

Effects of Driving Speed and Sign Reflectance on Nighttime Highway Sign Legibility Distance and Reading Time Requirements

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ABSTRACT

Nighttime highway sign legibility distance was evaluated as drivers maintained speeds of 5 versus 60 MPH. Effective legibility distance fell by approximately 30% when driving at high speed (114.9 versus 81.2 m at 5 and 60 MPH, respectively; $F(1,9) = 48.6$, $p < 0.001$). This finding suggests that past research, usually conducted under static viewing conditions (i.e., less than 5 MPH), probably overestimates the distance at which drivers can effectively read signs at night. In order to evaluate the appropriateness of new minimum sign reflectance levels proposed by the Federal Highway Administration (FHWA), legibility distance was also evaluated using 100% (new) versus 15% reflectance signs. Results indicate that nighttime legibility distance can be expected to fall by approximately 12% over the life cycle of a microprismatic retroreflective highway sign given the *proposed* FHWA minimum reflectance specification (104.2 versus 91.9 m for 100% and 15% reflectance, respectively; $F(1,9) = 20.6$, $p < 0.001$).

INTRODUCTION

Traditional studies of highway sign legibility distance have relied heavily upon static test conditions. Legibility data collected under laboratory conditions have often been used to predict real-world performance. When more appropriate field studies have been employed, the participants most often have been tested under stationary conditions. In the few cases where observations were collected under more dynamic viewing conditions, the observers either drove very slowly (e.g., 10-20 MPH) or did not drive at all (i.e., they were front seat passengers rather than drivers). This reliance upon relatively static observation conditions in the study of highway sign legibility is probably due to the fact that it has historically been very difficult to collect accurate legibility distance data from persons operating a vehicle at high rates of speed.

A recent study by Schieber, Burns, Myers, Willan and Gil-land (2004) attempted to overcome some of these constraints by using high-resolution, real-time differential global positioning system (D-GPS) and state-of-the-art eye tracking technology to measure legibility distance at highway driving speeds (i.e., 35 and 65 MPH). Among the findings of this study was the observation that nighttime legibility distances were much shorter than those that would have been expected given the results reported in the extant research literature. The authors of this study speculated that past investigations of highway sign legibility distance tended to significantly overestimate the effective

reading distance afforded by highway signs because they used less challenging static viewing conditions. Unfortunately, the Schieber, et al. (2004) study did not collect legibility distance data under static conditions; hence, no direct comparison of static versus dynamic legibility distance could be made. The current study was conducted in order to foster such a direct comparison.

The U.S. Congress has directed the Department of Transportation to revise the *Manual of Uniform Traffic Controls and Devices* to incorporate standards specifying the minimum level(s) of retroreflectivity that must be maintained by highway signs to assure adequate nighttime visibility (U.S. Congress, 1993). Following a decade of research, the Federal Highway Administration (FHWA) has proposed new minimum sign reflectance requirements to meet this congressional mandate (e.g., McGee & Paniati, 1998). A secondary aim of the current study was to provide a preliminary assessment of the appropriateness of these proposed minimum values within the context of black-on-white regulatory signs. To achieve this goal, legibility distance was assessed as a function of highway sign reflectance level as well as across slow (static) and fast (dynamic) driving speed conditions.

METHOD

Participants. Ten unpaid volunteers (5 male; 5 female; mean age = 24.3 years) with valid driver's licenses served as participants. All participant drivers had normal cor-

rected visual acuity at optical infinity (mean = 1.0 minarc; range = 0.85 – 1.25 minarc).

Stimulus Materials. Test signs were constructed of black 8-inch tall letters or numerals mounted on white retroreflective sheeting (3M VIP-Diamond grade; ASTM type IX). Each sign contained the word “TEST” followed by a single letter-numeral combination constructed using the Highway Series D font (see Figure 1). Signs were 30-in tall and 24-in wide. They were carefully mounted in the right “shoulder” adjacent to the driving lane at a constant height of 7 ft (bottom of sign) and a lateral offset of 22 ft (left edge of sign to right edge of driving lane). Half of the target signs were presented at 100% reflectance and half were presented at 15% reflectance. Effective reflectance was reduced by coating the entire sign surface with a 15% transmittance neutral density film. A reduced reflectance of 15% was chosen to yield an effective sign luminance that approximated the minimum nighttime levels recently proposed by the Federal Highway Administration (McGee and Paniati, 1998). See Schieber, et al. (2004) for details regarding the derivation of this benchmark value.



Figure 1. Sample experimental highway sign.

Apparatus. Participants drove a 1998 Toyota Avalon equipped with an automatic transmission. Vehicle headlamps were properly aimed, calibrated (Gilbar Engineering; Rochester, MI) and operated within controlled voltage specifications. An in-vehicle video capture system recorded the forward view of the road during all experimental trials. Real-time measurements of vehicle speed and position on the test track were made using a Starlink model 212-G differential global position system (D-GPS). This

information was integrated with the time-stamped video data, digitally recorded, and used subsequently for off-line determination of legibility distance and driving velocity. The D-GPS antenna was mounted on the vehicle roof directly over the driver's head.

Procedure. Participant drivers completed an informed consent procedure previously approved by the Institutional Review Board of the University of South Dakota. All data were collected on a single evening in October 2004 under clear skies – beginning 1 hour after civil twilight. Participants were required to drive the instrumented test vehicle around a circuit of a test track that was closed to all other traffic (3M Transportation Safety Research Center, Cottage Grove, MN). Low-beams were used at all times. Test signs were placed at one of two possible locations along a straight 0.8 mile segment of the test track. On each lap of the test circuit the drivers were required to read the letter-numeral stimuli on the test sign (e.g., “Z9”) from as far away as possible while maintaining safe control of the vehicle. They were carefully instructed to make their vocal responses clear and fast because their voices were being recorded for later determination of their distance from the test highway signs. Indeed, their vocal responses were clear, loud and rapid and recorded along with the time-stamped video, vehicle position and speed data (as described above). The experiment was conducted in two blocks of trials. In the *static* block, participants approached each test sign until they could just detect its presence. Thereafter, they were required to reduce their speed to between 3-5 MPH until they read the sign. In the *dynamic* block, drivers were required to approach each test sign at a speed of 60 MPH and maintain this speed until they read the test stimuli aloud. The experimenter, situated in the back seat, helped the drivers maintain their target speed by providing a vocal “read out” of GPS speed-overground. The order of the administration of these blocks was counterbalanced across subjects. Each participant read two signs under each speed condition (5 versus 60 MPH) and each level of sign reflectance (100 versus 15%) yielding a total of 8 observation per driver. The order of the sign reflectance manipulation was completely randomized.

RESULTS

Legibility distance for each sign was determined through off-line analysis. Video tapes (with audio) were digitized for computerized playback. The video frame at which the vocal identification of the sign had been completed was identified. Time stamp information on this video frame was used as a cross reference to the data file containing the real-time D-GPS position and vehicle speed information. Effective legibility distance was then calculated based upon the difference between the vehicle's real-time position estimate and the previously recorded latitude and longitude

of the test sign. This measurement technique has been shown to yield sub-meter levels of precision (Schieber, et al., 2004). Validity of these GPS-based distance measurements were verified by comparing them to concomitant measurements obtained using a highly accurate laser-range finding system (see Figure 2).

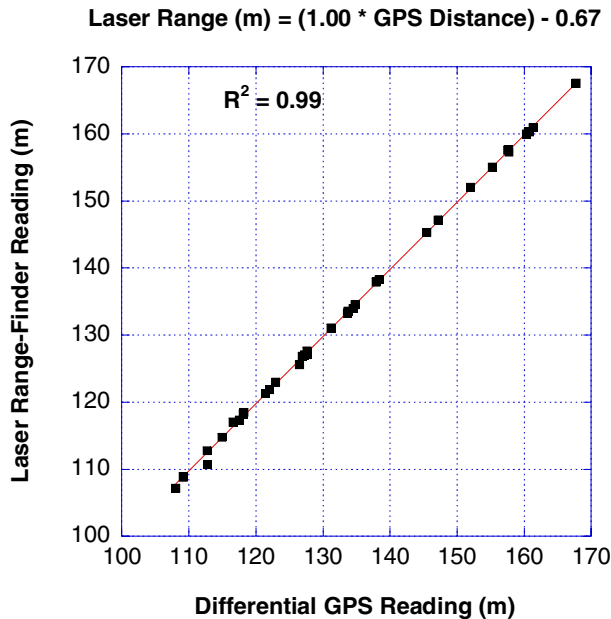


Figure 2. Results of Spring 2004 static laser rangefinder validation of GPS distance-from-sign measurements.

Legibility distance data were analyzed using a (2) Driving Speed by (2) Sign Reflectance repeated-measures ANOVA. The main effects were statistically significant but the interaction was not. Average legibility distance decreased from 114.9 m at the near stationary driving speed (mean speed = 3.69 MPH) down to 81.2 m at highway driving speed (mean speed = 58.8 MPH) ($F(1,9) = 48.6, p < 0.001$). Legibility distance also significantly decreased with reductions in sign reflectance ($F(1,9) = 20.6, p < 0.001$). Average legibility distances of 104.2 and 91.9 m were observed for the 100% and 15% reflectance levels, respectively.

Perception Response Time (PRT) assumptions are used extensively in traffic engineering and highway geometric design (e.g., AASHTO, 1994). The data collected in the current investigation allow one to estimate the modified-PRT required to read a traffic sign under dynamic conditions. The logic for the determination of this modified-PRT value is as follows: Given that (1) average legibility distance declined by 33.7 m in the high-speed condition and (2) the average driving speed while reading the signs in this condition was 26.5 m/sec (i.e., 58.8 MPH), it follows that the average time required to translate the contents of a

target sign into an action once threshold visibility levels had been achieved was approximately 1.28 sec (i.e., it took 1.28 sec to travel the 33.7 m difference in legibility distance in the dynamic relative to this static viewing condition).

DISCUSSION

Past engineering practice has determined the operational legibility distances of highway signs using *indirect* methods in which inexact estimates of perception-response time were used to modify threshold legibility distance estimates collected under static viewing condition. The results of the current study indicate that the effective legibility distance afforded by a given highway sign can be measured *directly* by observing legibility distances at operational highway speeds using readily available technology. The average legibility distance observed under the static conditions of the current study yielded an equivalent *legibility index* of 47 ft per inch of sign letter height (i.e., 114.9 m x 3.28 ft/m divided by the 8 in letter height). This value exceeds the 40 ft/in minimum recommended by the current edition of the *Manual of Uniform Traffic Control Devices* (MUTCD). However, the average effective legibility distance calculated while driving at approximately 60 MPH using the dynamic approach yielded an equivalent legibility index of only 33 ft/in (i.e., 81.2 m x 3.28 ft/m divided by 8-in letter height). This dynamic estimate of legibility distance, measured at representative highway driving speed, falls far short of the MUTCD recommendation.

A secondary goal of the current study was to estimate the reduction in legibility distance that would occur across the life-cycle of a highway sign given new end-of-service-life reflective minimums recently proposed by the Federal Highway Administration (FHWA). This was accomplished by comparing “new” retroreflective signs to a set of sign stimuli whose reflectance had been artificially reduced to 15% of new in order to approximate the minimum reflectance values for black-on-white regulatory signs as proposed by the FHWA. Collapsed across driving speed conditions, the average legibility distance afforded by the 15% reflectance sign (i.e., the proxy for the proposed FHWA minimum value) declined by approximately 12% relative to its “new” counterpart. Under most conditions, a life-cycle reduction in performance of this magnitude would probably be acceptable. Smaller relative declines in performance over the sign life-cycle would probably be expected to occur for signs made from non-prismatic materials (e.g., ASTM type I-IV) since their initial (new) values would be significantly lower than the ASTM type IX material used in the current study.

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