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Fixation distance and fixation duration to vertical road signs

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ABSTRACT

The distance of first-fixation to vertical road signs was assessed in 22 participants while driving a route of 8.34 km. Fixations to road signs were recorded by a mobile eye-movement-tracking device synchronized to GPS and kinematic data. The route included 75 road signs. First-fixation distance and fixation duration distributions were positively skewed. Median distance of first-fixation was 51 m. Median fixation duration was 137 ms with a modal value of 66 ms. First-fixation distance was linearly related to speed and fixation duration. Road signs were gazed at a much closer distance than their visibility distance. In a second study a staircase procedure was used to test the presentation-time threshold that lead to a 75% accuracy in road sign identification. The threshold was 35 ms, showing that short fixations to a road signs could lead to a correct identification.

1. Introduction

Although vision mechanisms of depth, distance, and motion perception are fairly well understood and have received a lot of attention in the past years (see, for example, Schiller and Tehovnik, 2015), the distance at which we tend to see objects and animated elements in a dynamic visual scene is a quite completely unexplored topic. Essentially, the question is: at what distance we tend to fixate a specific element in a dynamic visual scene? This question is particularly important when the target element has a regulatory or mandatory function as a traffic sign.

The distance at which road signs are first detected is of fundamental importance to allow drivers to respond appropriately. Road sign placement, in relation to the geometrical and functional characteristics of the road, is an integral part of road design, and represents one of the fundamental tools for road safety improvement (MUTCD, 2009).

Discetti and Lamberti (2011) have developed a mathematical model to investigate the relationship between sight distance and sign location. Monitoring sight distance for a road sign is also critical in case of visual obstructions such as curves or intersections (Ali et al., 2009). Fitzpatrick et al. (1998) have addressed the role of drivers' eye height in a vehicle in sight distance.

Different studies have examined the role of distance in road-sign visibility and legibility (Sivak and Olson, 1982; Zwahlen, 1987, 1988, 1993, 1995; Zwahlen et al., 2003), whereas the distance for road sign vision and detection has never been systematically investigated, and it is the main aim of this study. Usually it is assumed that a road sign is seen from the maximum sight distance prescribed by highway codes. In Italy, for example, the highway code establishes a visibility distance of 150 m for warning signs on motorways and primary roads; a visibility distance of 100 m on secondary roads, and a visibility distance of 50 m on tertiary and residential roads. These distances are increased to 250 m, 150 m, and 80 m for regulatory signs (Italian Highway Code, 1992).

Zwahlen et al. (2003) have studied the detection distance for ground-mounted diagrammatic guide signs placed before entrance ramps at highway-freeway interchanges. The overall median distance of the first look to the diagrammatic signs was 125 m. In the context of rural highways, Zwahlen (1981) found that the average distance of the first look for warning signs was about 137 m. In another study on stop ahead and stop signs (Zwahlen, 1988), the distance of the first look was 274 m during daytime and 204 m during nighttime.

The detectability and legibility of road signs with coatings of different reflectance were studied in night driving conditions by Dahlstedt and Svenson (1977). They found that a reflective intensity of a road sign in the range of 4–10 mcd/lux per cm^2 was optimal for detectability and legibility. For signs with a reflective intensity in this range it was shown that doubling the area of a sign increased detection distance of 600 m by 150–200 m. Opposing headlights in an oncoming car decreased detection distances of 500–900 m by about 100 m. They found that standard signs, with text 170 mm high, permitted reading from a distance of about 115 m.

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Despite the critical role played by vertical road signs in traffic safety and driver's behavior regulation, there is a conspicuous amount of evidence that they are often inattended. Costa et al. (2014), for example, have investigated visual fixations to vertical road signs in an ecological setting. Fixations were assessed by a mobile-eye-tracking system. The results showed that only 25.06% of vertical signs were fixated by drivers.

Paying attention to and remembering traffic signs was first studied by Johansson and Backlund (1970). Over 5000 drivers were stopped soon after they passed a traffic sign. Six signs were tested at the same location. Drivers were asked to identify the last traffic sign they had passed, with 76% of the drivers correctly remembering speed limit signs, whereas between 26% and 66% of them remembered the warning signs.

In a similar study (Shinar and Drory, 1983), drivers were stopped at an Israeli army checkpoint which was 90 km from the nearest town. Drivers were requested to recall all the warning signs along the road. Correct driver recall was only 4.5% during the day and 16.5% during the night. These results confirmed those by Johansson and Backlund (1970), revealing the difficulty of attending to and remembering warning signs.

In Sprenger et al. (1999), drivers were given verbal instructions to follow a route with which they were not familiar. Since street names and other direction signs were critical to their task, drivers saw 80% of them. They saw 60% of the speed limit signs, and about 50% of the other warning signs. It is quite difficult to interpret these results due to the fact that in these studies participant's awareness of the aims of the study is critical. If participants know or suspect that they are involved in a study on road sign vision, their visual attention to road signs will increase significantly, and the results would be strongly biased in comparison to a condition of real, ecological driving. In Inman (2012) drivers' glances to signs were recorded on a 54.7 km drive. Only about 20% of speed limit signs received glances. These results are explained in terms of inattentional blindness, automaticity in driving behavior, and the angular offset of the vertical signs to the driver.

The ability to identify traffic signs is strongly affected by driving experience and expectations. In Theeuwes and Hagenzieker (1993) participants had to search for a target traffic sign or a target road user embedded in a natural traffic scene. The target was located either at an expected or an unexpected position. In this latter case error rate was significantly higher. Following this line of research, Borowsky et al. (2008), recorded eye-movements to briefly presented traffic-scene pictures in which a traffic sign could be placed in an expected location or in an unexpected location. Experienced drivers were better in identifying the traffic sign only when its position conformed to expectations.

Compared to horizontal road signs, vertical ones have the advantage of being elevated above the carriageway and therefore should be more visible. In addition, the use of contrasting colors and reflective coating make them more conspicuous than horizontal signs. However, they are positioned with a lateral offset to the driver, and quite always require a glance and a specific saccadic movement to be fixated. The angle of the lateral saccadic movement is inversely proportional to the distance at which the driver glances at the sign. In addition to horizontal offset, vertical offset could also affect road sign conspicuity. Vertical signs are usually placed between 0.6 and 2.2 m above the highest point of the carriageway. In urban areas, the elevation is usually much higher to allow sufficient clearance for pedestrians (between 2.2 and 4.5 m). In a standard car, the driver's eyes are in a lower level than the vertical sign. This implies that the driver has to make an oblique lateral-up eye movement to look at the sign.

The aim of this study was to assess distance of first-fixation to vertical road signs under real driving conditions. Furthermore, we wanted to relate first-fixation distance to driver's speed and fixation duration. Finally, first-fixation distance, fixation duration, and speed were compared between fixations to signs placed in the same side of the driver, and signs placed at the opposite side.

The distance at which a sign should be legible at a given travel speed is influenced by the lateral clearance between the sign and the edge of the carriageway and the time needed to read and understand the sign content. A general guideline in road design is that drivers should not have to move their eyes more than 10° away from the road ahead (Department for Transport, UK Government, 1982). Therefore, the meaning of a sign must be fully processed before drivers reach the point where their observation angle exceeds 10°. The faster their approaching speed, the further away they should start reading a sign.

The greater the number of signs that drivers are exposed to, the higher the difficulty they have in assimilating the information, and the problem of dealing with information overload increases with age. This means that, in general, no more than two signs are placed on any one post. This includes the supplementary plate, giving further information, which is frequently placed below the main sign. There are many examples of roadways in urban settings with an excess of vertical traffic signs that could induce an information overload. When drivers are faced with more information than they can process, they may decelerate severely, drive too slowly, make late or erratic maneuvers, go the wrong way, ignore critical information, fail to consider other traffic, or take their eyes off the road for long intervals (Xu et al., 2011).

Paying attention to vertical signs is particularly critical when the road signs do not reflect the road layout, and when a sign applies to a long stretch of road. Jongen et al. (2011), for example, have examined how driving speeds change and how often speed limit signs should be repeated on roads where the speed limit is not in line (too low) with the physical condition of the road. They found that speed limits were exceeded more often when speed limit signs were repeated less frequently. When drivers were not reminded of the limit, their speed increased linearly. Speed tends to increase the further the driver is from the speed limit sign, and this increase is greatest when the speed limit is not repeated at all. Repeating the speed limit sign can induce drivers to manage their speed better and more consistently.

In this study, visual detection was assessed using a mobile eye tracker, a method that has been extensively used in driving research (Costa et al., 2014; Land and Tatler, 2009; Underwood, 1998; van Gompel et al., 2007). Mobile-eye-tracking systems have been mainly applied to the study of steering, braking, multitasking, city driving, learning, and race driving (Land and Tatler, 2009). They have been also successfully applied to the study of traffic sign detection. Zwahlen (1995), for instance, has examined reading distances for traffic signs during night driving.

Liu et al. (2011) have studied driver's eye movements when reading traffic signs containing various amounts of information while driving at different speeds. The fixation distribution had a high correlation with driving speed and the amount of information shown. As the driving speed and the quantity of information increased, the number of eye-fixations on the traffic sign area and their duration followed an increasing trend, with drivers spending less time looking ahead. When the signs contained more than five pieces of information there was an abrupt decrease of visual attention to the road.

Duration of fixations exhibits typically a positive-skewed distribution with a preponderance of short fixations and an extended tail of long fixations (Hooge et al., 2007; Sodhi et al., 2002). In eye movement research it is typical to cut off fixations lower than 100 ms in order to filter noise and saccades (Holmqvist et al., 2015). A close examination of the distribution of fixation duration to road signs (Fig. 4) revealed a mode value of 66 ms. This has convinced us to run a second study aiming to investigate the threshold for road sign detection. Due to the high dynamical context of road driving it could be that mean fixation duration is much lower than in other contexts and experimental settings. It was therefore critical to test if very short fixations of 66 ms could be enough for the driver to correctly identify a road sign.

In the second study we run a laboratory test, with an adaptive psychophysical method, to establish the duration threshold for a 75% accuracy in road sign detection. The study paralleled the methodology