

Driver Visual Behavior in the Presence of Commercial Electronic Variable Message Signs (CEVMS)



March 2011

Foreword

The advent of new electronic billboard technologies, in particular the digital Light-Emitting Diode (LED) billboard, has necessitated a reevaluation of current legislation and regulation for controlling outdoor advertising. In this case, one of the concerns is possible driver distraction. In the context of the present report, outdoor advertising signs employing this new advertising technology are referred to as Commercial Electronic Variable Message Signs (CEVMS). They are also commonly referred to as Digital Billboards and Electronic Billboards.

The present report documents the results of a study conducted to investigate the effects of CEVMS used for outdoor advertising on driver visual behavior in a roadway driving environment. The report consists of a brief review of the relevant published literature related to billboards and visual distraction, the rationale for the FHWA research study, the methods by which the study was conducted, and the results of the study, which used an eye tracking system to measure driver glances while driving on roadways in the presence of CEVMS, standard billboards, and other roadside elements. The report should be of interest to highway engineers, traffic engineers, highway safety specialists, the outdoor advertising industry, environmental advocates, Federal policy makers, and State and local regulators of outdoor advertising.

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16. Abstract This study was conducted to investigate the effect of CEVMS on driver visual behavior in a roadway driving environment. An instrumented vehicle with an eye-tracking system was used. Roads containing CEVMS, standards billboards, and areas not containing off-premises advertising were selected. Two experiments are reported that were conducted in two separate cities in which the same methodology was employed and differences with respect to such variables as the roadway visual environment were taken into account. The results showed that drivers did look at CEVMS a greater percentage of time than at standard billboards; however, the time spent looking at off-premise advertising was less than 5 percent when the signs were visible to the participants across the two experiments. Long glances at off-premises advertising were not evident. The longest glance at a CEVMS was less than 1.3 seconds and glances greater than 1 second were rare events. The percentage of time that drivers dedicated to the road ahead was not significantly affected by the presence of CEVMS or standard billboards. Rather, the overall clutter and complexity of the visual scene appeared to be the principal driver of glance time away from the road ahead. This was the case regardless of the presence or absence of off-premise advertising. The results suggest that overall visual complexity of the highway environment needs to be taken into account when considering driver glance behavior.			
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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

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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I. INTRODUCTION

“The primary responsibility of the driver is to operate a motor vehicle safely. The task of driving requires full attention and focus. Drivers should resist engaging in any activity that takes their eyes and attention off the road for more than a couple of seconds. In some circumstances even a second or two can make all the difference in a driver being able to avoid a crash.” – US Department of Transportation

The advent of new electronic billboard technologies, in particular the digital Light-Emitting Diode (LED) billboard, has prompted a reevaluation of regulations for controlling outdoor advertising. For outdoor advertisers, an attractive quality of these LED billboards, which are hereafter referred to as Commercial Electronic Variable Message Signs (CEVMS), is that advertisements can instantly change, and the changes can be controlled from a central office. Of concern is whether CEVMS may attract driver’s attention from their primary task in ways that compromise safety. The current FHWA guidance regarding CEVMS is that they not change content more frequently than once every 8 seconds (s);⁽¹⁾ however, according to Scenic America, the basis of the safety concern is that the “...distinguishing trait...” of a CEVMS “... is that it can vary while a driver watches it, in a setting in which that variation is likely to attract the drivers’ attention away from the roadway.”⁽²⁾ This study was conducted to provide the Federal Highway Administration (FHWA) with data to help clarify whether there is an empirical basis for regulating CEVMS differently than other off-premise advertising billboards and, if so, what those differences might entail.

A. BACKGROUND

A recent review of the literature by Molino et al. failed to find convincing empirical evidence that CEVMS, as currently implemented, constitute a safety risk greater than that of conventional vinyl billboards.⁽³⁾ Absence of persuasive evidence indicating a safety risk associated with CEVMS is not the result of a lack of research. A great deal of work has been focused in this area, but the findings of these studies have been mixed.^(3,4) A summary of the key past findings is presented here, but the reader is referred to Molino et al. for a comprehensive review of studies prior to 2009.⁽³⁾

Post-Hoc Crash Studies

Post-hoc crash studies review police traffic collision reports or statistical summaries of such reports in an effort to understand the causes of crashes that have taken place in the vicinity of some change to the roadside environment. In the present case, the change of concern is the introduction of CEVMS to the roadside or the replacement of conventional billboards with CEVMS.

The review of the literature conducted by Molino et al. did not show compelling evidence for a distraction effect attributable to CEVMS.⁽³⁾ The authors concluded that all post-hoc crash studies are subject to certain weaknesses, most of which are difficult to overcome. For example, the vast majority of crashes are never reported to police; thus, such studies are likely to underreport crashes. Also, when crashes are caused by factors such as driver distraction or inattention, the

involved driver may be unwilling or unable to report these factors to a police investigator. Another weakness is that police, under time pressure, are rarely able to investigate the true root causes of crashes unless they involve serious injury, death, or extensive property damage. Furthermore, to have confidence in the results, such studies need to collect comparable data before and after the change, and, in the after phase, at equivalent but unaffected roadway sections. Also, since crashes are infrequent events, data collection needs to span extended periods of time, both before and after introduction of the change. Few studies are able to obtain such extensive data.

Field Investigations

Field investigations include unobtrusive observation, naturalistic driving studies, on-road instrumented vehicle investigations, test track experiments, driver interviews, surveys, and questionnaires. The following focuses on relevant studies that employed naturalistic driving and on-road instrumented vehicle research methods.

Lee, McElheny, and Gibbons undertook an on-road instrumented vehicle study on Interstate and local roads near Cleveland, OH.⁽⁵⁾ The study looked at driver glance behavior toward digital billboards, conventional billboards, comparison sites (sites with buildings and other signs, including digital signs), and control sites (those without similar signage). The results showed that there were no differences in the overall glance patterns (percent eyes-on-road and overall number of glances) between event types. Drivers also did not glance more frequently in the direction of digital billboards than in the direction of other event types, but drivers did take longer glances in the direction of digital billboards and comparison sites than in the direction of conventional billboards and baseline sites. However, the mean glance length towards the digital billboards was less than 1 second. It is important to note that this study employed a video-based approach for examining driver's visual behavior, which has an accuracy of no better than 20 degrees.⁽⁶⁾ Whereas this technique is likely to be effective in assessing the level to which devices inside of the vehicle detract from focusing on the road ahead, they may not have sufficient resolution to discriminate what specific object the driver is looking at outside of the vehicle.

Beijer, Smiley, and Eizenman evaluated driver glances toward four different types of roadside advertising signs on roads in the Toronto, Canada area.⁽⁷⁾ The four types of signs included: (a) billboard signs with static advertisements; (b) roller bar signs with billboard advertisements placed on vertical rollers that could rotate to show one of three advertisements in succession; (c) scrolling text signs with a minor active component, which usually consisted of a small strip of lights that formed words scrolling across the screen or, in some cases, a larger area capable of displaying text but not video; and (d) signs with video images that had a color screen capable of displaying both moving text and, more importantly, moving images. The study employed an on-road instrumented vehicle with a head-mounted eye-tracking device. They found no significant differences in average glance duration or the maximum glance duration for the various sign types; however, the number of glances was significantly lower for billboard signs than for the roller bar, scrolling text, and video signs.

Smiley, Smahel and Eizenman conducted a field driving study that employed an eye tracking system that recorded driver's eye movements as participants drove past video signs located at three downtown intersections and along an urban expressway.⁽⁸⁾ The study route included static billboards and video advertising. The authors described the video advertising as presenting a

continuous stream of changing images. The results of the study showed that on average 76 percent of glances were to the road ahead. Glances at advertising, including static billboards and video signs, constituted 1.2 percent of total glances. The mean glance durations to advertising signs were between 0.5 s and 0.75 s, although there were a few glances of about 1.4 s in duration. Video signs were not more likely than static commercial signs to be looked at when headways were short; in fact, the reverse was the case. Furthermore, the number of glances per individual video sign was small, and so statistically significant differences in looking behavior were not found.

Kettwich, Kartsen, Klinger, and Lemmer conducted a 2008 field study where drivers' gaze behavior was measured with an eye tracking system.⁽⁹⁾ Sixteen participants drove an 11.5 mile (18.5 km) route comprised of highways, arterial roads, main roads, and one-way streets in Karlsruhe, Germany. The route contained advertising pillars, event posters, company logos, and video screens. Mean gaze duration for the four types of advertising was computed while the vehicle was in motion and when it was stopped. Gaze duration while driving for all types of advertisements was under 1 s. On the other hand, while the vehicle was stopped, the mean gaze duration for video screen advertisements was equal to 2.75 s. The study showed a significant difference between gaze duration while driving and while sitting still. The gaze duration was affected by the task at hand; that is, drivers tended to gaze longer while the car was stopped and there were few driving task demands.

Laboratory Studies

Laboratory investigations related to roadway safety can be classified into several categories: driving simulations, non-driving-simulator laboratory testing, and focus groups. The review by Molino et al. of relevant laboratory studies did not show conclusive evidence regarding the distracting effects of CEVMS. Moreover, the authors concluded that in the case of CEVMS, present driving simulators do not have sufficient visual dynamic range, image resolution, and contrast ratio capability to produce the compelling visual effect of a bright, photo-realistic LED-based CEVMS on a natural background scene. The following is a discussion of a driving simulator study conducted after the publication of Molino et al. This recent study focused on the effects of advertising on driver visual behavior.

Recently, Chattington, Reed, Basacik, Flint, and Parkes conducted a driving simulator study in the United Kingdom to evaluate the effects of static and video advertising on driver glance behavior.⁽¹⁰⁾ The researchers examined the effects of advertisement position relative to the road (left, right, center on an overhead gantry, and in all three locations), type of advertisement (static or video), and exposure duration of the advertisement (the paper does not provide these durations in terms of time or distance). For the advertisements presented on the left side of the road (comparable to our right side of the road), mean glance durations for static and video advertisements were significantly longer (approximately 0.65 to 0.75 s) when drivers experienced long advertisement exposure as opposed to medium and short exposures. Drivers looked more at video advertisements (about 2 percent on average) than at static advertisements (about 0.75 percent on average). They also spent more time looking at both types of advertisements under the long and medium exposure durations. In addition, the location of the advertisements had an effect on glance behavior. When advertisements were located in the center of the road or in all three positions simultaneously, the glance duration was about 1 s and was significantly longer than for signs placed on the right or left side of the road. For

advertisements placed on the left side of the road, there was a significant difference in glance duration between static (about 0.40 sec) and video (about 0.80 sec). Advertisement position also had an effect on the proportion of time that a driver spent looking at an advertisement. The percentage of time looking at advertisements was greatest when signs were placed in all three locations, followed by center location signs, then the left location signs, and finally the right location signs. Drivers looked more at the video advertisements relative to the static advertisements when they were placed in all three locations, placed on the left, and placed on the right side of the road. The center placement did not show a significant difference in percent of time looking between static and video.

Summary

The results from these key studies offered some insight into whether CEVMS pose a visual distraction threat, but they also revealed some inconsistent findings and potential methodological issues that were addressed in the current study. The studies conducted by Smiley et al. showed drivers glanced forward at the roadway about 76 percent of the time in the presence of video and dynamic signs. A few long glances of approximately 1.4 sec were observed, and this bears further investigation. However, the video and dynamic signs used in these studies present moving objects that are not evident in CEVMS as deployed in the US. In another field study employing eye tracking, Kettwich et al. found that gaze duration while driving for all types of advertisements that they evaluated was less than 1 s; however, when the vehicle was stopped, mean gaze duration for advertising was as high as 2.75 s.⁽⁹⁾ Collectively, these studies did not demonstrate that the advertising signs detracted from driver's glances forward at the roadway or at traffic control devices.

In contrast, the simulator study by Chattington et al. demonstrated that dynamic signs showing moving video or other dynamic elements may draw attention away from the roadway. Furthermore, the location of the advertising sign on the road is an important factor in drawing drivers' visual attention. Advertisements with moving video placed in the center of the roadway on an overhead gantry or in all three positions (right, left, and in the center) simultaneously are very likely to draw glances from drivers.

Finally, in a study that examined CEVMS as deployed in the United States, Lee et al. did not show any effect of CEVMS on driver glance behavior. However, the methodology that was employed probably did not employ sufficient sensitivity to determine what specific object in the environment a driver was looking at.

None of these studies combined all necessary factors to address the current CEVMS situation in the United States. Those studies that used eye-tracking on real roads had animated and video-based signs, which are not reflective of current CEVMS practice in the United States.

B. STUDY APPROACH

Based on an extensive review of the literature, Molino et al. concluded that the most effective method to use in an evaluation of the effects of CEVMS on driver behavior was the instrumented field vehicle method that incorporated an eye tracking system.⁽³⁾ The present study employed such an instrumented field vehicle with an eye tracking system and examined the degree to which CEVMS attract drivers' attention away from the forward roadway.

Land's review of eye movements in dynamic environments concluded that the eyes are proactive and typically seek out information required in the second before each activity commences.⁽¹¹⁾ Specific tasks (e.g., driving) have characteristic but flexible patterns of eye movement that accompany them, and these patterns are similar between individuals. Land concluded that the eyes rarely visit objects that are irrelevant to the task, and the conspicuity of objects is less important than objects' role in the task. Using devices in a vehicle such as a cell phone for texting are very likely to result in eye movement patterns that are incompatible with safe driving. However, for external stimuli, especially those near the roadway, the evaluation of eye glances with respect to safety is less clear. As part of the driving task one examines mirrors, the gauge cluster, side of the road, and so on. Research by Klauer et al. indicated that short, brief glances away from the forward roadway for the purpose of scanning the driving environment are safe and actually decrease near-crash/crash risk.⁽¹²⁾ Klauer et al. also concluded that glances away from the roadway for any purpose lasting more than 2 seconds increase near-crash/crash risk by at least two times that of normal, baseline driving.

Technology for measuring a driver's direction of gaze to reasonably high levels of accuracy has existed since at least the 1960s.⁽¹³⁾ Eye tracking systems used in on-road driving studies use light reflected off the cornea to compute the direction of gaze. These systems then overlay the direction of gaze on film or video of the forward roadway that is recorded at the same time as gaze data. Early systems used head-mounted sensors, but in recent years systems have been developed that utilize dashboard-mounted sensors. In addition, newer technology exists that can accurately measure gaze behavior in the presence of sun light, which has been an issue with many eye tracking systems.

The present study evaluated the effects of CEVMS on driver distraction under actual roadway conditions both in the day time and at night. Roads containing CEVMS, standard billboards, and areas not containing off-premise advertising were selected. The CEVMS and standard billboards were measured with respect to luminance, location, size, and other relevant variables to characterize these visual stimuli extensively. Unlike the previous studies, the present study examined CEVMS as deployed in two US cities that did not contain dynamic video or other dynamic elements. In addition, the eye tracking system that was employed had about a 2 degree level of resolution, which provided significantly more accuracy in determining what objects the drivers were looking at than the study by Lee et al.

Two studies are reported that were conducted in two separate cities employing the same methodology but taking into account differences with respect to such variables as the roadway visual environment. The study's primary research questions were:

- Do drivers look at CEVMS more than at standard billboards?
- Are there long glances at CEVMS that would be indicative of a decrease in safety?
- Do drivers look at CEVMS and standard billboards at the expense of looking at the road ahead?

II. EXPERIMENTAL APPROACH

The study used a field research vehicle (FRV) equipped with an eye-tracking system. The FRV was a 2007 Jeep® Grand Cherokee Sport Utility Vehicle (SUV). The eye-tracking system used (Smart Eye vehicle-mounted infra-red (IR) eye-movement measuring system) is shown in figure 1. The system consists of two IR light sources and three face cameras mounted on the dashboard of the vehicle. The cameras and light sources are small in size, and are not attached to the driver in any manner. The face cameras are synchronized to the IR light sources and are used to determine the head position and gaze of the driver.



Figure 1. Smart Eye Face Camera Placement.

As a part of this eye tracking system, the FRV was outfitted with a three-camera panoramic scene monitoring system for capturing the forward driving scene. The scene cameras are mounted on the roof of the vehicle directly above the driver's head position. The three cameras together provide an 80 degree wide by 40 degree high field of forward view. The scene cameras captured the forward view area available to the driver through the left side of the windshield and a portion of the right side of the windshield. The area visible to the driver through the rightmost area of the windshield was not captured by the scene cameras.

The FRV was also outfitted with equipment to record GPS position, vehicle speed, and vehicle acceleration. The vehicle was also equipped to record events entered by an experimenter. The FRV is pictured in figure 2.



Figure 2. FHWA’s Field Research Vehicle.

A. EXPERIMENTAL DESIGN OVERVIEW

The approach entailed the use of the instrumented vehicle in which drivers navigated routes in cities that presented CEVMS and standard billboards in areas of varying visual complexity. The drivers were instructed to drive the routes as they would normally drive paying attention to other traffic, speed limits, and other elements in the roadway. The drivers were not informed that the study was about outdoor advertising but rather it was about examining drivers’ glance behavior as they followed route guidance directions.

Site Selection

More than 40 cities were evaluated in the selection of the test sites. Locations with CEVMS displays were identified using a variety of resources that included State DOT contacts, advertising company websites, and Google EarthTM. A matrix was developed that listed the number of CEVMS in each city. For each site, the number of CEVMS along limited access and arterial roadways was determined.

One criterion for site selection was whether the location had practical routes that could be driven in about 30 minutes and pass by a number of CEVMS as well as standard (vinyl) off-premise billboards. Other considerations included access to vehicle maintenance personnel/facilities, proximity to research facilities, and ease of participant recruitment. Two cities were selected: Reading, PA, and Richmond, VA.

Table 1 presents the 16 cities that were included on the final list of potential study sites.

Table 1. Distribution of CEVMS by Roadway Classification for Various Cities.

<i>State</i>	<i>Area</i>	<i>Limited Access</i>	<i>Arterial</i>	<i>Other⁽¹⁾</i>	<i>Total</i>
VA	Richmond	4	7	0	11
PA	Reading	7	11	0	18
VA	Roanoke	0	11	0	11
PA	Pittsburgh	0	0	15	15
TX	San Antonio	7	2	6	15
WI	Milwaukee	14	2	0	16
AZ	Phoenix	10	6	0	16
MN	St. Paul/Minneapolis	8	5	3	16
TN	Nashville	7	10	0	17
FL	Tampa-St. Petersburg	7	11	0	18
NM	Albuquerque	0	19	1	20
PA	Scranton-Wilkes Barre	7	14	1	22
OH	Columbus	1	22	0	23
GA	Atlanta	13	11	0	24
IL	Chicago	22	2	1	25
CA	LA	3	71	4	78

(1) Other includes roadways classified as both limited access and arterial or instances where the road classification was unknown. *Source:* www.lamar.com and www.clearchannel.com

In both test cities, the following independent variables were evaluated:

- **The type of advertising.** This included CEVMS, standard billboards, or no off-premises advertising. (It should be noted that in areas with no off-premises advertising, it was still possible to encounter on-premise advertising; e.g., gas stations, restaurants, other miscellaneous stores and shops.)
- **Time of day.** This included both driving in the day time and night time.
- **The complexity of the visual scene in data collection zones.** This was classified in terms of visual complexity or clutter. This variable was handled differently in the two cities and is further discussed in subsequent sections. The results presented in this report are tied to the specific implementations of advertising that were present. The fact that the two cities contained CEVMS but differed in other respects is advantageous when attempting to extrapolate the results to other settings.

Photometric Measurement of Signs

Two primary metrics are used to describe the photometric characteristics of the target CEVMS and standard billboards: luminance (cd/m^2) and contrast (Weber contrast ratio). This part of the procedure serves to characterize the billboards that were evaluated in the study. Also if data are collected at other sites, the luminance and contract measures reported here can be used to determine the degree to which the current results may relate to another site with CEVMS and standard billboards.

Photometric Equipment

Luminance was measured with a Radiant Imaging ProMetric 1600 Charge-Coupled Device (CCD) photometer with both a 50 mm and a 300 mm lens. The CCD photometer provided a method of capturing the luminance of an entire scene at one time.

The photometric sensors were mounted in an SUV of similar size to the FRV. Figure 3 shows the set up for taking photometric measurements. The photometer was located in the experimental vehicle as close to the driver's position as possible and was connected to a laptop computer on the center console that stored data as the images were acquired.



Figure 3. CCD Photometer and Laptop Setup in Vehicle

Measurement Methodology

Luminance measurements were taken at each target billboard location. Images of the billboards were acquired using the Radiant Imaging ProMetric software installed on the laptop. An example of the software's interface is shown in Figure 4. Using the software provided with the system, the mean luminance of each billboard message was measured. In order to prevent overexposure of images in daylight, neutral density filters were manually affixed to the photometer lens and the luminance values were scaled appropriately. Standard billboards were typically measured only once; however, for CEVMS multiple measures were taken because the luminance can vary with advertising content.

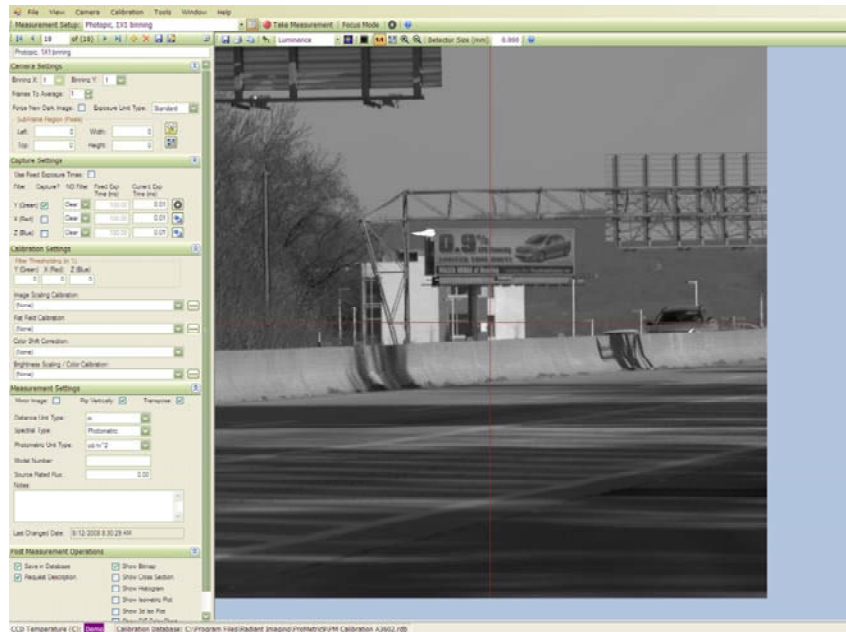


Figure 4. ProMetric Software Interface.

Photometric measurements were taken during day (between 8:15AM and 4:45PM) and at night (after 6:00PM). Measurements were taken by centering the billboard in the photometer's field of view with approximately the equivalent of the width of the billboard on each side and the equivalent of the billboard height above and below the sign. This was done to ensure adequate background luminance data in each image. The selected background region data was used in billboard contrast calculations. Figure 5 shows a target billboard and two adjacent areas (outlined in red) that were used to calculate the contrast ratio.



Figure 5. Regions of Background for Contrast Ratio Analysis.

Measurements of the standard billboards were taken at a mean distance of 284 ft (ranging from 570 ft to 43 ft). The mean measurement distance for measurements of the CEVMS was 479 ft (ranging from 972 ft and 220 ft). To include the background regions of appropriate size, the close measurement distances required the use of the 50 mm lens while measurements made further from the signs required the 300 mm lens.

The Weber Contrast Ratio was used because it characterizes a billboard as having negative or positive contrast when compared to its background area.⁽¹⁴⁾ Figure 6 shows differences in background behind a billboard. A negative contrast indicates the background areas have a higher mean luminance than the target billboard. A positive contrast indicates the target billboard has a higher mean luminance than the background. Overall, the absolute value of a contrast ratio simply indicates a difference in luminance between an item and its background.



Figure 6. Contrast Background Differences.

Visual Complexity

Regan, Young, Lee and Gordon presented a taxonomic description of the various sources of driver distraction.⁽¹⁵⁾ Potential sources of distraction were discussed in terms of: things brought into the vehicle; vehicle systems; vehicle occupants; moving objects or animals in the vehicle; internalized activity; and external objects, events, or activities. The external objects may include buildings, constructions zones, billboards, road signs, vehicles, and so on. A taxonomy suggested by Horberry and Edquist focuses on visual information outside of the vehicle. This suggested taxonomy includes four groupings of visual information: built roadway, situational entities, natural environment, and built environment.⁽¹⁶⁾ These taxonomies provide an organizational structure for conducting research; however, they do not currently provide a systematic or quantitative manner with which to classify the level of clutter or visual complexity present in a visual scene. The methods proposed by Rozenholtz, Li, and Nakano do provide quantitative and perhaps reliable measures of visual clutter.⁽¹⁷⁾ This approach measures the entropy or variance in a visual image.

The data collection zones were scaled in terms of overall visual complexity (i.e., clutter). Subband entropy was used as a measure of visual clutter in photographs taken in each data collection zone.⁽¹⁷⁾ The calculation of subband entropy is based on the assumption that the more organized a scene is, the less clutter it contains. Using this assumption, subband entropy calculates the organization or predictability of a scene (e.g., color, shape, size, and alignment of

items). Presumably, less cluttered images can be visually coded more efficiently than cluttered images. For example, visual clutter can cause decreased recognition performance and greater difficulty in performing visual search. For each data collection zone a single frame was captured from a color video and saved as a JPEG. The JPEGs were analyzed with MATLAB® routines that computed a measure of subband entropy for each image.

III. EXPERIMENT 1

The first on-road experiment was conducted in Reading, PA. The overall objectives of the study were to determine: (a) if drivers looked more at CEVMS than at standard billboards, (b) if there were long glances to off-premise billboards, and (c) if there is a tradeoff between looking at off-premise billboards and the road ahead. To address these objectives, the experiment examined the type of advertising (CEVMS, standard billboard, or no off-premise advertising) and time of day (day or night) as independent variables. Eye tracking was used to assess where participants looked and for how long while driving. The luminance and contrast of the advertising signs were measured to account for any photometric contributions to the results.

Participants drove two test routes (referred to as Route A and B) in Reading. Each route required 25 to 30 minutes to complete and included both freeway and arterial segments. Route A was 13 miles long and contained 12 data collection zones. Route B was 16 miles long and contained 8 data collection zones, for a total of 20 data collection zones. Although the data collection zones were selected because they included a specific type of advertising, some zones encompassed other off-premises and on-premises advertising. For example, one zone contained 2 CEVMS, and 10 standard billboards as well as commercial buildings and parking lots. This type of data collection zone was kept for analysis but classified as a separate category of visual complexity (referred to as CEVMS complex), a factor that was handled more fully in experiment 2. Scene visual complexity was quantified to ensure that the classification of these more visually complex CEVMS conditions was justified.

Other data collection zones were comprised of the single target billboard and no other forms of off-premise advertising. Each route also included two data collection zones that did not contain off-premise billboards; one contained minimal manmade structures (natural environment) and the other was comprised mostly of buildings and other manmade structures (built environment). Table 2 presents an inventory of target billboards in Reading and their relevant parameters.

Table 2. Inventory of Target Billboards in Reading with Relevant Parameters.

<i>Advertising Type</i>	<i>Copy Dimensions (ft)</i>	<i>Change Rate (sec)⁽¹⁾</i>	<i>Side of Road</i>	<i>Setback from Road (ft)</i>	<i>Data Collection Zone Length (ft)</i>	<i>Other Standard Billboards</i>
CEVMS	10.5x 22.75	6	L	35	960	2
CEVMS	10.5 x 22.75	10	R	47	960	3
CEVMS	14 x 48	10	L	188	960	2
CEVMS	14 x 48	10	R	142	960	2
CEVMS	10.5 x 22.75	8	L	92	960	3
CEVMS	10.5 x 22.75	8	R	54	960	0
CEVMS	10.5 x 22.75	10	R	128	960	2
CEVMS	14 x 48	10	L	188	960	2
CEVMS	14 x 48	10	R	142	960	2
CEVMS Complex	10.5 x 36	10	R	36	960	10
CEVMS Complex	14 x 48	8	R	22	1860	10
Standard	10.5 x 36	—	L	71	960	1
Standard	14 x 48	—	L	50	682	0
Standard	14 x 48	—	L	97	960	1
Standard	21 x 22.75	—	R	34	547	2
Standard	10.5 x 45.25	—	L	79	960	2

(1) Change rate is only calculated for CEVMS. The indicated value is the number of seconds each advertisement copy is on display. For Copy Dimensions, Setback from Road, and Data Collection Zone Length values: 1 ft = 0.305 m. *Source:* www.lamar.com and satellite imagery.

A. METHOD

Advertising Type

The type of advertising present in data collection zones was examined as an independent variable. Data collection zones fell into one of the following categories, which are listed in the third column of table 2:

- **CEVMS.** These were data collection zones that contained one target CEVMS with a relatively low level of scene complexity. Figure 7 shows an example of a CEVMS data collection zone with the CEVMS located in the center of the image.
 - **CEVMS complex.** This was an area that contained two CEVMS displays (about 800 feet or 243.84 m apart), 10 non-target standard billboards, and other built environment (e.g., buildings, parking lots). Figure 8 shows a picture of a portion of this data collection zone. The two CEVMS are highlighted with red rectangles in the figure.
- **Standard billboard.** These were data collection zones that contained one target standard billboard. Figure 9 is an example of a standard billboard data collection zone; the standard billboard is located in the top left corner.

- **No off-premise advertising conditions.** These data collection zones contained no off-premise advertising and were divided into the following categories:
 - **Natural environment.** These were data collection zones without off-premise advertising and principally contained trees. Figure 10 is an example of this type of data collection zone.
 - **Built environment.** These were data collection zones that contained buildings, businesses, parking areas, and other areas of built environment but not off-premise billboard advertising. Figure 11 is an example of this type of data collection zone.



Figure 7. Data Collection Zone with a Target CEVMS.



Figure 8. Visually Complex Data Collection Area with 2 CEVMS and 10 Non-Target Standard Billboards.



Figure 9. Data Collection Zone with a Target Standard Billboard.



Figure 10. Data Collection Zone with Natural Environment.



Figure 11. Data Collection Zone with Built Environment.

Photometric Measurements

Luminance: The mean daytime luminance of both the standard billboards and CEVMS was greater than at night. Nighttime luminance measurements reflect the fact that CEVMS use illuminating LED components while standard billboards are often illuminated from beneath by Metal Halide lamps. At night, CEVMS have a greater average luminance than standard billboards. Table 3 presents summary statistics for luminance as a function of time of day for the CEVMS and standard billboards.

Contrast: The daytime and nighttime Weber contrast ratios for both types of billboards are shown in table 3. Both CEVMS and standard billboards had contrast ratios that were close to zero (the surroundings were about equal in brightness to the signs) during the daytime. On the other hand, at night the CEVMS and standard billboards had positive contrast ratios.

Table 3. Summary of Luminance (cd/m²) and Contrast (Weber ratio) Measurements in Reading.

<i>Day</i>	Luminance (cd/m ²)			Contrast		
	<i>Min</i>	<i>Max</i>	<i>Mean</i>	<i>Min</i>	<i>Max</i>	<i>Mean</i>
CEVMS Complex	1,109	1,690	1,400	-0.59	-0.40	-0.50
CEVMS	1,544	4,774	2,631	-0.71	0.37	-0.19
Standard Billboard	291	6,752	2,277	-0.81	1.15	-0.13
<i>Night</i>						
CEVMS Complex	56	139	97	53	81	67
CEVMS	34	76	52	6	179	81
Standard Billboard	6	45	17	12	69	29

The mean contrast ratios of CEVMS complex and CEVMS were each greater than the mean contrast ratio of standard billboards. This is the result of greater mean luminance values of the two categories of CEVMS at night when compared to standard billboards.

Visual Complexity

Recall that the data collection zones were also scaled in terms of their overall visual complexity or clutter. Figure 12 shows the mean subband entropy measures for each of the data collection zone environments (note that due to the limited number of data collection zones, standard error information is not included). In addition, high (Times Square) and low (a desert road) clutter scenes are provided for comparison. The built environment and the CEVMS Complex data collection zones showed the greatest subband entropy values, followed by the natural environment and standard billboard zones. Finally, the CEVMS zone resulted in the lowest mean subband entropy value.

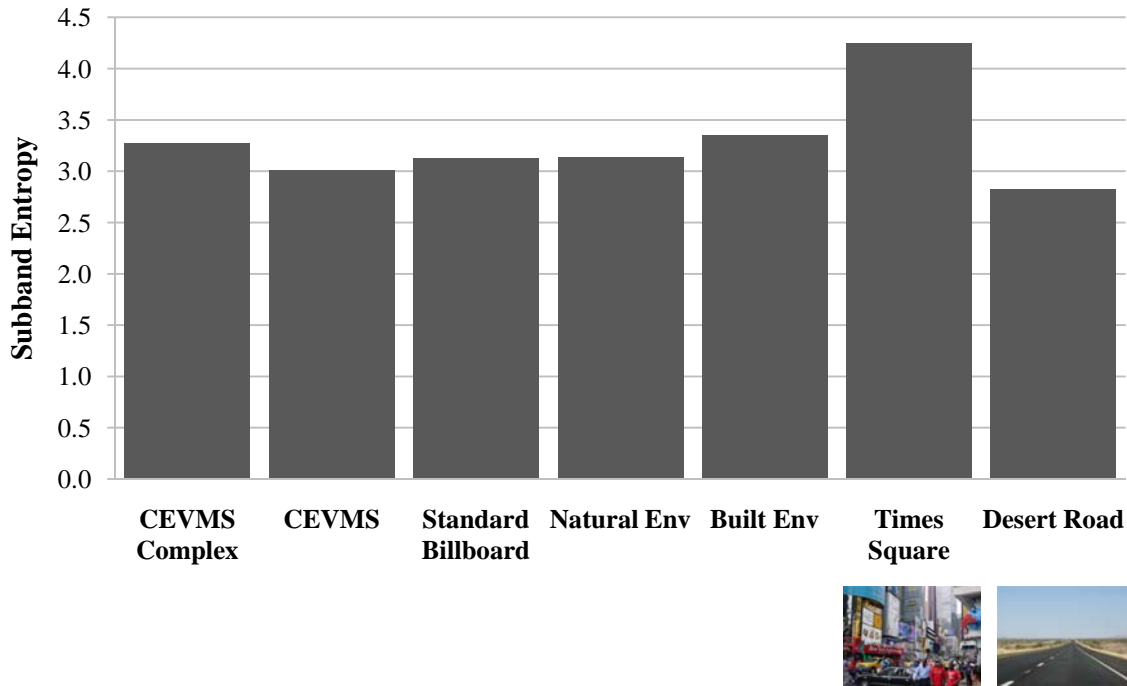


Figure 12. Mean Subband Entropy Measures for Each of the Data Collection Zone Types.

Participants

Participants were recruited at public libraries in the Reading, PA area. A table was set up so that recruiters could discuss the requirements of the experiment with candidates. Individuals who expressed interest in participating were asked to complete a pre-screening form, a record of informed consent, and a department of motor vehicles form consenting to release of their driving record.

All participants were between 18 and 64 years of age and held a valid driver's license. The driving record for each volunteer was evaluated to eliminate drivers with excessive violations. The criteria for excluding drivers were as follows: (a) more than one violation in the preceding year; (b) more than three recorded violations; and (c) any driving while intoxicated violation.

Forty-three individuals were recruited to participate. Of these, five did not complete the drive because the eye tracker could not be calibrated to accurately track eye movements. Data from an additional seven participants was excluded as the result of equipment failures (e.g., loose camera). In the end, usable data was collected from 31 participants (12 males, $M = 46$ years; 19 female, $M = 47$ years) 14 participated at night and 17 participated during the day. All participants were under the age of 64.

Procedures

Data were collected from two participants per day (beginning at approximately 12:45 PM and 7:00 PM). Data collection began on September 18, 2009, and was completed on October 26, 2009.

Pre-Data Collection Activities. Participants were greeted by two researchers and asked to complete a fitness to drive questionnaire. This questionnaire focused on drivers' self-reports of alertness and use of substances that might impair driving (e.g., alcohol). It was expected that if a participant did not appear to be fit to drive upon meeting then he or she would be disqualified from the study; however, no participants presented themselves in such a manner.

Next, the participant and both researchers moved to the eye-tracking calibration location in the test vehicle. If it was not possible to calibrate the eye tracking system, the participant was dismissed and paid for his or her time. Causes of calibration failure included reflections from eye glasses, participant height (which put their eyes outside the range of the system), and participants' eye lids obscuring a portion of the pupil (preventing a focus on the whole pupil).

Practice. After eye-tracker calibration, a short practice drive was made. Participants were shown a map of the route and written turn-by-turn directions prior to beginning the practice drive. Throughout the drive, verbal directions were provided by a GPS device.

During the practice drive, a researcher in the rear seat of the vehicle monitored the accuracy of eye-tracking. If the system was tracking poorly, additional calibration was performed. If the calibration could not be improved, the participant did not participate in the data collection drive. Instead participants were thanked (and paid) for their time and were dismissed.

Data Collection. Similar to the practice drive, participants were shown a map of the route and written turn-by-turn directions. A GPS device provided turn-by-turn guidance during the drive. Participants were not told that the focus of the study was related to billboards. Rather, participants were told that researchers were investigating eye-gaze behavior as it relates to driving while following auditory directions. The first half of the data collection for each participant lasted approximately 30 minutes. Roughly one half of the participants drove Route A first and the remaining participants began with Route B. A five minute break followed the completion of the first route.

During the drives, a researcher in the front passenger seat assisted the driver when additional route guidance was required. That researcher also recorded near misses or driver errors as necessary. The researcher in the rear seat monitored the performance of the eye tracker. If the eye tracker performance became unacceptable (i.e., loss of calibration), then the researcher in the rear asked the participant to park in a safe location so that the eye tracker could be recalibrated.

Debriefing. **After driving both routes, participants were asked to complete a driver feedback questionnaire and were given \$120.00 cash for their participation. Participants were informed of the study's true purpose after all data from that participant was collected.**

B. DATA REDUCTION

Selection of Data Collection Zone Limits

In evaluating eye gaze measures to CEVMS and standard billboards, it is important to take into consideration the abilities of the driver to see and read signs. Also, the capability of the data collection system and data analyses procedure needs to be taken into account when setting the limits of each data collection zone. In this study, data collection zones were defined as the distance leading up to a target billboard (CEVMS or standard) that is used in the analysis of the

gaze data. One must use caution when selecting data collection zone limits for many reasons. If a very long data collection zone length was selected where the drivers could not be expected to read the billboards and the eye tracking and video analysis system could not resolve the billboard, then the proportion of time that drivers were looking at billboards would tend to be underestimated. On the other hand, very short data collection zone lengths would result in missing gazes to the billboards that should have logically been captured.

The rationale for selecting the data collection zone limits took into account the geometry of the roadway (e.g., road curvature or obstructions that blocked view to the billboards) and capabilities of the eye-tracking system (two degrees of resolution). Nine hundred and sixty feet was accepted as the maximum approach length. The MUTCD 2009 guideline of 30 ft (9.14m) per inch (25.4 mm) of letter height was used to estimate the sign legibility distance. Given an average letter height of 32 in (812.8 mm) for the CEVMS, a maximum distance of 960 ft (292.61 m) was computed (actual distances can be seen in table 2). An exception was made in the case where a CEVMS data collection zone overlapped with a collection zone of the previous CEVMS; in this case the data collection zone was greater than 960 ft (292.61 m). The start of the second data collection zone was defined as the location of the preceding. If the target billboard was not visible from 960 ft (292.61 m) due to roadway geometry or other visual obstructions, such as trees or an overpass, then the data collection zone was shortened to a distance that prevented these objects from interfering with the driver's vision of the billboard. In data collection zones with target off-premise billboards, the end of the data collection zone was marked by that billboard. If the area contained no off-premise advertising, then the end of the data collection zone was defined by a physical landmark.

In Reading, the average billboard height was 12.8 ft (3.90 m) and the average width was 36.9 ft (11.25 m). At a distance of 960 ft (292.61 m), a 12.8 ft (3.90 m) by 36.9 ft (11.25 m) sign would subtend a horizontal visual angle of 2.20 degrees and a vertical visual angle of 0.76 degrees. Given these values, the billboards were resolved by the eye tracking system and could be read by the participants.

Researchers attempted to examine glances to the billboards at very long distances (up to 3,883 ft or 1,183.54 m). However, at these long distances an eye glance that may have been to a billboard could not be differentiated from a glance to another object nearby, the roadway, or the sky. Table 2 shows the data collection zone limits utilized in this experiment.

Eye Tracking Measures

The images recorded from the three cameras mounted on the roof of the research vehicle were stitched into a single panoramic view. Glance behavior was reduced by observing gaze location indicated by a cursor that was overlaid onto the panoramic view. The cursor location approximated where the participant's gaze was directed within 2 degrees on a frame-by-frame basis. The panoramic view was generated at 25 frames per second. In addition, a text file containing parameters from the eye tracking system was generated. The text file included information regarding eye-gaze vectors and their quality, gaze location in relation to a world model, and other gaze variables (e.g., eye blinks, pupil diameter). A second text file was also produced that contained GPS coordinates, vehicle speed data, and distance from the beginning of the trip. The eye tracker recorded at 60Hz and was down sampled and matched to the

corresponding video frames that were output at 25Hz. The digital data containing the GPS and speed data were also processed such that these data would correspond to the 25Hz frame rate.

The video data was reduced on a frame-by-frame basis and recorded in a relational database. Glance locations were classified as follows:

1. **Road ahead.** This category of glances included the roadway surface from edge of shoulder to edge of shoulder or curb to curb. That is, the physical roadway (for both directions of travel) between the research vehicle and the vanishing point of the roadway was included. Distant trees and buildings defining the path of the roadway ahead, as well as bridges, guard rails, embankments, etc. were also classified as road ahead as were traffic control devices, other vehicles, and pedestrians who could potentially interact with the vehicle.
2. **Target CEVMS.** These were glances to a pre-determined digital billboard in its respective data collection zone.
3. **Target standard billboard.** These were glances to a pre-determined standard billboard in its respective data collection zone.
4. **Other standard off-premise billboards.** These were glances to other non-target standard (vinyl) billboards present in a data collection zone. These other non-target off-premise billboards occurred in both CEVMS and standard billboard data collection zones.
5. **Miscellaneous.** This category included glances to areas of extraneous built environment (such as building structures, houses, hotels, commercial and industrial buildings, malls, parking lots, etc.) and natural environment (fields, forests, foliage, trees, bushes, mountains, lakes, rivers, clouds, sky, etc.) which did not assist in defining the roadway.
6. **Indeterminate.** These were video frames where the eye-tracking cursor was not present or the cursor was outside the panoramic field of view. This category included glances to the vehicle instruments and rear view mirrors, as well as glances to areas of the roadway outside the panoramic view. A proportion of the indeterminate glances were later classified as to the gauge cluster based on analysis of the data; this ultimately resulted in glances to seven categorical areas.

Analysts coded each frame of the data collection zone using one the six categories listed above (the sixth category was later subdivided allowing glances to the gauge cluster to become its own category). On each frame, the cursor needed to touch a given object for the analyst to score a category glance to that object category. Figure 13 illustrates a video frame that was scored as a glance to a target CEVMS.

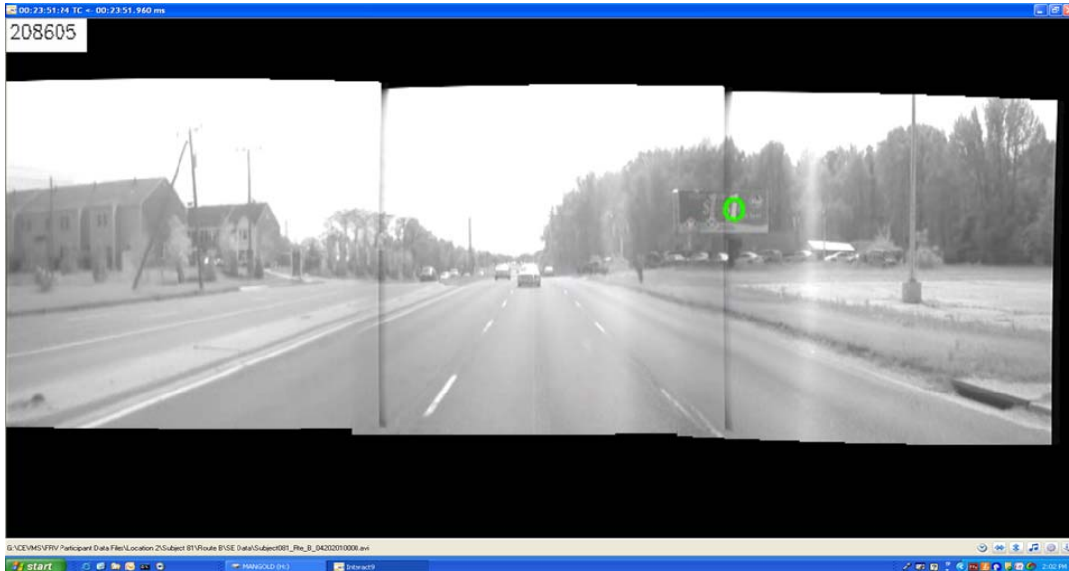


Figure 13. Panoramic Video with the Eye-Tracking Cursor (Highlighted by the Green Circle) in the Center of a CEVMS.

After the video data was reduced, data validation and processing procedures were carried out. Software programs insured that frames were not accidentally double-coded, the beginning and end of each data collection zone were correct, and the correct codes were used for target billboards.

Data Processing

Data processing resulted in a data file that could be used for calculating glance duration to the different pre-defined objects and categories (Road Ahead, CEVMS, etc.).

Gaze Calculation. Within each data collection zone, the processed data files were examined to determine the number of consecutive frames that were scored as being in the same category. Each group was considered one gaze and it was possible for a gaze to contain only a single frame (0.04 sec. duration). Previous research has shown that gazes cases do not need to be separated into saccades and fixations before calculating such measures as percent of time looking to the road ahead.⁽¹⁸⁾ The analyses performed in this report are therefore based on gaze data.

Ultimately, calculating gazes resulted in a data file that contained gazes and gaze durations as a function of scoring categories and data collection zones for each participant.

Performance Measures. **The following performance measures were computed from the gaze data files.**

Mean Percent of Time: Within each data collection zone, the mean percent of time spent looking at a given object or class of objects was computed for each of the following categories:

1. Road ahead.
2. Target CEVMS.
3. Target standard billboard.
4. Other standard billboard.
5. Miscellaneous.
6. Unknown (these were indeterminate glances that could not be classified to the gauge cluster).
7. Gauge cluster.

For each data collection zone, the sum of the percent of time across the above seven categories equaled 100. That is, all gazes were accounted for in data analysis and none were excluded.

Mean Rate of Eye Gazes: The mean rate of eye gazes was defined as the frequency of eye gazes to a particular object category divided by the amount of time available in the data collection zone. If a data collection zone consisted of 23 frames (23/25 of a second or 0.92 sec), then the mean rate of eye gazes for the target CEVMS category would be equal to two gazes divided by 0.92 sec, or approximately 2.17 gazes per second. This measure was computed for the target CEVMS and target standard billboard categories within their respective collection zones. Note that this metric was not sensitive to the duration of eye glances.

Mean Duration of Eye-Gazes: The mean duration of eye-gazes was defined as the average length of each gaze to a particular object category (i.e., the total duration of eye glances divided by the number of separate gazes). This measure was calculated for the target CEVMS and standard billboard categories within their respective data collection zones.

Driving Behavior Measures: During data collection the front-seat researcher observed the drivers' behaviors and the driving environment. The following categories were used to score researcher observations:

- **Driver Error:** Signified any error on behalf of the driver in which the researcher felt slightly uncomfortable, but not to a significant degree (e.g., driving on an exit ramp too quickly, turning too quickly).
- **Near Miss:** Signified any event in which the researcher felt uncomfortable due to driver response to external sources (e.g., slamming on brakes, swerving). A near miss is the extreme case of a driver error.
- **Incident:** Signified any event in the roadway which may have had a potential impact on the attention of the driver and/or the flow of traffic (e.g., crash, emergency vehicle, animal, construction, train).

These observations were entered into a notebook computer linked to the FRV data collection system. However, neither driver errors nor near misses occurred in the limits of a data collection zone.

C. RESULTS AND DISCUSSION

The results are presented principally to address three key experimental questions: (a) do drivers look more at CEVMS than at standard billboards, (b) are there long glances to off-premise advertising billboards, and (c) is there a tradeoff between looking at off-premise advertising billboards and the road ahead? However, the overall distribution of time spent looking at the different target categories for each of the billboard and no off-premise advertising environments are presented to give an overall picture of the results.

All statistical analyses used an alpha level of .05. All error bars presented in the following figures show \pm two standard errors about the mean (which closely approximate a 95 percent confidence interval).

Mean Percent of Time

Table 4 presents the mean percent of time participants spent gazing at each of the areas of interest as a function of data collection zone type. As previously noted, the data collection zones are classified in terms of the presence or absence of off-premise advertising and the type of advertising (CEVMS or standard billboards). The data in table 4 are averaged across time of day. This table illustrates the tradeoffs between gazing at different objects and areas in the visual scene. As the table shows, gaze activity in the CEVMS, standard billboard, and built environment data collection zones resulted in approximately the same percent of time for the road ahead, ranging from 83.3 percent to 84.3 percent. The natural environment shows the highest percent of time looking to the road ahead.

Table 4. Mean Percent of Time Looking to Areas of Interest Based on Data Collection Zone Type.

	Road Ahead	Misc	Unknown	Gauges	Target Billboards	Non-Target Standard Billboards	<i>Total</i>
CEVMS	83.3%	6.9%	5.4%	1.2%	2.8%	0.4%	100%
Standard Billboards	84.3%	7.2%	4.7%	1.3%	1.6%	1.0%	100%
Built Environment	82.3%	14.2%	3.0%	0.5%	—	—	100%
Natural Environment	87.3%	4.5%	5.7%	2.5%	—	—	100%
<i>Mean</i>	84.3%	8.2%	4.7%	1.4%	2.2%	0.7%	—

Data were analyzed using a 2 (time of day) x 4 (data collection zone type) mixed design ANOVA on each target category. Because the raw percentages are positively skewed (deviating from normality), additional analyses were performed using transformed data. Data were transformed using the arcsine of the square root of the proportions. This transformation works

on measures distributed between zero and one and thus proportions rather than percentages were used. ⁽¹⁹⁾

Mean Percent of Time to Target Advertising

Participants spent significantly more time looking at CEVMS than at standard billboards: $F(1, 29) = 9.88, p < .01$. As can be seen in Table 4, the mean percent of time drivers spent looking at CEVMS (2.8 percent) was nearly double that of standard billboards (1.6 percent).

Overall, participants directed a significantly greater percent of glances to billboards during the daytime (2.9 percent) as they did at nighttime (1.3 percent): $F(1, 29) = 14.24, p < .01$. There was not a significant interaction between billboard type and the time of day.

Mean Percent of Time to Road Ahead

Figure 14 shows the main effect for advertising: $F(3, 87) = 3.93, p < .05$. The percent of time looking to the road ahead was the greatest for the natural environment and lowest for the built environment. As figure 14 shows, the CEVMS, standard billboard and built environment data collection zones did not significantly differ from each other but each significantly differed from the natural environment: $p < .05$. Participants spent significantly more time gazing at the road ahead at night (89 percent) than during the day (81 percent): $F(1, 87) = 9.07, p < .01$. This is true for all data collection zones.

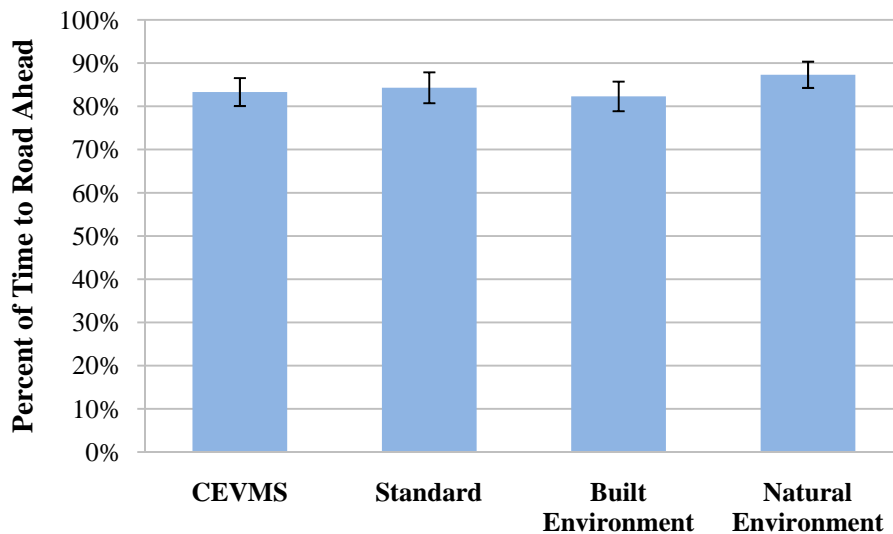


Figure 14. Percent of Time to Road Ahead as a Function of Data Collection Zone Type.

Mean Duration of Eye Gazes

Overall, data collection zone type did not significantly affect mean glance duration: $F(1, 29) = 1.52, p > .05$. Averaged across data collection zones, the mean glance duration, was 0.07 s (standard deviation 0.06 s).

The mean duration of gazes to the road ahead were also examined ($M = 0.59$ s), revealing no significant differences based upon data collection zone type: $F(1, 29) = 0.34, p > .05$.

Mean gaze durations may be misleading when the distribution of the duration of glances is skewed, which, as can be seen in Figure 15, was the case for glances to billboards. The figure shows the proportion of glance durations to CEVMS and standard billboards under nighttime and daytime conditions. All of these distributions show a positive skew with most of the gaze durations being relatively short.

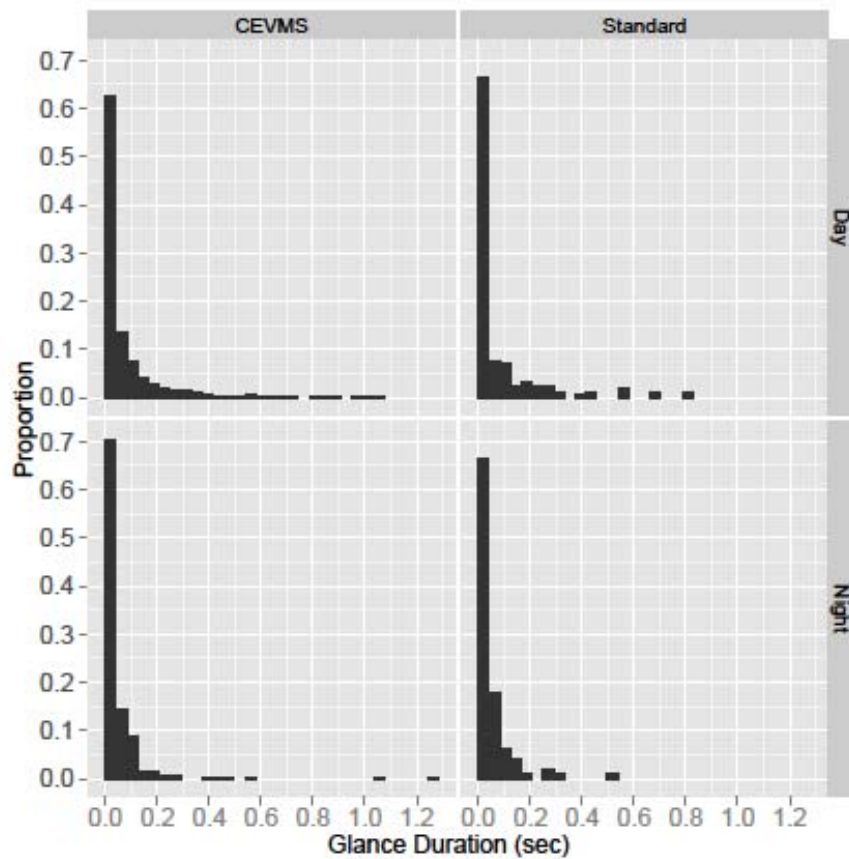


Figure 15. The Proportion of Gaze Duration for CEVMS and Standard Billboards under Daytime and Nighttime Driving Conditions.

Table 5 shows the total number of glances to target billboards summed over participants and target billboards. Although the shapes of the distributions are similar, there were approximately four times more gazes toward CEVMS than standard billboards. This difference in the number of gazes is principally due to the fact that there were 11 CEVMS and only 5 standard (target) billboards in the study. The numbers presented in parenthesis in this table are the result of the total number of glances to billboards divided by the number of billboards multiplied by the number subjects in each condition. Even when accounting for the number of billboards, there was still a higher frequency of glances to CEVMS than to standard billboards. Overall, there also were more glances to billboards during the day than at night.

Table 5. Total Number of Gazes for the CEVMS and Standard Billboard Conditions as a Function of Time of Day.

Advertising Condition	Time of Day	
	Day	Night
CEVMS	668 (3.57)*	404 (2.62)
Standard Billboard	155 (1.82)	96 (1.37)

* Numbers in parenthesis are the glance frequency totals divided by the number of billboards and participants in the respective conditions.

Figure 15 shows that a small percentage of glances exceeded 1 s in duration. The following section presents analyses of these glances. Previous research has shown that glances away from the forward roadway exceeding 2 s have increased crash risk.⁽¹²⁾ As a conservative measure, a value of shorter duration was selected for the analyses.

Long Duration Eye Gazes

Table 6 presents a summary of participant glances longer than 1 s to target billboards. The long glances were to CEVMS and were as likely to happen during the day as at night. Long glances to off-premises advertising were rare events. Of the total 1,072 glances to target CEVMS, only 5 exceeded 1 s (0.47 percent; ranging from 1.0 – 1.28 s).

Table 6. Summary of Long Gazes to Off-Premises Advertising in Reading.

Data Collection Zone	Time of Day	Advertising	Duration (sec)	Horizontal Offset (ft)	Distance from Sign (ft)	Horizontal Angle (deg)
1	Day	CEVMS Complex	1.04	22	402	3.13
5	Day	CEVMS	1.28	50	605	4.72
17	Day	CEMVS	1.00	92	824	6.37
19	Night	CEMVS	1.28	54	241	12.63
19	Night	CEMVS	1.04	54	464	6.64

Figure 16 shows the CEVMS (horizontally offset 54 ft from the roadway) in data collection zone 19, a relatively uncluttered visual environment. That sign had two long glances, both at night, beginning at 464 ft and 241 ft away. The visual angle subtended by the sign at these distances and offset was close to the area defined as road ahead. As a result of its proximity to the roadway, drivers may have felt comfortable directing longer glances to this sign. In other words, because this billboard was so close to the roadway, it is possible that it captured longer glances than if it were a greater distance from the vehicle path.



Figure 16. Data Collection Zone 19.

Mean Percent of Time to Other Non-Target Standard Billboards

Participants spent a significantly greater percentage of their time looking at standard non-target billboards in standard billboard data collections zones (.99 percent) than in CEVMS zones (.38 percent): $F(1, 29) = 11.06, p < .01$.

Participants also directed more glances at other non-target standard billboards during the day (1.02 percent) than at night (0.26 percent): $F(1, 29) = 16.35, p < .01$.

Mean Percent of Time Looking at Miscellaneous

Participants looked at many miscellaneous objects along the roadway, including buildings, parking lots, on-premises advertising, and other built environments away from the roadway. The amount of time participants spent looking at miscellaneous objects was significantly affected by data collection zone type: $F(3, 87) = 44.7, p < .01$. As can be seen in Figure 17, in the built environment, participants spent the most amount of time looking at miscellaneous objects, followed by the CEVMS and the standard billboard data collection zones. No significant difference in the percent of time spent looking at miscellaneous objects was found between the CEVMS and standard billboard zones: $p > .05$. The natural environment data collection zone showed the lowest percent of time gazing at miscellaneous objects; participants spent about 4.5 percent of the time looking at trees: $p < .05$.

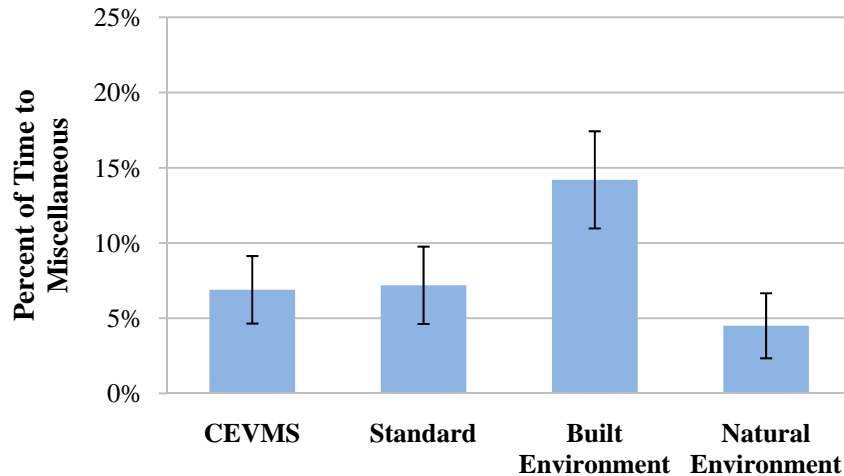


Figure 17. Percent of Time Looking at Miscellaneous as a Function of Data Collection Zone Type.

There were more glances toward miscellaneous objects in the daytime (10.9 percent) than the nighttime (4.9 percent): $F(1, 87) = 9.07, p < .01$.

Mean Percent of Time to the Gauge Cluster

Advertising type had a significant effect on glances to the vehicle gauge cluster: $F(3, 87) = 11.89, p < .01$. Figure 18 illustrates that there were more glances to the gauge cluster in natural environment data collection zones than in any of the others. The built environment data collection zone showed the lowest percentage of glances to the gauge cluster. The CEVMS and standard billboard zones did not significantly influence the amount of time participants spent looking at the gauge cluster. The built environment data collection zone showed the lowest percentage of glances to the gauge cluster. The CEVMS and standard billboard zones did not significantly influence the amount of time participants spent looking at the gauge cluster: $p > .05$.

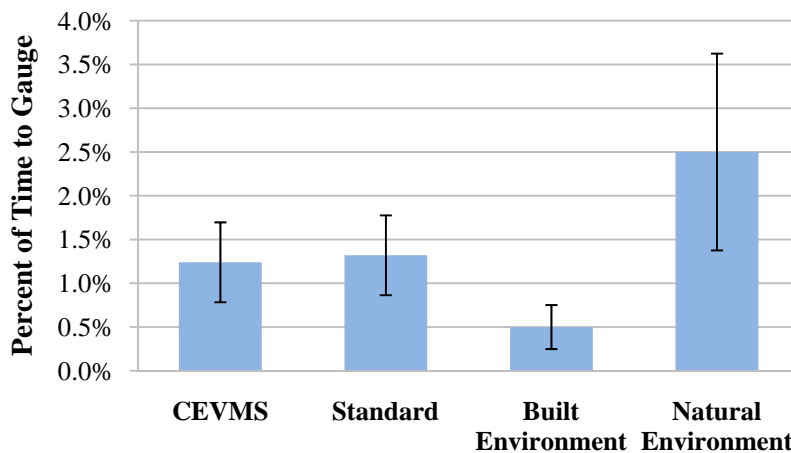


Figure 18. Percent of Time Looking to the Gauge Cluster as a Function of Data Collection Zone Type.

Mean Percent of Time Glances at Unknown Objects

The percent of time that glances could not be classified also varied significantly with data collection zone: $F(3, 87) = 7.45, p < .01$. As can be seen in Figure 19, there were significantly fewer glances at unknown objects in the built environments than in the other three environments (natural, standard, CEVMS) which did not differ from each other: $p < .05$. There were no other significant differences $p > .05$.

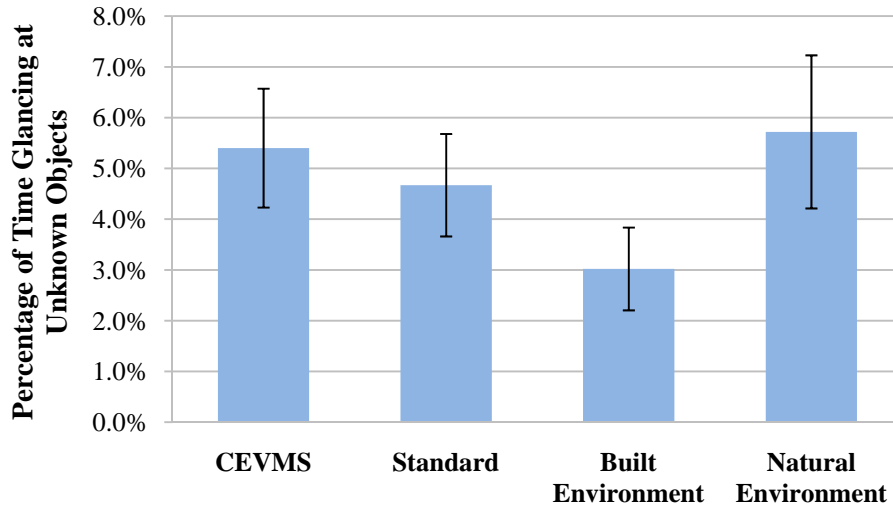


Figure 19. Percentage of Time Glancing at Unknown Objects as a Function of Data Collection Zone Type.

Mean Rate of Glances

Overall there were low rates of glances to both types of billboards. When separated by billboard type, participants showed a greater mean rate of glances at target CEVMS than at target standard billboards: $F(1, 29) = 15.54, p < .01$. In the CEVMS data collection zones, the average rate of glances at target advertising is about 0.42 per s, or 4.2 glances every 10 s. In the standard billboard data collection zones, a rate of 0.20 per s, or 2 glances every 10 s, was found. Overall, the rate of glances was higher during the day (0.39 glances per second) than at night (0.21 glances per s): $F(1, 29) = 8.32, p < .01$.

There were no significant differences for mean rate of glances at the road ahead as a function of time of day or data collection zone type. The mean rate of glances at the road ahead was 5.00 gazes per second.

Relationship between Photometric Measures and Glance Behavior

Analyses were conducted to determine if there was a relationship between sign luminance or contrast and participant glance behavior. Correlational analyses were conducted among glance duration and luminance and the Weber contrast measures for the individual signs. Separate correlational analyses were conducted for CEVMS and standards billboards during nighttime and daytime. The correlations among glance duration and the photometric measures were all low and not statistically significant ($p > .05$).

CEVMS Correlations. For the daytime, the correlation between glance duration and luminance was $r = -.007$. For the nighttime the correlation was $r = 0.037$. The correlation between glance duration and contrast were $r = 0.049$ for daytime and $r = -.071$ for nighttime. None of these correlations were significant ($p < .05$).

Standard Billboard Correlations. The correlation between glance duration and luminance was $r = 0.053$ for the daytime and $r = -0.147$ for the nighttime. The correlation between glance duration and contrast was $r = 0.07$ in the daytime and $r = 0.160$ for the nighttime. None of these correlations were significant ($p < .05$).

Observation of Driver Behavior

No near misses or driver errors were observed in data collection zones experiment 1.

Results Including CEVMS Complex

As noted previously, the CEVMS complex condition included two CEVMS, multiple standard billboards, and a visually complex built environment (hotel, car dealership, restaurants, and parking lots). Table 7 shows the percent of time glances were directed at different objects or areas (e.g., road ahead) in the driving environment. The CEVMS complex data collection zone shows the lowest percent of time looking to the road ahead. The largest difference between the CEVMS complex and the CEVMS/standard billboard data collection zones is the percent of glances to miscellaneous objects. The following presents statistical results for percent of time measures and glance duration.

Table 7. Mean Percentage of Time Looking at Areas of Interest Based on Data Collection Zone Type.

	Road Ahead	Misc	Unknown	Gauges	Target Billboards	Non-Target Standard Billboards	Total
CEVMS Complex	75.9%	10.4%	5.6%	1.7%	3.8%	2.5%	100%
CEVMS	83.3%	6.9%	5.4%	1.2%	2.8%	0.4%	100%
Standard Billboards	84.3%	7.2%	4.7%	1.3%	1.6%	1.0%	100%
Built Environment	82.3%	14.2%	3.0%	0.5%	—	—	100%
Natural Environment	87.3%	4.5%	5.7%	2.5%	—	—	100%
Mean	82.6%	8.6%	4.9%	1.4%	2.7%	1.3%	—

There were significantly more glances at target CEVMS relative to target standard billboards: $F(2, 57) = 7.02, p < 0.002$. Figure 20 presents the mean percentage of time spent looking at target billboards as a function of data collection zone.

The results including the CEVMS complex data collection zone were similar to those presented earlier. The percent of eye glances to target advertising in the CEVMS complex and CEVMS environments were not significantly different from each other ($p > .05$); however, participants spent a significantly greater percentage of time glancing at target advertising in both types of CEVMS environments than in the standard billboard zones ($p < .05$).

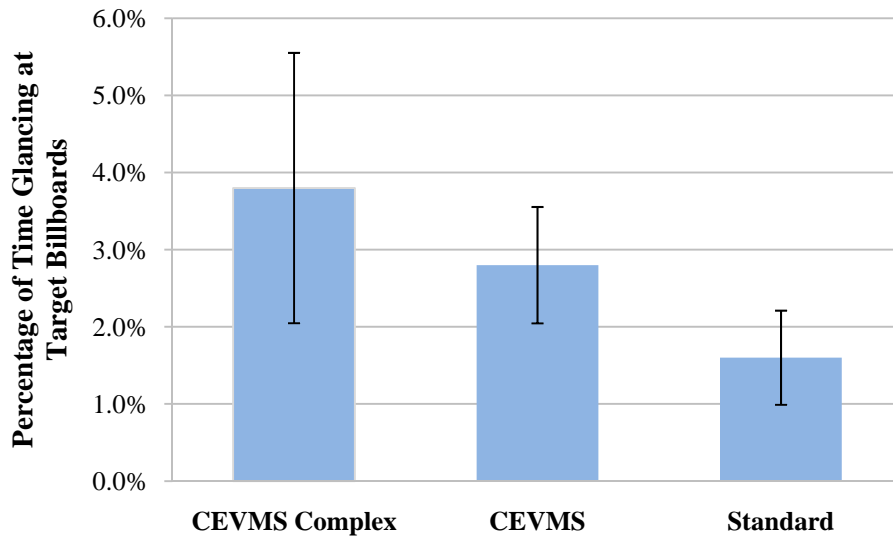


Figure 20. Percent of Time Glancing at Target Advertising as a Function of Data Collection Zone Type.

The participants directed a greater percentage of glances at target billboards during the daytime (3.4 percent) than during the nighttime (1.8 percent): $F(1, 29) = 6.76, p < .02$. The time of day did not interact with target billboard type.

The percentage of time spent looking at the road ahead was significantly influenced by the type of data collection zone: $F(4, 115) = 12.90, p < .01$. Figure 21 presents these results. The percent of time looking to the road ahead was the highest for the natural environment and lowest for the CEVMS complex data collection zone. CEVMS, standard billboard, and built environment zones did not differ from each other, but differed from the CEVMS complex and natural environment conditions. This finding suggests that whereas visual attention to CEVMS and standard billboards did not result in a tradeoff of time spent looking at the road ahead, there was evidence of such a tradeoff in the CEVMS complex zone.

The participants spent significantly more time gazing at the road ahead at night (87 percent) than during the daytime (79.2 percent): $F(1, 29) = 6.80, p < .05$. The time of day did not interact with data collection zone type. In each of the data collection zone types, drivers spent more time looking at the road ahead at night.

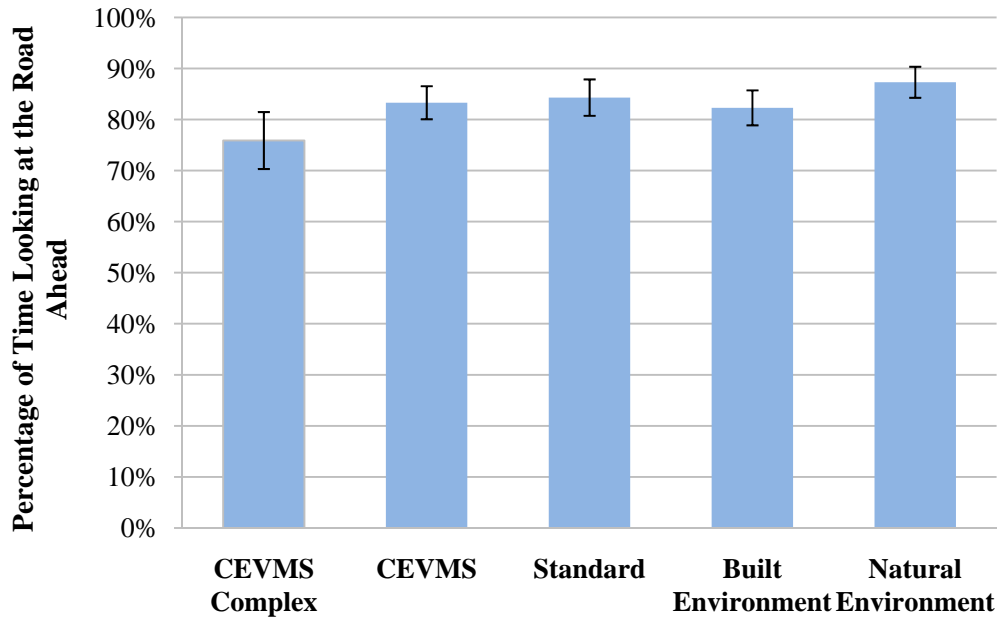


Figure 21. Percent of Time Looking at the Road Ahead as a Function of Data Collection Zone Type.

Figure 22 shows the mean duration of glances at target off-premise billboards. There were no significant differences in mean glance duration among the three advertising types (CEVMS complex, CEVMS, and standard). The CEVMS complex data collection zone shows a mean duration of approximately 0.08 s; however, the variability is such that it is not statistically different from the other data collection zones. The average glance duration regardless of advertising type was 0.070 s (standard deviation 0.058 s).

The average duration of glances at the road ahead was also evaluated for the CEVMS complex, CEVMS, and standard billboard data collection zones. The analysis showed no statistically significant differences. On average, glances to the road ahead were 0.59 s (standard deviation 0.19 s).

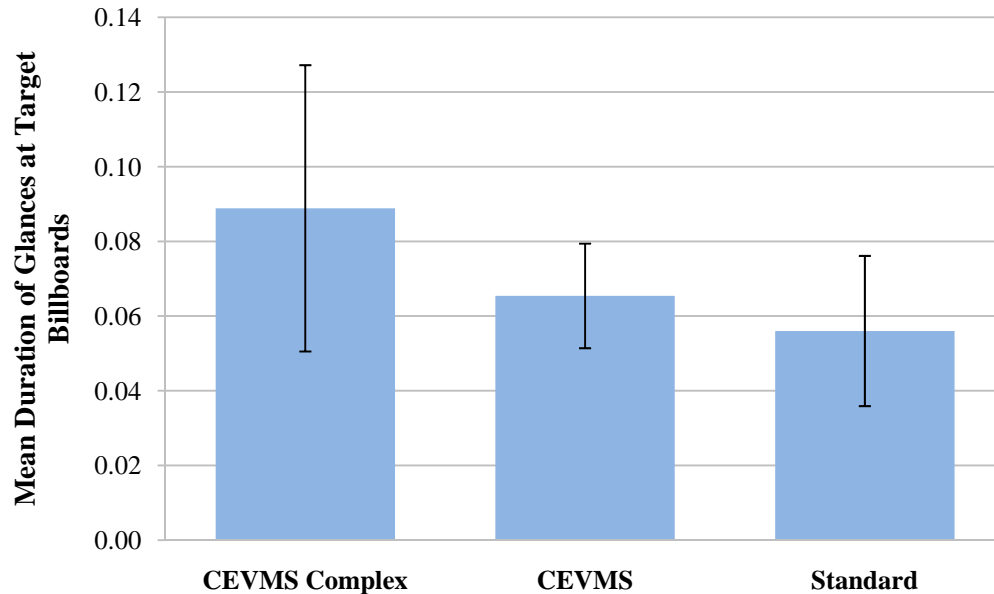


Figure 22. Mean Duration of Glances at Target Billboards as a Function of Data Collection Zone Type.

Discussion

A road experiment was conducted to examine the following three experimental questions regarding CEVMS and visual attention:

- Do drivers look at CEVMS more than at standard billboards?
- Are there long glances at CEVMS that would be indicative of a decrease in safety?
- Do drivers look at CEVMS and standard billboards at the expense of looking at the road ahead?

The drivers did look more at CEVMS than at standard billboards. The percentage of time spent glancing at CEVMS was 2.8 percent and at standard billboards 1.6 percent. These are small percentages; however, they are statistically different from each other. In the CEVMS complex data collection zone, time spent glancing at CEVMS was 3.8 percent; however this data collection zone had two CEVMS and so the percent per CEVMS averaged 1.9 percent. These results are consistent with previous finding from Smiley et al. showing a relatively small percentage of glances at advertising.⁽⁸⁾ Smiley et al. recorded 0.2 percent of glances at billboards and 2 percent at video advertising.

There were no differences between CEVMS and standard billboard conditions with respect to the average duration of glances. On average the glance duration was about 0.07 s for both CEVMS and target standard billboards, and there were only five eye glances to CEVMS in the entire study that were equal to or greater than 1 s in duration. The longest glance at a CEVMS was of 1.28 s. Klauer et al. observed increases in near-crash/crash risks of more than two times normal, baseline driving where the duration of eyes off the forward roadway exceeded 2 s.⁽¹²⁾ None of the glance durations to CEVMS approached this length.⁽¹²⁾ Horrey and Wickens focused on how safety-related phenomena may be more strongly linked to those observations that lie in the tail of

a given distribution and not necessarily to the mean.⁽²⁰⁾ In their research they used a threshold of eye glances longer than 1.6 s away from the forward roadway as an indication of poor driving and an increase in risk.⁽²¹⁾ The current results are also below this more conservative threshold.

The CEVMS, standard billboard, and built environment conditions did not differ significantly from each other (83, 84, and 82 percent, respectively) in the percent of glances to the road ahead. In these areas drivers also gazed at objects that were on the side of the road for about an equal amount of time. In the case of CEVMS and standard billboard areas, drivers gazed at off-premises advertising as well as other objects on the side of the road. In the case of built environment, about 14 percent of the time the drivers were looking at the side of the road where no off-premises advertising was present. In these three areas there appear to have been trade-offs as to where the drivers directed their gazes away from the roadway while maintaining about the same percentage of time looking at the road ahead.

The degree to which drivers gazed toward the road ahead was affected by the nature and quantity of visual information on the roadside. The CEVMS complex area was included in the analysis to examine the effect of a complex roadway scene with a large quantity of off-premise advertising on driver visual behavior. In this area, participants spent the lowest percentage of time looking at the road ahead (76 percent). Overall, participants spent about 10 percent of the time, on average, gazing at objects on the side of the road (i.e., buildings, on-premises advertising, parked cars in a car dealership, etc.).

In natural environment zones, drivers gazed at the road ahead 87 percent of the time, which was significantly more than for the other data collection zones in the study. These natural environment data collection zones principally contained trees and other foliage on the side of the road.

The results also showed that drivers spent more time looking at billboards (both CEVMS and standard billboards) in the daytime than at night. As one would expect, at night, the CEVMS complex and CEVMS zones had higher luminance and contrast than the standard billboards. However, these differences in sign luminance did not appear to affect gaze behavior in this study. This finding is supported by previous research by Olson, Battle, and Aoki, who reported that drivers devote more of their time to the road ahead at night than in the day.⁽²²⁾ In the present study, at night, the drivers focused more of their gazes on the road ahead and devoted less time to CEVMS, target standard billboards, other standard billboards, and other objects on the side of the road (e.g., miscellaneous). Objects along the side of the road generally receive less illumination (i.e., are of lower contrast) at night and are subsequently more difficult to see than during the daytime.

The study indicated that as the overall clutter or complexity of the roadside visual environment increases, drivers will look at it, and glances to the road ahead will decrease. This effect was evident in the CEVMS complex and built environment data collection zones, where drivers spent 10.4 and 14.2 percent of the time, respectively, looking at object along the roadside. Clutter was defined in terms of the amount of visual information and included buildings, signs, businesses, parked cars, and so on. Areas with high levels of clutter tended to be on arterials with associated businesses on the sides of the road. This aspect of the high-clutter areas also relates to the potential for safety risks (e.g., vehicle coming out of a business) and thus more glances to the left and right sides of the road cannot definitively be attributed to distraction alone.

IV. EXPERIMENT 2

The objectives of the second experiment were the same as those in the first experiment, and the design of experiment 2 was very similar to experiment 1. The independent variables included the type of data collection zone (CEVMS, standard billboard, or no off-premises advertising) and time of day (day or night). In addition, the data collection zones in this experiment were grouped into those presenting low and moderately high visual complexity. In total, experiment 2 included the following independent variables: time of day (day or night), type of data collection zone (CEVMS, standard billboards, no off-premise advertising), and visual complexity (low and high). As with experiment 1, the time of day was a between-subjects variable and the other variables were within subjects.

On average, the test routes for Richmond, VA were slightly longer in duration than those for Reading, lasting approximately 30 to 35 minutes. As in Reading, the routes represented a variety of freeway and arterial driving segments. Route A was 15 miles long and contained five target CEVMS, three target standard billboards, and two no off-premise advertising data collection zones. Route B was 20 miles long and had four target CEVMS, three target standard billboards, and two no off-premise advertising data collection zones. Table 8 is an inventory of the target billboards along the Richmond data collection routes with relevant parameters.

Table 8. Inventory of Target Billboards in Richmond with Relevant Parameters.

<i>Visual Complexity</i>	<i>Advertising Type</i>	<i>Copy Dimensions (ft)</i>	<i>Change Rate (sec)</i>	<i>Side of Road</i>	<i>Setback from Road (ft)</i>	<i>Approach Length (ft)</i>	<i>Other Standard Billboards</i>
High	CEVMS	11'0" x 23'0"	10	R	35	960	0
High	CEVMS	10'6" x 36'0"	10	L	88	960	0
High	CEVMS	12' 6" x 42' 0"	10	L	227	960	5
High	Standard	14'0" x 48'0"		R	134	889	3
High	Standard	10'6" x 45'3"		L	124	960	2
High	Standard	10'6" x 22'9"		L	76	863	0
Low	CEVMS	12'5" x 40'0"	10	R	82	960	2
Low	CEVMS	14'0" x 36'0"	10	R	69	960	2
Low	CEVMS	14'0" x 36'0"	10	L	128	960	2
Low	CEVMS	14'0" x 28'0"	20	L	119	960	0
Low	CEVMS	10'6" x 36'0"	10	R	42	960	2
Low	CEVMS	14'0" x 28'0"	10	R	56	960	0
Low	Standard	14'0" x 48'0"		L	195	960	0
Low	Standard	14'0" x 48'0"		R	125	960	3

A. METHOD

Advertising Type

Three data collection zone types (similar to those used in experiment 1) were used in Richmond:

- **CEVMS.** Data collection zones contained one target CEVMS.
- **Standard billboard.** Data collection zones contained one target standard billboard.

- **No off-premise advertising.** Data collection zones did not contain any off-premise advertising.

The zones were further categorized in terms of visual complexity (described in greater detail below). This categorization considered the presence or absence of buildings, businesses, and on-premise advertising.

Table 9 presents a breakdown of the data collection zones for the three advertising conditions as a function of visual complexity.

Table 9. Advertising Conditions by Level of Visual Complexity.

Advertising	<i>Level of Visual Complexity</i>	
	High	Low
CEVMS	3	6
Standard Billboard	3	2
No Advertising	2	2

Figures 23-36 below represent various pairings of data collection zone type and visual complexity. Target off-premise billboards are indicated by red rectangles.



Figure 23. Example of a CEVMS Data Collection Zone with High Visual Complexity.



Figure 24. Example of CEVMS Data Collection Zone with Low Visual Complexity.



Figure 25. Example of a Standard Billboard Data Collection Zone with High Visual Complexity.



Figure 26. Example of a Standard Billboard Data Collection Zone with Low Visual Complexity.

Photometric Measurement of Signs

The photometric measurements in Richmond were performed using the same equipment and procedures that were employed in Reading with a few minor changes. Photometric measurements were taken during the day (between 8:20AM and 11:20AM) and at night (between 5:40PM and 10:45PM). Measurements of the standard billboards were taken at an average distance of 284 ft, with maximum and minimum distances of 570 ft and 43 ft. The average distance of measurements for the CEVMS was 479 ft, with maximum and minimum distances of 972 ft and 220 ft.

Luminance: The mean luminance of CEVMS and standard billboards disaggregated by visual complexity, during daytime and nighttime are shown below in Table 10.

Table 10. Luminance Values (cd/m²) for the Low and High Visual Complexity Conditions.

	High Complexity			Low Complexity		
	<i>Min</i>	<i>Max</i>	<i>Average</i>	<i>Min</i>	<i>Max</i>	<i>Average</i>
<i>Day</i>						
CEVMS	1,339	2,536	2,027	1,422	3,357	2,228
Standard Billboard	1,014	1,567	1,258	4,424	7,149	5,787
<i>Night</i>						
CEVMS	26	53	42	39	79	61
Standard Billboard	7	11	9	5	16	11

Contrast: The daytime and nighttime Weber contrast ratios for both types of billboards are shown in Table 11. During the daytime, the contrast ratios of both CEVMS and standard billboards were close to zero (the surroundings were about equal in brightness to the signs). At night, the CEVMS and standard billboards had positive contrast ratios. Similar to Reading, PA, the CEVMS produced greater contrast ratios at night than during the day.

Table 11. Weber contrast values in low and high visual complexity environments.

	High Complexity			Low Complexity		
	<i>Min</i>	<i>Max</i>	<i>Average</i>	<i>Min</i>	<i>Max</i>	<i>Average</i>
<i>Day</i>						
CEVMS	-0.56	-0.41	-0.48	-0.47	0.64	-0.05
Standard Billboard	-0.14	0.28	0.06	-0.26	0.73	0.24
<i>Night</i>						
CEVMS	19.20	123.60	67.80	15.82	162.11	68.85
Standard Billboard	7.22	15.18	12.44	-0.01	6.02	3.00

Visual Complexity

As with experiment 1, the subband entropy measure was used to estimate the level of visual complexity/clutter in the data collection zones. For each zone, a single frame was captured from a color video and saved as a JPEG image. The JPEGs were analyzed with MATLAB routines that computed a measure of subband entropy for each image. Figure 27 shows the mean subband entropy measures for each of the advertising conditions (note that due to the limited number of data collection zones, standard error information is not included). The subband entropy measures correlate well with the categorization of the data collection zones into two levels of visual complexity.

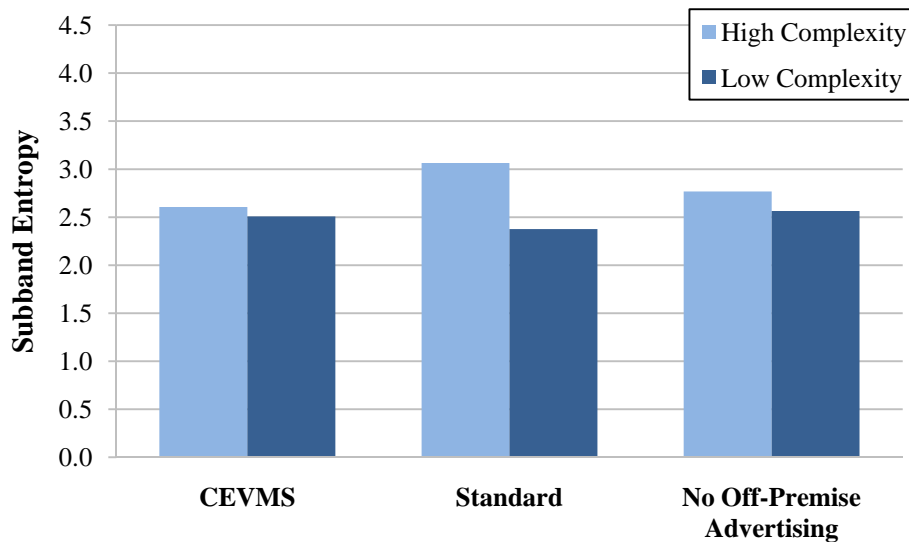


Figure 27. Subband Entropy Measures for the Data Collection Zones.

Participants

A total of 41 participants were recruited for the study. Of these, six participants did not complete data collection because of an inability to properly calibrate with the eye-tracking system and eight were excluded because of equipment failures. A total of 27 participants (16 male, $M = 28$ years; 11 female, $M = 22$ years) successfully completed the drive. All participants were under the age of 64. Fourteen people participated during the day and 13 participated at night.

Procedures

Research participants were recruited locally by means of visits to public libraries, student unions, community centers, etc. A large number of the participants were recruited from a nearby university, resulting in a lower mean participant age than in experiment 1.

Participant Testing

Two people participated each day. One person participated during the day beginning at approximately 12:45 PM. The second participated at night beginning at around 7:00 PM. Data collection ran from November 20, 2009, through April 23, 2010. There were several long gaps in the data collection schedule due to holidays and inclement weather.

Pre-Data Collection Activities. This was the same as in experiment 1.

Practice Drive. Except location, this was the same as in experiment 1.

Data Collection. The procedure was much the same as in Reading. However, the data collection drives in Richmond were longer than those in Reading. As a result, the eye-tracking system had problems dealing with these large files. To mitigate this technical difficulty, participants were asked to pull over in a safe location during the middle of each data collection drive so that new data files could be initiated.

Upon completion of the data collection, the participant was instructed to return to the designated meeting location for debriefing.

Debriefing. This was the same as in experiment 1.

B. DATA REDUCTION

Selection of Data Collection Zone Limits

Selection of data collection zone limits for Richmond was the same as in Reading. Data collection zone distances of 960 ft or less were selected. In Richmond, the average target CEVMS height was 12.9 ft and the average width was 37.7 ft. At 960 ft, a 12.9 ft by 37.7 ft sign would subtend a horizontal visual angle of 2.25 degrees and a vertical visual angle of 0.77 degrees. Thus, at 960 ft (292.8 m) the eye glances to CEVMS billboards could be resolved by the eye-tracking system and could be read by the participants. Attempts to identify glances at billboards at longer distances were not feasible with the equipment used in this study, and in any case it is unlikely that messages on the billboards could be resolved by participants from a distance greater than 960 ft.

With the exception of defining data collection zones as having low or high visual complexity, all other aspects of the data reduction were the same as that described for experiment 1.

C. RESULTS AND DISCUSSION

As with experiment 1, results are presented to address three key experimental questions: (a) do drivers look more at CEVMS than at standard billboards, (b) are there long glances to off-premise billboards, and (c) is there a tradeoff between looking at off-premise billboards and the road ahead? The results of the visual complexity factor are also presented within the context of the questions above.

All statistical analyses used an alpha level of .05. All error bars presented in the following figures show \pm two standard errors about the mean (which closely approximate a 95 percent confidence interval).

Mean Percent of Time

The average percent of time was calculated by time-of-day and visual complexity for the following seven categories that were discussed earlier:

1. Road ahead.
2. Target CEVMS.
3. Target Standard Billboard.
4. Other Standard Billboard.
5. Miscellaneous.
6. Unknown.
7. Gauge cluster.

In the low visual complexity data collection zones there were more glances to target advertising relative to the high visual complexity approaches. The difference in glance behavior between CEVMS and standard billboard conditions was most evident at night in low visual complexity data collection zones.

Table 12 and table 13 present the mean percent of glance time for each of seven categories as a function of data collection zone type. In experiment 2 these variables significantly affected drivers' glance behavior. As a result, separate tables are presented to show the tradeoff in glance behavior across visual complexity and time of day.

The following sections provide the results of statistical analysis for each of the above seven dependent measures (areas of glances). The statistical model used was a 2 (time of day) x 2 (visual complexity) x 3 (data collection zone type) mixed design analysis of variance. Because the raw percentages are positively skewed (deviating) from normality, additional analyses were performed using transformed data. Data were transformed using the arcsine of the square root of the proportions. This transformation works on measures distributed between zero and one, and thus proportions rather than percentages were used. The results with and without the transformation were similar. All the reported analysis of variance statistics used the transformed data.

Table 12. Mean Percentage of Time for All Object Categories as a Function of Data Collection Zone Type for Low and High Visual Complexity Data Collection Zones During the Daytime.

DAYTIME		Road Ahead	Misc	Unknown	Gauges	Target Billboards	Non-Target Standard Billboards	Total
High Visual Complexity	CEVMS	70.3%	16.1%	1.1%	1.4%	1.0%	1.1%	100%
	Standard Billboards	72.7%	15.7%	15.7%	1.8%	0.5%	1.0%	100%
	No Off-Premise Advertising	72.7%	17.2%	7.5%	2.6%	—	—	100%
	Mean	71.9%	16.3%	8.1%	1.9%	0.8%	1.1%	—
Low Visual Complexity	CEVMS	79.2%	8.1%	7.9%	1.2%	2.9%	0.7%	100%
	Standard Billboards	87.6%	4.0%	5.1%	0.7%	2.2%	0.4%	100%
	No Off-Premise Advertising	85.6%	3.4%	9.2%	1.8%	—	—	100%
	Mean	84.1%	5.2%	7.4%	1.2%	2.6%	0.6%	—
Overall Mean		78.0%	10.8%	7.8%	1.6%	1.7%	0.8%	—

Table 13. Mean Percentage of Time for all Object Categories as a Function of Data Collection Zone Type for Low and High Visual Complexity Data Collection Zones During The Nighttime.

NIGHTTIME		Road Ahead	Misc	Unknown	Gauges	Target Billboards	Non-Target Standard Billboards	Total
High Visual Complexity	CEVMS	72.6%	13.4%	11.0%	1.0%	0.8%	1.2%	100%
	Standard Billboards	72.0%	14.0%	10.7%	1.1%	0.7%	1.4%	100%
	No Off-Premise Advertising	69.1%	17.5%	12.0%	1.4%	—	—	100%
	Mean	71.2%	15.0%	11.2%	1.2%	0.8%	1.3%	—
Low Visual Complexity	CEVMS	76.7%	6.2%	10.8%	1.2%	4.5%	0.6%	100%
	Standard Billboards	80.9%	5.0%	11.5%	1.3%	1.0%	0.3%	100%
	No Off-Premise Advertising	81.1%	3.5%	13.2%	2.2%	—	—	100%
	Mean	79.6%	4.9%	11.8%	1.6%	2.8%	0.5%	—
Overall Mean		75.4%	9.9%	11.5%	1.4%	1.8%	0.9%	—

Mean Percent of Time to Target Advertising

The interaction of time of day, advertising, and visual complexity was statistically significant: $F(1, 75) = 6.03, p < .05$. Figure 28 (also table 12 and table 13) illustrates the interaction among these three variables. There were no significant differences between CEVMS and standard billboards under high visual complexity during the day or nighttime. Unlike in experiment 1, the only time in which target CEVMS billboards attracted more glances than standard billboards was at night in low visual complexity environments.

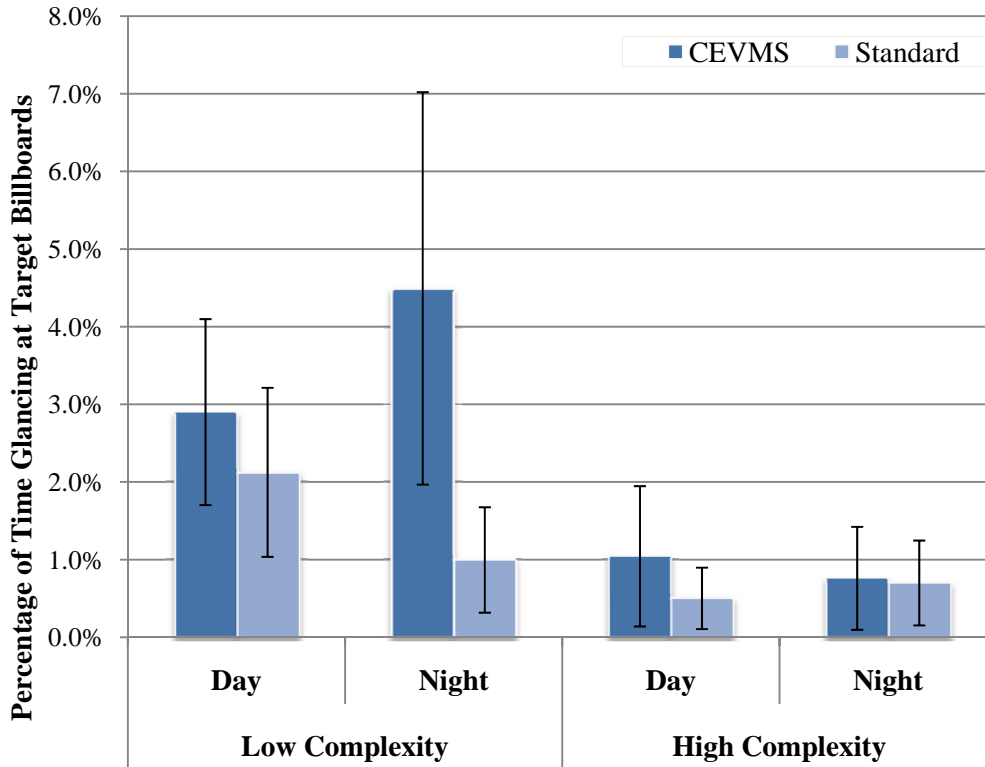


Figure 28. Percentage of Time Glancing at Target Billboards as a Function of Visual Complexity and Time of Day.

Mean Percentage of Time Looking at the Road Ahead

Time spent looking at the road ahead was significantly less in areas of high visual complexity ($M = 72$ percent) than in low visual complexity zones ($M = 82$ percent): $F(1, 125) = 65.81, p < .01$. The mean time spent glancing to the road ahead (averaged across CEVMS, standard, and no off-premise advertising) was 77 percent. There were no other statistically significant results for road ahead.

Mean Duration of Glances

There were no statistically significant differences between mean duration of glances to target CEVMS or standard billboards. Visual complexity of the environment also did not affect the mean duration of glances. Further, no significant interaction between billboard type and visual complexity was found. Overall, the mean glance duration to target billboards was 0.097 s.

When looking at the mean duration of glances to the road ahead, no significant differences for billboard type or visual complexity were found. Further, no significant interaction between billboard type and visual complexity was found. Overall, the mean duration of gazes at the road ahead was 0.69 sec.

Figure 29 shows the distribution of gaze durations as a function of time of day and billboard type. (Since the effect of visual complexity was not significant, this variable is omitted from the figure.) Table 14 shows the frequency of glances used to generate the distribution of glance durations. Across all data collection drives there were 901 glances at target CEVMS signs and 172 glances at target standard billboards. The shapes of the distributions for CEVMS and standard billboards are similar. The difference in the frequency of glances between the conditions is principally due to the fact that there were nine target CEVMS and only five target standard billboards. After accounting for exposure, the glance preference for CEVMS remained. There was also a trend toward more glances at billboards during the day than at night.

Table 14. Frequencies of Glances for the CEVMS and Standard Billboard Conditions as a Function of Time of Day.

V. Billboard Type	Time of Day	
	Day	Night
CEVMS	537 (4.26)*	364 (3.11)
Standard Billboard	112 (1.60)	60 (0.92)

*Numbers in parenthesis are the glance frequency totals divided by the number of billboards and participants in the respective conditions.

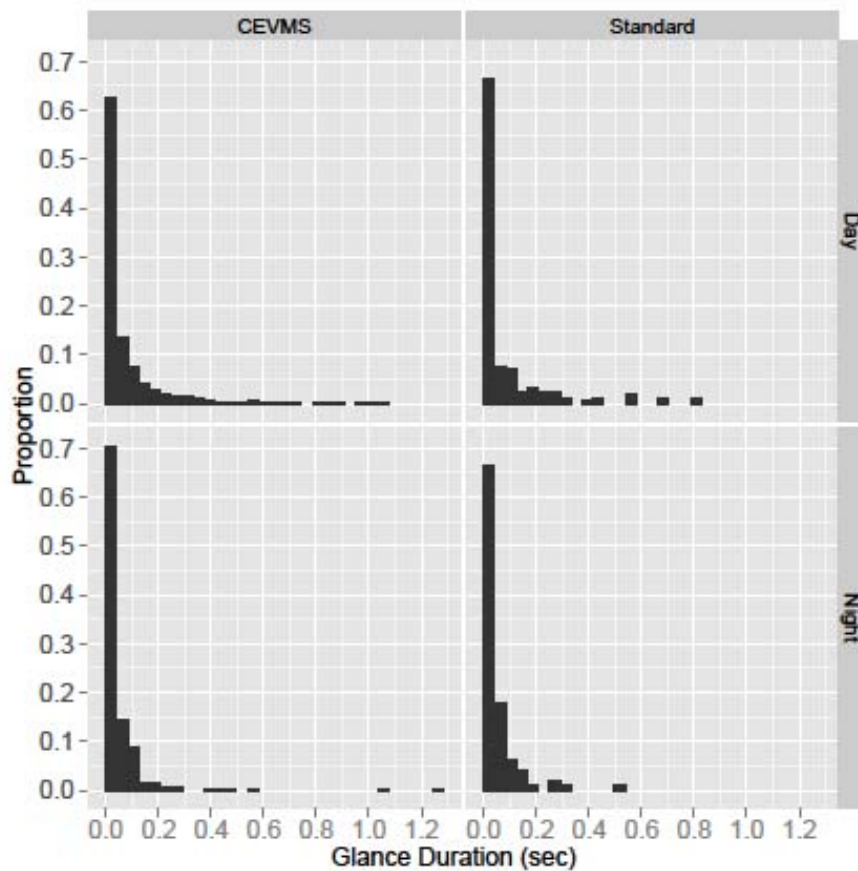


Figure 29. Proportion of Gaze Duration for CEVMS and Standard Billboards under Daytime and Nighttime Driving Conditions.

Long Duration Eye Glances

Table 15 presents a summary of the seven glances at target billboards that were equal to or greater than 1 s. All long glances were to CEVMS, ranging from 1 s to 1.28 s and all but one occurred at night. Glances equal to or greater than 1 s represent 0.78 percent of all glances at CEVMS.

Table 15. Summary of Long Glances at Off-premise Advertising in Richmond.

<i>Data Collection Zone</i>	<i>Time of Day</i>	<i>Advertising</i>	<i>Duration (sec)</i>	<i>Horizontal Offset (ft)</i>	<i>Distance from Sign (ft)</i>	<i>Horizontal Angle (deg)</i>
2	Night	CEMVS	1.12	82	334	13.79
10	Night	CEMVS	1.28	128	317	22.02
13	Day	CEMVS	1.00	119	554	12.12
16	Night	CEMVS	1.04	42	375	6.40
17	Night	CEMVS	1.00	56	141	21.68
17	Night	CEVMS	1.24	56	298	10.64
17	Night	CEMVS	1.04	56	142	21.58

Figure 30 shows the CEVMS (horizontally offset 56 ft from the roadway) in data collection zone 17, a relatively uncluttered environment (in the image, the CEVMS is highlighted with a red rectangle and is on the right side of the road). This billboard had three long glances (all at night), beginning at 141, 142, and 298 ft away. The visual angle subtended by the sign at these distances and offset was close to the area classified as road ahead. There is a traffic signal in close proximity to this billboard, but examination of individual records showed that no driver was stopped at this signal on any of the data collection drives.



Figure 30. Data Collection Zone 17 in Richmond.

Mean Percentage of Time Spent Glancing at Other Non-Target Standard Billboards

The analysis for percentage of time spent glancing at other standard billboards did not yield any significant differences. The overall average percentage of time for glances at non-target, off-premise, standard billboards was 0.84 percent.

Mean Percentage of Time Spent Glancing at Miscellaneous

Overall, there were more glances at miscellaneous objects in high visual complexity zones ($M = 16$ percent) than in low complexity zones ($M = 5$ percent): $F(1, 125) = 161.05, p < .01$. A significant interaction between visual complexity and advertising was found, $F(2, 125) = 6.55, p < .01$. As can be seen in figure 31, the interaction is the result of a large difference in the percentage of glances (at miscellaneous objects) between high and low complexity areas in the no advertising zones.

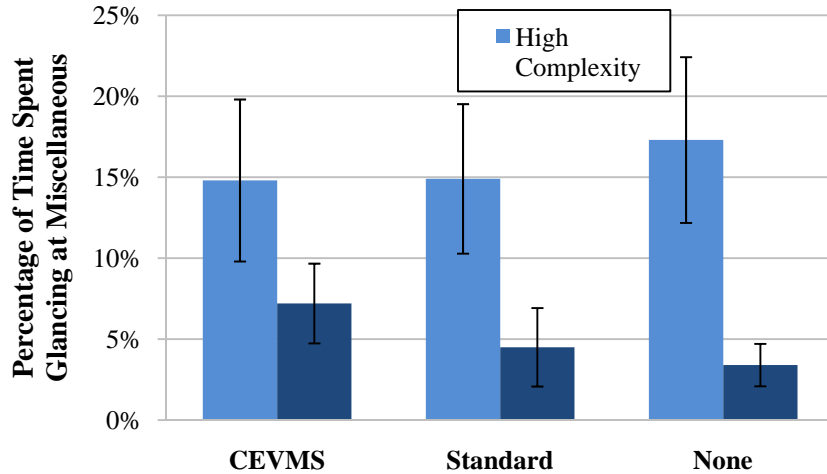


Figure 31. Percentage of Time Spent Glancing at Miscellaneous as a Function of Data Collection Zone Type and Visual Complexity.

Mean Percentage of Time Spent Glancing at Unknown Objects

There were no significant differences for percentage of time spent glancing at unknown areas. Overall, the mean percentage of time spent glancing at unknown areas was 9.7 percent.

Mean Percentage of Time Spent Glancing at the Gauge Cluster

The type of advertising zone (i.e., CEVMS, standard billboard, no off-premises advertising) significantly affected the percentage of time participants spent looking at the gauge cluster: $F(2, 125) = 4.15, p < .05$. Figure 32 shows the main effect for this variable. Participants spent significantly more time looking at the gauge cluster in zones with no off-premises advertising, than in zones with target billboards (i.e., CEVMS, standard billboards).

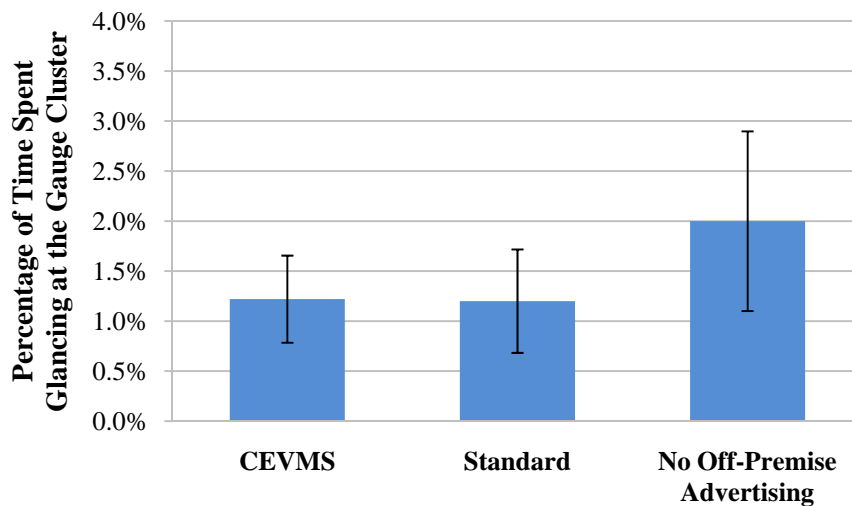


Figure 32. Percentage of Time Spent Glancing at the Gauge Cluster as a Function of Data Collection Zone Type.

Mean Rate of Glances

Overall, the mean rate of glances per second to CEVMS was 0.448. This was significantly greater than the mean rate of 0.277 glances per second to standard billboards: $F(1, 54) = 21.63, p < .01$. These rates are similar to those observed in experiment 1 (.42 and .20, respectively).

The mean rate of glances per second to target advertising in high visual complexity zones was 0.319, which was significantly less than the mean rate of 0.554 glances per second in low visual complexity zones: $F(1, 54) = 7.85, p < .01$. This finding suggests that drivers looked more frequently at the target advertising (regardless of CEVMS or standard billboards) when there were fewer information sources in and along the roadway environment (i.e., less visual complexity).

Relationship Between Photometric Measures and Glance Behavior

Analyses were conducted to determine if there was a relationship between photometric measures (luminance and sign contrast) and glance behavior. Correlational analyses compared glance duration to both luminance and Weber contrast measures for the individual signs. Separate correlational analyses were conducted for CEVMS and standard billboards during daytime and nighttime conditions. None of the correlations between glance duration and the photometric measures are statistically significant ($p > .05$). Exact correlational values follow:

CEVMS Correlations. In the daytime, the correlation between glance duration and luminance was $r = -.040$. At night the correlation was $r = 0.067$. The correlation between glance duration and contrast are $r = 0.020$ during the day and $r = 0.044$ at night. None of these correlations were significant ($p < .05$).

Standard Billboard Correlations. The correlations between glance duration and the luminance of standard billboards were $r = -0.015$ during the day and $r = -0.113$ at night. The correlation between glance duration and contrast of standard billboards with their background were $r = -0.061$ during the day and $r = -0.115$ at night. None of these correlations were significant ($p < .05$).

Observation of Driver Behavior

No near misses or driver errors were detected by the observers in the vehicle, or in later reviews of the recorded video.

Discussion

A second road experiment was conducted to examine the following three experimental questions regarding CEVMS and visual attention.

- Do drivers look at CEVMS more than at standard billboards?
- Are there long glances at CEVMS that would be indicative of a decrease in safety?
- Do drivers look at CEVMS and standard billboards at the expense of looking at the road ahead?

This experiment also included visual complexity as a factor since higher visual complexity had an impact on the results from the first experiment. In this experiment, the data collection zones were classified with respect to the visual complexity, or evident clutter, in the overall driving scene as defined by buildings, shopping areas, and other built environments^(16,17). In addition, subband entropy was calculated for representative images from the routes.⁽¹⁷⁾ This measure correlated well with the categorization of the data collection zones.

In response to the first question, the results from this study showed that drivers glanced more at off-premises advertising (CEVMS and standard billboards) under low levels of visual complexity than under high levels of visual complexity. During the daytime, the percentage of time spent looking at CEVMS and standard billboards was about equal (with a higher percentage of time in low visual complexity areas). At night, however, the percent of time spent glancing at CEVMS was greater than that spent glancing at standard billboards under low levels of visual complexity. In fact, it was this difference in the nighttime and low visual complexity condition that appeared to be principally responsible for the observed greater visual attention paid to CEVMS than to standard billboards.

Regarding the second question, average durations of glances did not vary between CEVMS and standard billboard areas. On average, the gaze duration was about 0.097 s for both CEVMS and standard billboards. There were seven glances at CEVMS that were 1 s or greater in duration, and the longest glance was 1.28 s in duration. There were no glances of 1 sec or longer at standard billboards. Glances at advertising that were equal to or greater than 1 s in duration were rare in the study, and occurred at distances between 554 and 141 feet, at horizontal angles of 22 degrees or less, and when the surrounding environment had low visual complexity.

Overall, the rate of glances toward CEVMS (4.48 glances per 10 s) was higher than for standard billboards (2.77 glances per 10 s). The rate of glances at advertising (CEVMS and standard billboards) was higher under low visual complexity (5.54 gazes per 10 s) than under high levels of visual complexity (3.19 glances per 10 s). The drivers tended to direct more glances at off-premises advertising when the complexity of the visual environment was low, and in general directed more glances at CEVMS than at standard billboards.

In terms of the tradeoff in looking at the road ahead, visual complexity had an effect on the percentage of time that drivers devoted to the road ahead. Under high levels of visual complexity, drivers devoted an average 72 percent of the time to the road ahead, whereas they devoted an average 82 percent of the time to the road ahead in low visual complexity zones. In high visual complexity zones drivers glanced at non-billboard items on the side of the road more frequently than in low visual complexity zones. Drivers devoted approximately the same amount of time to looking at the road ahead in CEVMS, standard billboard, and no advertising zones. As in experiment 1, the drivers did look at the advertising; however, this did not appear to be at the expense of looking at the road ahead.

The nighttime luminance of the CEVMS ranged between 26 and 79 cd/m². Furthermore, the CEVMS in the high visual complexity areas had lower mean luminance than those in the low visual complexity areas. The combination of less visual clutter and higher luminance at night generally leads to greater conspicuity. It is likely that this led to the resulting higher percentage of time spent glancing at CEVMS than at standard billboards. Under high levels of visual complexity at night, the percentage of time spent glancing at CEVMS and standard billboards was equally low (0.8 percent and 0.7 percent, respectively). This result suggests that, at

luminance levels observed in Richmond, the overall background in which the billboards appear affects glance probability. In other words, the visual complexity of the sign's surroundings (and not just the sign itself) influences drivers' gaze behavior.

In summary, the results of experiment 2 showed that drivers looked more at CEVMS than at standard billboards, but only at night under low levels of visual clutter. However, this did not appear to be at the expense of looking at the road ahead, where the average time spent looking was 77 percent across all conditions (with and without off-premise advertising). Rather, glance behavior was affected by the visual complexity of the scene, such that under high levels of visual complexity, percentage of time spent looking at the road ahead decreased and percentage of time spent looking at miscellaneous objects increased. The average duration of glances at CEVMS and standard billboards was about .097 s, which was up considerably from experiment 1 where the average was .07 s. However, both durations are well below the more than 2 s duration of eyes off the forward roadway at which Klauer et al. observed near-crash/crash risks more than two times those of normal, baseline driving.^(12,20) When looking at the tails of the distributions of durations, there were very few glances that were equal to or greater than 1.0 s, with the longest glance being equal to 1.28 s.^(20,21)

V. GENERAL DISCUSSION

This study was conducted to investigate the effect of CEVMS on driver visual behavior in a roadway driving environment. An instrumented vehicle with an eye tracking system was used. Roads containing CEVMS, standard billboards, but that did not contain off-premise advertising were selected. The CEVMS and standard billboards were measured with respect to luminance, location, size, and other relevant variables to characterize these visual stimuli. Unlike previous studies on digital billboards, the present study examined CEVMS as deployed in two US cities that did not contain dynamic video or other dynamic elements. These billboards changed content approximately every 8 to 10 seconds (s), consistent within the limits provided by FHWA guidance.⁽¹⁾ In addition, the eye tracking system used had nearly a 2-degree level of resolution that provided significantly more accuracy in determining what objects the drivers were looking at as compared to previous field studies examining CEVMS. Two experiments were conducted that were conducted in two separate cities where the same methodology was used but taking into account differences with respect to such variables as the roadway visual environment. The results and conclusions from this study are presented in response to the three main research questions listed below.

1. Do drivers look at CEVMS more than at standard billboards?
2. Are there long glances to CEVMS that would be indicative of a decrease in safety?
3. Do drivers look at CEVMS and standard billboards at the expense of looking at the road ahead?

In general, drivers devoted more glances at CEVMS than at standard billboards; however, there were no significant decreases in the proportion of time spent looking at the road ahead (i.e., eyes on the road) that could be directly attributed to the CEVMS at the measured luminance and contrast levels. In experiment 1, the proportion of time spent looking at CEVMS was greater than for standard billboards (2.8 versus 1.6 percent). In a visually complex data collection zone with CEVMS, the proportion of time spent looking at CEVMS was 3.8 percent; however, this data collection zone had two CEVMS, which would represent an average of 1.9 percent per CEVMS. In experiment 2, drivers looked more at CEVMS than standard billboard at night under low levels of visual complexity (4.5 versus 1 percent). There were no significant differences between CEVMS and standard billboards under any of the other tested conditions. Regardless of experiment or type of billboard, the mean percentage of time drivers spent looking at target billboards was less than 5 percent.

Glances away from the forward roadway of greater than 2 s or 1.6 s duration have been proposed as indicators of increased risk of crashes.^(12,20,21) In the current experiments there were no long glances at billboards meeting or exceeding 1.6 s. The longest glance at a target billboard was less than 1.3 s in both studies. Glances with a duration of 1 s or greater were rare: there were 5 in Reading (0.47 percent of the glances to CEVMS) and 7 in Richmond (0.78 percent of the glances to CEVMS). All of the glances greater than 1 s were to CEVMS.

Looking at the number of glances at advertising (per sign), the results from both experiments show substantially more glances at CEVMS than at standard billboards both during day and night conditions. As shown in table 16, drivers do dedicate more glances at CEVMS than to standard billboards; however, long glances considered as having the potential to increase risk were not observed.

Table 16. Number of Glances per Sign to CEVMS and Standard Billboards in Day and Night Conditions for Both Experiments.

	Day		Night	
	CEVMS	Standard	CEVMS	Standard
Experiment 1	3.57	1.82	2.62	1.37
Experiment 2	4.26	1.60	3.11	0.92

Drivers in experiment 1 devoted between 76 and 87 percent of their time looking at the road ahead. The highest percent was in the natural environment condition, where there were principally trees to the side of the road. The CEVMS complex data collection zone showed the lowest percentage of glances at the road ahead. This data collection zone had 2 CEVMS, 10 non-target standard billboards, and businesses and other on-premises advertising. Drivers in the CEVMS and standard billboard data collection zones devoted about the same percentage of time to looking at the road ahead (83 percent for CEVMS and 84 percent for standard billboards). The percentage of time devoted to looking at the road ahead measured in this experiment is comparable, but slightly higher, than those measured in other studies. Lee et al. observed 76 percent of driver time spent looking at the road ahead for the CEVMS scenario and 75 percent for the standard billboards scenario.

Drivers in experiment 2 devoted between 69 and 88 percent of their time to looking at the road ahead. The highest percentage of time spent looking at the road ahead was in the low clutter standard billboard data collection zones during the daytime. The lowest percentage of time spent looking at the road ahead was for data collection zones without off-premises advertising but with high visual clutter during nighttime conditions. In experiment 2 the percentage of time spent looking at the road ahead was affected by the level of visual clutter present in the data collection zones regardless of the presence or absence of CEVMS or standard billboards (82 percent for low clutter and 72 percent for high clutter zones).

Visual complexity, or visual clutter, has been shown in past research to have an effect on visual search performance.⁽¹⁷⁾ Drivers may have difficulty with visual search (for example, searching for street signs) in environments that are highly cluttered.⁽¹⁶⁾ In the experiments reported here, areas with high levels of clutter tended to be on arterials with businesses on the sides of the road. Increased glances away from the forward roadway in a high clutter environment also relates to the potential for safety risks (e.g., vehicle coming out of a business) and thus more glances the side of the road and away from the road ahead cannot be wholly attributed to distraction; however, it does appear to contribute to a decrease in the time drivers devote looking at the road ahead.

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