Effect of Luminance on Information Acquisition Time and Accuracy from Traffic Signs

Principal Investigator: Thomas Schnell, Ph.D.
Department: Operator Performance Laboratory (OPL), Center for Computer Aided Design (CCAD)
Institution: The University of Iowa
Address: 2135 Seamans Center, Iowa City, IA 52242-1527, USA
E-mail: thomas-schnell@uiowa.edu
Telephone: 319-631-4445
Fax: 319-335-5669
Report Authors: Tom Schnell, Lora Yekhshatyan, Ron Daiker, and Jeff Konz
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EXECUTIVE SUMMARY

Although visual performance was measured in terms of visual response time in many psychophysical studies, such approach was not used in evaluating the effect of luminance on traffic sign legibility performance. Traffic sign and retroreflective sign sheeting performance at night have been historically identified with the threshold (farthest) distance for legibility, and in many cases from stationary vehicles with no restrictions on viewing time. Since traffic signs are not always read at threshold distances or threshold luminances and since the time to read traffic signs are usually limited in the real world, a proper assessment of sign legibility performance requires determining information acquisition times above threshold conditions.

This study investigated the effect of (legend) luminance and letter size on the information acquisition time and transfer accuracy from simulated traffic signs. Luminance on the sign legend was administered at five levels; 3.2 cd/m\(^2\), 10 cd/m\(^2\), 20 cd/m\(^2\), 40 cd/m\(^2\) and 80 cd/m\(^2\), on positive-contrast textual traffic sign stimuli with contrast ratios of 6:1 and 10:1. The luminance of 3.2 cd/m\(^2\) was chosen as the minimum, as it was found in earlier studies to be the minimum required luminance for the median driver above the age of 65 years for guide and street name signs viewed at 40 foot/inch legibility index. Maximum luminance was chosen as 80 cd/m\(^2\) based on earlier research recommending this level as the optimal sign luminance. The simulated signs were positioned at 33 foot/inch and 40 foot/inch legibility indices viewed under conditions simulating a nighttime driving environment. Nineteen (19) participants over the age of 55 years were recruited locally from Iowa City area, all with valid driver's licenses.

A high-definition LCD display was used to simulate the traffic signs, where the task of the subject was to determine the exit number for a target street name. A software program was developed for this experiment to control sign viewing times, display the signs, and record participant responses. Sign viewing times were varied based on an algorithm called “Up-Down Transformed Rule” (UDTR), with the objective to determine the sign viewing times required to achieve 50-percent and 84-percent accuracy in the responses.

The findings suggest that increasing the sign luminance significantly reduced the time to acquire information. Similarly, increasing the sign size (or reducing the legibility index) also reduced the information acquisition time. Furthermore, as the text size decreased, the reading times showed a much more dramatic increase at lower luminance levels. These findings suggest that larger and brighter signs are more efficient in transferring their message to the driver by reducing information acquisition time, or alternatively, by increasing the transfer accuracy. In return, reduced sign viewing durations and increased reading accuracy is likely to improve roadway safety.
1. **Introduction**

Luminance levels required for traffic sign legibility have historically been reported for threshold levels. In many studies, these thresholds were determined under static viewing conditions where observers sometimes had unlimited exposure times to read signs. Some laboratory studies use a paradigm in which the luminance and/or contrast is changed gradually until the observer can first read a traffic sign. These thresholds are typically established for a given percentile driver or a typical driver of a certain age, i.e. 85th percentile, or average 55 year-old driver. In real world driving, drivers do not have unlimited time to read a traffic sign.

Sign reading takes time and is driven by other information acquisition requirements imposed upon the driver by the situation. Although omitted in many studies, exposure time has been shown to affect reading accuracy (1,2), which is a critical factor in the context of conveying the message to the driver. If a hypothetical material follows the threshold demand curve established under no exposure time limitation and static viewing condition for a particular driver, such a sign may not serve the same driver under dynamic driving conditions, where information has to be acquired quickly from the sign. Therefore, how quickly and accurately a message is conveyed to the driver form a sign is a visual performance measure that follows whether the driver can read the sign.

These performance measures may contribute to the understanding of traffic sign performance especially in nighttime, and help the practitioner to control sign size, or luminance indirectly through retroreflection. Recent changes in the MUTCD (3) stress the importance of increasing sign size. As for luminance, the retroreflective traffic sign sheeting technology has evolved since its introduction in 1930s, first with exposed bead sheeting, then enclosed and encapsulated beaded sheetings, microprismatic sheetings with truncated-cube design, and most recently, a microprismatic sheeting featuring full-cube optics was introduced into the market in 2005. While these developments were taking place, the question regarding the benefits of increased luminance provided by highly efficient optics has come into question. This research study helps to quantify the relationship between luminance of a traffic sign, the time it takes to acquire information from that traffic sign, and the accuracy of the acquired information. We tested this hypothesis by manipulating the exposure time using the Up/Down Transform Response (UDTR) statistical model for varying legend sizes and background luminances. We were able to determine the minimum required exposure time for a selected percentile of correct responses.

1.1. **Problem Statement**

Currently, there is little understanding of the quantifiable benefits of additional luminance over threshold legibility luminance provided by very-highly efficient retroreflective optics such as the full-cube optics for drivers within the functional legibility range. The question that this study aims to address is whether increasing the overall luminance of a sign is beneficial to the driver even when the sign is at or above the legibility luminance threshold.

More specifically, the purpose of this research was to empirically test the hypotheses that (a) providing luminance above legibility threshold yields faster information acquisition and (b)
when exposure is limited, brighter signs provide more accurate information transfer. The study determined the relationship between luminance (high and typical contrast levels, positive signs), exposure time, visual angle subtended by the text on the sign (or legibility index), and information transfer accuracy for a sample driver population over the age of 55 years.

1.2. Literature Review

The scientific literature features many studies that investigated the relationship between luminance, luminance contrast, visual angle subtended by the text or symbol, font face or critical detail on the legend, and resulting legibility distance. In general, higher luminance provided longer legibility distance \((5,6)\). In these studies, luminance generally referred to the luminance of the brighter part of the sign (sign legend for positive contrast signs – i.e. white on green signs, and the luminance of the sign background for negative contrast signs – i.e. black legend such as speed limit and most warning signs).

Sivak and Olson \((7)\) conducted a review of earlier studies in an effort to determine optimal and minimum (replacement) luminance levels, and identified 75 \(\text{cd/m}^2\) as the optimal and 2.4 \(\text{cd/m}^2\) as the minimum luminances for the brighter component of the sign. Russell \((8)\) determined 3.2 \(\text{cd/m}^2\) as the minimum (threshold) luminance required for reading traffic signs. Jenkins et al. also reported 3.2 \(\text{cd/m}^2\) as the minimum. At 40 foot/inch legibility index for the median driver above the age of 55 years, Carlson and Hawkins \((9)\) reported 2.3 \(\text{cd/m}^2\) as the minimum luminance for legibility of guide signs with Standard Highway Series E-Modified legends, and 3.9 \(\text{cd/m}^2\) for street name signs with Standard Highway Series C legends. When drivers over the age of 65 years, the minimum luminance was found to be 3.2 \(\text{cd/m}^2\). Schnell, Aktan, and Li \((5)\) determined 80 \(\text{cd/m}^2\) as the luminance above which the legibility distance plateaud.

Naturally, the minimum legibility luminance depends on the font type of the text among other factors such as contrast. As such, there is no universal agreement on the minimum or the optimal luminance levels. However, when the minimum luminance levels were determined, exposure time was usually unlimited. In natural driving conditions, the exposure time is hardly unlimited. Sign legibility performance is not solely a function of the maximum distance where the sign can be read with unlimited exposure time, but also how quickly the driver can acquire the information at the time s/he tries to read the sign. Concepts such as “visibility level” and “relative visual performance” were introduced to address legibility performance at or above the threshold luminance levels.

The concept of “Visibility Level”, or VL, was introduced as the ratio of available contrast to threshold contrast, in an effort to relate to suprathreshold performance based on threshold performance \((10,11)\). However, VL alone does not constitute a human performance metric, because luminance and contrast both contribute to the performance.

Later, relative visual performance (RVP) model was introduced to determine visual performance by measuring the time to complete a visual numerical comparison as a function of contrast and luminance by Rea \((1,12)\). Later, Rea and Ouellette \((2)\) used a very simple task of detecting the presence of a square target using younger subjects. From a reading task performance point of view, RVP offers a sound methodology at a fundamental level. However, the information on traffic signs can be complex in nature involving more
cognitive and visual search components, and the luminances on traffic signs at night can be lower than those used in the development of the RVP model. In the study described herein, a visual performance measure quantifying both reading time and accuracy level for older observers was employed for more realistic traffic sign stimuli, contrasts, luminances, and information acquisition task.

A practical way of investigating the interrelationship between exposure time, information transfer accuracy, and overall luminance of a sign is to limit the exposure time, and determine the percent success level of information acquisition at varying luminance levels and visual angles (or distance to the sign). An algorithm called “Up-Down-Transformed Rule” (UDTR) developed by Wetherill (13) provides a simple yet methodical investigation protocol for forced-choice psychophysical responses, and therefore was used to collect the data in this study. UDTR is a method to converge on a desired level of performance by systematically increasing and decreasing an independent variable of interest based on the preceding responses.

An adaptive procedure of the method allows the evaluation of an average stimulus level. According to the specific rules, which are based on response sequences, the reactions on the stimulus are classified as an “up” if the response is assumed “incorrect” and a “down” if the response is assumed “correct”. If an “up” response is obtained, the stimulus level is increased by the constant step size and if a “down” response is obtained, the stimulus level is decreased by the same step size.

The statistical theory of the methods is based on the assumption that the probabilities of occurrence of the “up” and “down” responses are equal (14). The UDTR strategy tends to converge on that stimulus level where the probability of a “down” response sequence equals the probability of an “up” response sequence. Based on the selected rules provided in Table 1, the psychometric function converges to a given percentage of positive responses. Once the stimulus level is reached, the psychometric function oscillates around that value. The peaks and valleys of this oscillation can then be used to estimate the actual value of the stimulus level. In the context of this experiment, UDTR works by selecting an initial value of exposure time for a given set of the independent variables such as luminance and legibility index.

The minimum luminance level in this study was chosen as 3.2 cd/m² based on a set of earlier studies: a FHWA study (8) and a study conducted in Australia (15). The chosen level was also above the minimum luminance of 2.3 cd/m² level used in determining the minimum retroreflectivity levels for guide and street name signs (9), which thereafter had been incorporated into the Manual on Uniform Traffic Control Devices (MUTCD) (3) by FHWA in January of 2008. The highest luminance level was chosen as 80 cd/m² based on Schnell et al. (5). The intermediary luminance levels were chosen in logarithmic fashion, doubling at each interval.

Literature refers to 50 foot/inch (or 6 m/cm) of legibility index as a benchmark legibility distance for young drivers, which is also commonly used rule-of-thumb among traffic engineers. 40 foot/inch (4.8 m/cm) legibility index have been typically the benchmark for older drivers. MUTCD also refers to 40 foot/inch as threshold legibility guideline, although there is a proposed revision being considered at the time of this report to decrease the guideline to 30 foot/inch to better accommodate older drivers. In studies where dynamic
driving conditions were administered, legibility typically occurred around 33 foot/inch (16), and between 24 and 34 foot/inch legibility index (17). Mace (18) also recommends 33 foot/inch legibility index as a guideline. Therefore, in this study, two legibility index levels were chosen; 40 foot/inch and 33 foot/inch referring to the MUTCD guideline and actual legibility distances observed in the field in dynamic driving conditions.
2. **Method**

An algorithm called “Up-Down-Transformed Rule” (UDTR) developed by Wetherill (13) provides a simple yet methodical investigation protocol for forced-choice psychophysical responses, and therefore was used to collect the data in this study. UDTR is a method to converge on a desired level of performance by systematically increasing and decreasing an independent variable of interest based on the preceding responses.

### 2.1. The Use of UDTR in the Experiment

The 50th and 84th percentiles were chosen as the convergence points for information acquisition times (4). These values correspond to the entry 1 and 8 respectively (Table 1). Higher percentiles require a larger number of trials to evoke the UP rule. We chose the 84th percentile as a reasonable compromise between run-length and practical validity. To reduce the estimation bias while evaluating the stimulus level, we continued testing for each set of independent variables until the seven reversals were noted. We took the last five reversals to obtain an even number of the maximum-likelihood values. Those values were assumed to be the middle points between the peaks and valleys for each change of the stimulus level (Figure 1). We averaged the obtained maximum-likelihood values to get the 50th or 84th percentile of the stimulus correct identification.

### Table 1. Rules for UDTR (Source: 4)

<table>
<thead>
<tr>
<th>Entry</th>
<th>Response Sequences</th>
<th>$p$</th>
<th>MGL*</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Up</td>
<td>Down</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>$-$ or</td>
<td>$+$</td>
<td>0.500</td>
<td>1.00 Levitt (1971)</td>
</tr>
<tr>
<td>2</td>
<td>$+$ or $-$ or</td>
<td>$+$ or $+$ or $+$</td>
<td>0.550</td>
<td>2.36</td>
</tr>
<tr>
<td>3</td>
<td>$+$ or $-$ or</td>
<td>$+$ or $+$</td>
<td>0.597</td>
<td>1.84</td>
</tr>
<tr>
<td>4</td>
<td>$+$ or $-$ or</td>
<td>$+$ or $-$</td>
<td>0.648</td>
<td>2.42</td>
</tr>
<tr>
<td>5</td>
<td>$+$ or $-$ or</td>
<td>$+$</td>
<td>0.707</td>
<td>1.71 Levitt (1971)</td>
</tr>
<tr>
<td>6</td>
<td>$+$ or $-$ or</td>
<td>$+$</td>
<td>0.794</td>
<td>2.42 Levitt (1971)</td>
</tr>
<tr>
<td>7</td>
<td>$+$ or $-$ or</td>
<td>$+$</td>
<td>0.841</td>
<td>3.14 Levitt (1971)</td>
</tr>
<tr>
<td>8</td>
<td>$+$ or $-$ or</td>
<td>$+$</td>
<td>0.891</td>
<td>4.58 Wetherill &amp; Levitt (1965)</td>
</tr>
</tbody>
</table>

Note—The stimulus level should be increased after an up sequence and decreased after a down sequence. *Mean group length.
2.2. **EXPERIMENTAL DESIGN**

Stimulus presentation in this study was performed in a dark room by generating the designed road signs on a High-Definition LCD screen. The stimuli were guide sign simulations with three lines of text. Each line consisted of a street name, and a corresponding exit number. Street names were selected from a sample set of actual six-letter street names in the US. Sign stimulus generation was driven by software developed for this experiment, where each street name was randomly chosen from the database and each exit number was a two digit random number followed by the letter A, B, C, D or E, again assigned at random. A sample stimulus guide sign is shown in Figure 2. Due to the random nature of the stimuli, each stimulus was unique in content.
A font emulating the Clearview™ type was used to generate the street names. The font used was a true-type font publicly available and known as “Roadgeek”. One of the three street names was given as the target (or “cue”) street name to the subject before the onset of the actual sign stimulus. The task of the subject was to identify the exit number for that target street name. The target street names appeared on any of the three rows (top, middle, and bottom) on the sign equal times for each participant, where the order of presentation was randomized.

### 2.2.1. Independent Variables

The following independent variables were administered in a full-factorial, within-subjects design:

1. **Luminance of legend.** The variation of sign luminance was achieved by changing the RGB values for white text and green background while keeping a ratio of 6:1 for the low level of contrast (5 levels) and 10:1 for the high level of contrast (2 levels). Thus, the luminance of the were administered at seven levels. For the positive contrast ratio of 6:1, five levels of luminance for the white text typical contrast were administered (the luminance of the green background was one-sixth of the corresponding white letters):

   - 3.2 cd/m$^2$ (Contrast 6:1)
   - 10 cd/m$^2$ (Contrast 6:1)
   - 20 cd/m$^2$ (Contrast 6:1)
   - 40 cd/m$^2$ (Contrast 6:1)
   - 80 cd/m$^2$ (Contrast 6:1)

   For the positive contrast ratio of 10:1 (high contrast) two levels of luminance (of the white legend text) was administered:

   - 20 cd/m$^2$ (Contrast 10:1)
   - 80 cd/m$^2$ (Contrast 10:1)

2. **Text size.** The visual angle subtended by the sign and the text was varied by changing the distance of the subjects to the display. Two levels of legibility indices were administered. Here, legibility index is defined as the distance to the display [ft] divided by the letter height of the first capital letter of the text [inch]

   - 33 foot/inch
   - 40 foot/inch

3. **Percentile Accuracy.** Two levels of information transfer accuracy were investigated:

   - 50th percentile accuracy (50 percent chance of correct response)
   - 84th percentile accuracy (84 percent chance of correct response)

### 2.2.2. Dependent Variables

The dependent variable was the information acquisition time. The information acquisition (exposure) time of stimulus was limited in the range from 200 to 5000 milliseconds (ms). It
was varied at 200 ms steps according to the UDTR algorithm to determine 50th percentile and 84th percentile exposure time required for correct identification for each subject. The starting point was 700 ms for 50th percentile stimulus correct identification. Then the obtained average of maximum-likelihood values for 50th percentile was used as a starting point for 84th percentile correct stimulus identification.

2.2.3. Subjects

A total of 19 subjects participated in the experiment. The subjects ranged from 55 years to 82 years in age, with an average age of 66 years. The percent of the females and males was 48% (9 out of 19) and 52% (10 out of 19), respectively.

2.3. Apparatus

Stimulus presentation was performed on a 46-inch high-contrast Samsung LCD display located in front of a semispherical 12-foot radius projection dome. A uniform background luminance of 2-3 cd/m² was used to generate the realistic backdrop on the semispherical projection dome by means of a diffuse lamp that was installed behind the screen (Figure 3).

In an effort to more accurately represent an adapting field, a 15-inch LCD display (adapting display) was placed horizontally on a tripod in front of the subjects below the eye level (see Figure 4) simulating the luminance of the roadway generated by vehicle headlamps. The Tarvip model (19,20,21) was used to determine realistic roadway luminance values to simulate headlight illumination on the roadway. A luminance of 3 cd/m² to 5 cd/m² was found to be a realistic luminance level representing the luminance of asphalt pavement illuminated by a median US low-beam headlight (22). The solid visual angle subtended by
this adapting display from the viewpoint of the observer approximated the actual headlight footprint on the roadway. The height adjustment of the display was verified for each subject to get a clear view of the generated stimuli.

A calibrated Radiant Imaging Prometric CCD photometer was used to measure and calibrate the stimulus display. During the calibration stage, the photometric characteristics of the sign for each level of luminance were measured. The photometer was positioned at driver eye height and the target point was in the center of the green background of the sign. The green color of the display was within the green color specifications for traffic signs. For measurements of background and foreground (left and right shoulders) luminance, the target points were chosen on the projection dome and stimulus display respectively. The same measurements were also performed with another handheld luminance meter (Minolta LS-110) before or after each session as a quick verification of luminance constancy of the display. The display showed no sign of variability once stabilized.
2.4. **Experimental Procedure**

A sign stimulus software program was developed to generate the guide sign stimuli under simulated night time viewing conditions. The facility allowed having a dark environment during the day, so the experiments could be run during the daytime.

The sign stimulus program started with a screen showing a target street name to the subject on the stimulus display. Then the target street name disappeared, and 1500 ms later, the actual guide sign stimulus was shown for the predetermined limited exposure time. The stimulus was always shown at the same location, so there was no search task involved for the sign itself. The task of the subject was to identify the exit number next to the target street name that was given to him in the previous screen. Figure 5 illustrates the screenshots from the experimental a sample set of stimulus seen by the subjects (a) the cue street name, and (b) the ensuing guide sign stimulus from which the subjects extracted the information. The order of presentation for varying luminance levels was randomized. Depending on the subject’s response the UDTR rules determined how long the next sign was going to be shown for. Figure 6 shows the flowchart sign presentation UDTR algorithm for the 84th percentile stimulus correct identification for a single set of parameters. A similar UDTR algorithm was used for the median correct identification. The sign stimulus program was written in C# language. The general idea of the UDTR algorithm is to increase or decrease the exposure time until a desired percentage of correct responses were elicited from a given subject.

An experimenter controlled the software from a computer connected to the stimulus display. A control window for the software contained the street name, corresponding exit number, number of iterations, number of changes, and buttons to record correct and incorrect responses. All data was recorded into a text file in real time. Figure 7 shows the experimenter control window interface. The “Sign Characteristics” box contained information about the sign type that was being shown. The “Correct” and “Incorrect” button was used to record the subject responses. The “Backspace” button was designed to remove the previous record in case the subject inadvertently missed the sign. Since the exposure times were short in general, full attention was required from the subjects. The “Can’t Read” button was used if the subject was not able to read any information on the simulated sign within the maximum exposure time.
Figure 5. Sign stimulus presentation: (a) street name target (cue), (b) simulated road sign

Figure 6. Flowchart of the sign presentation process for a single set of parameters (84\textsuperscript{th} percentile stimulus correct identification)
Figure 7. Experimental Control Panel Interface
3. **Analysis and Results**

The summary of the statistical data of the stimulus correct identification time for the 84th and 50th percentiles is presented in Figure 8 (a summary table of the basic statistical data is also given in Table B-1 in Appendix B). Some subjects had difficulty reading the information, especially with the lower levels of luminance and 40 ft/inch legibility index. Out of the 19 subjects; nine subjects could not read the sign at 3.2 cd/m$^2$, and five subjects could not read the sign at 10 cd/m$^2$ at the 40 ft/inch legibility index. Three of the subjects could not read the signs at 3.2 cd/m$^2$ and at 10 cd/m$^2$ luminance levels at the 33 ft/inch legibility index. Note that the maximum time allowed to read the signs was five seconds.
Figure 8. The summary of the statistical data for (a) 50\textsuperscript{th} and (b) 84\textsuperscript{th} percentile

* – an unusually large observation; the bottom of the box – 25\% of the data values are less than or equal to this value;
the top of the box - 75% of the data values are less than or equal to this value; middle line of the box – median; the lower whisker – the lowest data value; the upper whisker – the highest data value, circles with crossticks show the means

For statistical analysis purposes, if the subject could not read the sign within five seconds, we still assigned a 5-second reading time for that trial. Therefore, for the lower luminance levels, the statistics given here are slightly optimistic as more of such unsuccessful trials occurred at lower luminance levels, especially at 3.2 \( \text{cd/m}^2 \) luminance level. In 12% of the cases, the subjects achieved the 50\(^{th}\) percentile correct identification within five seconds, but they were unable to achieve the 84\(^{th}\) percentile correct identification level within five seconds.

A repeated measures correlated-data (within subjects) ANOVA indicated that luminance (p<0.001), legibility index (or letter size, p<0.001), and percentile accuracy (p<0.001) were all statistically significant factors affecting information acquisition time at 95% confidence level (\(\alpha=0.05\)). The ANOVA summary table for the 84\(^{th}\) percentile accuracy is given in Table 2. A main effect plot is given in Figure 9.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Type</th>
<th>Levels</th>
<th>Values</th>
</tr>
</thead>
<tbody>
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<td>19</td>
<td>1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19</td>
</tr>
<tr>
<td>Percentile</td>
<td>fixed</td>
<td>2</td>
<td>50, 80</td>
</tr>
<tr>
<td>Index</td>
<td>fixed</td>
<td>2</td>
<td>33, 40</td>
</tr>
<tr>
<td>Luminance</td>
<td>fixed</td>
<td>5</td>
<td>3.2, 10.0, 20.0, 40.0, 80.0</td>
</tr>
</tbody>
</table>

Table 2. Correlated-Data (Within Subjects) Repeated-Measures ANOVA Summary Table
3.1. **Effect of Legibility Index**

The effect of legibility index on information acquisition time was statistically significant. Two letter sizes were administered corresponding to 40 foot/inch (40 feet from the display for every inch of letter height) and 33 foot/inch legibility indices. Both 50\textsuperscript{th} and 84\textsuperscript{th} percentile correct identification levels were achieved much quicker at 33 foot/inch than at 40 foot/inch, simply suggesting that larger letters (or a smaller legibility index by reducing distance) provided much quicker sign reading. Table 3 provides the information acquisition times for the two indices at each luminance and percent accuracy level.
Table 3. Stimulus correct information acquisition times for the two legibility indices

<table>
<thead>
<tr>
<th>Luminance (cd/m²)-Contrast</th>
<th>Time of stimulus correct identification [ms]</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>50th percentile</td>
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<td>50th percentile</td>
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<td>84th percentile</td>
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</tr>
<tr>
<td></td>
<td>33 ft/inch</td>
<td>40 ft/inch</td>
<td>33 ft/inch</td>
<td>40 ft/inch</td>
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<td>40 ft/inch</td>
<td>33 ft/inch</td>
<td>40 ft/inch</td>
<td>33 ft/inch</td>
</tr>
<tr>
<td>3.2 – typical</td>
<td>2659.4</td>
<td>4707.5</td>
<td>77.0%</td>
<td>1431.3</td>
<td>2692.5</td>
<td>88.1%</td>
<td></td>
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</tr>
<tr>
<td>10 – typical</td>
<td>1853.9</td>
<td>2998.2</td>
<td>61.7%</td>
<td>1115.8</td>
<td>1410.7</td>
<td>26.4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 – typical</td>
<td>1701.3</td>
<td>2480.6</td>
<td>45.8%</td>
<td>997.4</td>
<td>1500.0</td>
<td>50.4%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 – high</td>
<td>1656.6</td>
<td>2461.8</td>
<td>48.6%</td>
<td>990.8</td>
<td>1388.2</td>
<td>40.1%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 – typical</td>
<td>1585.5</td>
<td>2321.1</td>
<td>46.4%</td>
<td>943.4</td>
<td>1343.4</td>
<td>42.4%</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>80 – typical</td>
<td>1397.4</td>
<td>1801.5</td>
<td>28.9%</td>
<td>900.0</td>
<td>1157.4</td>
<td>28.6%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>80 – high</td>
<td>1316.7</td>
<td>2215.8</td>
<td>68.3%</td>
<td>875.0</td>
<td>1309.2</td>
<td>49.6%</td>
<td></td>
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</tr>
</tbody>
</table>

3.2. Effect of Percent Accuracy Level

Percentile accuracy level also had a statistically significant effect on information acquisition time. Not surprisingly, a more accurate information transfer sign reading required a longer viewing time.

3.3. Effect of Luminance

Increasing the luminance reduced the information acquisition time, indicating that brighter signs were read much quicker. The effect was prominent at both 33 foot/inch and 40 foot/inch legibility indices, particularly for the 84th percentile correct identification level. For both 33 foot/inch and 40 foot/inch legibility indices, the minimum time to achieve 84th percentile correct identification was achieved at the highest luminance level at 80 cd/m².

Pairwise comparisons for luminance showed that all luminances were statistically significantly different than one another on their effect in information acquisition time. When 40cd/m² and 80 cd/m² were analyzed separately, there was a statistically significant interaction between percentile accuracy and luminance (p=0.034). The effect of increasing luminance from 40 cd/m² to 80 cd/m² level was much stronger at 84th percentile accuracy level (p=0.042) than it was for 50th percentile. Each time the luminance was increased, there was a statistically significant improvement in the information acquisition time. Table 4 provides the P values for all ten pairwise comparisons for the five luminance levels administered in the experiment. Table 5 provides the additional time required to achieve each percentage accuracy level for the two legibility indices from 80 cd/m² baseline luminance level.
Table 4. P Values for Pairwise Comparisons for Luminance

<table>
<thead>
<tr>
<th>Luminance</th>
<th>10 cd/m²</th>
<th>20 cd/m²</th>
<th>40 cd/m²</th>
<th>80 cd/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2 cd/m²</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>versus 10 cd/m²</td>
<td>---</td>
<td>p=0.001</td>
<td>p&lt;0.001</td>
<td>p&lt;0.001</td>
</tr>
<tr>
<td>20 cd/m²</td>
<td>---</td>
<td>---</td>
<td>p=0.011</td>
<td>p=0.003</td>
</tr>
<tr>
<td>40 cd/m²</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>p=0.047</td>
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</table>

Table 5. Stimulus correct identification time difference for the two legibility indices and the five luminance levels, expressed in additional percent time required over 80 cd/m² level.

<table>
<thead>
<tr>
<th>Luminance and Contrast</th>
<th>33 ft/inch [ms]</th>
<th>Additional Time vs. 80 cd/m² [ms]</th>
<th>40 ft/inch [ms]</th>
<th>Additional Time vs. 80 cd/m² [ms]</th>
<th>84th percentile response accuracy</th>
<th>50th percentile response accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2 cd/m² – 6:1 contrast</td>
<td>2659.4 90.3%</td>
<td>4707.5 161.3%</td>
<td>1431.3 59.0%</td>
<td>2692.5 132.6%</td>
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<td></td>
</tr>
<tr>
<td>10 cd/m² – 6:1 contrast</td>
<td>1853.9 32.7%</td>
<td>2998.2 66.4%</td>
<td>1115.8 24.0%</td>
<td>1410.7 21.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 cd/m² – 6:1 contrast</td>
<td>1701.3 21.7%</td>
<td>2480.6 37.7%</td>
<td>997.4 10.8%</td>
<td>1500.0 29.6%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 cd/m² – 10:1 contrast</td>
<td>1656.6 18.5%</td>
<td>2461.8 36.7%</td>
<td>990.8 10.1%</td>
<td>1388.2 19.9%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 cd/m² – 6:1 contrast</td>
<td>1585.5 13.5%</td>
<td>2321.1 28.8%</td>
<td>943.4 4.8%</td>
<td>1343.4 16.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80 cd/m² – 10:1 contrast</td>
<td>1316.7 -5.8%</td>
<td>2215.8 23.0%</td>
<td>875.0 -2.8%</td>
<td>1309.2 13.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Optimal level – 80 typical</td>
<td>1397.4 0.0%</td>
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<td>900.0 0.0%</td>
<td>1157.4 0.0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.4. Statistically Significant First Level Interactions

The interaction between Legibility Index and Luminance was also statistically significant at $\alpha=0.05$ level ($p=0.002$), which indicates that the effect of text size on information acquisition time was dependent on luminance. This interaction is illustrated in Figure 10. Increasing the luminance had a non-homogenous effect between the two legibility indices. The difference between the information acquisition times for the two legibility indices was much lower at high luminance levels, suggesting that distance, or letter size has a smaller effect on information acquisition time at higher luminances.

![Figure 10. The interaction between Luminance and Legibility Index (Letter size)](image)

3.5. The Effect of Contrast

At 20 cd/m$^2$ and 80 cd/m$^2$ luminance levels for the legend, the background luminances were varied without changing the legend luminance levels to generate two different contrast levels between the legend and the green sign background. In general, increasing the contrast from 6:1 to 10:1 had a slightly negative but statistically insignificant effect (nearly a 5% increase) on information acquisition time. The negative effect was more prominent at especially farther from the sign stimuli (at 40 foot/inch legibility index), where decreasing the background luminance (increasing the mathematical contrast) increased the information acquisition time.
Figure 11. Effect of contrast on information acquisition time as a function of luminance
4. Discussion and Conclusions

The sole function of a traffic signs is to convey its information to the driver. Conveying information is achieved visually, which is not an instantaneous task. While driving, traffic sign reading is not the primary task, but it requires the driver to divert visual attention and have an eye-fixation on the sign. Sign reading has to be effortless and quick, allowing the driver to redirect visual attention back to the roadway and attend to the driving task. Therefore, how quickly a driver can read a sign with high accuracy is just as important as whether the sign is legible and where reading takes place. In fact, it can significantly influence the latter two measures.

This study investigated the effect of luminance and letter size on the information acquisition time and transfer accuracy from simulated traffic signs. Luminances ranged from 3.2 cd/m$^2$ to 80 cd/m$^2$ on positive-contrast textual traffic sign stimuli with contrast ratios of 6:1 and 10:1, positioned at 33 foot/inch and 40 foot/inch legibility indices viewed under conditions simulating a nighttime driving environment.

The findings suggest that increasing the sign luminance significantly reduced the time to acquire information. Similarly, increasing the sign size (or reducing the legibility index) also reduced the information acquisition time. Following are the key interpretations:

- Higher sign luminance provides faster information acquisition thereby shorter time is required to reach a certain reading accuracy.
- If the viewing time is limited, higher sign luminance and/or larger letter sizes provide more accurate sign reading.
- Larger sign size has a very similar positive effect in legibility performance. Larger signs improve information transfer performance.
- Information acquisition times are less affected by distance (or letter size) if the sign luminance is maintained at a high level.
- Information transfer accuracy improves with increasing exposure time.

Larger and brighter signs are efficient, and require less time in providing very high reading accuracy. A 50-percent reduction in luminance required an additional 20-percent reading time on average (to achieve the same response accuracy level). The improvement was also statistically significant at each step from 3.2 cd/m$^2$ to 80 cd/m$^2$, with the following percentage differences between adjacent luminance levels:

- 80 cd/m$^2$ to 40 cd/m$^2$: 22% additional reading time
- 40 cd/m$^2$ to 20 cd/m$^2$: 7.1% additional reading time
- 20 cd/m$^2$ to 10 cd/m$^2$: 16% additional reading time
- 10 cd/m$^2$ to 3.2 cd/m$^2$: 52% additional reading time
For real world applications, a 50th percentile accuracy level in sign reading is probably too low to be acceptable. 84th percentile accuracy can constitute a more appropriate target. At that accuracy level, more than half the participants failed to read the test signs at 3.2 cd/m² luminance level within the five second exposure time at 40 foot/inch legibility index. This luminance level was chosen as the benchmark minimum in many earlier studies. High percentage of misses indicate that when the exposure time is limited and a high accuracy is desired, a luminance of 3.2 cd/m² may fall short of accommodating a considerable percentage of drivers above the age of 55 years. Note that the luminance level chosen for determining the minimum retroreflectivity levels for guide and street name signs was 2.3 cd/m². Therefore, it is strongly advisable that those values are considered absolute minimums, and signs be replaced before they reach to luminance levels as low as 3.2 cd/m² in an effort to accommodate drivers over the age of 55 years.

Decreasing the letter size (from 33 foot/inch to 40 foot/inch legibility index) required an additional 38-percent reading time on average (to achieve the same response accuracy level), which was also significant. Also, improving the percentage of correct responses from 50-percent to 84-percent required nearly an additional full second (from 1.2 seconds to 2.2 seconds), which was another significant 80-percent increase in time. On the other hand, increasing the contrast from 6:1 to 10:1 did not have a significant effect on information acquisition time at the investigated luminance levels.

Strictly from the perspective of variables addressed in this study and that of a practitioner, increasing the sign luminance by either adding auxiliary lighting or by using highly-efficient retroreflective sheeting, increasing the physical letter sizes on the signs, or increasing both variables together will reduce traffic sign reading times and/or improve the accuracy of the acquired information from traffic signs. In return, larger and/or brighter signs are expected to not only transfer the information quickly and efficiently, but also provide a more conspicuous target to the nighttime driver especially when scene complexity increases. Such signs are expected to occupy driver attentional resources for shorter durations and have the potential to reduce driver workload and improve safety. We also expect that this psychometric laboratory study will lay the foundation in offering an additional viewpoint for traffic sign and sign sheeting performance for future studies.
5. **REFERENCES**


6. **Appendix A. LCD Display Specifications**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
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<tr>
<td>Warranty Terms - Parts</td>
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</tr>
<tr>
<td>Warranty Terms - Labor</td>
<td>1 year</td>
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<td>Language Options</td>
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<td>V-Chip</td>
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</tr>
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<td>Sleep/Alarm Timer</td>
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<td>Energy Star</td>
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<td>Box Dimensions</td>
<td>34&quot;H x 50-3/4&quot;W x 16-1/2&quot;D</td>
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## Appendix B. Summary Table of Statistical Data

Table B-1. Summary of statistical data

<table>
<thead>
<tr>
<th>Legibility Index</th>
<th>Luminance (cd/m²)</th>
<th>Contrast</th>
<th>50 percentile</th>
<th>84 percentile</th>
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<tr>
<td></td>
<td></td>
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<td>AVER</td>
<td>StDev</td>
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</tr>
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<td>575.9</td>
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</tr>
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