

THE EFFECT OF VISUAL CLUTTER ON DRIVER EYE GLANCE BEHAVIOR

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Summary: Drivers' eye glance behavior was examined as they drove on a variety of roadways that varied in visual clutter and the presence or absence of advertising billboards. Eye glance behavior appeared to be more heavily influenced by the nature of the driving task than by the stimulus attributes along the roadside. The mean proportion of glances to the road ahead ranged between 0.80 and 0.87 across conditions. The lowest mean proportion of glances to the road ahead was seen in conditions of high visual clutter, which contained off-premise billboards. Under high levels of clutter, drivers directed more glances to the left and right side of the road than under conditions of low clutter. The longest mean glance durations away from the forward roadway were to the right side of the road (0.105 s) and not to billboards. Mean glances to billboards were 0.078 s and 0.087 s under low and high clutter environments, respectively. The results showed that level of visual clutter present in the highway environment affects how drivers glance at scenes. However, this did not appear to be at the expense of focusing on the forward roadway.

INTRODUCTION

It has been asserted that irrelevant visual information presented to drivers along the roads may make it difficult for drivers to detect and process driving relevant information, and may also result in driver information overload (Lerner et al., 2003). In addition, information that is not relevant to the driving task may distract drivers to the degree that safety is impaired (Horberry & Edquist, 2009). The effects of excessive visual information and driver performance are complex and mediated by a host of other factors such as driver age and experience, weather and visibility, and traffic.

Driving tasks require a significant amount of information processing. In order to maintain safe driving behaviors, the driver gathers information from the environment, interprets that information, makes decisions, and carries out actions. There is an interaction between the driver and the environment as the driver monitors the results of previous actions and gathers new information (Sheridan, 2004). The driver is exposed to a significant amount of visual information while moving through the road environment, some relevant to the driving task and some that may distract from it.

How to reliably and validly classify visual information as irrelevant and perhaps distracting is not straight forward. One concept that may be useful is that of visual clutter. Rozenholtz, Li and Nakano (2007) defined clutter as "the state in which excess items, or their representation or organization, lead to a degradation of performance of some task." In the context of information in the roadway, this could mean that visual clutter may: impair the search for driving relevant

information, result in driver distraction by irrelevant information, and possibly result in information overload. Rozenholtz, Li and Nakano proposed metrics such as feature congestion, subband entropy, and edge density as measures of visual scene clutter.

Regan, Young, Lee and Gordon (2009) presented a taxonomic description of the various sources of driver distraction. 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, construction zones, billboards, road signs, vehicles, and so on. A taxonomy suggested by Horberry and Edquist (2009) 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. 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 (2007) do provide quantitative and perhaps reliable measures of visual clutter. However, this approach has been principally applied to the evaluation of static images (e.g., maps, photographs) and not to complex roadway scenes.

An additional challenge in evaluating the effects of visual clutter on driving performance is the need for measures that are related to the concept of distraction. The measurement of eye glances and how drivers scan the environment can be used to measure the degree to which drivers are not attending to the information relevant to safe driving. Eye movements have been used to examine the degree to which external stimuli attract driver eye glances (Crundall, VanLoon and Underwood, 2006). Research by Klauer et al. (2006) indicated that glances lasting more than 2 seconds away from the roadway for any purpose increase near-crash/crash risk by at least two times that of normal, baseline driving.

The review by Land (2006) of eye movements in dynamic environments concluded that the eyes are proactive, and typically seek out information required in the second before each act commences. 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 likely to result in eye movement patterns that are incompatible with safe driving (e.g., glances greater than two seconds away from the roadway). 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. (2006) 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.

The objectives of the present study were to examine driver eye glance behavior to off-premise vinyl billboards under varying levels of visual clutter. Eye glance behavior was also examined when billboards were not present. Billboards were present in areas with both high and low levels

of other visual clutter. It should be noted that areas without off-premise billboards may have a significant number of other forms of advertising and potentially distracting stimuli.

METHOD

Data from 12 subjects was selected from a larger data set that was previously collected in Richmond, VA. The selected 12 subjects were those who completed data collection runs during the daytime. The data collection runs started at about 12:45 PM and lasted about two hours. Of the 12 subjects, 5 were female. The ages of males ranged from 19 years to 60 years ($M = 36$ years). The ages of females ranged from 18 years to 22 years ($M = 20$ years).

The research vehicle, a 2007 Jeep Grand Cherokee, was equipped with an eye-tracking system (Smart Eye) that used vehicle-mounted infra-red sensors. The system consisted of two IR light sources and three face cameras mounted on the dashboard of the vehicle. The cameras and light sources were small in size, were not attached to the driver in any manner, and did not interfere with driver field of view. The face cameras were synchronized to the IR light sources and were used to determine the head position and eye gaze vectors.

The vehicle was outfitted with a three-camera panoramic scene monitoring system for capturing the forward driving scene. The scene cameras were mounted on the roof of the vehicle directly above the driver's head position. The three cameras together provided an 80 degree wide by 40 degree high field of forward view. The scene cameras captured the area that the driver could see through the left side of the windshield and a portion of the right side of the windshield. The system recorded eye movement data at a rate of 60Hz. The scene cameras recorded at 25Hz and were later synchronized with the eye movement data.

Procedure

Pre-data collection activities. After obtaining informed consent, the eye tracking system was calibrated to the participant. If it was not possible to calibrate the system the participant was dismissed and paid for his or her time. Causes of calibration failure included reflections off of eye glasses, participant height (which put their eyes outside the range of the system), and participant eye lids that obscured the pupils.

Practice. After calibration, a short practice drive was made. Before the practice drive began the participant was shown a map of the route and written turn-by-turn directions. During the drive, verbal directions were provided by a GPS device and a researcher in the rear seat of the vehicle monitored the accuracy of eye-tracking. If the system was tracking poorly, an additional calibration was performed. If the calibration could not be improved then the participant was paid for his or her time and transported to the start location for dismissal.

Data collection. As with the practice drive, participants were shown a map of a test route and provided written turn-by-turn directions. A GPS device provided turn-by-turn guidance during the drive. There were two 30 minute test routes (each approximately 17 miles). All participants drove both routes and the order of routes was counterbalanced across participants. There was a five minute break between test routes.

Design and Analysis

The independent variables were the amount of visual clutter in selected data collection areas (low or high) and the presence or absence of off-premise advertising signs. Off-premise billboard characteristics were used to define the length of relevant data collection areas. The default length of data collection zones was set at 960 ft, the distance at which billboards might conceivably be read by participants based upon MUTCD legibility guidelines.

There were four data collection zones containing off-premise billboards; two billboards were on the left side of the road and two were on the right side. Two of the data collection zones had low levels of visual clutter and two had high levels of clutter. The four data collection zones without off-premise advertising were also categorized as containing low or high levels of visual clutter (two areas of each level). The level of visual clutter was defined by visual inspection and verified by computing measures of entropy for representative pictures from the data collection zones (Rosenholz, Li & Nakano, 2007). Clutter was defined in terms of the amount of visual information and considered buildings, signs, businesses, parked cars, and so on. Table 1 shows the mean entropy measures as a function of advertising and level of clutter. The measures correlated with the categorization used for level of clutter (e.g., higher values of entropy correlated with higher level of visual clutter). Figure 1 shows samples of low and high visual clutter data collection zones.

Table 1. Mean entropy measures as a function of advertising and level of clutter

Off-premise Advertising	Level of Clutter	
	High	Low
Present	3.11	2.48
Not Present	2.77	2.56



Figure 1. Examples of high (left) and low (right) visual clutter data collection zones

The dependent variables examined were proportion of glances to specified locations or objects in the visual scene or inside of the vehicle. MAPPS software was used to process the eye glance data. Regions of interest (ROIs) in the forward video were defined for the following: road ahead; right side of the road; left side of the road; off-premise billboard; and inside the vehicle (gauge cluster and right inside of the vehicle). Figure 2 shows an overlay of the ROIs on an image for the panoramic scene camera. Mean duration of eye glances to the ROIs were also computed.



Figure 2. Panoramic video showing eye gaze direction (small circle near center) and ROIs for road ahead, left side of road, right side of road, and off-premise billboard (to the left)

RESULTS

The generalized linear model technique was used in the statistical software package SAS to analyze the data. A gamma distribution and identity link function were assumed for the response probability distributions.

Proportion of Glances

Table 2. The mean proportion of glances to the different ROIs based on clutter and advertising conditions
(proportions do not sum to one due to glances to other undefined areas)

Off-premise Advertising	Level of Clutter	Road Ahead	Inside the Car	Right Side of Road	Left Side of Road	Billboards
Present	High	0.7986	0.0543	0.0750	0.0380	0.0171
	Low	0.8425	0.0429	0.0204	0.0189	0.0375
Not Present	High	0.8316	0.0607	0.0575	0.0475	
	Low	0.8687	0.0686	0.0307	0.0276	

The mean proportion of glances to the different ROIs is shown in Table 2. The proportion of glances to the road ahead was greater in low clutter ($M = 0.8556$) than in high clutter areas ($M = 0.8151$), $\chi^2(1) = 4.46$, $p = 0.0346$. The proportion of glances to the road ahead was greater with no advertising present ($M = 0.8502$) than when advertising was present ($M = 0.8205$), $\chi^2(1) = 9.97$, $p = 0.0016$. The interaction between clutter and advertising was not significant. There were no statistically significant effects for the proportion of glances to the inside of the car. On average, glances inside of the vehicle accounted for 0.0566 proportion of all glances. The proportion of glances to the right and left side of the roadway varied with level of clutter. Under low levels of clutter, the drivers glanced less frequently to the right side ($M = 0.0255$) than under high levels of clutter ($M = 0.0662$), $\chi^2(1) = 10.16$, $p = 0.0014$. For the left side of the road the results were similar: drivers glanced less frequently to the left side under low levels of clutter ($M = 0.0232$) than under high levels of clutter ($M = 0.0427$), $\chi^2(1) = 5.52$, $p = 0.0188$. There were no other significant effects for these ROIs. A higher frequency of glances to billboards was observed under low levels of clutter ($M = 0.0375$) than under high levels of clutter ($M = 0.0171$), $\chi^2(1) = 3.92$, $p = 0.0477$.

Mean Duration of Glances

The mean duration of glances to the different ROIs is shown in Table 3. There were no significant effects in the mean duration of glances to the road ahead; the overall mean duration of glances was 0.2090 s. There were also no significant effects in the mean duration of glances to inside the vehicle; the overall mean duration of glances was 0.0421 s. The mean duration of glances to the right side of the road under high levels of clutter ($M = 0.1030$ s) was greater than under low levels of clutter ($M = 0.0392$ s), $\chi^2(1) = 9.34$, $p = 0.0022$. The mean duration of glances to the left side of the road were also greater under high levels of clutter ($M = 0.0650$ s) than under low levels of clutter ($M = 0.0316$ s), $\chi^2(1) = 11.22$, $p < 0.001$. For glance durations to the left side of the road there was also an effect of advertising. When no off-premise advertising was present, the mean glance duration to the left side of the road was longer ($M = 0.0685$ s) than when advertising was present ($M = 0.0282$ s), $\chi^2(1) = 17.23$, $p < 0.001$. Mean glance duration to off-premise billboards did not differ as function of the level of clutter; the overall mean duration of glances was 0.0412 s.

Table 3. The mean duration of glances (in seconds) to the different ROIs based on clutter and advertising conditions

Off-premise Advertising	Level of Clutter	Road Ahead	Inside the Car	Right Side of Road	Left Side of Road	Billboards
Present	High	0.2385	0.0445	0.1007	0.0463	0.0433
	Low	0.1727	0.0215	0.0335	0.0100	0.0390
Not Present	High	0.2098	0.0539	0.1052	0.0837	
	Low	0.2151	0.0486	0.0449	0.0532	

DISCUSSION

Results suggest that the level of visual clutter in the driving scene affects drivers' eye glance behavior. Under higher levels of clutter there were a greater proportion of glances to the right and left sides of the road with an associated small, but reliable, decrease in the proportion of glances to the road ahead. Off-premise billboards operated in an additive manner along with other visual clutter. That is, when billboards were present there was also a small decrease in the proportion of glances to the road ahead. The level of clutter also had an effect on glance duration. The maximum glance duration away from the road ahead was 0.75 s and it was to the left side of the road. The second largest glance duration away from the road ahead was 0.65 s to an off-premise billboard. As was shown in Table 3, mean glance durations to the left and right sides of the road (where commercial areas tend to be located) were greater in areas of high clutter than in areas of low clutter. However, the two largest maximum glance durations away from the road ahead were much lower than the 2 s threshold proposed by Klauer et al. (2006). This suggests that even in areas of high clutter, glances away from the road ahead are not likely to result in adverse or safety critical events.

Due to the connotative definition of clutter, 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., vehicles coming out of a business) and thus more glances to the left and right side of the road cannot definitively be attributed to distraction.

Further partitioning of these areas may be helpful in determining glances of distraction versus glances of situational awareness.

Drivers looked at billboards a greater proportion of time in low clutter than in high clutter areas (as shown in Table 2). Under low levels of clutter, billboards may have been more conspicuous or simply made up a greater proportion of the visual clutter lining the road. The analysis method employed singled out off-premise billboards when analyzing eye glance behavior to the sides of the road. As billboards made up part of the visual clutter, they were looked at more often when not surrounded by other clutter.

The categorization of the roadway environment into areas varying in clutter was useful in the analysis and interpretation of the results. However, additional research and analysis is needed to develop systematic and reliable methods for quantifying the visual complexity, or clutter, present in driving scenes.

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