged over levels of text color and border presence), legibility distances for messages with the symbol on the right (mean=528ft) were significantly longer than those for text-only messages (mean=513ft, p<.001) and messages with the symbol in the top center (mean=517ft, p<.05). Messages with the symbol on the right and messages with the symbol on the left were not significantly different (p=.99). Additionally, the legibility distances for messages with the symbol on the left (mean=527ft) were significantly longer than those for text-only messages (mean=513ft, p<.001). These findings are depicted in figure 51.

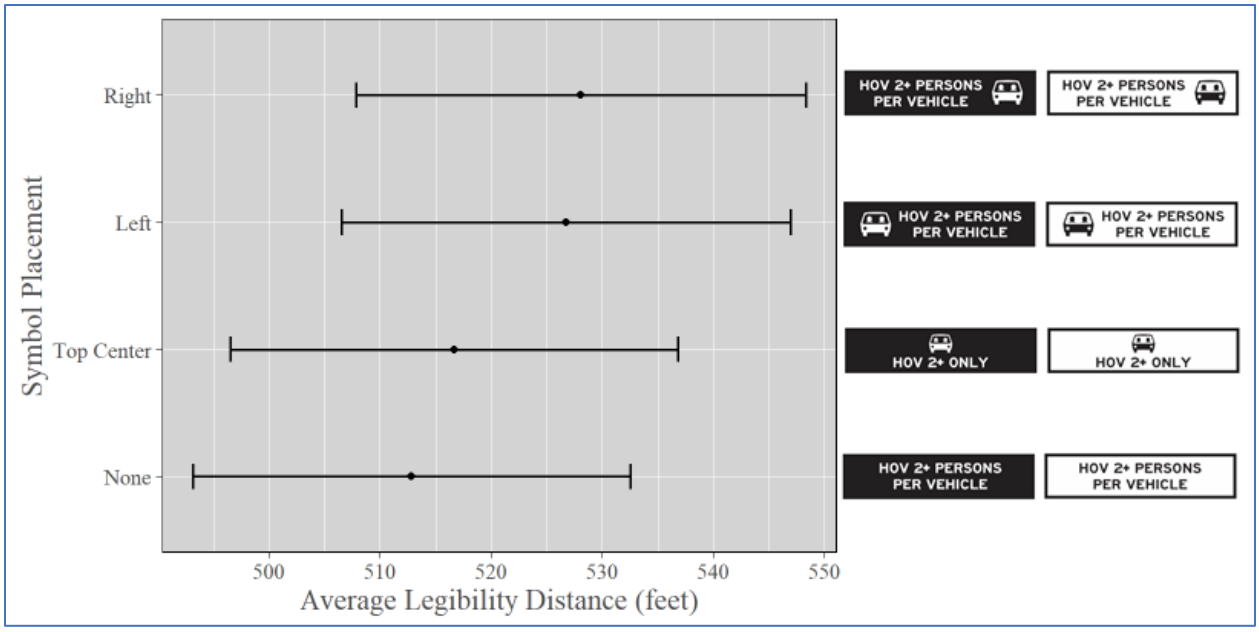


Figure 51. Graph. Legibility distances for HOV 2+ messages by symbol placement.
Source: Federal Highway Administration

When separating symbol location out by text color, the findings are a bit different. For the black-on-white messages, the legibility distances for the messages with the symbol in the top center (mean=520ft) were significantly longer than those for the text-only messages (mean=498ft, p=.0001) and the messages with the symbol on the left (mean=500ft, p=.0023). Similarly, the legibility distances for the messages with the symbol on the right (mean=524ft) were also significantly longer than those of the text-only messages (mean=498ft, p<.0001) and the messages with the symbol on the left (mean=500ft, p=.0003).

For the white-on-black signs, the legibility distances for the messages with the symbol in the top center (mean=514ft) were significantly shorter than all other messages including messages with the symbol on the right (mean=533ft, p=.0099), text-only (mean=528ft, p=.0313), and messages with the symbol on the left (mean=553ft, p<.0001). Additionally, the legibility distances for the messages with the symbol on the left (mean=553ft) were significantly longer than those for all other messages including text-only (mean=528ft, p<.0001), messages with the symbol on the right (mean=533ft, p=.0065), and messages with the symbol in the top center (mean=514ft, p<.0001). These findings are depicted in figure 52.

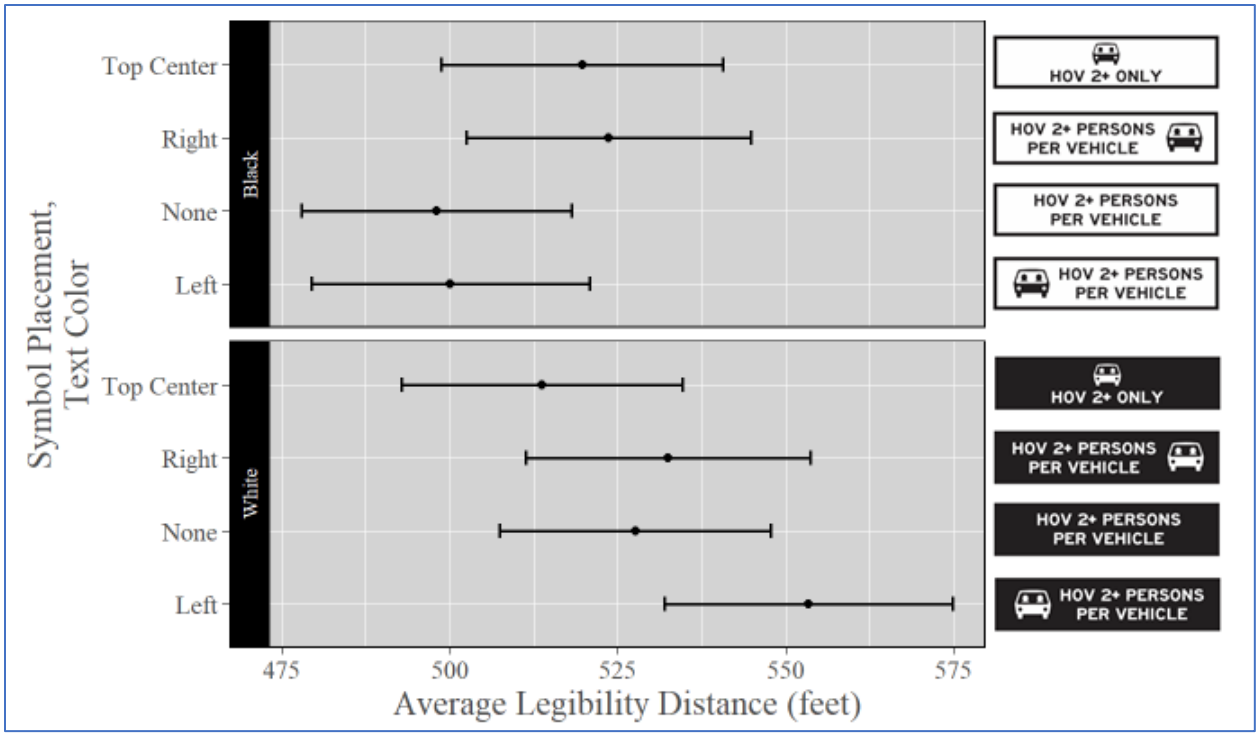


Figure 52. Graph. Legibility distance for HOV 2+ messages by text color and symbol placement.

Source: Federal Highway Administration

For the HOV messages, the text-only message alternatives were the only ones that examined border presence. When averaging over level of text color, there was no significant difference in legibility distances for messages with a border and signs without a border (p=0.32).

Fasten Seat Belt

When evaluating legibility distance as a function of text color (i.e., averaging over level of symbol placement), legibility distances were significantly shorter (mean=455ft) for the symbol-only signs than they were for black-on-white messages (mean=546ft, p<.0001) and the white-on-black messages (mean=569ft, p<.0001). Additionally, the legibility distances for the white-on-black messages were significantly longer than those for the black-on-white messages (p<.0001). These finding are depicted in figure 53.

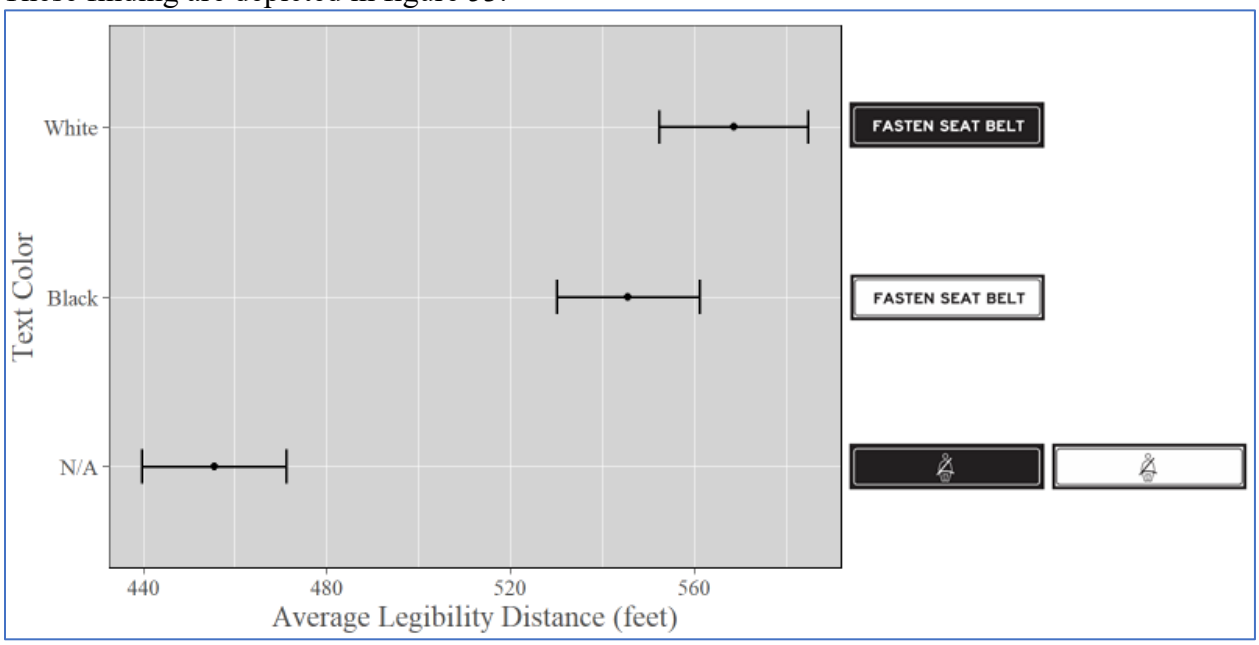


Figure 53. Graph. Legibility distances for Fasten Seat Belt messages by text color.
Source: Federal Highway Administration

When examining symbol placement by text color, there are no significant differences between messages with different symbol placement for the black-on-white messages. For the white-on-black messages, the average legibility distance of the text-only sign alternative (mean=583ft) is significantly longer than the alternative with the symbol on the right side of the message (mean=553ft, p=.0049) and the alternative with the symbol in the top center of the message (mean=559ft, p<.05). Additionally, the legibility distance for the alternative with the symbol on the left side of the message (mean=579ft) is also significantly longer than that with the symbol on the right side of the message (mean=553ft, p<.05) and that with the symbol in the top center of the message (mean=559ft, p=.0049). These findings are depicted in figure 54.

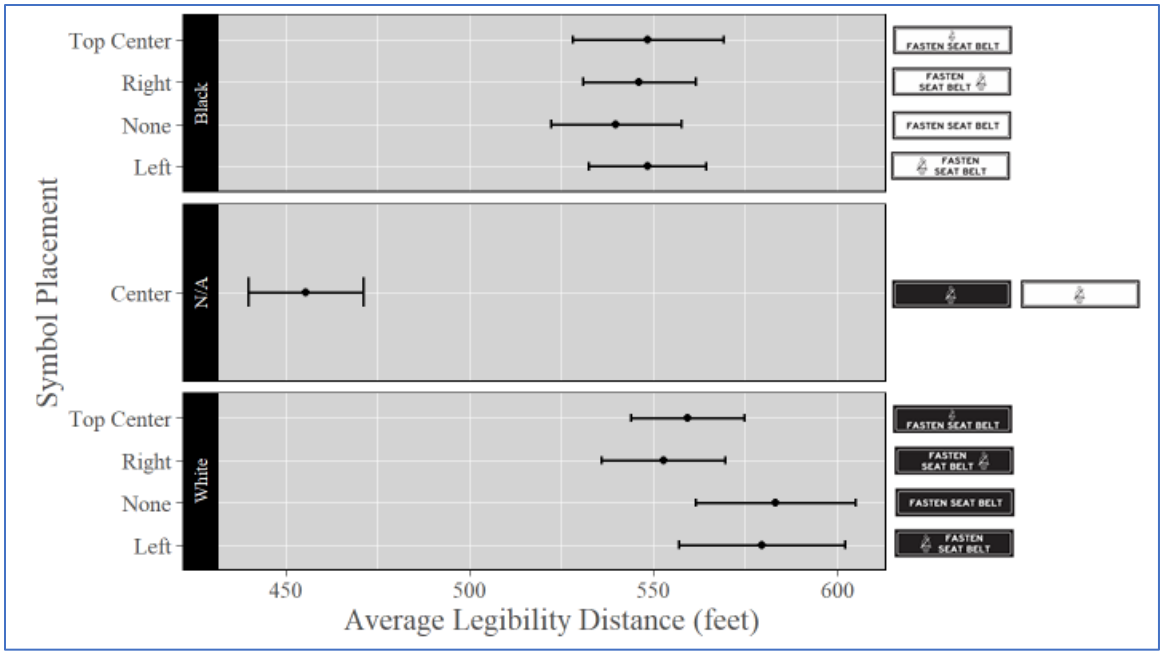


Figure 54. Graph. Legibility distance of Fasten Seat Belt message by text color and symbol placement.

Source: Federal Highway Administration

There were three Seat Belt message alternatives (symbol left, symbol right, and text-only) that included the additional text "State Law" at the top of the message. These messages were compared to their counterparts (same symbol placement, without the "State Law" text) to determine if the additional text had any influence on legibility distance. For either sign type (those that included "State Law" and those that did not), there was no significant difference between legibility distances of messages where the symbol was on the right and messages where the symbol was on the left, but in both cases (law, no law), the text-only messages had significantly shorter legibility distances than the messages that include a symbol. Additionally, the model predicts a 43.6ft shorter legibility distance among the messages that mention the law. These findings are depicted in figure 55.

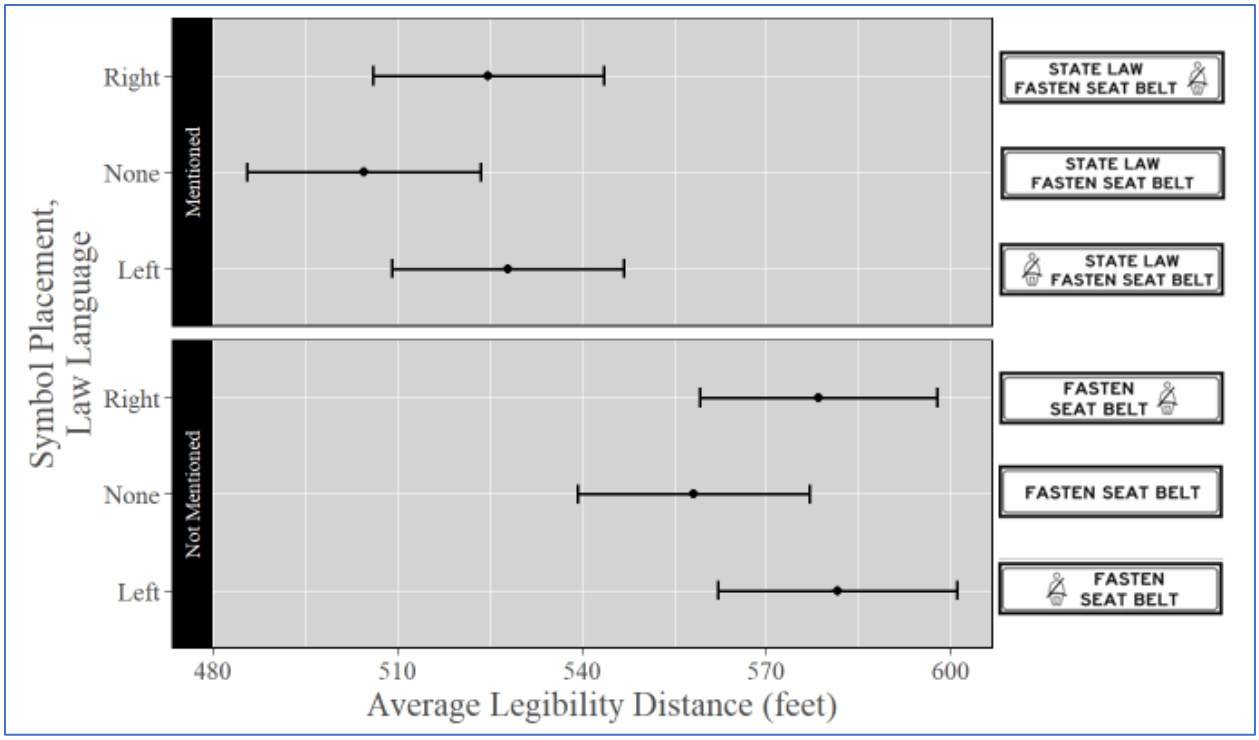


Figure 55. Graph. Legibility distances of Fasten Seat Belt messages by symbol placement and "State law" text presence.
Source: Federal Highway Administration

Toll Cost

When estimating legibility distance as a function of text/background color combination (i.e., averaging over level of color-coding of toll costs), legibility distances were significantly longer (mean=471ft) for yellow-on-black messages than they were for white-on-green messages (mean=448ft, p<.0001), as shown in figure 56.

There was no effect of color-coding when averaged across text/background color combinations, however, when looking at color-coding by text/background color, the yellow-on-black messages had significantly longer legibility distances than the white-on-green messages when no color-coding was used (p<.05) and when color-coding was used (p<.0001). These findings are depicted in figure 57.

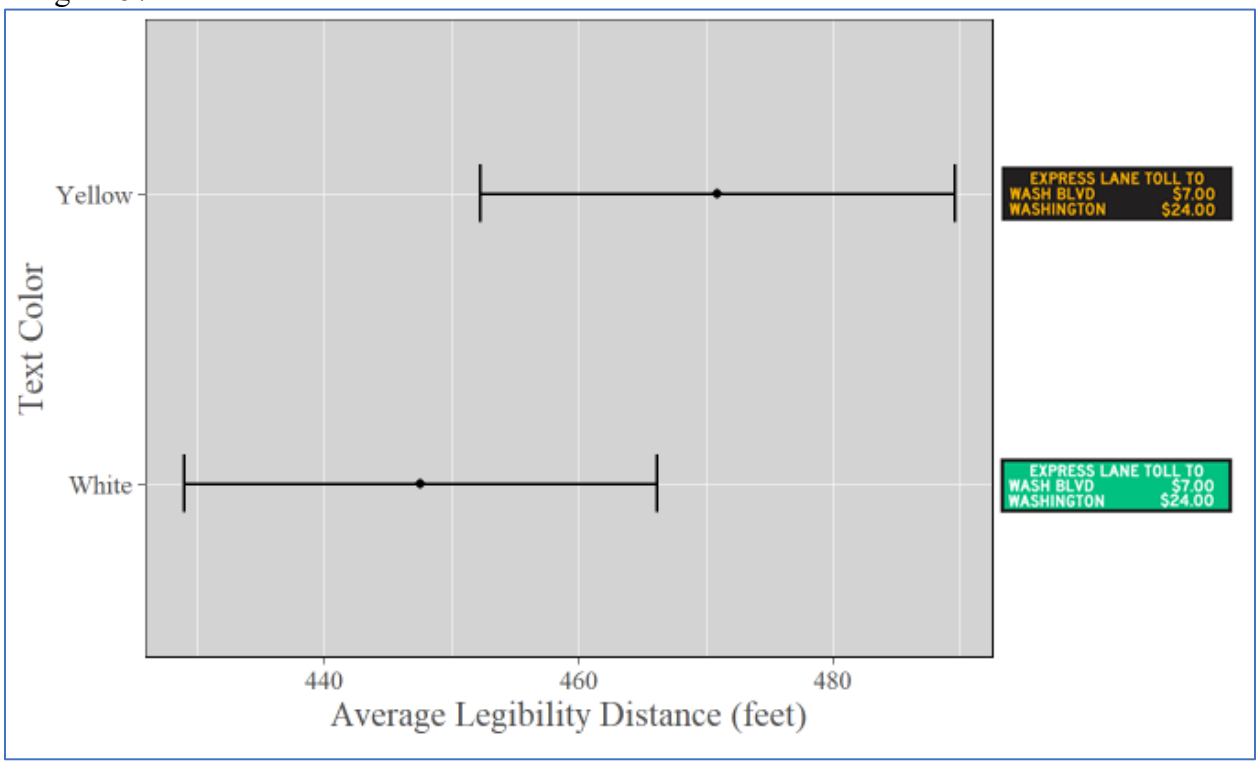


Figure 56. Graph. Legibility distances for Toll Cost messages by text color.
Source: Federal Highway Administration

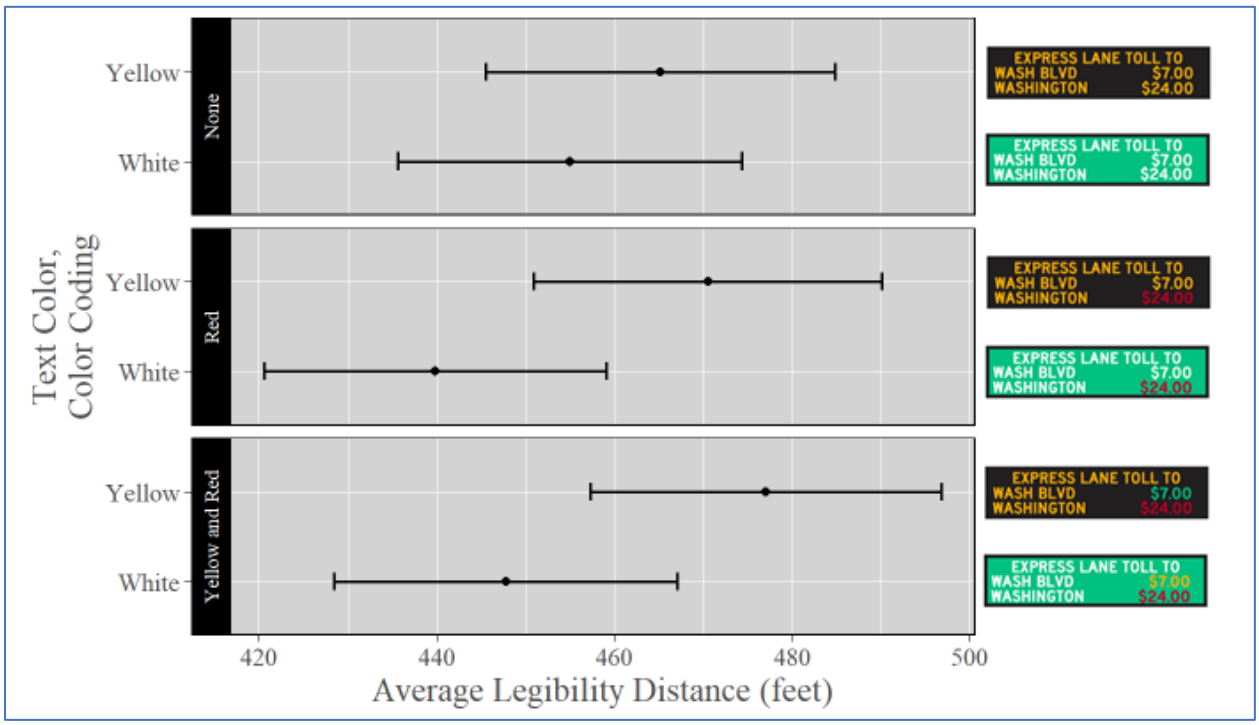


Figure 57. Graph. Legibility distances of Toll Cost messages by text color and color-coding.
Source: Federal Highway Administration

Travel Time

When evaluating legibility distance as a function of text/background color and level of color-coding (i.e., averaging over level of border presence), there were no significant differences in legibility distances between the message alternatives. In other words, neither the text/background color nor the level of color-coding significantly influenced legibility. Border presence also had no significant effect on legibility distances.

Road Closed Ahead

When evaluating legibility distance as a function of text/background color combination, legibility distances were significantly shorter for the red-on-black message (mean=491ft) than for all other message alternatives, including black-on-pink (mean=539ft, p<.0001), black-on-yellow (mean=548ft, P<.0001), and yellow-on-black (mean=553ft, p<.0001). These finding are depicted in figure 58.

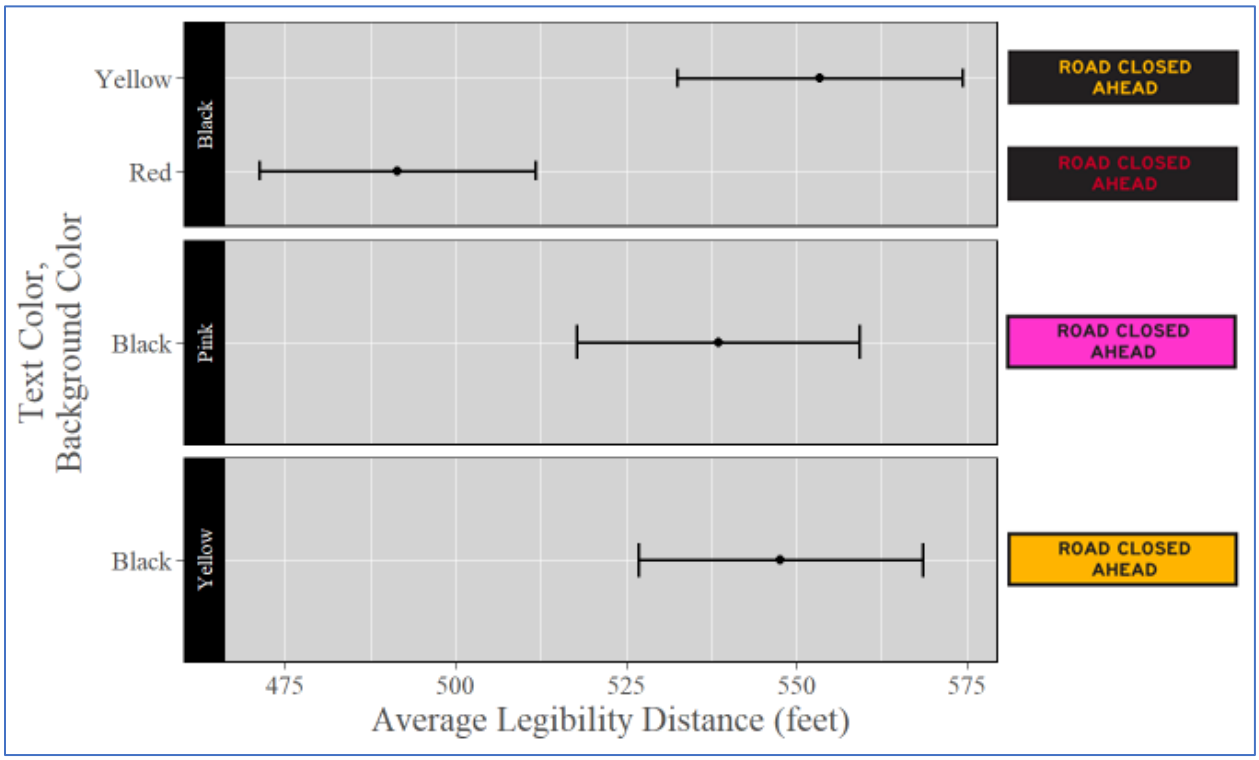


Figure 58. Graph. Legibility distances for Road Closed Ahead message by text/background color combination.

Source: Federal Highway Administration

Summary of Results

The following sections discuss the computer-based comprehension and legibility testing by research category. Table 13 lists the research categories and which research questions are addressed in each.

Table 13. Research Questions for Computer-Based Testing

Research Category	Computer-Based Comprehension Testing	Computer-Based Legibility Testing
Symbol Use and Placement	• Which symbols are well understood, and which are not? • Is there an optimal placement of symbols on CMSs?	• When should symbols be used instead of text on full-matrix CMSs? • Is there an optimal placement of symbols on CMSs?
Use of Color	• Does the use of color help to convey messages more easily?	• Does color influence legibility?
Border Presence	• When replicating a static sign, are borders required on CMSs?	N/A

Symbol Use and Placement

The use of symbols had no effect on message comprehension for any of the sign categories that included symbols. Message comprehension rates were typically between 90-100 percent for all sign categories, with comprehension falling below 90 percent for only two sign categories.

Symbols also typically had no effect on reaction times for the comprehension questions. However, for the Ramp Closed sign category, the alternatives with center symbol placement (route shield within the text) were associated with a 0.4s faster reaction time than average ($p<0.01$), and message alternatives with left symbol placement were associated with a 0.6s slower reaction time than average ($p<0.01$).

Although the depiction of the speed limit sign itself is not technically a symbol, for data analysis purposes it was coded as such to differentiate it from the text-only messages, and thus is discussed in this section of the results. For the Speed Limit messages, the depiction of the speed limit sign itself had 0.4s faster reaction time than the text-only alternatives. Participants also rated this sign higher than its text-only counterparts. Interestingly, the legibility testing showed the opposite result for this sign. The legibility results indicated that the sign depicting the static speed limit sign had significantly shorter legibility distances that all other message alternatives (which were text-only messages with varying color and border presence). One possible explanation for this is that the static Speed Limit sign is highly recognizable, and therefore participant familiarity led to faster reaction times and higher subjective ratings for that message alternative.

The Ramp Closed sign category was the only other instance where symbols influenced reaction times. The message alternatives with center symbol placement (route shield within the text) were

associated with a 0.4s faster reaction time than average ($p<0.01$), and the message alternatives with left symbol placement were associated with a 0.6s slower reaction time than average ($p<0.01$).

When exploring participant ratings on how well they thought different message alternatives would work to convey the intended meaning of the equivalent sign, participants consistently rated messages that included both text and a symbol the highest. There were five different sign categories (No Trucks, Slippery When Wet, Road Work Ahead, HOV 2+, and Fasten Seat Belt) that included alternatives with varying symbol placement (e.g., symbol-only, text-only, symbol left, symbol right, and/or symbol top center). In all five cases, participants rated the symbol-left (symbol to the left of the text) and symbol-right (symbol to the right of the text) message alternatives higher than all other message alternatives. In most cases these were followed by the text-only messages and then the symbol-only messages, though the differences between text- and symbol-only messages were typically subtle. Furthermore, participant ratings seemed to be primarily based on symbol use and symbol placement; other design factors (border presence, text/background colors) seemed to have little influence on participant ratings.

Participants were asked to rank-order the Ramp Closed messages (rather than rate them) based on their preference for different message designs. When shown three message alternatives—text-only, symbol (route shield) to the left of the text, and symbol (route shield) center (within the text)—participant preference was similar for the symbol-left and symbol-center message alternatives, both of which they preferred more (ranked higher) than the text-only message alternatives.

When examining legibility distance of sign categories, including symbols, legibility distances for symbol-only messages were significantly shorter than other messages with symbol placement alternatives (e.g., symbol-left) across the board. There were five sign categories (No Trucks, Speed Limit, Slippery When Wet, Road Work Ahead, and Fasten Seat Belt) that evaluated symbol-only alternatives (or depiction of a static sign, in the case of Speed Limit signs) as compared to others varying symbol placement (text-only, symbol-left, symbol-right, symbol-top center). In each of these cases, the symbol-only messages had statistically significantly shorter legibility distances than the other alternatives, indicating that participants had to be significantly closer to the CMS in order to identify and comprehend the message. If included, a symbol-top-center (symbol above the text) message typically had the next shortest legibility after the symbol-only messages. The symbol-right, symbol-left, and text-only messages usually had the best (longest) legibility compared to other symbol placement categories.

When looking at interactions between two different message variables (e.g., symbol placement *and* text color), there were occasionally some additional legibility findings. For example, when averaging the Road Work Ahead messages on the CMS across all other variables (i.e., looking at symbol placement alone), the symbol-only messages had significantly shorter legibility distances than symbol-right, symbol-left, and text-only messages (with no significant differences between those three alternatives). However, when examining the interaction between symbol placement *and* text color, the results also show that for a white-on-black message, the symbol-left sign also had significantly longer legibility than the text-only messages. No other Road Work Ahead messages with different color combinations (yellow-on-black or black-on-orange) showed this

finding. In instances like this, although this finding may be statistically significant, it is not necessarily practically significant if it is not a trend that is being captured across multiple sign categories.

Overall, the symbols examined in this laboratory study did not typically influence the comprehension of the messages being displayed on a CMS. However, participant ratings indicated a preference for messages that include a symbol to the right or left of the text, as opposed to symbol-only or text-only messages. Messages that include a symbol to the left or right of the text tended to have similar legibility distances as text-only messages. However, symbol-only messages consistently had the shortest legibility distances.

Use of Color

Different text and/or background colors were evaluated for all 13 sign categories. The use of color did not influence message comprehension for any sign category. Reaction times were also not influenced by color, except for the HOV messages. For the HOV messages tested, the black-on-white messages were associated with a 0.6s faster reaction time than the white-on-black messages ($p=0.01$).

When exploring participant ratings on how well they thought different message alternatives would work to convey the intended meaning, the findings suggest that participants likely based their ratings more on symbol placement than on color. However, there were a few instances where specific text/background colors seemed to be rated slightly higher than others in a message category. Only four of the tested message categories (Slippery When Wet, Road Work Ahead, Don't Text and Drive, and Road Closed Ahead) showed participant ratings that seem to differ for different text/background colors. These are also the only four message categories that included alternatives with yellow or orange background colors. The Slippery When Wet message category included yellow-on-black and black-on-yellow signs. Symbol-left and symbol-right messages were rated highest, followed by text-only messages, and lastly the symbol-only messages. However, within each of those symbol placement alternatives, the black-on-yellow (i.e., yellow background) messages were rated slightly higher than the yellow-on-black messages (black background). There was a similar finding for the Road Work Ahead message category, where the black-on-orange (orange background) messages were rated slightly higher than the white-on-black (black background) messages within each symbol placement category. The Don't Text and Drive message category included text-only messages in black-on-yellow, white-on-black, yellow-on-black, and black-on-white. The black-on-yellow (yellow background) messages were rated higher than all other colors. Finally, in the Road Closed Ahead message category, participants rated the black-on-yellow (yellow background) highest, followed by yellow-on-black, black-on-pink, and red-on-black. For all other message categories that did not include alternatives with yellow or orange backgrounds, there were no noticeable differences in rankings based on text and/or background color. Figure 59 shows the ranking orders of the message categories that did indicate differences by color, and figure 60 shows the ranking orders of the sign categories that did not show differences by color.

Figure 59. Graphic. Ranking order for sign categories for which participant rankings varied by color used.
Source: Federal Highway Administration

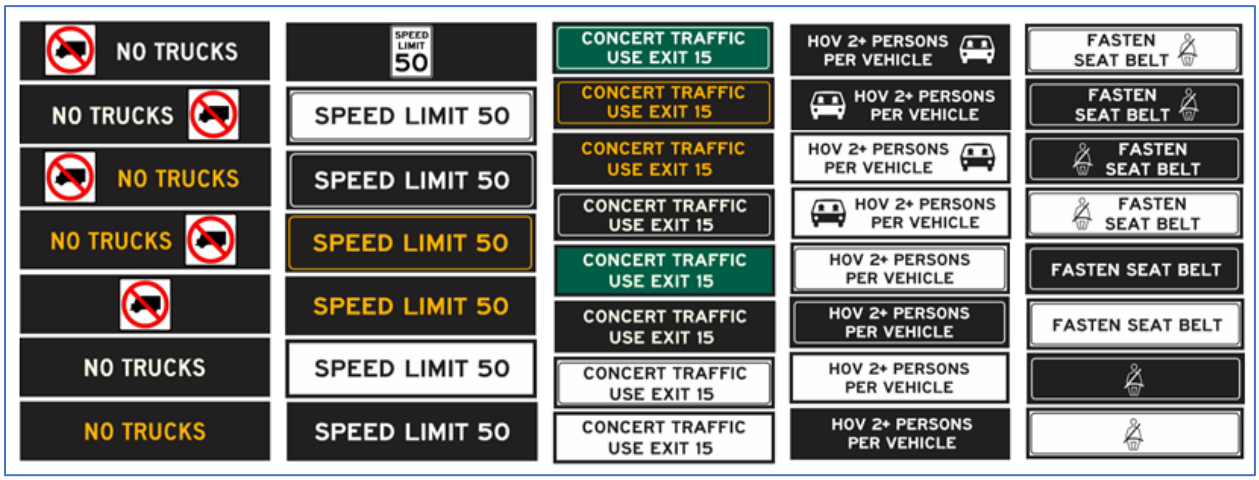


Figure 60. Graphic. Ranking order for sign categories for which participant rankings did not vary by color used.
Source: Federal Highway Administration

Even after being told the intended meaning of the Don't Text and Drive messages (that it is illegal to text and drive), participants still rated the black-on-yellow messages higher than all others (with no differences between the ratings of the other message colors). This could indicate either that (1) participants don't know whether a sign is a warning or a law/rule based on color alone, or (2) if participants do understand that yellow/black is used for warning messages and white/black is used for regulatory messages, they still felt that the black-on-yellow signs would work better to convey the meaning of the message.

Similarly, when viewing two different text colors (yellow and white) for the No Trucks messages (see figure 13), the majority of participants did not think that the different text colors conveyed any difference in meaning. Of the 13 percent of participants who *did* think there was a difference in the meaning of the messages, most participants said that they thought the yellow text conveyed more caution. One participant said that yellow text meant a warning and white text meant illegality.

There were a few other follow-up questions that sought to understand participant interpretation of color displayed in messages. For both the Toll Cost and Travel Time messages, participants were asked what they thought the different colors (color coding) were telling them. Approximately 54 percent of participants perceived a correct meaning of the color coding for the Toll Cost messages, and approximately 71 percent perceived a correct meaning for the Travel Time signs.

Figure 61. Graphic. Road Closed Ahead message alternatives
Source: Federal Highway Administration

Participants were asked a similar question for the Road Closed Ahead message. The TMC PFS was particularly interested in examining the fluorescent pink color used with displaying incident management-related messages on CMSs; test participants were asked to provide feedback on the colors used in this message category. When participants were asked "What do you think the different colors are telling you?" (see figure 61), 54 percent of participants thought the different colors conveyed different meanings or were used to attract attention. In general, participants tended to think messages with brighter background colors (messages B and D) stood out more than the others. Participants also tended to interpret yellow (messages A and D) as conveying caution. Further, participants tended to think that the yellow background (Message D) conveyed more caution than yellow text (Message A). This finding could be related to why participants tended to rate messages with yellow or orange backgrounds slightly higher than messages with black backgrounds. Although many participants interpreted red (message C) as a strong warning, or more serious than yellow, most indicated that the red text was too difficult to read. This is likely because there is less contrast between the red text and black background than there is between the other text/background color combinations. In general, participants did not know what the pink color meant. Additionally, when asked to rank these messages based on their urgency, the black-on-pink message (message B) was ranked as conveying the least urgency, while the black-on-yellow (message D) ranked as conveying the most urgency. This finding, like other findings (i.e., Don't Text and Drive ratings), suggests that an average motorist may not fully understand the meaning behind certain colors in the messages tested. In this case, however, it should be noted that fluorescent pink incident management messages are not commonly used in Virginia, where most participants were run through the study.

Participants were also asked to rank-order the Ramp Closed messages (rather than rate them) based on their preference for different message designs. When shown three text-only message alternatives—white-on-green, white-on-black, and yellow-on-black—participant preference was

similar for the white-on-green and yellow-on-black messages, both of which they preferred more than the white-on-black.

When examining how color influences legibility distance, there were a few message categories that showed differences in legibility by text/background color. The significant findings generally indicated that positive contrast messages (e.g., white-on-black) had longer legibility distances than negative contrast messages (e.g., black-on-white). For example, for both the HOV and Fasten Seat Belt message categories, the white-on-black messages had statistically significantly longer legibility distances than the black-on-white messages. Similarly, for the Don't Text and Drive message category, the white-on-black messages and the yellow-on-black messages both had significantly longer legibility distances than the black-on-yellow and the black-on-white messages. The Wipers On, Headlights On message category yielded similar results. The white-on-black messages had longer legibility distances than both the black-on-white and yellow-on-black messages, and the yellow-on-black messages had longer legibility distances than the black-on-white messages. The color-related legibility findings for both message categories are shown in figure 62.

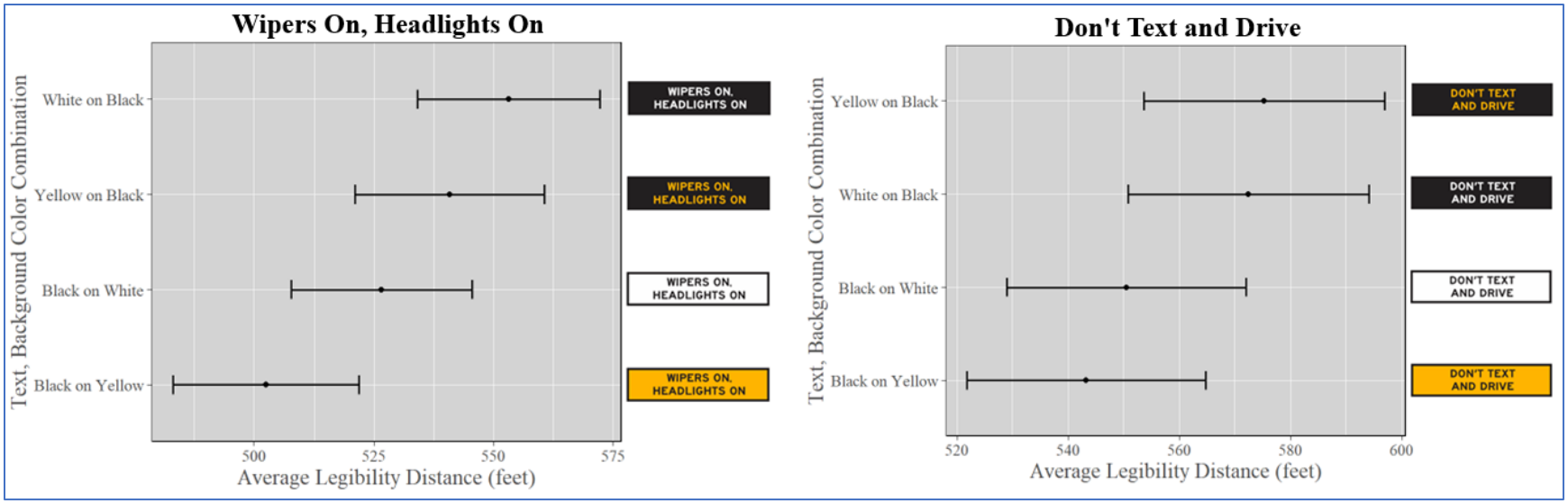


Figure 62. Graph. Legibility findings for Wipers On, Headlights On (left) and Don't Text and Drive (right) by text/background color combination.
Source: Federal Highway Administration

For the Special Event (Concert Traffic) messages, the white-on-black signs had longer legibility distances than all others, including yellow-on-black, white-on-green, and black-on-white, as shown in figure 63.

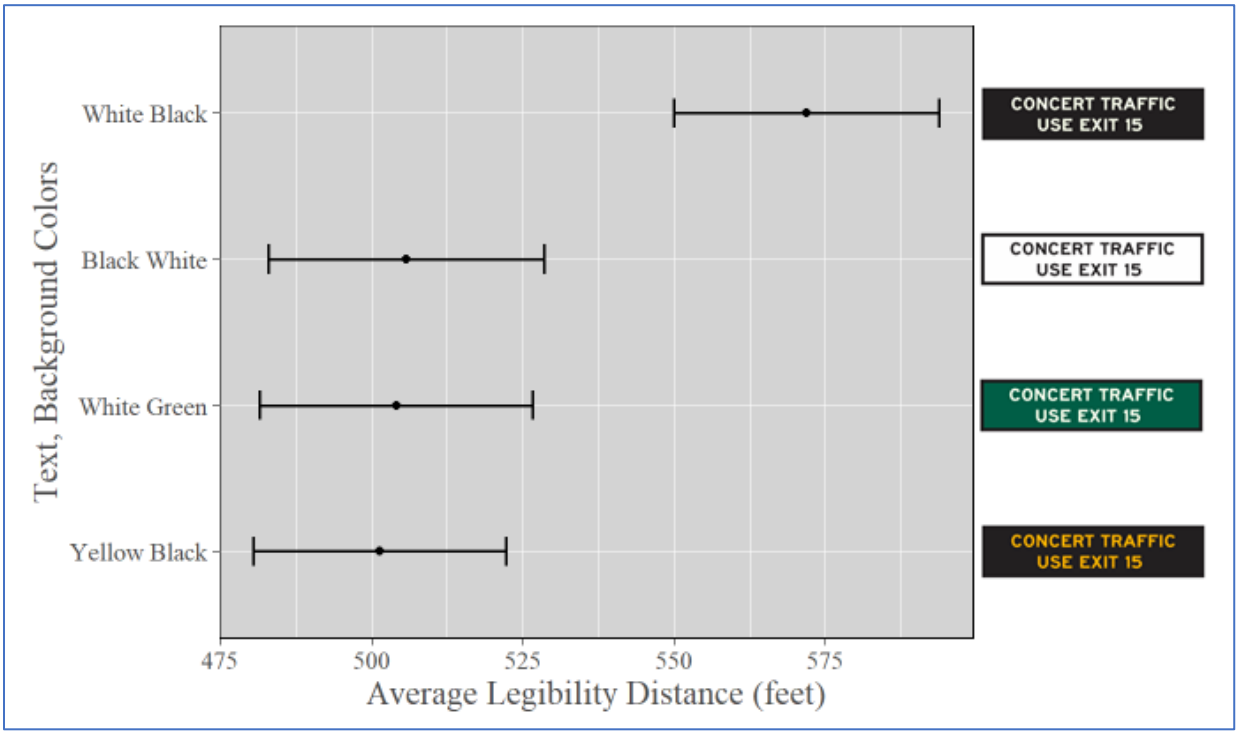


Figure 63. Graph. Legibility distances for Special Event (Concert Traffic) messages by text and background color combination.
Source: Federal Highway Administration

Similarly, the Toll Cost messages showed that yellow-on-black text had significantly longer legibility distances than the white-on-green messages, however, the Travel Time messages showed no significant differences between these same color combinations.

As mentioned previously, when looking at interactions between two different message design variables, there were occasionally some additional significant legibility findings. For example, when examining legibility distances of Road Work Ahead messages by symbol placement *and* text color, the results also show that for text-only messages, legibility distances were longer for yellow text than for white text. On the contrary, when examining No Trucks messages by symbol placement and color, the results show that for symbol-right messages, legibility distances were longer for white text than for yellow text.

Overall, the use of color in this laboratory study did not influence comprehension of messages displayed on the CMS. Furthermore, some findings suggest that average motorists may not fully understand the meaning behind certain colors (e.g., pink for incident management, white for regulatory) in messages displayed on CMSs. Although participant ratings varied primarily by symbol placement, some findings suggest that participants tend to prefer yellow or orange backgrounds over other background colors. This could be because many people associate yellow

with a warning, and may feel a strong warning color will convey messages more effectively. The legibility findings tended to indicate the opposite; negative contrast messages (e.g., black-on-yellow) tended to have shorter legibility distances than positive contrast messages (e.g., yellow-on-black).

Border Presence

There were no significant differences in comprehension, reaction time, or participant ratings by border presence. Interestingly, in 4 out of 5 cases (83 percent) where participants evaluated black-on-white messages with and without a border, border presence affected legibility distance. In half of these cases, legibility distances for the black-on-white messages were longer with a border than without (Special Event; Don't Text and Drive), and in the other half of these cases, legibility distances were longer without the border than with the border (Speed Limit; Wipers On, Headlights On). On the contrary, there was never a significant effect of border presence for white-on-black messages. In fact, there were only two other instances where there was a significant effect of border presence. For the yellow-on-black Special Event message, legibility distance was significantly longer for messages with a border (mean=535ft) than for messages without a border (mean=468ft, $p < .0001$). For the black-on-yellow Don't Text and Drive messages, legibility distances were longer without a border (mean=503ft) than with a border (mean=473ft, $p<.0001$).

Table 14 shows all cases that included a border, and indicates whether there was a statistically significant effect of border presence on legibility distance.

Table 14. Summary of findings regarding effect of border presence on legibility distance.

Sign Category	Text/Background Color Combination	Effect of Border Presence?	Findings
Speed Limit	White-on-Black	NO	No effect
Speed Limit	Black-on-White	YES	Legibility longer without border
Speed Limit	Yellow-on-Black	NO	No effect
Road Work Ahead	White-on-Black	NO	No effect
Road Work Ahead	Black-on-Orange	NO	No effect
Special Event (Concert Traffic)	White-on-Black	NO	No effect
Special Event (Concert Traffic)	Black-on-White	YES	Legibility longer with border
Special Event (Concert Traffic)	Yellow-on-Black	YES	Legibility longer with border
Special Event (Concert Traffic)	White-on-Green	NO	No effect
Wipers On, Headlights On	White-on-Black	NO	No effect
Wipers On, Headlights On	Black-on-White	YES	Legibility longer without border
Don't Text and Drive	White-on-Black	NO	No effect
Don't Text and Drive	Black-on-White	YES	Legibility longer with border
Don't Text and Drive	Yellow-on-Black	NO	No effect
Don't Text and Drive	Black-on-Yellow	YES	Legibility longer without border
HOV	White-on-Black	NO	No effect
HOV	Black-on-White	NO	No effect
Travel Time	White-on-Green	NO	No effect

There were no other significant findings related to border presence.

CHAPTER 3. FIELD TESTING

METHOD

Objective

The laboratory study examined legibility and comprehension of different messages displayed on a CMS, as well as driver preference for the design of different messages. Therefore, the focus of the field study was to gather information on legibility using a real CMS, focused specifically on the effects of font and color on legibility. Additionally, the field study also gathered subjective feedback to evaluate the design of different messages. The field testing addressed the following research questions:

1. Do legend (text) and background colors influence legibility?
2. Does font influence legibility?
3. What are participant preferences for various sign design features, and do these design features affect subjective ratings? More specifically:
    a. Are borders helpful on messages displayed on CMSs?
    b. Is there an optimal placement of symbols in messages?
    c. Does the use of color (i.e., color coding) help to convey messages more easily?
4. What are the considerations for displaying messages on CMSs in daytime versus nighttime?
5. Does color influence participant feedback on sign brightness?

Stimulus Development

Introduction

To address the research questions identified above, the field study was organized into two parts. The first part investigated message legibility using different fonts and different color combinations for the legend (text) and background. The second part investigated participant preferences for different design elements of messages displayed on a CMS.

Part 1 – Legibility

Ten different messages were developed for the legibility testing. These messages varied in legend color, background color, and font. Five background colors were tested (black, green, white, orange, and yellow) and five legend colors were tested (black, red, yellow, green, and white), though not every background color and legend color were tested together. Three different fonts were evaluated: Series D, Series E, and an LED-style font. Although the Series D and Series E styles cannot be exactly recreated on a CMS as they are on static signs, the high resolution of the CMS used for this study enabled the fonts to be displayed so they visually appear the same as those used on static signs. The LED-style font represented the font style that is traditionally used on CMSs. The three different fonts were evaluated on a single

legend/background color combination; all other messages were developed using Series D font. Figure 64 shows the 10 messages that were developed for field legibility testing.

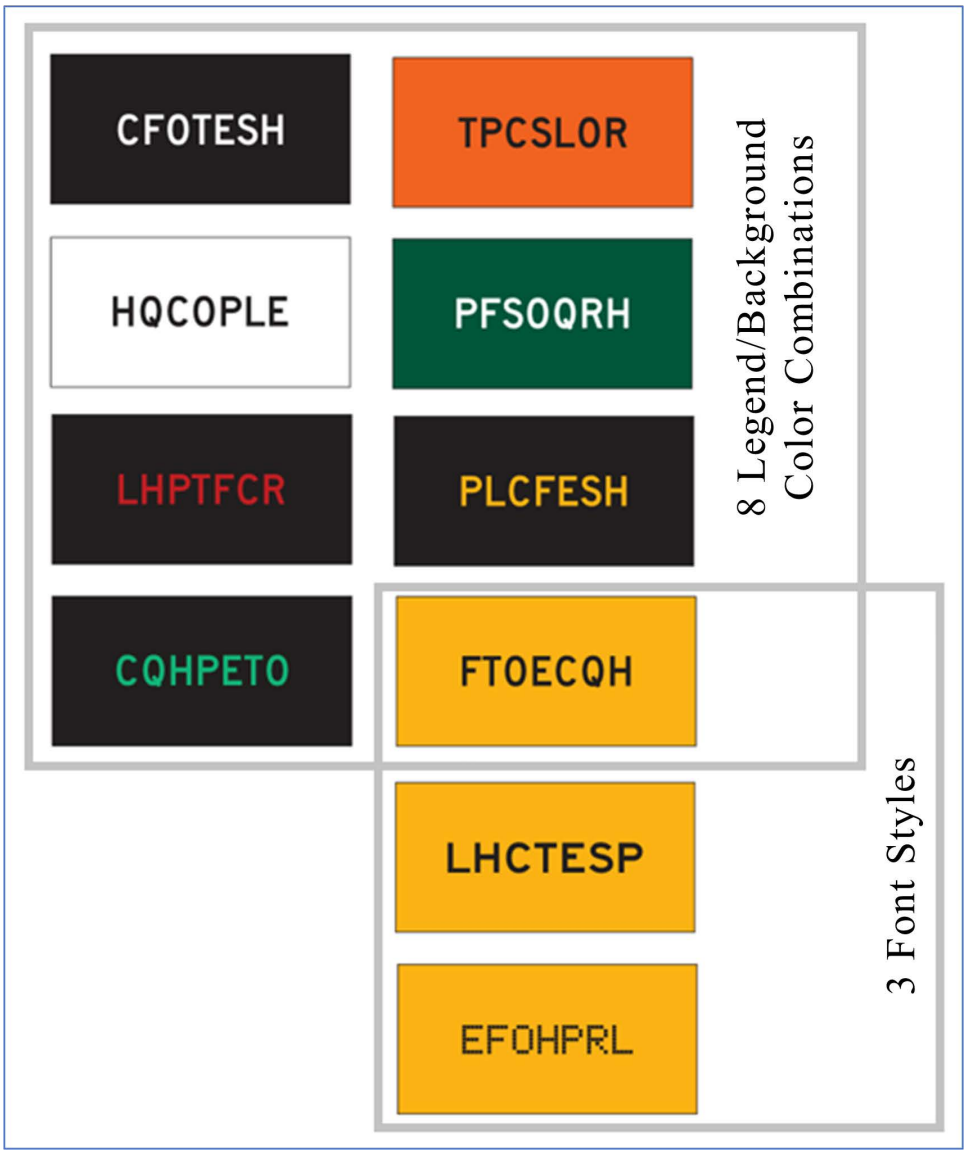


Figure 64. Graphic. Example Messages Tested During the Field Study Part 1.
Source: Federal Highway Administration

The legend and background color combinations were selected to include both positive contrast (e.g., white-on-black) and negative contrast (e.g., black-on-white) messages. The white-on-green, yellow-on-black, black-on-yellow, and black-on-orange color combinations were included because these are common color combinations used on static signs and newer color CMSs. Some participants in the laboratory study indicated that it was difficult to see red text on a black background, therefore, the red-on-black color combination was included in the field study in order to determine if there were similar findings when using a real CMS. The green-on-black

color combination was included because this was the green included on the color-coded Travel Time and Toll Cost message included in the laboratory study.

The messages were developed using FHWA Color Specifications, in Standard RGB, as shown in table 15.

Table 15. Color Specifications for Field Study Messages

Color Name	Screen-Normalized sRGB
Black	51, 51, 51
White	251, 255, 237
Red	196, 0, 39
Yellow	255, 181, 0
Orange	253, 105, 2
Green	0, 95, 71

The only exception to these standard RGB codes was the green used for the legend on the green-on-black messages. This shade of green was intended to match the green used in the color-coded versions of the Toll Cost and Travel Time messages (see table 2). As indicated in chapter 2, the research team determined the same green used for background colors was not likely to contrast enough with the black background. Therefore, the research used a green that was more easily differentiated from the black background, and which was intended to visually represent the shade of green used in LEDs for traffic signals or lane control arrows.

Each of the 10 message designs displayed a string of 7 uppercase letters. None of the messages formed a word in the English language; rather, they appeared as a random sequence of letters, similar to an eye chart used for vision screening. The research team created three versions of each of the 10 messages, for a total of 30 messages. Each version of a message included the same 7 letters that are shown in figure 64, but presented in a different random order. For example, the white-on-black message always included the letters C, F, O, T, E, S, and H, but versions one, two, and three of that message had those seven letters presented in a different order. This was done to prevent participants from becoming familiar with the order in which letters were presented, thus reducing the chances that participants could recite letters by memory (rather than relying solely on reading the message). The order of the message displayed was developed to prevent participants from viewing messages with the same color and letter combination in succession. All participants viewed the messages in the same sequence.

Part 2 – Subjective Feedback

The second part of the field test gathered participant preference for different message designs, including color (i.e., color coding), border presence, and symbol placement. This entailed the participants viewing seven groups of messages. Six of these seven message groups investigated participant preferences for different designs within each group of messages. Two groups of messages were used to test each of the three design elements of interest (symbol placement, border presence, and color coding). Table 16 shows the messages and testing goals.

Disclaimer: Subjective feedback on participant preferences is not necessarily indicative of effectiveness of a message or a message element, as there are any number of reasons a specific preference might be given. Preferential responses should not be used in designing messages, display, or policy decisions.

Table 16. Messages Tested During the Field Study Part 2

Message	Number of Messages	Testing Goal	Message Design
ROAD WORK AHEAD	2	Investigate participant preference for a sign border	
RAMP CLOSED TO I-95 NORTH	2	Investigate participant preference for a sign border	
NO TRUCKS	3	Investigate participant preference for the inclusion and placement of a symbol.	

Table 16. Messages Tested During the Field Study Part 2 (Continued)

Message	Number of Messages	Testing Goal	Message Design
RAMP CLOSED TO I-95 NORTH	3	Investigate participant preference for the inclusion and placement of a symbol.	
TRAVEL TIME	2	Investigate participant preference for a legend with multiple colors.	
TOLL COST	2	Investigate participant preference for a legend with multiple colors.	

The seventh group of messages all had the same legend: ROAD CLOSED AHEAD (figure 65). This group of messages varied in background color (black, white, and yellow) as well as legend color (white, red, and black). During this part of the study, experimenters showed participants one sign at a time and asked participants to provide feedback on brightness level (e.g., too bright, too dim). Each message was shown at the message's brightest level, which was the default setting.

Figure 65. Graphic. Messages Studied for Brightness
Source: Federal Highway Administration

Apparatus

Introduction

This section details the hardware and software used for the field study. This section also describes issues, challenges, and limitations the team encountered while conducting the field study.

Hardware

The CMS used for this experiment was a 4 x 8ft high-resolution, full-color sign. The CMS had a pixel pitch of 4 millimeters, a pixel density of 62,500 pixels per square meter, and a cabinet resolution of 640 x 320 pixels. The research team mounted the sign to the side of a trailer for portability. The CMS set-up is shown in figure 66.

Figure 66. Photo. Experimenter and Participant during the Field Test Part 2
Source: Toxcel

The research team used a digital light meter to measure the ambient light level before beginning the experiment with participants. All measurements were taken in foot-candles (Fc). The digital light meter has an operating range of 0 Fc to 40,000 Fc. Measurements were taken at the location of the CMS. To prevent capturing light from the CMS, the light meter was positioned behind the CMS.

Software

The messages that were displayed on the CMS were developed using a vector graphics editor, using the FHWA color specifications chart and various highway-style fonts. These messages were then exported in JPEG file format for use with the experimental software.

The message files were loaded into the computer which was used to manage and operate the CMS, with the order and timing of the messages, and the applicable CMS's brightness level (figure 67). The CMS's brightness level was set to maximum during the experiment. There were no limitations with the messages or colors that could be programmed into the CMS. The CMS accepted images in most common formats (e.g., .GIF, .PNG) and allows the user to configure the

size and placement of the selected image(s) on the CMS's screen. All images and messages programmed into the CMS displayed as expected.

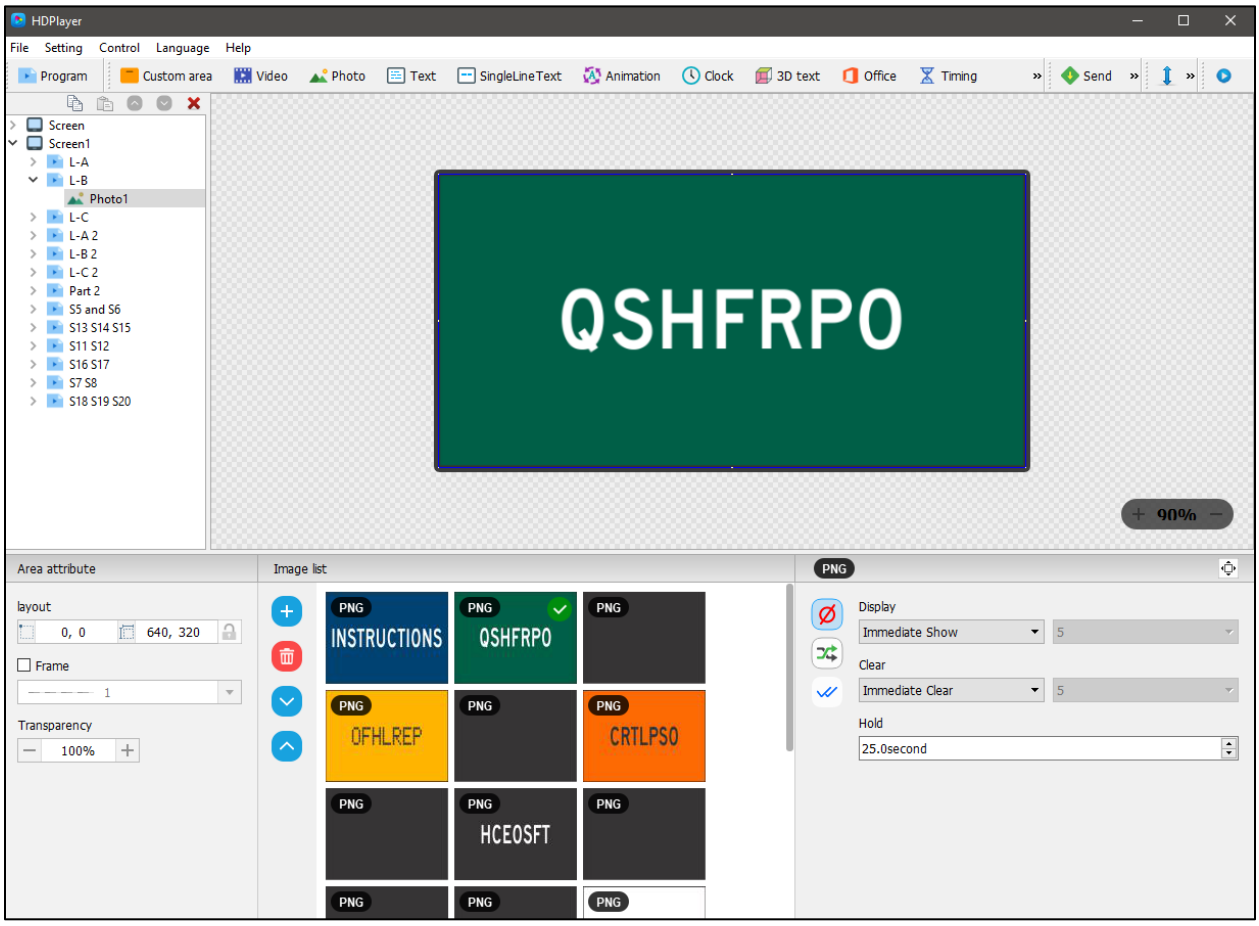


Figure 67. Screenshot. Computer Display of Messages.
Source: Federal Highway Administration

Challenges and Limitations

The research team overcame several apparatus-related challenges when planning and conducting the field study. The software controlling the CMS required a computer to be connected via an Ethernet cable. It was not practical for the experimenter to control the CMS via the Ethernet connection, because the field study required participants to be at various distances from the CMS. A second experimenter remaining with the CMS could have addressed this issue. However, this approach would result in extra labor and coordination.

The research team implemented an approach that loaded the messages into a pre-timed program. The program included placeholder messages for logistical activities (e.g., instructions, questions, repositioning the study vehicle). This approach worked well. The only issue encountered was that occasionally, there was time reserved for questions when the participants had none. In these cases, the research team could have shortened the duration of the experiment if they had the ability to manually advance to the next message.

Powering the CMS was also a challenge. The initial experiment configuration had an inverter generator capable of delivering 3000 watts (running) and 3500 watts (starting). This configuration powered most of the messages programmed into the CMS, but failed for messages with white backgrounds due to a higher current draw for those messages. The final configuration required two 3000-watt inverter generators wired in parallel (6000-watt total) to provide the necessary power for the CMS.

For some participants, the messages displayed on the CMS included several discolored pixels. These discolorations occurred during the legibility testing only and were located outside of the area where the letters were displayed. As such, these discolorations did not affect participants' ability to read the messages.

Participants

A total of 27 people participated in the field study, though only 26 participants produced usable data; one participant arrived late and was unable to provide responses to many of the questions, and so was excluded from the data analysis. Of the 26 participants with usable data, 15 completed the study during the day and 11 completed the study at night. Participants ranged from 19-67 years old with an average age of 43 years. Forty-one percent of the participants were male (average age 53 years) and 59 percent were female (average age 37 years). Participants were required to be at least 18 years of age to participate. Their vision was scored using a Snellen Eye Chart. All participants had at least 20/40 vision in one or both eyes, corrected if necessary.

Participants were primarily recruited through an online advertisement (appendix G), as well as by word-of-mouth. The advertisement provided general information about the study with a link to an online form that people could complete to submit their interest to participate in the research. The following information was included in the advertisement: the purpose of the study, who was sponsoring the research, the amount of time to participate, compensation details, and how to sign up to participate. Interested participants were directed to a Participant Intake Form, which included fields to collect the following information: name, gender, age, phone number, and email address. A designated member of the research team would contact prospective participants by phone to review the details about the study and answer any questions. If the person was still interested in participating, an appointment would be scheduled, and a confirmation email was sent to the participants with the date and time of their appointment and instructions for where to meet the experimenter. Confirmation emails also provided contact information for the research team and included other pertinent instructions (e.g., to bring any corrective lenses used while driving, to call and reschedule if the participants were feeling any flu or cold-like symptoms). Reminder emails were sent to participants the day before their scheduled appointment.

Field Data Collection

The field study was conducted in Blacksburg, Virginia on an access road that was closed to normal traffic and provided a controlled environment where participants could not be distracted by other traffic. The access road was approximately 2000 feet long, and the section of road used as the test road for the study was approximately 800ft in length with a small vertical curve and no horizontal curves. This configuration gave participants an unobstructed view of the CMS throughout the entire duration of the study.

Field data was collected between 7:30 a.m. and 9:30 p.m. ET to analyze legibility in both daytime and nighttime conditions. As mentioned previously, a light meter was used to measure the amount of ambient lighting at the time that each participant started the study.

Weather was favorable for most of the study. However, snowfall during the second day of data collection forced the rescheduling of all daytime appointments due to hazardous road conditions and limited visibility. Conditions improved enough to maintain the evening schedule. The only other day with unfavorable conditions occurred on the last day of data collection, when there was drizzle/light rain in the afternoon.

One experimenter worked with one participant at a time. The experimenter met each participant in a lighted, paved parking lot across the street from the test road. The experimenter introduced themselves upon the participant's arrival and asked the participant to follow the experimenter over to the test road. Participants were instructed to park their personal vehicle in the parking area at the test road and enter the research vehicle. The participants did not drive the research vehicle; the experimenter and participant were only seated in the front seat of the research vehicle to view the signs and stay out of the cold.

Once inside the research vehicle, the experimenter would explain the study procedures and provide a Briefing Statement (appendix H) for the participant to read. The experimenter would ask if the participant had any questions and then confirm if the participant wanted to continue participation in the study. After obtaining their verbal consent, the participant was driven to the CMS so they could see it up close. The experimenter then administered a vision screening using a Snellen Eye Chart mounted inside the CMS trailer. Participants were asked to stand at a marked location that was 10ft from the eye chart and asked to read the lowest line they could easily see. Participants' vision scores were recorded on a form. All participants had at least 20/40 vision in one or both eyes, corrected if necessary.

After the vision screening, the experimenter used the light meter to establish the amount of ambient lighting. The measurement was recorded on the vision screening form. The experimenter would then power-on the sign and drive the participant to the furthest marked distance from the sign, which was 900ft.[1]

Once the experimenter and participants were situated at the farthest marked distance from the sign, the program began, and the participants viewed each of the ten messages shown in figure 64. As described previously, each message included a random string of capital letters that

[1] Legibility testing distances were measured ahead of the field study and marked with reflective driveway markers.

did not form a word. Participants viewed one message at a time and were instructed to read the letters on the sign aloud, as they could see them, similar to what they might do for an eye exam. The experimenter recorded the letters participants read into a spreadsheet on a laptop computer. The experimenter advised participants to let them know if they could not see a letter, or to let the experimenter know if they thought they could see a letter but were partially guessing. If participants were undecided between two letters (e.g., O or Q), the experimenter would ask them to make their best decision. After responding to the first message, the participants repeated that process for all 10 messages.

After viewing all 10 messages at the farthest distance, the experimenter and participants moved to the next closest distance from the message and repeated the same process of viewing all 10 messages. This process occurred at six different pre-determined distances from the message: 900ft, 750ft, 600ft, 525ft, 450ft, and 300ft.[2] The order of the letters on the message, and the order of the messages within a group, were randomized and differed at each distance.

After the participants concluded the legibility testing at all six distances (Part 1), the experimenter and participants remained at the 300ft distance for Part 2 of the field study. The second part of the field study consisted of showing participants seven different sets of messages and asking for their subjective feedback and preference for different message designs within a given group of messages. The 300ft distance was a comfortable viewing distance from which the message would be clearly legible to participants.

During this part of the testing, participants were asked questions about the order of the elements displayed in the messages to determine their preferences. Participant preferences were measured for the following message elements: border presence, symbol presence, symbol placement, color coding, and brightness. Each set of messages included at least two different designs that incorporated one of the message elements in different ways. The participants viewed each message within a group twice, and then the experimenter would ask the participants if they noticed any differences between the messages. The experimenter recorded participant responses on a laptop computer. Next, the experimenter told the participants the intended meaning of the current messages they were viewing and asked the participants to rate each alternative within that message group. The participants saw each message again and rated each one on a scale of 1 to 5 to indicate how well they thought the message conveyed the intended meaning. The rating scale provided to the participants is shown in figure 68.

[2] The distances were initially set to 900ft, 750ft, 600ft, 450ft, 300ft and 150ft, but based on an initial analysis of data, the research team decided to remove the 150ft distance, due to the high level of accuracy achieved at the 300ft distance, and add the 525ft distance due to the large disparity in accuracy between the 600ft and 450ft distances.

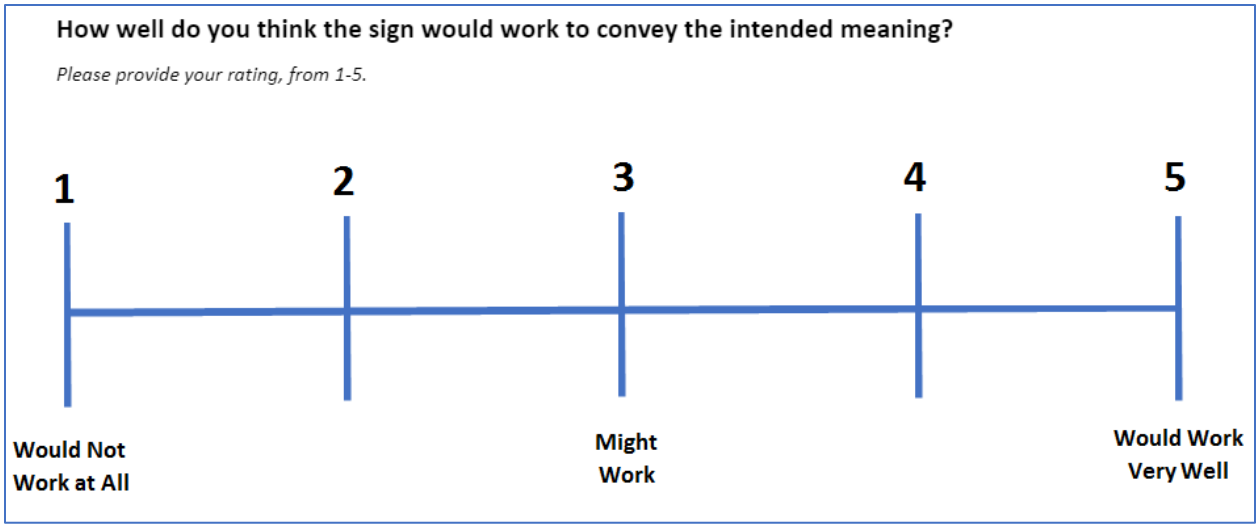


Figure 68. Graphic. Rating scale used by participants.
Source: Federal Highway Administration

After recording the participant's ratings, the experimenter asked participants if they preferred one message design over the other(s), or if they had any additional feedback that they wanted to provide about the message they just viewed. The researcher recorded any feedback or information that the participants provided. This process was repeated for each of the six message groups described in table 16. The seventh set of messages (figure 65) was used to gauge participants' reactions to brightness levels. During this part of the study, participants saw the Road Closed Ahead message in four different text and background color combinations. Each time a message appeared, the participants were asked for their feedback on the brightness level (i.e., if the sign was too bright or too dim). The experimenter recorded the participants' feedback on each sign's brightness level, and this concluded their participation in the study.

RESULTS

For the legibility testing, participants were shown a message at each of the six marked distances and asked to read the letters out loud. These were then compared against the actual letters to calculate a score for each trial ranging from 0 percent (0 of 7 letters correctly identified) to 100 percent (all 7 letters correctly identified). The maximum distance at which each participant could correctly identify all letters served as the dependent variable in statistical models. There were 11 cases in which participants could not identify all letters at any distance; these cases were assigned a legibility distance value of 0 feet. Mixed-effects linear models were fit to allow for fixed effects of light (daytime vs. nighttime) and colors (and their interaction), and random effects of vision and participant-specific intercepts. Various response distributions were assessed, but the Normal always performed best (yielded the lowest Akaike Information Criterion, or AIC,[3] value).

[3] AIC is used to compare nested models. The model with the lowest AIC is generally considered to be the best.

The results of the field testing are organized by the findings related to each of the field study research questions.

Do legend and background colors influence legibility?

Figure 69 shows the mean accuracy for each message at each distance. The black-on-orange color combination garnered the longest average legibility distance (484ft) and was statistically significantly greater than that of all other messages, with the exception of black-on-yellow and white-on-black. Green-on-black had the shortest legibility distance (262ft), which was not statistically different from white-on-green (290ft). As mentioned previously, the green used for the green-on-black message was intended to match the green used in color-coded versions of the Toll Cost and Travel Time messages. As a result, this green included a higher blue value than the RGB code used for the standard white-on-green messages, and thus may have influenced legibility as visual resolution of fine detail is typically poor for blue.

Distance (feet)

	900	750	600	525	450	300	150
FTOECOH	0%	0%	15%	11%	54%	100%	71%
PFSOQRH	0%	0%	0%	5%	23%	73%	100%
PLCFESH	0%	0%	7%	37%	77%	100%	100%
TPCSLOR	0%	0%	22%	58%	85%	96%	100%
HQCOPLE	0%	0%	7%	26%	58%	88%	100%
CFOTESH	0%	0%	7%	26%	50%	92%	100%
COHPETO	0%	0%	0%	0%	12%	73%	100%
LHPTFCR	0%	0%	0%	21%	62%	92%	100%

Figure 69. Chart. Mean accuracy for each message alternative at each distance.
The percentages represent the percentage of participants who were fully correct (i.e., correctly identified each letter on the message).
Source: Federal Highway Administration

The CMS used for the field testing was a 4x8ft message, and therefore font size was scaled to 10.4-inch letters to fit properly on the CMS.

Table 17 can be used to extrapolate what the legibility distances would likely be if using a full-size CMS with the standard 18-inch letter heights for highway signs.

Table 17. Conversion of Legibility Distances in Feet for Study Conditions to Expected Roadway Conditions

Message	FIELD STUDY 4ft x 8ft sign 10.4-inch letters	16-inch letters	18-inch letters	20-inch letters
TPCSLOR	480	738	831	923
HQCOPLE	424	652	734	815
FTOECQH	406	625	703	781
CQHPETO	289	445	500	556
LHPTFCR	411	632	711	790
CFOTESH	400	615	692	769
PFSOQRH	317	488	549	610
PLCFESH	439	675	760	844

The overall effect of light (daytime vs. nighttime) was insignificant ($p > 0.05$), but the legibility of one color combination was affected: for yellow-on-black, daytime legibility averaged 495ft versus 392ft at night (difference = 103ft, $p < 0.05$). Note: Intercharacter spacing was not adjusted to meet MUTCD provisions for CMS text messages, therefore the values shown are for comparative purposes only.

Does font influence legibility?

Figure 70 shows the mean legibility distance for each font. Series E garnered the longest legibility distance (509ft), which was statistically significantly greater than the distance associated with Series D (406ft, difference = 103ft, $p<0.01$) and LED (439ft, difference = 69ft, $p<0.01$). The effect of light was not statistically significant.

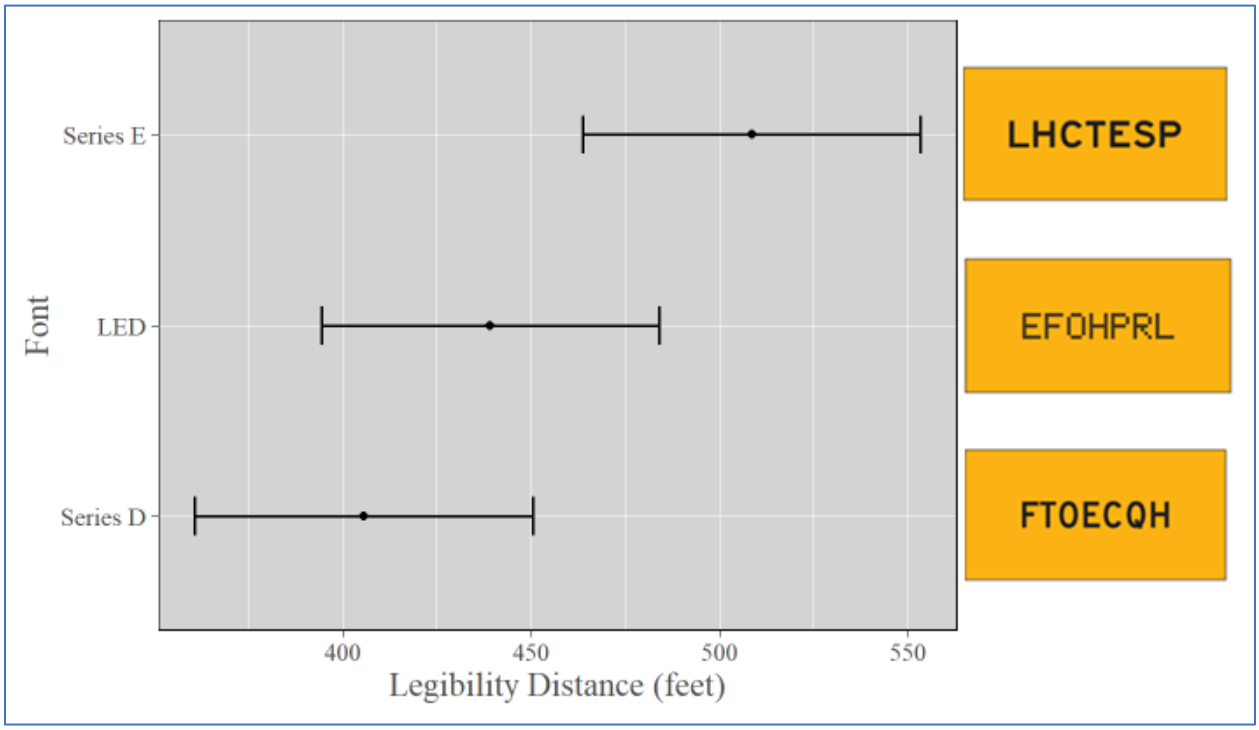


Figure 70. Graph. Average legibility distance (feet) for each font.
Source: Federal Highway Administration

Do various design features affect subjective ratings?

Participants were shown six different message categories, each with two to three message alternatives (as shown in table 16). Each message category was used to investigate one of three design features: border presence, the use of color coding, and symbol placement. Participants rated each stimulus from 1 (worst) to 5 (best), using the scale shown in figure 68. Similar mixed-effects statistical models were estimated here, using the numeric rating as the dependent variable. Participants were also given an opportunity to provide open-ended feedback on each message category, including preference for different designs or any other feedback they wished to provide.

Border Presence

"Road Work Ahead" and "Ramp Closed" messages included alternatives with and without borders. The border alternative garnered higher subjective ratings of the Road Work Ahead messages (mean without border = 3.9, mean with border = 4.5, difference = 0.6, $p < 0.01$). The presence of a border did not affect Ramp Closed message ratings. Figure 71 depicts findings for the Road Work Ahead message with and without a border.

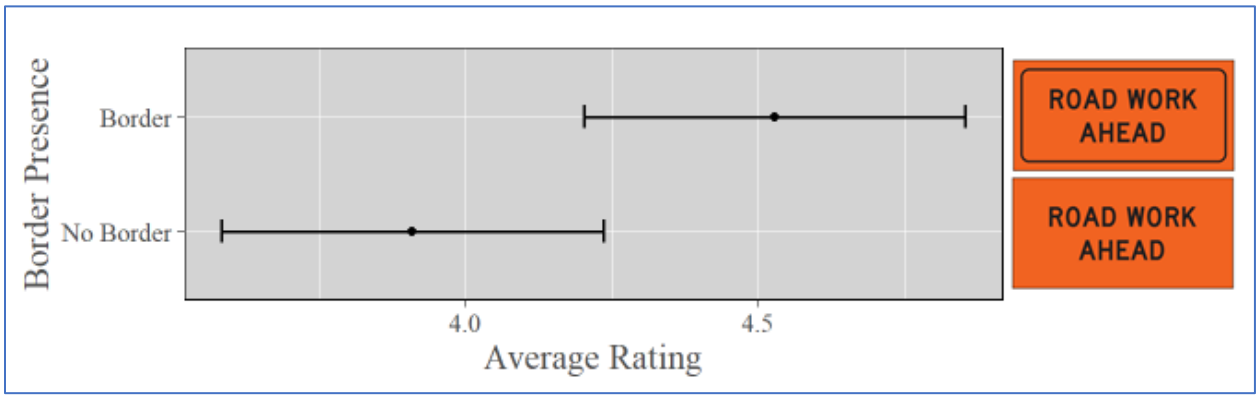


Figure 71. Graph. Average rating for Road Work Ahead messages.
Source: Federal Highway Administration

For both the Road Work Ahead and Ramp Closed message groups, participants were shown both message alternatives within the group back-to-back and were asked if they noticed a difference between the two messages. They were also asked if they preferred one message alternative over the other. A summary of participant responses is shown in tables 18 through 21.

Table 18. Experimental Messages Used for Questions Regarding Messages With and Without Borders

Road Work Ahead		Ramp Closed	
			

Table 19. Participant responses to "Did you notice a difference between those two messages?" (Borders)

Sign	Yes – border	Yes – some other change in sign	No difference
Road Work Ahead	70%	19%	11%
Ramp Closed	89%	7%	4%

Table 20. Participant responses to question "Do you have a preference for one message or the other?" (Borders)

Sign	Prefer with border	Prefer without border	No preference
Road Work Ahead	70%	19%	11%
Ramp Closed	73%	16%	11%

Table 21. Most common participant responses to support preference for each message (Borders)

Sign	With Border	Without Border
Road Work Ahead	• Emphasizes or makes the sign stand out more • Looks crisper and more "finished" • Makes it easier to read/makes the text stand out more • Color jumps out, conveyed more caution and emphasized the sign message Makes background less overpowering	• Border is distracting / focused more on lettering without border • Less cluttered without border

Sign	With Border	Without Border
Ramp Closed	• The border grabs your attention and makes the sign stand out more (makes you notice the sign more) • Used to seeing regular signs with borders	• Simpler and less cluttered without the border • Border seems unnecessary – want only the info that is needed • Sign with border looked too busy, too crowded • Sign is simpler and clearer without the border

The Road Work Ahead message was used as an example where there was less text and more space between the legend and the horizontal edges of the sign, whereas the Ramp Closed message was used as an example where there was very little background space remaining between the text and the horizontal edges of the sign. Although the average ratings for the message with a border were similar for Road Work Ahead (4.53) and for Ramp Closed (4.47), the ratings for the message without borders were slightly higher for Ramp Closed (4.22) than they were for Road rWork Ahead (3.91). Additionally, 70 percent of participants indicated that they preferred the Road Work Ahead message with the border, compared to 56 percent who indicated that they preferred the Ramp Closed message with the border (even though more participants noticed the border on the Ramp Closed message than they did on the Road Work Ahead). These findings could be an indication that participants may gravitate toward a border, particularly when there is excess free space on a message. However, further research would be required to examine this issue. The laboratory study findings did not indicate that participant ratings were influenced by border presence, but rather were influenced by symbol use and placement or text and background color.

The effect of light was insignificant for both messages.

Color Coding

Travel Time and Toll Cost messages included alternatives with yellow text and multi-colored text. The yellow-only alternative garnered higher subjective ratings for the Travel Time messages (mean with yellow text = 4.2, mean with multi-colored text = 3.6, difference = 0.6, $p < 0.05$). However, this difference only appears among the daytime participants (daytime difference = 0.9, $p < 0.05$; nighttime difference = 0.4, $p > 0.05$). The Toll Cost message ratings were not affected by text color or light ($p > 0.05$). Figure 72 depicts the average participant rating for Travel Time messages by time of day.

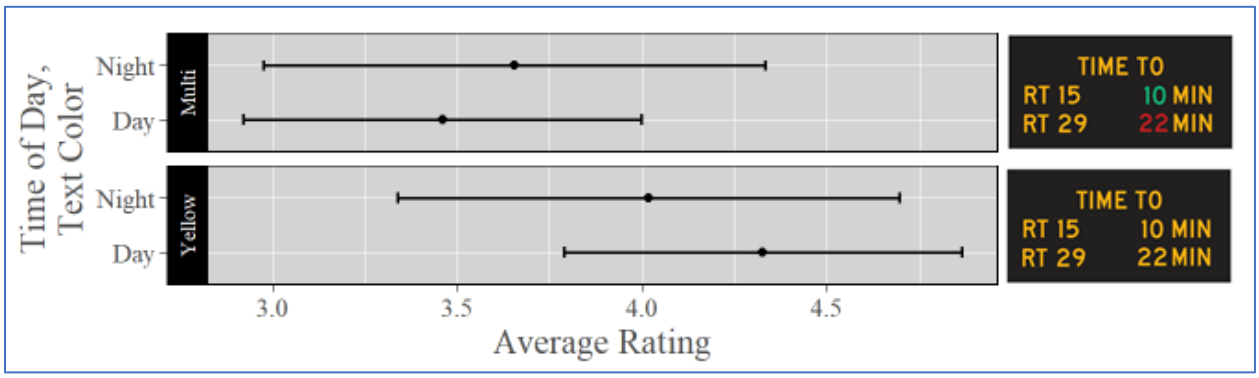


Figure 72. Graph. Average participant rating for Travel Time messages.
Source: Federal Highway Administration

For both the Travel Time and Toll Cost message groups, participants were shown both alternatives within the group back-to-back and were asked if they noticed a difference between the two messages. They were also asked if they preferred one alternative over the other. A summary of participant responses is shown in Tables 22 through 25.

Table 22. Experimental Messages Used for Questions Regarding Messages With and Without Color-Coding

Travel Time	Toll Cost
	

Table 23. Participant responses to question "Did you notice a difference between those two messages?" (Color-coding)

Sign	Yes – colors	No difference
Travel Time	100%	0%
Toll Cost	100%	0%

Table 24. Participant responses to question "Do you have a preference for one message or the other?" (Color-coding)

Sign	Prefer yellow only	Prefer color coded	No preference
Travel Time	56%	26%	19%
Toll Cost	52%	30%	19%

Table 25. Most common participant responses to support preference for each message (Color-coding)

Sign	Yellow Only	Color Coded
Travel Time	• The color coding is distracting • The color coding is difficult to read • The colors are confusing (don't understand the meaning)	• Gives you more information/ signifies traffic • Color draws attention to the numbers
Toll Cost	• Colors are distracting – focused on that and not the rest of sign • Colors make you have to think more while driving • Colors more difficult to read than yellow • Colors not necessary • Don't know the meaning of the colors	• Colors draw more attention to the price

Although participants in the laboratory were not asked their preference for the Travel Time or Toll Cost messages, they were asked what they thought the colors (i.e., color coding) were trying to tell them. For the Toll Cost signs, about 54 percent of participant responses indicated a general understanding of the intended meaning of the color coding (indicating amount of traffic and/or cost relative to normal). For the Travel Time messages, about 71 percent indicated a general understanding of the intended meaning (indicating amount of traffic and/or travel times relative to normal times). With participant preference for Toll Cost and Travel Time messages at 52 percent and 56 percent, respectively, and participant understanding of the meaning behind the color coding (54 percent and 71 percent, respectively), it is possible that preference for messages (yellow only vs. color coded) could be influenced by their understanding of the color coding.

Symbol Placement

Ramp Closed and No Trucks messages included alternatives with three different symbol placement options. The presence of a symbol (whether placed in the center or on the left) garnered higher subjective ratings of the Road Closed messages (mean without symbol = 3.2, mean with symbol in center = 4.1, mean with symbol on left = 4.5; difference between no symbol and center = 0.9, $p < 0.01$; difference between no symbol and left = 1.3, $p < 0.01$; difference between center and left = 0.4, $p > 0.05$). Center-placement (symbol-only) garnered lower ratings of the No Trucks alternatives (mean symbol in center = 3.0, mean with symbol on left = 4.2, mean with symbol on right = 4.5; difference between center and left = 1.2, $p < 0.01$; difference between center and right = 1.5, $p < 0.01$; difference between left and right = 0.2, $p > 0.05$). The effect of light was insignificant for both messages. Figure 73 depicts the average participant rating for symbol placement in a Ramp Closed message.

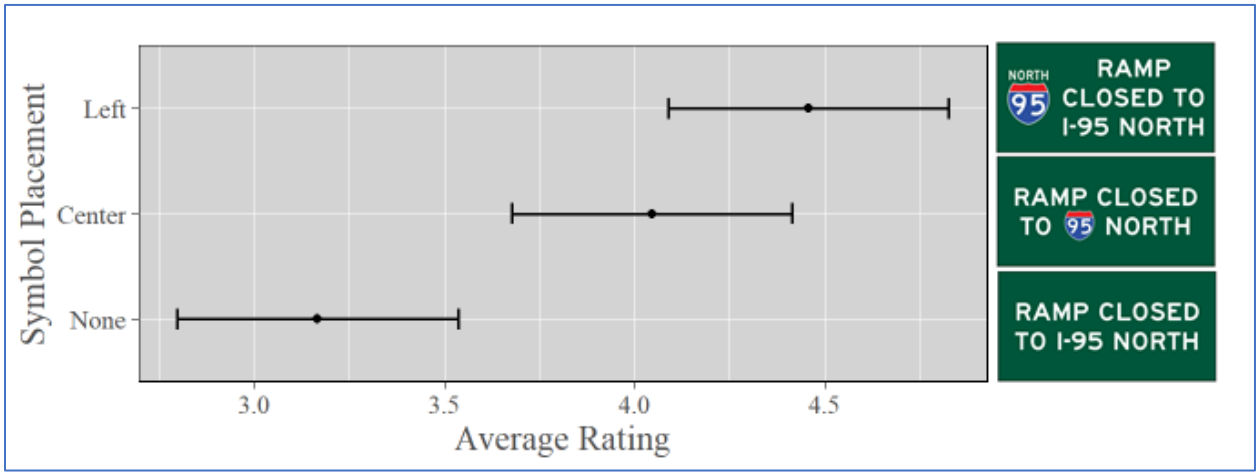


Figure 73. Graph. Average participant rating for Ramp Closed messages.
Source: Federal Highway Administration

For the No Trucks sign group, participants were asked if they had any preference for certain messages over the others. Eighty-two percent of participants preferred a message with both the symbol and the text, as opposed to the symbol-only message. Approximately 42 percent of participants specified that they particularly prefer the symbol to the right of the text, whereas 19 percent specified that they prefer the symbol to the left of the text. The findings are similar to

the laboratory findings regarding No Trucks messages. Participants rated the messages with both symbols and text higher than the symbol-only messages. Figure 74 depicts the average participant ratings for symbol placement within the No Trucks messages.

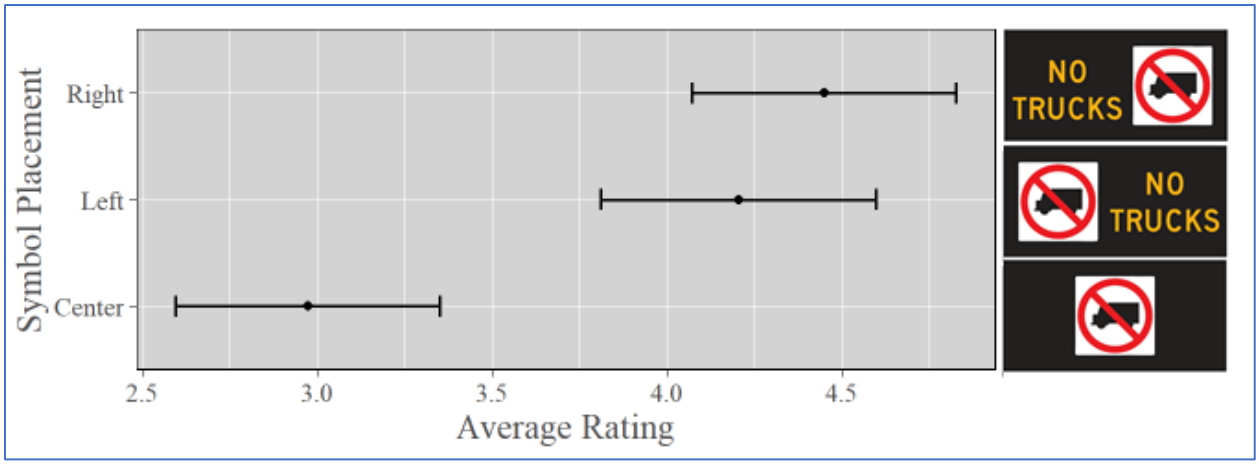


Figure 74. Graph. Average participant ratings for No Trucks messages.
Source: Federal Highway Administration

Participants were also asked to indicate if they had any preference for certain messages in the Ramp Closed message group. Thirty-five percent of participants indicated that they prefer the message with the route shield to the left of the text, 31 percent preferred the message with the route shield within the text, 15 percent preferred either message that included a route shield, 15 percent preferred the text-only message, and 4 percent had no preference. The participants who preferred the route shield to the left of the text (35 percent) liked that this message had both the symbol (route shield) and the text. They also tended to like that the route shield was larger on this message, which they reported was helpful if a driver is looking for I-95, and also helpful if a driver is not looking for I-95, because they would see the route shield first, know that the sign doesn't apply to them, and thus not have to read the rest of the message. The participants who preferred the message with the route shield within the text (31 percent) liked that this message had both text and symbol (route shield), but generally thought that this message "flowed" the best. They liked that it included both the symbol (route shield) and the text, but indicated that it seemed less crowded than the message with the route shield to the left of the text. Participants liked that this message could be read like a sentence and was more intuitive than the message with the route shield on the left, because when the symbol is to the left, they had to connect what the symbol and words are saying. They also felt like the message with the route shield within in text did not feel as cramped as the message with the route shield to the left of the text. The participants who preferred the message with only text (15 percent) indicated that this was simple and easiest to read. These findings were similar to the Ramp Closed findings from the laboratory study. Although reaction times were slightly higher than average for the symbol-center, and slightly lower than average for the symbol-right, the rankings indicated that participants preferred either message that included the symbol with the text over the text-only message.

In general, the laboratory and field study findings regarding symbol placement are similar, in that participants preferred messages that included both symbols and text more than text-only messages or symbol-only messages. However, given that participant preferred having the text to the left of the symbol, it is reasonable to conclude that participants found reading the text first—the standard way English messages are read (i.e., left to right)—most helpful. This suggests that

the added symbol is redundant and unnecessary in conveying the message, may ultimately serve no traffic control purpose, and may not have any benefit on safety or mobility.

Participant Feedback on Brightness for Different Legend and Background Colors

Participants were shown four different legend and background color combinations for a Road Closed Ahead message, and they provided feedback on the brightness of each message. Participant responses were coded into one of three categories based on the feedback they provided about the brightness: "too bright" (+1), "good level of brightness" (0), and "too dim" (-1).

A mixed-effects linear model was fit to allow for fixed effects of light and colors (and their interaction), and random effects of vision and participant-specific intercepts.

Color Combination

The findings, depicted in figure 75, indicated that text/background color combinations influence how bright participants rate a message. The black-on-white message alternative was rated as the brightest color combination (mean rating = 0.64, 95 percent CI: 0.45, 0.83), while the red-on-black was rated as the dimmest (mean rating = -0.28, 95 percent CI: -0.48, -0.07). Black-on-white was rated as significantly brighter than all other combinations ($p < 0.05$). Red-on-black was rated as significantly dimmer than black-on-white (difference = 0.9, $p < 0.01$) and black-on-yellow (difference = 0.5, $p < 0.01$), but not white-on-black (difference = 0.3, $p > 0.05$). Black-on-yellow and white-on-black were not statistically significantly different from one another ($p > 0.5$).

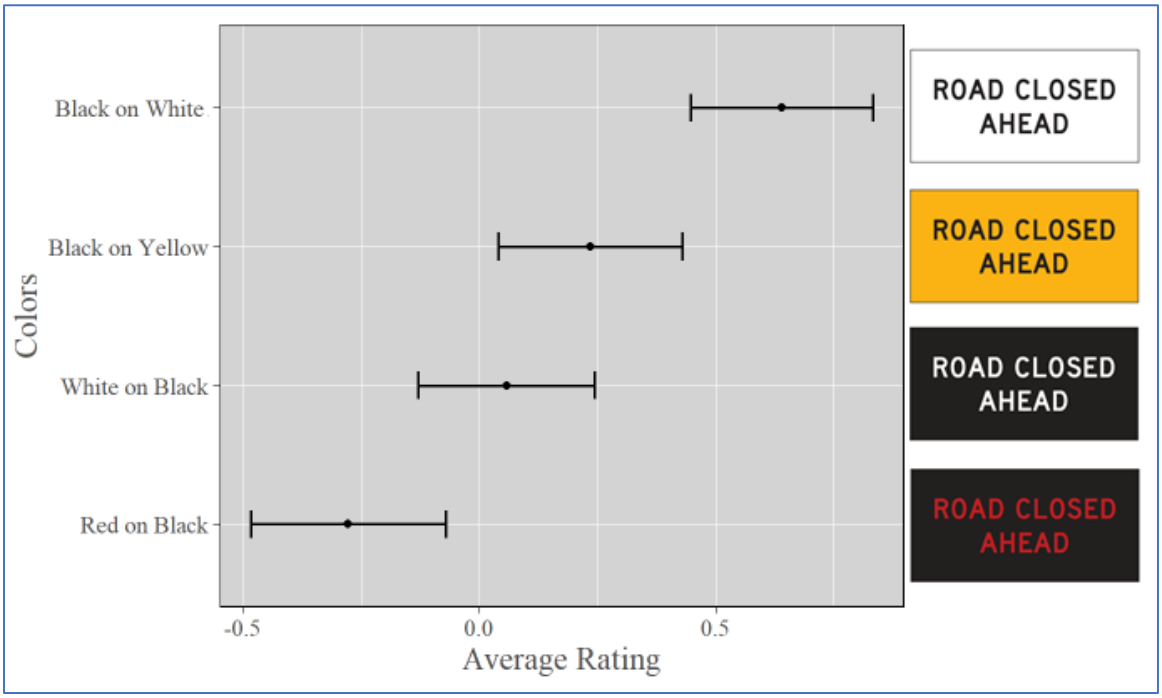


Figure 75. Graph. Average message brightness rating (1 = too bright, 0 = good level of brightness, -1 = too dim).
Source: Federal Highway Administration

Time of Day

The research team conducted an analysis to determine if perception of brightness for each message varied by time of day (daytime vs. nighttime). Overall, participants rated the messages at night as brighter than those rated during the day (difference = 0.3, $p < 0.01$). However, the statistical significance of this difference disappears when examining each message individually ($p > 0.05$). These findings are depicted in figure 76.

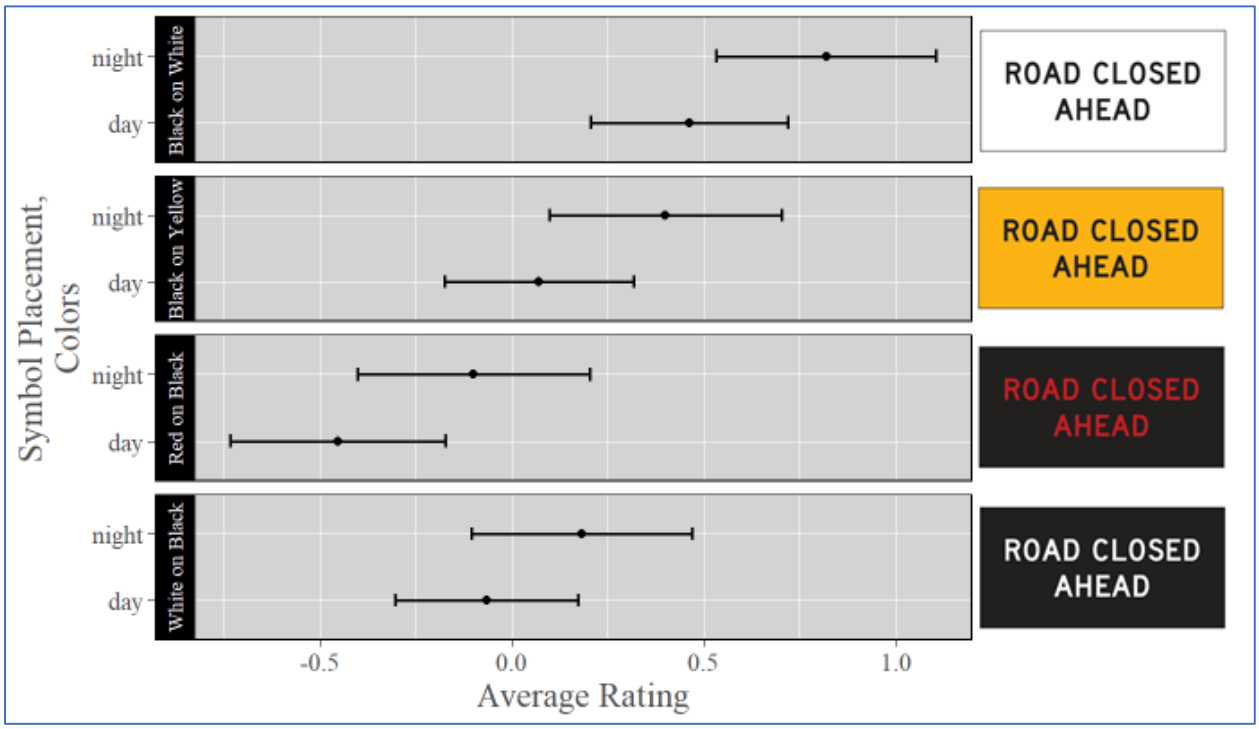


Figure 76. Graph. Average message brightness ratings by time of day (daytime vs. nighttime).

Source: Federal Highway Administration

CHAPTER 4. DISCUSSION

In the course of this study, data was collected using computer-based comprehension testing, computer-based legibility testing, and closed-course field legibility testing. A wide variety of messages with different designs were developed for testing, but the primary design elements of interest included symbol use and placement, use of color (including text color, background color, and color-coding sign message elements), and border presence. Font style, perception of message brightness, and effects of daytime versus nighttime were examined only in the field study. This section highlights the prominent findings, as well as any common themes that were identified in the results of both the computer-based testing and the field testing. It also discusses any limitations of the research effort and identifies potential areas for future research.

SYMBOL USE AND PLACEMENT

The symbols examined in this study did not influence comprehension (i.e., understanding of the meaning of the sign) for any of the message categories tested that included symbols. Overall, comprehension rates were typically between 90-100 percent for all message categories, with comprehension falling below 90 percent for only two message categories.

The only symbols that influenced reaction time were the route shield on the Ramp Closed messages. For the Ramp Closed messages, placing the route shield within the text resulted in an approximate half-second faster reaction time than average, and placing the route shield to the left of the text resulted in an approximate half-second slower reaction time than average. Similarly, for the Speed Limit messages, the depiction of the conventional Speed Limit sign resulted in an approximate half-second faster reaction time than the alternatives displaying the same text-only message in a different format. These symbols/depictions may have influenced reaction time when other symbols did not because they are both seen often by drivers and are highly recognizable, whereas other symbols (Seat Belt, No Trucks, Slippery When Wet, Road Work, HOV) are likely not seen as frequently by motorists.

The legibility findings indicated that the addition of symbols to text-only messages, with the symbols to the left or right of the text, performed equally as well as the text-only versions. Symbol-only messages, on the other hand, generally had the shortest legibility distances. This, coupled with the finding that symbols did not influence comprehension, suggests that the text alone is generally sufficient in conveying a message on CMSs.

Overall, this study did not indicate that the addition of symbols to text messages improved comprehension. Though the study did suggest that participants preferred messages with both symbols and text, this subjective rating of preference is not necessarily indicative of the performance of a sign or message, and is based on a relatively small sampling of participants and a small sample size of messages. Further research would be required to determine if comprehension is influenced by symbols for different messages other than the seven messages that included symbols in this study. For example, research on other messages not included in this study may indicate that text-only messages that are not as comprehensible could benefit from the use of a symbol (e.g., to benefit non-native English speakers).

USE OF COLOR

The use of color did not influence message comprehension, and only influenced reaction time in one instance. When exploring participant subjective ratings of messages, participants primarily based their ratings on symbol placement over text/background color. However, there were four categories in which participants' ratings seemed to also differ by text/background color. In each of these cases, messages with yellow or orange backgrounds were rated higher than other background colors (within similar symbol placement categories).

The laboratory legibility testing indicated that legibility distances were generally longer for positive contrast messages (e.g., white-on-black, yellow-on-black) than they were for negative contrast messages (e.g., black-on-white, black-on-yellow). The findings for white-on-green messages, however, were a little less clear. For Special Event messages, white-on-green had significantly shorter legibility distances than white-on-black messages, but were not significantly different from yellow-on-black or black-on-white. For Toll Cost messages, legibility for white-on-green was significantly shorter than that of yellow-on-black messages; however, for Travel Time messages, there were no significant differences between those same color combinations.

Although the black-on-white, white-on-black, black-on-yellow, and yellow-on-black color combinations were evaluated for multiple message categories, there were less-commonly used color combinations (e.g., red-on-black, black-on-pink, black-on-orange) that were evaluated in one message category each. When examining the Road Closed Ahead messages, legibility distances were significantly shorter for the red-on-black than for all other alternatives, including black-on-pink, black-on-yellow, and yellow-on-black. Special Event messages evaluated other colors (red, blue, green) in addition to the primary text colors (white, yellow). That is, some signs included two different text colors; the primary text color (yellow or white) for the "USE EXIT 15" text and a secondary text color (red, blue or green) for the "CONCERT TRAFFIC" text. The findings indicated that the addition of blue text resulted in significantly shorter legibility distances than messages that did not include any additional secondary colors, the messages that included red text, and those that included green text. On the contrary, the addition of green text resulted in longer legibility distances than messages that did not include any additional colors, messages with red text, and messages with blue text.

When examining the Road Work Ahead messages, the black-on-orange messages had significantly shorter legibility distances than both the white-on-black and yellow-on-black messages. The field study, however, indicated that the black-on-orange messages resulted in the longest average legibility distance and was significantly greater than all other messages except for the white-on-black and black-on-yellow messages. The field study also indicated the shortest legibility for green-on-black messages, followed by white-on-green messages. The field study yielded no statistically significant differences between the white-on-black, yellow-on-black, black-on-white, and black-on-yellow messages.

It should be noted that the goals, and thus evaluation methods, were different for the laboratory and field legibility testing. For example, the laboratory legibility testing evaluated the effects of multiple variables (color, symbol placement, border presence) and, therefore, the color-based

legibility findings were averaged across levels of other variables (i.e., symbol placement, border presence). Additionally, because message categories varied not only by message, but also by the levels of other variables that were applied to the alternatives, results were analyzed within each message category (rather than across all message categories). On the contrary, the field testing examined only the effects of text and background color on legibility.

Many of the sign categories included in the laboratory testing included the use of colors to convey specific messages (i.e., related to specific sign classifications). For example, the Road Closed Ahead messages examined the fluorescent pink background color, which is used for incident management messages. Additionally, many message categories used various combinations of black and white or yellow and black to compare colors' effects as warning messages (e.g., Slippery When Wet) and messages conveying regulatory information (e.g., Speed Limit, Don't Text and Drive). The findings, as detailed in the Summary of Results section of chapter 2, suggest that motorists may not fully understand the meaning behind certain message colors. The exception was yellow; participants generally seemed aware that yellow conveys caution. However, it is still unclear whether motorists understand the difference between regulatory and advisory messages based on color use with CMSs. This could present a problem if advisory and/or regulatory messages are presented on CMSs in a context not previously experienced by motorists. For example, the Perez et al. (2016) findings discussed in the Computer-Based Comprehension Results section indicated that participants misinterpreted an advisory variable speed limit message as a regulatory speed limit message.

When examining the concept of color coding, participant field ratings of the Travel Time and Toll Cost messages garnered higher ratings for the yellow-only (not color coded) alternatives for Travel Time messages (for daytime participants only), with no difference for Toll Cost messages. For both the Travel Time and Toll Cost categories, more participants (52 and 56 percent, respectively) further mentioned that they preferred the yellow-only messages than those who mentioned they preferred the color-coded message (26 and 30 percent, respectively), with 19 percent (in both sign categories) indicating no preference. The laboratory study indicated that the use of color coding did not influence overall comprehension of the message (i.e., participant ability to correctly identify the Toll Cost or Travel Time of their target destination). The findings also indicated that understanding of the meaning of the color coding for Travel Time and Toll Cost message was approximately 71 percent and 54 percent, respectively. It is possible that low preference for color coding could be based on lack of understanding of the concept, or because color coding does not influence participants' ability to identify the necessary information (toll costs and travel times).

Future research could consider potential issues with messages being displayed on CMSs with low-contrast color combinations (e.g., red-on-black) and colors that may present issues with visual acuity and legibility (e.g., blue-on-black). Additional research is needed to determine if adjustments to color codes, sign brightness, or other factors (e.g. environment) influence the legibility of these messages. Additional research should investigate which color codes may work best in messages displayed on CMSs.

USE OF BORDERS

Based on the laboratory study findings, there were no significant differences in comprehension, reaction time, or participant preference ratings for the use of borders around messages displayed on CMSs. The legibility testing did indicate, however, that in most cases (4 out of 5) where participants evaluated black-on-white messages with and without a border, border presence always affected legibility. However, in some cases, the border was associated with longer legibility distances, and in others it was associated with shorter legibility distances.

In the field study, participant subjective ratings for the Road Work Ahead messages were significantly higher for the sign with the border than the sign without the border. Although more participants noticed the border for the Ramp Closed messages than they did on the Road Work Ahead messages, fewer participants mentioned that they prefer the messages with the border for the Ramp Closed than for the Road Work Ahead messages. These findings could be due to the amount of text that is included on the messages. The Ramp Closed message has more text that extends to the edge of the border, whereas the Road Work Ahead message includes more free space between the text and the border. However, the messages were also presented in different text/background color combinations.

Additional research, focused on the presence of borders, is needed to better understand why borders might improve legibility, and to further examine the effects of background color and amount of text on preference for borders.

CONSIDERATIONS FOR USE OF CMSs IN DAYTIME VERSUS NIGHTTIME

Legibility distances in the field study did not vary significantly in the daytime versus nighttime, except for yellow-on-black messages. For these messages, legibility distance was significantly longer during the daytime than at nighttime. Participant subjective ratings of messages with varying design features (border presence, color coding, symbol placement) were not affected by light (daytime vs. nighttime), except for the Travel Time messages. For these messages, participants rated the yellow-only messages significantly higher than the messages with multi-colored text, but only during the daytime.

Participants were shown four different legend/background color combinations (black-on-white, black-on-yellow, red-on-black, white-on-black) for a text-only message and provided feedback on the brightness of each message. Overall, participants rated messages during the night as brighter than those rated during the day. However, the statistical significance of this difference disappears when examining each message individually.

FONT STYLE

Font style was only examined in the field study. The findings indicated that Series E had the longest average legibility distance, which was significantly longer than Series D and the LED-style font. This is not a surprising finding, as Series E has wider letters and was designed to be read from further than Series D, even on static signs. Additional testing is required to examine the effects of font using different text/background colors and under different environmental conditions while being displayed on a CMS. A more comprehensive font study could also examine the effects of messages using mixed case on CMSs.

LIMITATIONS AND FUTURE RESEARCH

A limitation of the current study is the limited number of individuals that participated in the laboratory and field studies. Thus, the number of observations and results of the tests conducted reduce how applicable the research is to designing effective messages to display on a CMS.

Subjective evaluations conducted during the closed-course field study only provide preferences of study participants, which are not necessarily indicative of the actual effectiveness of the elements studied for specific messages or how they were displayed. Preference ratings are influenced by many factors and can vary based on unknown reasons. Participant ratings only provided limited information, and therefore should not be used directly or relied on for making decisions on the elements to include in the design and display of messages on CMSs.

The implications of varying font style in CMS messages was only evaluated using one text/background color combination. This limited investigation indicated some font styles may be more effective than other font styles that might be used in messages displayed on full-matrix color CMSs; however, a more comprehensive study is required to determine the impacts of font use in full-matrix color CMSs. Additionally, the influence of the layout and design of text-only messages (e.g., spacing between characters, lines of text) was not examined in this study. Therefore, a more comprehensive study looking at legibility of various fonts and the design or layout of text-only messages is needed before conclusions from these results can be drawn.

Due to the design of the current field study, the full-matrix color CMS (which was mounted to a trailer) essentially resembled a ground-mounted sign. Additional research is needed to evaluate impacts of full-matrix color CMSs mounted on overhead or elevated structures.

Additionally, although the current study included an investigation of the effects of color on perception of sign brightness, additional research is needed to determine what (if any) conclusions can be drawn as to how brightness and lighting levels impact motorists under varying lighting conditions.

Additional research is also needed to determine which symbols are highly recognizable to motorists and which are not when they are included on messages displayed on a CMS. Though some research has been conducted on symbol-only signs using static signs, additional research is needed to determine what symbols and factors enhance motorists' symbol recognition.

CHAPTER 5. REFERENCES

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3. United States Census Bureau (2018). American Community Survey Demographic and Housing Estimates for Blacksburg, VA. Retrieved from https://data.census.gov/cedsci/table?q=blacksburg,%20va&g=1600000US5107784&hidePreview=false&table=DP05&tid=ACSDP5Y2018.DP05&vintage=2018&cid=DP05_0001E&layer=place&lastDisplayedRow=17 accessed on January 31, 2020.

APPENDIX A. DESCRIPTION OF LABORATORY STUDY TEST MESSAGES

Table 26. Descriptions of Laboratory Study Test Messages

Sign Classification / Sign Type	Message Alternative	Message	Text Color	Background Color	Symbol Placement	Border Present	Other Colors
Regulatory Signs	1	No Trucks	N/A	Black	Center	No	–
Regulatory Signs	2	No Trucks	Yellow	Black	Left	No	–
Regulatory Signs	3	No Trucks	White	Black	Left	No	–
Regulatory Signs	4	No Trucks	Yellow	Black	Right	No	–
Regulatory Signs	5	No Trucks	White	Black	Right	No	–
Regulatory Signs	6	No Trucks	Yellow	Black	Top Center	No	–
Regulatory Signs	7	No Trucks	White	Black	Top Center	No	–
Regulatory Signs	8	No Trucks	Yellow	Black	None	No	–
Regulatory Signs	9	No Trucks	White	Black	None	No	–
Regulatory Signs	1	Speed Limit	Black	White	None	No	–
Regulatory Signs	2	Speed Limit	Black	White	None	Yes	–
Regulatory Signs	3	Speed Limit	White	Black	None	No	–
Regulatory Signs	4	Speed Limit	White	Black	None	Yes	–
Regulatory Signs	5	Speed Limit	N/A	Black	Center	No	–
Regulatory Signs	6	Speed Limit	Yellow	Black	None	No	–
Regulatory Signs	7	Speed Limit	Yellow	Black	None	Yes	–
Warning Signs	1	Slippery When Wet	N/A	Yellow	Center	No	–
Warning Signs	2	Slippery When Wet	Black	Yellow	None	No	–
Warning Signs	3	Slippery When Wet	Black	Yellow	Top Center	No	–
Warning Signs	4	Slippery When Wet	Black	Yellow	Left	No	–
Warning Signs	5	Slippery When Wet	Black	Yellow	Right	No	–
Warning Signs	6	Slippery When Wet	N/A	Black	Center	No	–
Warning Signs	7	Slippery When Wet	Yellow	Black	None	No	–

Sign Classification / Sign Type	Message Alternative	Message	Text Color	Background Color	Symbol Placement	Border Present	Other Colors
Warning Signs	8	Slippery When Wet	Yellow	Black	Top Center	No	–
Warning Signs	9	Slippery When Wet	Yellow	Black	Left	No	–
Warning Signs	10	Slippery When Wet	Yellow	Black	Right	No	–
Warning Signs	1	Road Work Ahead	N/A	Black	Center	No	–
Warning Signs	2	Road Work Ahead	White	Black	Left	No	–
Warning Signs	3	Road Work Ahead	White	Black	Right	No	–
Warning Signs	4	Road Work Ahead	White	Black	None	No	–
Warning Signs	5	Road Work Ahead	White	Black	None	Yes	–
Warning Signs	6	Road Work Ahead	Yellow	Black	Left	No	–
Warning Signs	7	Road Work Ahead	Yellow	Black	Right	No	–
Warning Signs	8	Road Work Ahead	Yellow	Black	None	No	–
Warning Signs	9	Road Work Ahead	Black	Orange	None	Yes	–
Warning Signs	10	Road Work Ahead	Black	Orange	None	No	–
Warning Signs	11	Road Work Ahead	Black	Orange	Left	No	–
Warning Signs	12	Road Work Ahead	Black	Orange	Right	No	–
Guide Signs	1	Travel Time	Yellow	Black	None	No	–
Guide Signs	2	Travel Time	Yellow	Black	None	No	Green/Red
Guide Signs	3	Travel Time	Yellow	Black	None	No	Red
Guide Signs	4	Travel Time	White	Green	None	No	–
Guide Signs	5	Travel Time	White	Green	None	No	Yellow/Red
Guide Signs	6	Travel Time	White	Green	None	No	Yellow
Guide Signs	7	Travel Time	White	Green	None	Yes	–
Guide Signs	8	Travel Time	White	Green	None	Yes	Yellow/Red
Guide Signs	9	Travel Time	White	Green	None	Yes	Yellow
Guide Signs	1	Ramp Closed to I-95 North	Yellow	Black	None	No	–
Guide Signs	2	Ramp Closed to I-95 North	Yellow	Black	Left	No	–

Sign Classification / Sign Type	Message Alternative	Message	Text Color	Background Color	Symbol Placement	Border Present	Other Colors
Guide Signs	3	Ramp Closed to I-95 North	Yellow	Black	Center	No	–
Guide Signs	4	Ramp Closed to I-95 North	White	Black	None	No	–
Guide Signs	5	Ramp Closed to I-95 North	White	Black	Left	No	–
Guide Signs	6	Ramp Closed to I-95 North	White	Black	Center	No	–
Guide Signs	7	Ramp Closed to I-95 North	White	Green	None	No	–
Guide Signs	8	Ramp Closed to I-95 North	White	Green	Left	No	–
Guide Signs	9	Ramp Closed to I-95 North	White	Green	Center	No	–
Guide Signs	1	Concert Traffic Use Exit 15	White	Black	None	No	–
Guide Signs	2	Concert Traffic Use Exit 15	White	Black	None	No	–
Guide Signs	3	Concert Traffic Use Exit 15	Black	White	None	No	–
Guide Signs	4	Concert Traffic Use Exit 15	Black	White	None	Yes	–
Guide Signs	5	Concert Traffic Use Exit 15	White	Green	None	Yes	–
Guide Signs	6	Concert Traffic Use Exit 15	Yellow	Black	None	No	–
Guide Signs	7	Concert Traffic Use Exit 15	Yellow	Black	None	Yes	–
Guide Signs	8	Concert Traffic Use Exit 15	White	Black	None	No	Green

Sign Classification / Sign Type	Message Alternative	Message	Text Color	Background Color	Symbol Placement	Border Present	Other Colors
Guide Signs	9	Concert Traffic Use Exit 15	White	Black	None	No	Blue
Guide Signs	10	Concert Traffic Use Exit 15	White	Black	None	No	Red
Guide Signs	11	Concert Traffic Use Exit 15	Yellow	Black	None	No	Green
Guide Signs	12	Concert Traffic Use Exit 15	Yellow	Black	None	No	Blue
Guide Signs	13	Concert Traffic Use Exit 15	Yellow	Black	None	No	Red
Guide Signs	14	Concert Traffic Use Exit 15	White	Green	None	No	–
Toll Signs	1	Toll Costs	White	Green	None	No	–
Toll Signs	2	Toll Costs	White	Green	None	No	Yellow/Red
Toll Signs	3	Toll Costs	White	Green	None	No	Red
Toll Signs	4	Toll Costs	Yellow	Yellow	None	No	–
Toll Signs	5	Toll Costs	Yellow	Yellow	None	No	Yellow/Red
Toll Signs	6	Toll Costs	Yellow	Yellow	None	No	Red
Miscellaneous	1	Fasten Seatbelt	N/A	Black	Center	Yes	–
Miscellaneous	2	Fasten Seatbelt	White	Black	Left	Yes	–
Miscellaneous	3	Fasten Seatbelt	White	Black	Right	Yes	–
Miscellaneous	4	Fasten Seatbelt	White	Black	Top Center	Yes	–
Miscellaneous	5	Fasten Seatbelt	White	Black	None	Yes	–
Miscellaneous	6	Fasten Seatbelt	N/A	White	Center	Yes	–
Miscellaneous	7	Fasten Seatbelt	Black	White	Left	Yes	–
Miscellaneous	8	Fasten Seatbelt	Black	White	Right	Yes	–
Miscellaneous	9	Fasten Seatbelt	Black	White	Top Center	Yes	–
Miscellaneous	10	Fasten Seatbelt	Black	White	None	Yes	–
Miscellaneous	11	Fasten Seatbelt	Black	White	Left	Yes	–

Sign Classification / Sign Type	Message Alternative	Message	Text Color	Background Color	Symbol Placement	Border Present	Other Colors
Miscellaneous	12	Fasten Seatbelt	Black	White	Right	Yes	–
Miscellaneous	13	Fasten Seatbelt	Black	White	None	Yes	–
Miscellaneous	1	Wipers On, Headlights On	White	Black	None	No	–
Miscellaneous	2	Wipers On, Headlights On	White	Black	None	Yes	–
Miscellaneous	3	Wipers On, Headlights On	Black	White	None	No	–
Miscellaneous	4	Wipers On, Headlights On	Black	White	None	Yes	–
Miscellaneous	5	Wipers On, Headlights On	Yellow	Black	None	No	–
Miscellaneous	6	Wipers On, Headlights On	Black	Yellow	None	No	–
Miscellaneous	1	Don't Text and Drive	White	Black	None	No	–
Miscellaneous	2	Don't Text and Drive	Black	White	None	No	–
Miscellaneous	3	Don't Text and Drive	Yellow	Black	None	No	–
Miscellaneous	4	Don't Text and Drive	Black	Yellow	None	No	–
Miscellaneous	5	Don't Text and Drive	White	Black	None	Yes	–
Miscellaneous	6	Don't Text and Drive	Black	White	None	Yes	–
Miscellaneous	7	Don't Text and Drive	Yellow	Black	None	Yes	–
Miscellaneous	8	Don't Text and Drive	Black	Yellow	None	Yes	–
Miscellaneous	1	HOV 2+ Persons Per Vehicle	White	Black	None	No	–
Miscellaneous	2	HOV 2+ Persons Per Vehicle	Black	White	None	No	–
Miscellaneous	3	HOV 2+ Persons Per Vehicle	White	Black	Left	No	–
Miscellaneous	4	HOV 2+ Persons Per Vehicle	White	Black	Right	No	–

Sign Classification / Sign Type	Message Alternative	Message	Text Color	Background Color	Symbol Placement	Border Present	Other Colors
Miscellaneous	5	HOV 2+ Only	White	Black	Top Center	No	–
Miscellaneous	6	HOV 2+ Persons Per Vehicle	White	Black	None	Yes	–
Miscellaneous	7	HOV 2+ Persons Per Vehicle	Black	White	None	Yes	–
Miscellaneous	8	HOV 2+ Persons Per Vehicle	Black	White	Left	No	–
Miscellaneous	9	HOV 2+ Persons Per Vehicle	Black	White	Right	No	–
Miscellaneous	10	HOV 2+ Only	Black	White	Top Center	No	–
Miscellaneous	1	Road Closed Ahead	Yellow	Black	None	No	–
Miscellaneous	2	Road Closed Ahead	Red	Black	None	No	–
Miscellaneous	3	Road Closed Ahead	Black	Pink	None	No	–
Miscellaneous	4	Road Closed Ahead	Black	Yellow	None	No	–

APPENDIX B. IMAGES OF LABORATORY STUDY MESSAGES

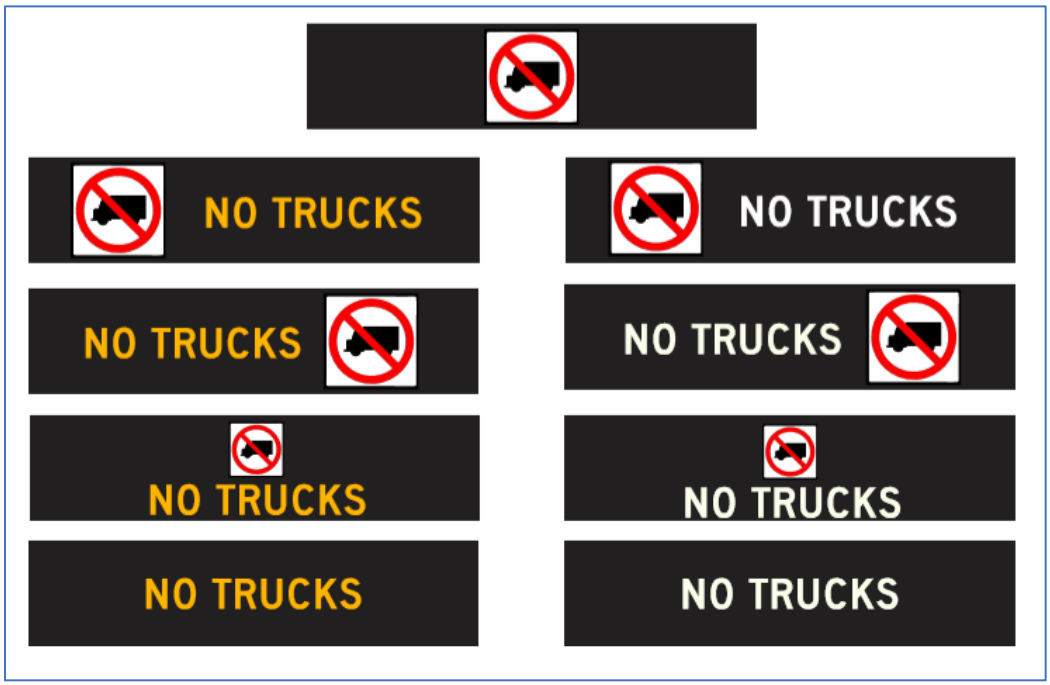

Figure 77. Image. No Trucks Laboratory Study Signs.
Source: Federal Highway Administration

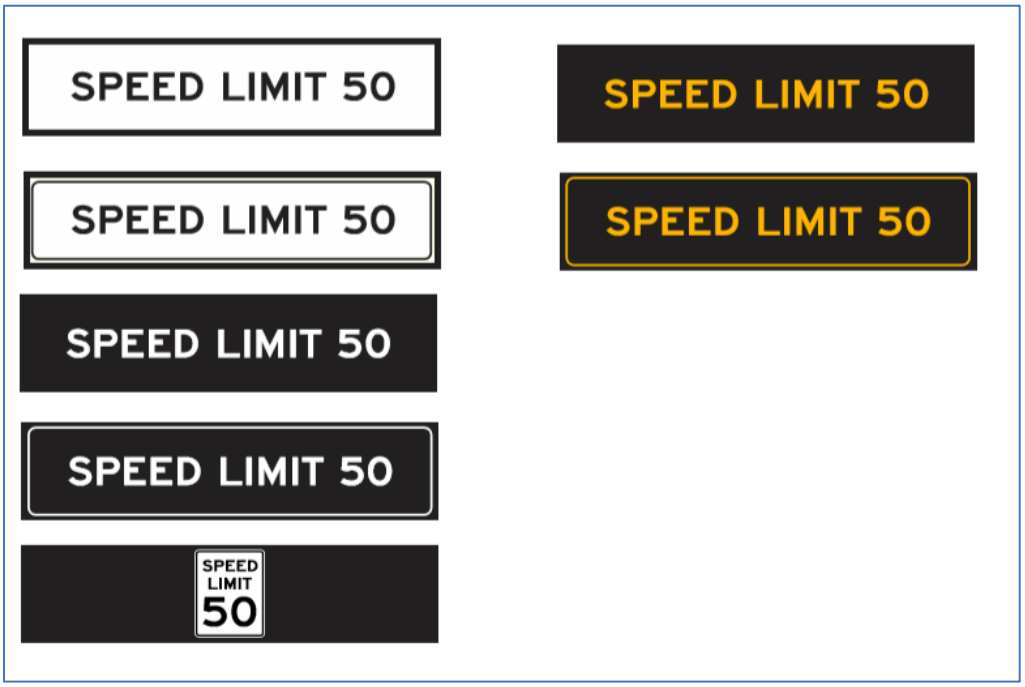

Figure 78. Image. Speed Limit Laboratory Study Signs.
Source: Federal Highway Administration

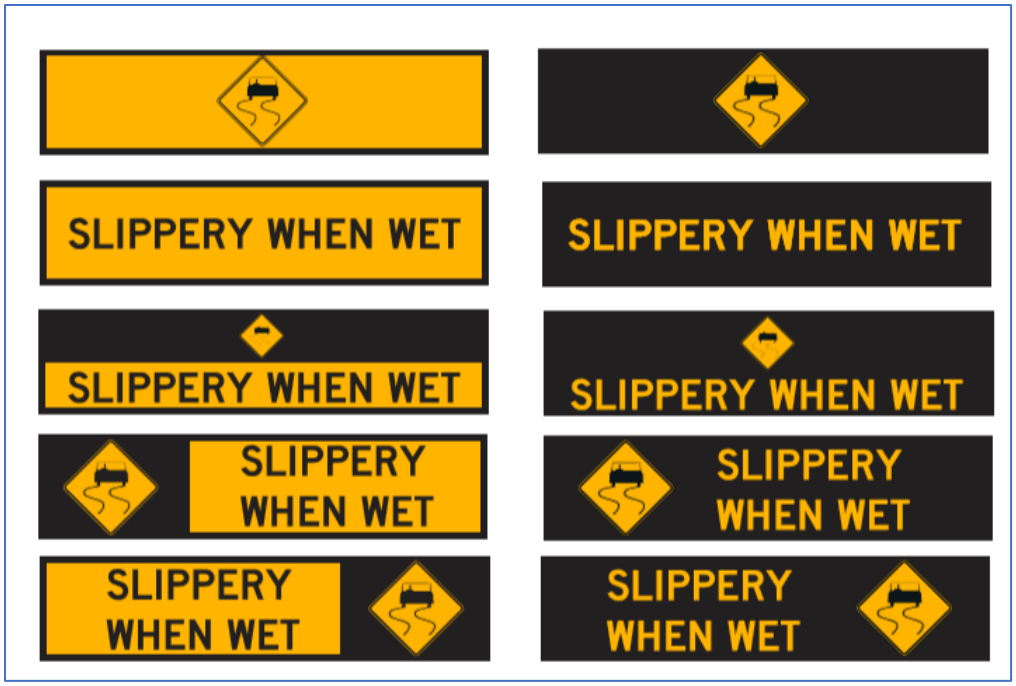

Figure 79. Image. Slippery When Wet Laboratory Study Signs.
Source: Federal Highway Administration

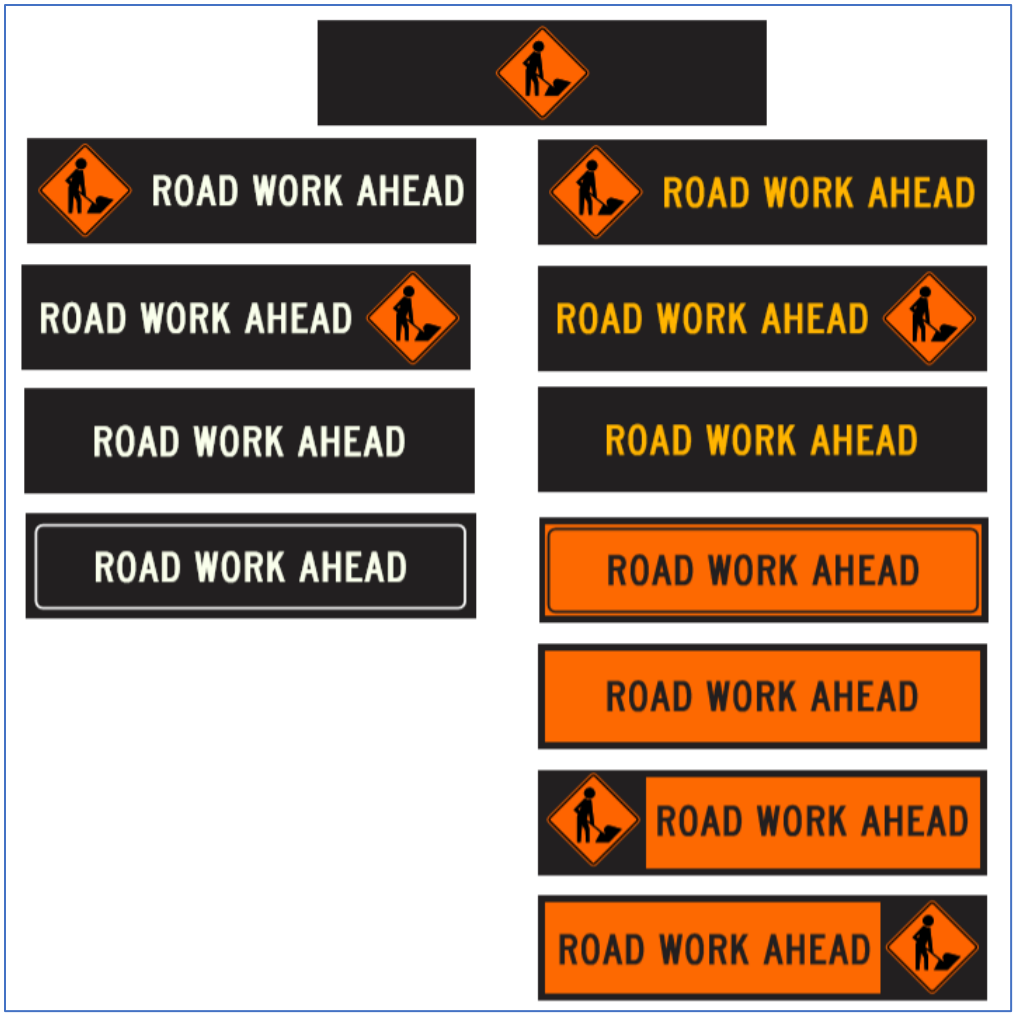

Figure 80. Image. Road Work Ahead Laboratory Study Signs.
Source: Federal Highway Administration

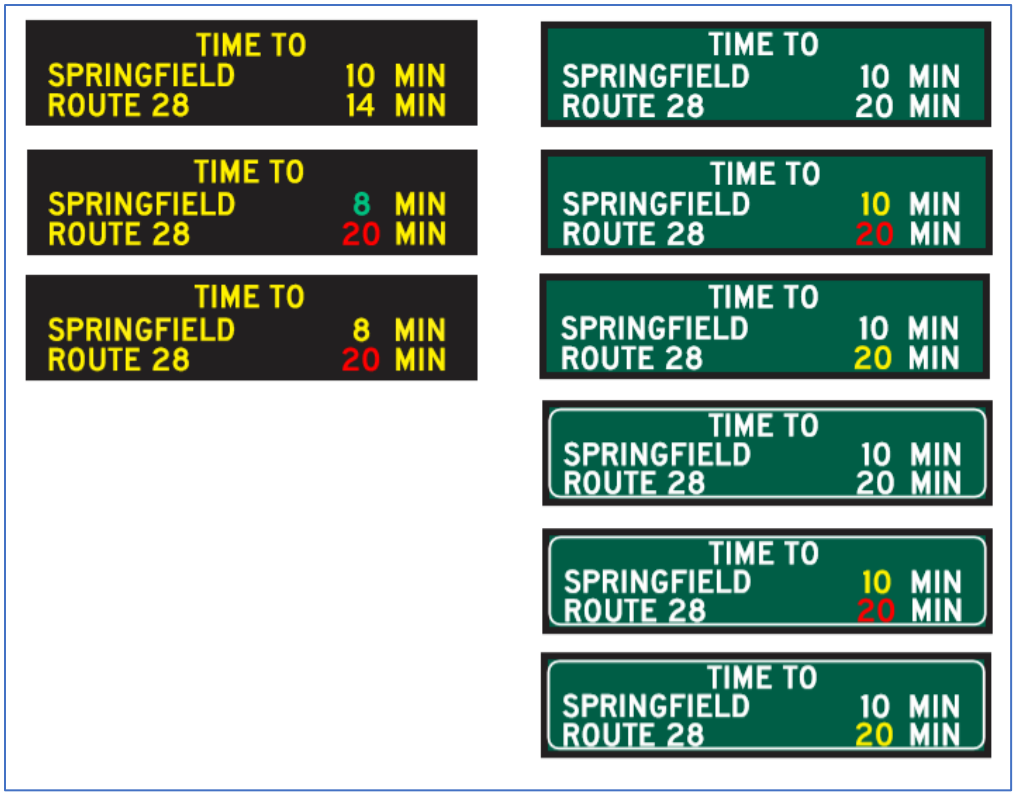

Figure 81. Image. Time to Destination Laboratory Study Signs.
Source: Federal Highway Administration

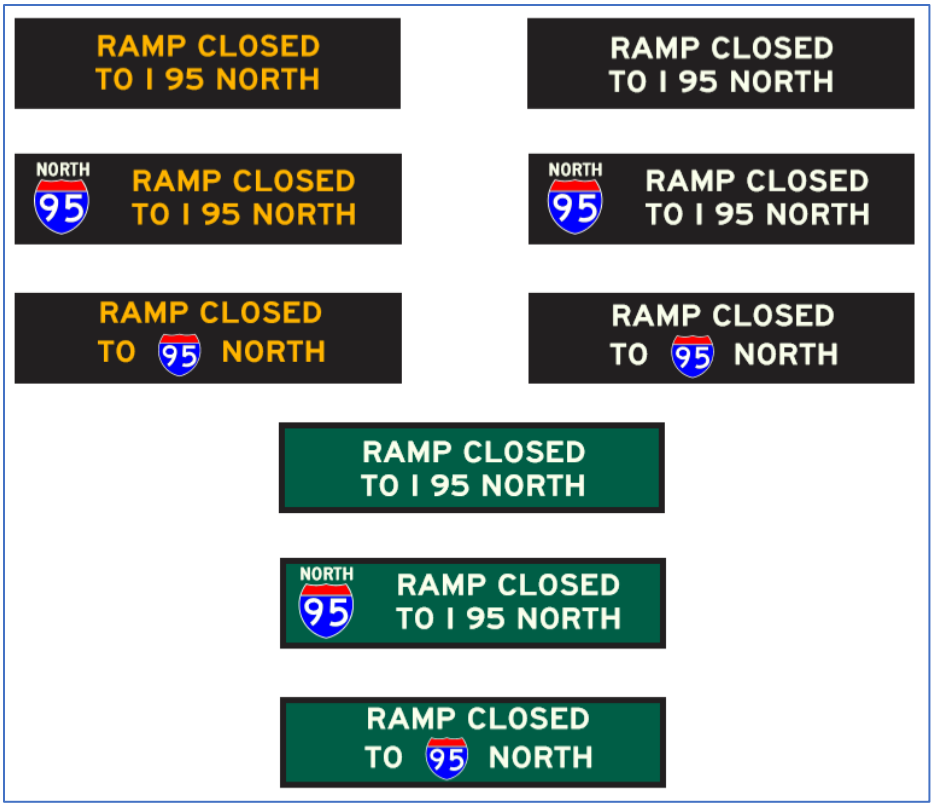

Figure 82. Image. Ramp Closed to I-95 North Laboratory Study Signs.
Source: Federal Highway Administration

Figure 83. Image. Special Event (Concert Traffic) Laboratory Study Signs.
Source: Federal Highway Administration

Figure 84. Image. Express Lane Toll Laboratory Study Signs.
Source: Federal Highway Administration

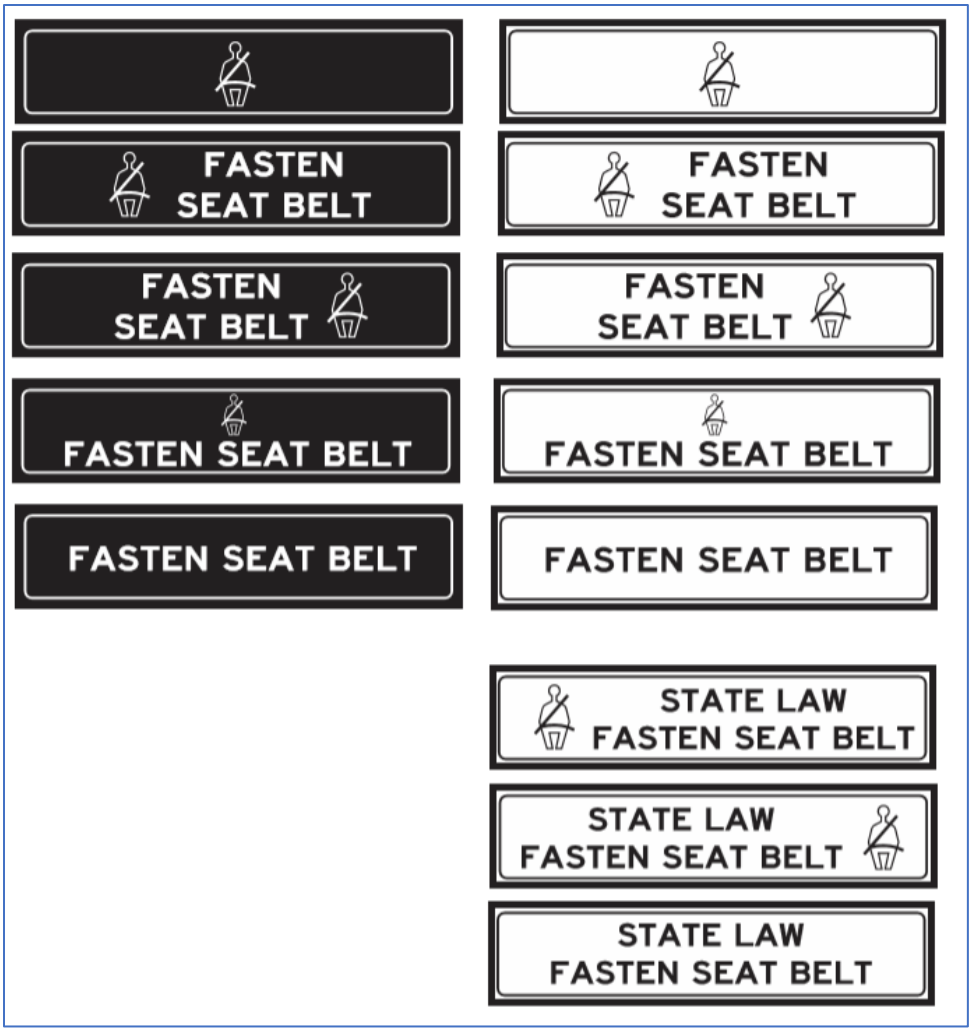

Figure 85. Image. Fasten Seat Belt Laboratory Study Signs.
Source: Federal Highway Administration

Figure 86. Image. Wipers On, Headlights On Laboratory Study Signs.
Source: Federal Highway Administration

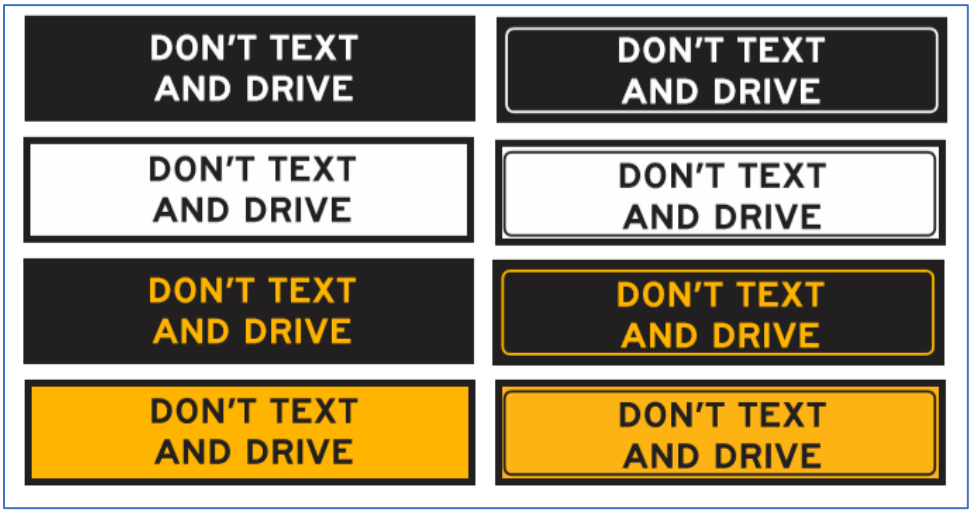

Figure 87. Image. Don't Text and Drive Laboratory Study Signs.
Source: Federal Highway Administration

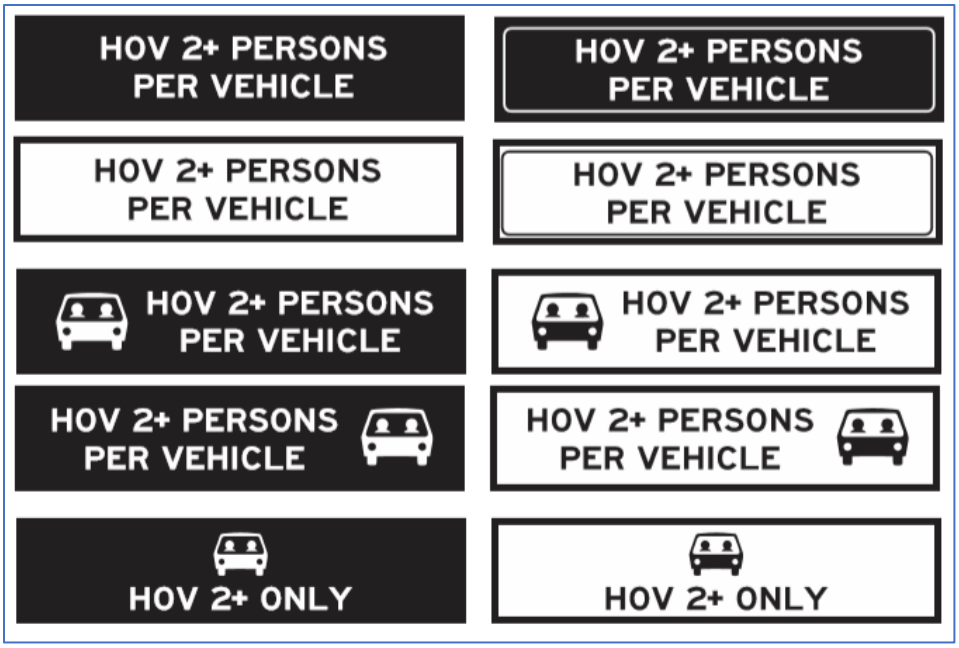

Figure 88. Image. High Occupancy Vehicle (HOV) of Two or More Passengers Laboratory Study Signs.

Source: Federal Highway Administration

Figure 89. Image. Road Closed Ahead Laboratory Study Signs.

Source: Federal Highway Administration

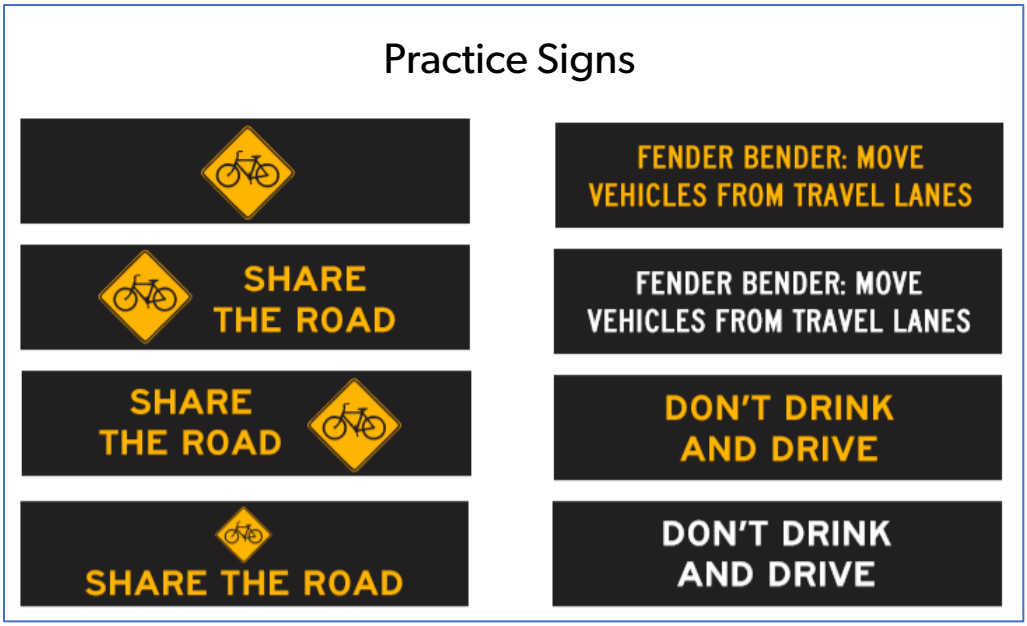

Figure 90. Image. Practice Laboratory Study Signs: Share the Road, Fender Bender, and Don't Drink and Drive.

Source: Federal Highway Administration

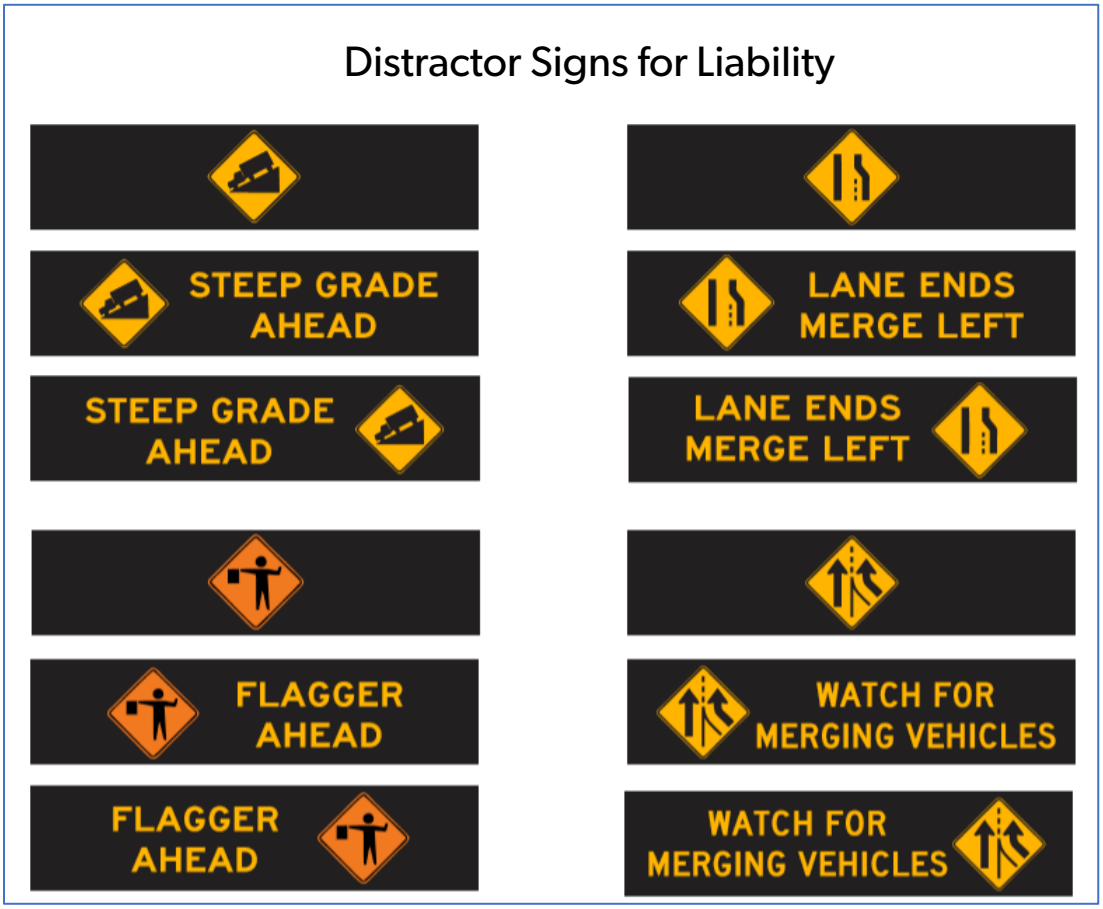

Figure 91. Image. Distractor Laboratory Study Signs for Visibility.

Source: Federal Highway Administration

APPENDIX C. TEXT FOR COMPUTER STUDY ADVERTISEMENT

PARTICIPATE IN A RESEARCH STUDY (BLACKSBURG)

The Federal Highway Administration is sponsoring research to measure perceptions of changeable message signs (electronic signs) and sign messages in a research study. The findings of this study will help researchers and traffic engineers improve the safety and efficiency of the Nation's highway system.

Researchers will be in Gainesville, VA on <INSERT DATES>, and we are currently scheduling appointments for interested participants. The study requires approximately 1 hour of your time and you will be paid $40 upon full completion of the study.

Participation in this study is voluntary and confidential.

Research participants must be at least 18 years old.

For more information or to make an appointment to participate in the study, please complete our Participant Intake Form on this website: https://www.surveymonkey.com/r/NDBT2D3

After completing the form, you will be contacted by our research staff to schedule an appointment.

APPENDIX D. COMPUTER STUDY BRIEFING STATEMENT

Participant Number _____

Briefing Statement – FHWA Computer Study:

Section I. General

The U.S Federal Highway Administration (FHWA) has asked Battelle and Toxcel to conduct a research study to learn more about how drivers respond to changing roadway message signs. We would like to ask you to be part of our research study because you are a legal adult driver and have a valid driver's license. Your part in this study will take about 1 hour. We believe that the results of this study will help the FHWA to improve the safety and efficiency of the nation's highway system.

After the study is completed, we will give you $40 for your time, travel and effort. You must complete the study in its entirety to receive a full payment of $40.00. If you want to, you may stop at any time and for any reason. If you decide to stop, we will give you $20.00 for each one half-hour (30 minutes) that you complete.

Section II. Study Procedures:

At the beginning of the experiment, we will ask you to read this Briefing Statement. Please ask us any questions about anything that you may not understand. If you agree to take [art in our study, we will give you a vision-screening test. To be in our study, you must have visual acuity of at least 20/40. If you wear eyeglasses or contact lenses, you may wear them for the vision testing.

If you are accepted to be part of our study, we will show you to a computer testing station and give you specific instructions on how to work the station. We will give you a chance to practice using the station before we start the actual testing.

The testing will occur in two different parts. During the first part of the study, we will show you pictures of different roadway signs on a basic roadway background. We will ask you different types of questions about each sign. There are no right or wrong answers. During the second part of the study, we will show you a picture of a roadway sign. You will not be moving but it will appear that the sign is getting bigger just as if you were driving toward it. We will ask you to press a button as soon as the sign becomes easy to see and read to you. We will then ask you some questions about the sign. Again, there are no right or wrong answers. What is important to us is what you think about the sign.

After you finish both parts of the computer testing, we will ask you to complete a short survey so you can share your thoughts and opinions about the signs you viewed. After you have completed the survey, a member of our research team will work with you to complete your payment form and your part in the study will be over.

Section III. Risks, Risk Reduction, and Confidentiality:

We believe that the risks to you from taking part in our study will be minimal. If you need to take a break from your time at the computer station, please tell us and we will be glad to do so. There is a small risk that any information you share with us could be compromised, but we have taken steps to minimize any risk. Any information that could identify you, like your name and the contact information you gave us when you let us know that you might be interested in this research study, will be kept separate from any data that you provide to the study. All of the information you give us while you are considering the signs will be labeled with a "Study ID Number", which is completely unrelated to you. All printed study data will be stored in locked containers and will only be accessible to authorized researchers. Any electronic study data will only be available to authorized researchers who have approved passwords to access the data.

Some persons, other than the research team, may have access to your study data. For example, the Battelle Institutional Review Board, a committee that reviews and approves human subjects research may review study documentation to make certain that everything was done to assure your safety, privacy, and data security. FHWA personnel may review study data as part of an audit, assessment, or study follow-up, but will not have access to any information that could identify you.

Section IV. Benefits:

There are no direct benefits to you from taking part in this study. We do think that society, in general, will benefit if our study helps to support improvements in highway safety and operations.

Section V. Voluntariness:

It's entirely your decision whether you take part in this research study. You can decide to end your participation at any time and for any reason If you are injured as a direct result of taking part in this research study, the researcher will contact an Emergency Medical Service to transport you to your personal physicians or a medical center. Battelle, Toxcel LLC, nor the U.S. Federal Highway Administration will not be able to provide you with any medical treatment or financial compensation, except as provided though remedies available by law.

Section VI. For Further Information:

If you have any questions about this research or if you believe that you have received an injury related to this research, please contact:

Jimmy Chu
Federal Highway Administration
1200 New Jersey Ave, S.E.
Washington, D.C. 20590
(202) 366-3379

OR

William Perez, Ph.D.
Battelle
1550 Crystal Drive, Suite 601
Arlington, VA 22202
(703) 413-7293

If you have any questions about your rights as a human research subject, please contact the Battelle IRB Administrator at 1-877-810-9350.

Battelle Institutional Review Board; Approved on 9 July 2019

APPENDIX E. COMPUTER STUDY DEBRIEFING

Debriefing

Thank you for participating in this study today! This study is part of a project sponsored by the Federal Highway Administration, The purpose of this computer-based evaluation is to assess motorists understanding of, and reactions to, a variety of messages displayed on color changeable message signs. More specifically, this study looks at different variables including text and background color, the use of borders on signs, the use and placement of symbols on signs, and color-coding of sign messages to determine

- if different sign designs bare an influence on drivers' ability to comprehend the symbols and messages,
- the legibility of the sign messages,
- the amount of time it takes the driver to read and comprehend the message displayed on the sign
- drivers' message display style preference.

The results of the study will be used to develop guidelines to assist transportation agencies in identifying when and what types of messages (e.g.,, combination of text and symbols, symbols only). font styles, and backgrounds are most effective, efficient, and acceptable to use to improve or assist in communicating formation to drivers. Please don't discuss the tasks you performed today with anyone until the study is complete to maintain the integrity of the research.

If you have any further questions, you may contact the Principal Investigator and Project Manager listed below.

Bryan J. Katz
Toxcel
2000 Kraft Drive
Blacksburg VA 24060
Bryan.Katz@toxcel.com
(703) 754-0248 (x201)

OR

William Perez, PhD.
Battelle
1550 Crystal Drive, Suite 601
Arlington VA 23202
(703) 413-1293

Thank you again for participating!

APPENDIX F. RECEIPT FOR PAYMENT

RECEIPT FOR PAYMENT

Date: _____

Received Cash From: _____

Amount Received: _____ Dollars and_____/100 cents

Payment for Participation in Research

Study Task#

_____

Participant Name (printed)

_____

Street Address

_____

Participant Signature

Disclaimer: Personal information provided on this document will only be used for purposes of financial record keeping. Your information will not be distributed to a third-party vendor for any reason.

APPENDIX G. TEXT FOR FIELD STUDY ADVERTISEMENT

PARTICIPATE IN A RESEARCH STUDY (BLACKSBURG)

The Federal Highway Administration is sponsoring research to measure perceptions of changeable message signs (electronic signs) and sign messages. The findings of this study will help researchers and traffic engineers improve the safety and efficiency of the nation's highway system.

Researchers will be in Blacksburg, VA on January 6-10, 2021, and we are currently scheduling appointments for interested participants. The study requires approximately 1 hour of your time and you will be paid $40 upon full completion of the study.

Participation in this study is voluntary and confidential.

Research participants must be at least 18 years old.

For more information or to make an appointment to participate in the study, please complete our Participant Intake Form on this website: https://www.surveymonkey.com/r/NDBT2D3

After completing the form, you will be contacted by our research staff to schedule an appointment.

APPENDIX H. FIELD STUDY BRIEFING STATEMENT

Participant Number _____

Briefing Statement - FHWA Field Study:

Section I. General:

The U.S. Federal Highway Administration (PHWA) has asked Battelle and Toxcel to conduct a research study to learn more about bow drivers might react to changing roadway messages signs. We would like to ask you to be part of our research study because you are a legal adult driver and have a valid driver's license. Your part in this study will take about 1 hour. We believe that the results of this study will help the FHWA to improve the safety and efficiency of the nation's highway system After the study is completed, we will give you $40 for your time, travel and effort. You must complete the study in its entirety to receive a full payment of $40.00. If you want to, you may stop at any time and for any reason. If you decide to stop, we will give you $20.00 for each one-half hour (30 minutes) that you complete.

Section II. Study Procedures:

At the beginning of the experiment, we will ask you to read this Briefing Statement. Please ask us any questions about anything that you may not understand. If you agree to take part in our study, we will give you a vision-screening test To be in our study, you must have visual acuity of at least 20/40. If you wear eyeglasses or contact lenses, you may wear them for the vision testing. If you are accepted to be part of our study, we will go to the field location and ask you to stand at varying distances from a changeable message (electronic) road sign. At each distance you stand from the sign, we will ask you to describe what you see, including any text or symbols. There are no right or wrong answers. What is important to us is what you think about the sign.

Before we begin the formal field period, we will let you practice on a sign and let you ask any questions about the procedure before the testing starts so you will feel comfortable during the test.

After you finished the field testing, we will ask you to complete a short survey so you can share your thoughts and opinions about the signs you viewed. After you have completed the survey, a member of our research team will work with you to complete your payment form and your part in the study will be over.

Section III. Risks, Risk Reduction, and Confidentiality:

We believe that the risks to you from taking part in our study will be minimal. If you need to take a break from your time at the computer station, please tell us and we will be glad to do so. There is a small risk that any information you share with us could be compromised, but we have taken steps to minimize any risk. Any information that could identify you, like your name and the contact information you gave us when you let us know that you might be interested in this research study, will be kept separate from any data that you provide to the study. All of the information you give us while you are considering the signs will be labeled with a "Study ID Number", which is completely unrelated to you. All printed study- data will be stored in locked containers and will only be accessible to authorized researchers. Any electronic study data will only be available to authorized researchers who have approved passwords to access the data.

Some persons, other than the research team, may have access to your study data. For example, the Battelle Institutional Review Board, a committee that reviews and approves human subjects research, may review study documentation to make certain that everything was done to assure your safety, privacy and data security. FHWA personnel may review study data as part of an audit, assessment or study follow-up, but will not have access to any information that could identify you

Section IV. Benefits:

There are no direct benefits to you from taking part in this study. We do think that society, in general, will benefit if our study helps to support improvements in highway safety and operations.

Participant Number _____

Section V. Voluntariness:

It's entirely your decision whether you take in this research study. You can decide to end your participation at any time and for any reason. If you are injured as a direct result of taking part in this research study, the researcher will contact an Emergency Medical Service to transport you to your personal physician or a medical center. Battelle, Toxcel LLC, nor the U.S. Federal Highway Administration will not be able to provide you with any medical treatment or financial compensation, except as provided through remedies available by law.

Section VI. For Further Information:

If you have any questions about this research or if you believe that you have received an injury related to this research, please contact:

Jimmy Chu
Federal Highway Administration
1200 New Jersey Ave S.E.
Washintgon, D.C. 20590
(202) 366-3379

OR

William Perez, Ph D.
Battelle
1550 Crystal Drive, Suite 601
Arlington, VA 22202
(703) 413-7293

If you have any questions about your rights as a human research subject, please contact the Battelle IRB Administrator at 1-877-310-9530.

APPENDIX I. FIELD STUDY DEBRIEFING

Debriefing

Thank you for participating in this study today! This study is part of a project sponsored by the Federal Highway Administration. The purpose of this field evaluation is to assess the legibility of and motorists reactions to a variety of messages displayed on color changeable message signs. More specifically, this study looks at different variables including text and background color, the use of borders on signs, the use and placement of symbols on signs, color-coding of sign messages, and sign brightness and resolution to determine the legibility of the sign messages, as well as drivers' message display style preference.

The results of the study will be used to develop to develop guidelines to assist transportation agencies in identifying when and what types of messages (e.g., combination of text and symbols, symbols only), font styles, and backgrounds are most effective, efficient, and acceptable to use to improve or assist in communicating information to drivers. Please don't discuss the tasks you performed today with anyone until the study is complete to maintain the integrity of the research.

If you hare any further questions, you may contact the Principal Investigator listed below.

Bryan J. Katz
Toxcel
2000 Kraft Drive
Blacksburg. VA 24060
Bryan.Katz@toxcel com
(703) 754-0248 (x201)

Thank you again for participating!

U.S. Department of Transportation
Federal Highway Administration

U.S. Department of Transportation
Federal Highway Administration
Office of Operations (HOP)
1200 New Jersey Avenue, SE
Washington, DC 20590

https://ops.fhwa.dot.gov

FHWA-HOP-20-030
July 2021