TRAFFIC SIGN DETECTION AND IDENTIFICATION

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Summary: Previous studies using eye-trackers have suggested that drivers can extract information from traffic signs and markings without fixating them. The first study reported here examined the angle of gaze away from signs that enables sign detection: *detection conspicuity angle*. A second study examined the angle of gaze away from signs that enables identification of the signs' messages: *identification conspicuity angle*. Because conspicuity is viewed as a product of the properties of objects and their surrounding environment, both studies manipulated the background of the signs. Detection conspicuity was sensitive to the background environment, particularly for regulatory signs, for which detection conspicuity was reduced with light-colored or cluttered backgrounds. Background environment had little measureable effect on sign message identification. It is recommended that sign backgrounds be considered when locating signs, and that if the background does not provide adequate contrast, conspicuity enhancement strategies should be considered.

INTRODUCTION

The experiments described here examined the conspicuity of speed limit and warning signs. Conspicuity is generally defined as the probability of being noticed. However, there is no common measure of whether an object is noticed. Cole and Jenkins (1982) defined objects' conspicuity based on how often observers fixate them. This definition is probably too simple as Luoma (1988) found that only 8 percent of drivers in his study were able to recall pedestrian warning signs they had just passed, while 62 percent of those drivers had fixated on the signs. Also, there are some cases in which signs can be perceived without being fixated; a study that employed an eye tracking system (Inman, 2012) reported that drivers correctly identified 53.3 percent of the signs on which their gaze had not fallen.

Wertheim (2010) proposed the critical conspicuity distance measure. This is the lateral distance away from an object that a person can gaze and still detect or identify the object. Variations on his technique were used in the experiments reported here. Although only the central 2 degrees of vision (foveal vision) provide resolution sharp enough for recognizing fine detail, research has shown that information can be read with parafoveal vision, which encompasses about 10 degrees of central vision (Rayner, Inhoff, Morrison, Slowiaczek, & Bertera, 1981). This implies that traffic signs with large lettering and limited content may be read without foveal fixation.

METHODS

Sign Detection. The detection conspicuity angle of speed limit and warning signs was assessed in both laboratory and field settings. In the laboratory, static scenes were projected on to a curved screen while participants sat in the cab of a driving simulator. Participants indicated whether they thought a sign was present or not in briefly presented scenes. The dependent measure was the mean angle at which participants could reliably distinguish when particular signs were present. In the field, participants observed actual signs and indicated the maximum angle that they could look away from the signs and still perceive sign presence. The field method used the “naked eye” technique described by Wertheim (2010).

Stimuli. Three signs described in the Manual on Uniform Traffic Control Devices (Federal Highway Administration, 2009) served as detection targets in both the laboratory and the field. These were a speed limit sign, a yellow pedestrian crossing warning sign, and a fluorescent yellow-green pedestrian warning sign. In the laboratory, the signs were presented against four backgrounds: a suburban roadway, an urban roadway, a copse, and a parking lot. These backgrounds are labeled A, B, C and D respectively in Figure 1. In the field, the copse and parking lot shown in Figure 1 served as backdrops.

Figure 1. The four background stimuli for the laboratory experiments

In the laboratory, participants sat behind the steering wheel of a compact car. The screen radius was 2.7 m (8.9 ft) and the driver eye point was 2.9 m (9.5 ft) back from the center of the screen. The stimuli were projected by 5 projectors, each with 2048 by 1536 resolution. Outside, participants stood 26 m (85 ft) from the signs. A 0.9 m (3 ft) high sign at a distance of 26 m (85 ft) subtends a visual angle of approximately 2 degrees. In the laboratory, the projected height of the speed limit sign subtended 2 degrees of visual angle. The projected warning signs subtended a visual angle of 2.3 degrees. The average luminance of the white portion of the projected speed limit sign was 7.8 cd/m^2. The mean luminance of the black characters was 0.5 cd/m^2. The mean luminance of the yellow areas on the projected yellow warning sign was 6.8 cd/m^2. The luminance of image areas immediately to the left and right of the signs averaged 1.2 cd/m^2.

Outside, sign luminance and contrast were much greater than in the laboratory. On a typical day, the white portion of the speed limit sign measured 1900 cd/m^2 and 2910 cd/m^2 with the trees and parking lot, respectively, as backgrounds. Average luminance of the areas to the right and left of the signs (0.2 degree aperture) were 366 cd/m^2 and 899 cd/m^2 with trees and parking lot respectively. However, specular reflections from nearby car windows exceeded 288,000 cd/m^2. The yellow portion of the yellow pedestrian warning sign averaged 999 cd/m^2 and 1331 cd/m^2 with the trees and parking lot backgrounds, respectively. The fluorescent yellow-green portion of the fluorescent yellow-green pedestrian warning sign averaged 2786 cd/m^2 and 4063 cd/m^2 with the trees and parking lot backgrounds, respectively.

Laboratory Procedure. A staircase variation of the method of limits (Trygg, 1971, p. 20) was used to obtain the critical conspicuity detection angle for each sign and background pair. Detection trials were in blocks of 16, with the same sign within each block. After a block was completed, the horizontal offset of the fixation cross from the left of the sign center was adjusted by 3 degrees. Whether angle was increased or decreased depended on observer performance. If the observer was correct on all four trials with a background, then the offset with that background was increased. If an error was made on one or more trials with a background, then the offset for that background was decreased. Presentation of blocks of 16 trials continued until the direction of change had reversed a minimum of 5 times with each background. The critical angle for detection of each sign and background pair was computed by averaging the offset angles when the direction of change had reversed. The first reversal was not included in the average, as it is more dependent than later trials on the angle at which testing begins.

In each trial, a fixation cross was presented on a grey screen for 1 s. Participants were instructed to turn their head toward the fixation cross and focus their eyes on it. The stimulus sign and background was then presented for 0.1 s. A neutral grey screen followed. Each sign was tested in a separate session of about 12 min. Within each block of 16 trials, each background was presented four times; twice with the sign present and twice with the sign absent. The order of backgrounds was randomized within blocks. Participants indicated sign presence or absence by pressing buttons on a handheld device. Each response initiated the next trial.

Outdoor Procedure. A 0.9 m (36 in) tall speed limit sign and two 0.9 m (36 in) pedestrian warning signs, one yellow and one fluorescent yellow-green, served as stimuli. Participants stood 85 ft (26 m) from the signs. The instructions were to point to the sign and then to slowly point away, leftward, while gazing at the pointed to spot. The leftward gaze movement was to continue until the sign could no longer be detected in peripheral vision. Participants indicated where the sign became undetectable by rotating a compass pointer until it was aligned with the location where the sign became undetectable. The procedure was repeated three times with each sign and background. The order of testing of signs and backgrounds was counterbalanced across subjects.

Participants. Thirteen individuals participated; 7 females (mean age 31 years, range 19 to 56) and 6 males (mean age 47 years, range 30 to 67). All participants were licensed drivers with minimum corrected foveal visual-acuity in each eye of 20/30 or better. Seven participants completed the laboratory task first and six completed the outdoor task first.

Sign Identification

The sign identification experiment was conducted with the same laboratory setup as in the laboratory detection experiment. Five speed limit signs, 25 through 45 mph, and five warning signs with five different text messages from the MUTCD served as stimuli. Each of the five signs was presented against each of six roadway environments that varied in degree of built structures and clutter on the road sides. The lateral offset of the fixation cross from the signs varied from trial to trial with offsets of -9, -6, 0, 3, 6, 9, 12, and 15 degrees. A different random order of offsets was used for each subject. The signs were presented at a location in the background scene where an actual traffic sign appeared in the original photograph. The warning and speed limit signs were presented in separate blocks of 240 trials. Participants were informed beforehand of the five alternative messages. Each trial began with the presentation of a fixation cross on a grey background. The fixation cross was displayed for 1 s, followed by a panoramic scene with sign for 0.15 s, and then by a grey background. Participants were instructed to maintain their gaze at the location of the fixation cross, name the message on the sign if possible, and to guess when unsure.

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

RESULTS

Sign Detection

Laboratory. Mean detection angles are shown in Figure 2. Error bars represent 95 percent confidence limits for the means. The maximum measureable angle was 60 degrees, beyond which the vehicle A-pillar obstructed the screen. This resulted in a performance ceiling. When a participant reached the 60 degree angle with few or no reversals, the session was terminated before the criterion of 5 reversals was reached and a conspicuity angle of 60 degrees was assigned. Despite the ceiling, clear differences in detection conspicuity were obtained. The detection angles were submitted to a 3 (signs) by 4 (backgrounds) repeated measures analysis of variance.

The sign by background interaction was significant, $F(6, 6) = 11.3$, $p < .005$, $\eta_p^2 = .92$, as were the main effects of sign type, $F(2, 10) = 47.7$, $p < .001$, $\eta_p^2 = .91$ and background, $F(3, 9) = 116.1$, $p < .001$, $\eta_p^2 = .98$. The mean detection angle with the copse background (54 degrees) was significantly greater than those of the urban (29 degrees) and parking lot (39 degrees) backgrounds but was not significantly different from the mean detection angle with the suburban background (51 degrees). The mean detection angle of the fluorescent yellow-green sign (50 degrees) was significantly greater than that of the speed limit sign (36 degrees), $F(1,11) = 74.5$, $p < .001$, $\eta_p^2 = .87$, and that of the yellow warning sign (45 degrees), $F(1,11) = 5.2$, $p = .04$, $\eta_p^2 = .80$. The interaction of sign and background can be traced to the comparison of the speed limit sign with the fluorescent yellow-green sign; the interaction is significant when the urban environment is compared to the trees, $F(1,11) = 14.8$, $p < .01$, and when the parking lot is compared with the trees, $F(1,11) = 14.6$, $p < .01$, but not when the suburban environment is

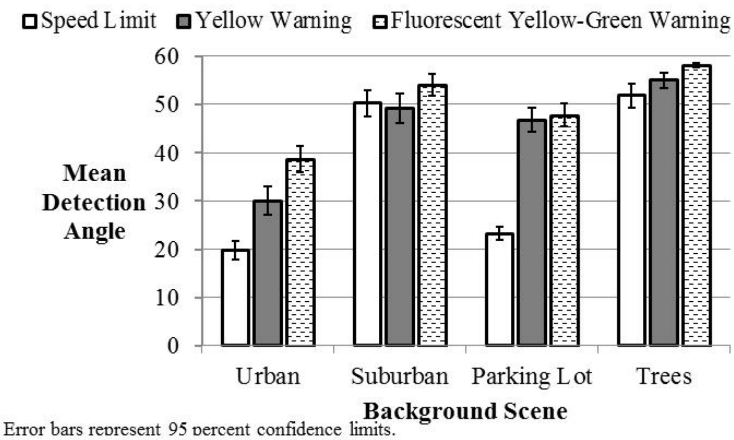

Figure 2. Laboratory findings for the critical detection conspicuity angle of three TCDs in four backgrounds

compared with trees (p = .46). When only the two warning signs were included, all interactions with background were non-significant (p > .10). With the suburban and tree backgrounds, the differences in detection angle between sign types were not significant (p = .07) nor was there a significant difference in detection angle with between those backgrounds (p = .09).

Outdoor Results. Mean offset detection angles from the outdoor procedure are shown in **Figure 3**. Error bars represent 95 percent confidence limits. The sign by background interaction was significant, $F(2, 11) = 9.9$, $p < .01$, $\eta_p^2 = .64$. The overall effect of background was not significant, (p = .08). Although the fluorescent yellow-green sign had a significantly greater detection angle than the yellow sign, regardless of background, $F(1,12) = 11.3$, $p < .01$, $\eta_p^2 = .48$, the speed limit sign was less conspicuous than the fluorescent yellow-green sign with the parking lot background, $F(1,12) = 8.1$, $p = .02$, $\eta_p^2 = .40$, but not with the copse background (p = .15).

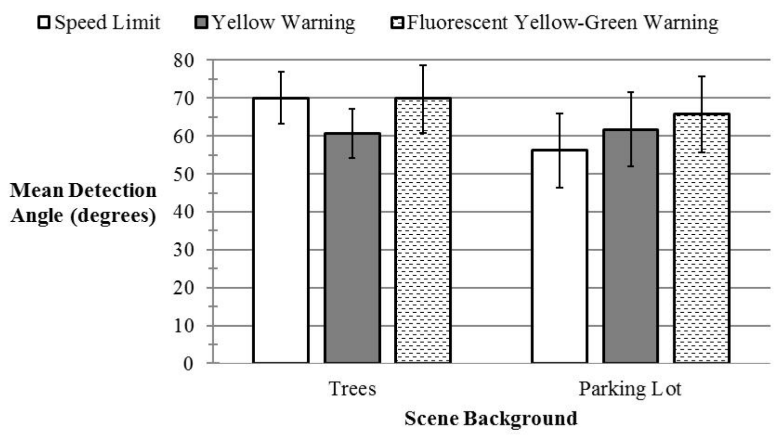

Figure 3. Mean outdoor detection conspicuity angles using a procedure suggested by Wertheim (2010)

Sign Identification Results.

As can be seen in Figure 4, the mean proportion of speed limit signs identified correctly was greater than that for warning signs, $F(1, 11) = 221.2$, $p < .001$, $\eta_p^2 = .95$. Identification performance for both sign types decreased as the angle away from the fixation point increased, $F(1, 11) = 35.8$, $p < .001$, $\eta_p^2 = .77$.

There was an interaction between sign type and scene background, $F(5, 55) = 2.9$, $p = .04$, $\eta_p^2 = .21$, which resulted because background scene had a significant effect on warning sign identification, $F(5, 55) = 2.9$, $p = .03$, $\eta_p^2 = .24$, but not on speed limit sign identification, $p = .11$. The variation in warning identification accuracy as a function of background was small, and did not appear systematically related to either clutter, built environment or any other factor that the investigators could identify.

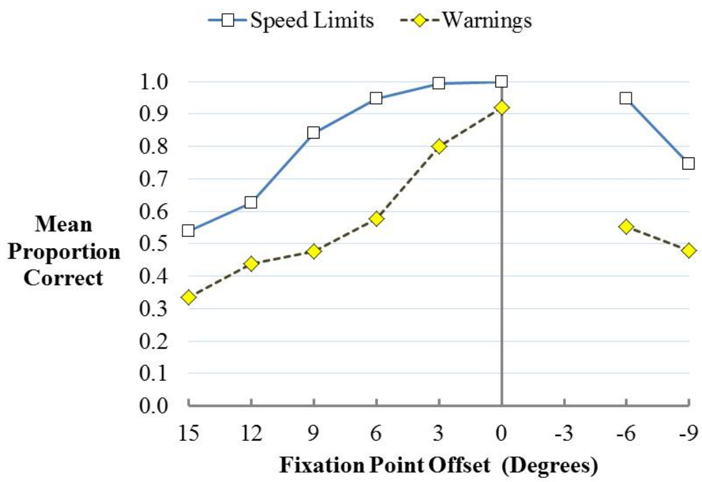

Figure 4. Proportion correct sign identification responses as a function of fixation point offset and sign type

DISCUSSION

The detection experiment showed that sign surround is important to sign detection and that black and white regulatory signs are more susceptible to degradation in detectability than are warning signs. The staircase variation on the method of limits appears to be an efficient method of determining the critical angle for sign detection. The identification experiment showed that signs can be identified in the absence of visual fixation and that the background effect is small.

Signs must be detected before they are processed. The sign detection experiment showed that both speed limit and warning signs can be detected at angles of 60 degrees or more from the point of gaze. In a low contrast environment, such as in the laboratory, the detection angles was substantial—over 50 degrees with an uncluttered background that provided reasonable color contrast. With busy or cluttered backgrounds with little contrasting color or luminance (such as the speed limit sign with the parking lot background), the detection angle can be substantially reduced.

In the laboratory detection experiment, the participants' only task was to actively monitor for signs. In the real-world drivers must monitor other vehicles and lane position and do not necessarily actively monitor for speed limits or warnings. Thus, it is reasonable to assume that detection angles would be less in actual driving than were reported here. Nevertheless, the finding that background makes a difference is relevant to real-world signing. If a warning or speed limit message is to communicate, then consideration of factors that maximize the probability of detection are important. The speed limit sign stood out against backgrounds of leafy green trees. The same sign was much less conspicuous against a background of sky, cars, pavement, advertising signs, and other objects. With light-colored surrounds, strong consideration should be given to making speed limits and other regulatory signs more conspicuous. The present experiments do not suggest how this should be done, but two common approaches are to make the signs larger or to use a conspicuous contrasting border.

In the United States, the decision to address sign conspicuity issues has been left to engineering judgment, with little guidance as to the factors that should be considered. Research is needed to provide guidance on when a conspicuity enhancement is needed, which enhancements appropriate for specific conditions, and (3) for identifying additional enhancements.

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