Traffic Sign Luminance Requirements of Nighttime Drivers

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How does better signage improve safety?

- Driving is a highly visual task (some say 90%)
- Although a quarter of total miles is driven at night, about half the crashes occur at night, and fatalities are three times higher in nighttime
- Decreased visibility at night is a problem, which warrants particular focus
- Signs need to “communicate” with the driver in nighttime just as in daytime
- Sign brightness (luminance) in nighttime improves “communication” with the drivers

Literature Review
Where do Drivers Read Signs?
Where do drivers read signs?

Where can we first start reading signs?

- **Legibility index** gives some measure of the reading distance as a function of letter height (with adequate contrast of 5:1 or more)

  \[ \frac{D}{h} = 480 \text{ (or 4.8 m/cm of letter height)}^{1} \]

Do drivers read the signs at 4.8 m/cm?

- Not necessarily. Reading occurs in a range, average of 4m/cm.

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Luminance need in legibility range

- Minimum required brightness is around 3.2 cd/m² for median driver above the age of 65¹.
- 80 cd/m² is recommended as optimal for maximizing legibility range².
- Literature varies in recommendation of luminances from 3.2 cd/m² to 120 cd/m², based on the adaptation level, age, legend, letter size, font, contrast, etc.

Problem Statement

- If a sign at 3.2 cd/m$^2$ luminance can be read, why increase its luminance?
- Is maximizing the “legibility index” (or legibility range) the only metric for legibility performance?
- If there is a benefit, what is the metric to measure the improvement?
- It is expected that faster information acquisition will lead to more eyes-on-the-road time, which is critical for safety\(^1\).

\(^1\) Dewar et al, “Human Factors in Traffic Safety”
Hypotheses

- Brighter signs “communicate” with the drivers much more effectively
  - Providing luminance above legibility threshold yields faster information acquisition and
  - When exposure is limited, brighter signs provide more accurate information transfer.
  - These hypotheses are valid within the legibility range
Method

- Use actual street names, guide sign, 3.2 cd/m² up to 80 cd/m²
- Limit the exposure time, change luminance and contrast, measure accuracy
- Use “Up-Down Transformed Rule” (UDTR) for forced-choice psychophysical responses

CUE (Street Name) 1sec. Exposure… What is the exit number?
Method

- Try to determine “acquisition time” to achieve 50\textsuperscript{th} percentile and 84\textsuperscript{th} percentile accuracy levels
  - UDTR was employed to change the exposure time as a function of correct/incorrect responses in a sequence
- Study was performed in a dark room by generating designed road signs on a calibrated HD LCD screen.
- Clearview was chosen as the sign copy font
Method

- **Independent Variables:**
  - Luminance of legend:
    - 3.2 cd/m² (6:1 Contrast)
    - 10 cd/m² (6:1 Contrast)
    - 20 cd/m² (6:1 Contrast, 10:1 Contrast)
    - 40 cd/m² (6:1 Contrast)
    - 80 cd/m² (6:1 Contrast, 10:1 Contrast)
  - Text Size
    - 33 foot/inch
    - 40 foot/inch
  - Percentile Accuracy
    - 50th Percentile Accuracy
    - 84th Percentile Accuracy

- **Dependent Variable**
  - Information Acquisition Time (Limited to 200-5,000ms)
Method

- **Subjects:**
  - 19 Subjects, 55 years – 82 years of age. 9 females, 10 males

- **Apparatus**
  - 46” high-contrast Samsung LCD display in front of 12-foot radius projection dome
  - Uniform background luminance of 2-3 cd/m²
  - 3-5 cd/m² simulated roadway luminance via an adapting display
Method

- Subjects had many practice runs before the experiment to understand their tasks
- A code randomly drew three street names, one was shown as the cue
- 1,500 ms gap between cue and the stimulus, both shown on the same display and location (not a sign search task)
Results

• 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/m²,
• Five subjects could not read the sign at 10 cd/m² at the 40 ft/inch legibility index.
• Three of the subjects could not read the signs at 3.2 cd/m² and at 10 cd/m² luminance levels at the 33 ft/inch legibility index.
• Note that the maximum time allowed to read the signs was five seconds
• If a subject could not read the sign within the allocated 5-sec exposure time, the response time was assumed to be 5-seconds.
Results

50th Percentile Accuracy

Time [msec]

Luminance [cd/m²]

Index [foot/inch]

3.2 10.0 20.0 40.0 80.0

3.2 10.0 20.0 40.0 80.0
Results

84th Percentile Accuracy

- Time [ms]
- Luminance [cd/m^2]
- Index [foot/inch]

4033
80.0
40.0
20.0
30.0
0

4000
3000
2000
1000
0

84th Percentile Accuracy
**Results**

- A repeated measures correlated-data (within subjects) ANOVA indicated the below were all three independent variables had a statistically significant effect on information acquisition time at 95% confidence level ($\alpha=0.05$).
  - luminance ($p<0.001$),
  - legibility index (or letter size, $p<0.001$), and
  - percentile accuracy ($p<0.001$)
- Pairwise comparisons for luminance showed that all luminances were statistically significantly different than one another on their effect in information acquisition time.
- The effect of increasing luminance from 40 cd/m$^2$ to 80 cd/m$^2$ level was much stronger at 84$^{th}$ percentile accuracy level ($p=0.042$) than it was for 50$^{th}$ percentile.
## Results

![Main Effect Plot]

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="chart" alt="Mean of Time [msec]" /></td>
<td><img src="chart" alt="Luminance" /></td>
</tr>
</tbody>
</table>

### Mean of Time [msec]

- 50: 1500
- 84: 2500
- 33: 1500
- 40: 2000

### Luminance

- 3.2: 2500
- 10.0: 2000
- 20.0: 1500
- 40.0: 1000
- 80.0: 3000
### Results

Increase in acquisition time as a function of luminance

<table>
<thead>
<tr>
<th>Luminance - Contrast</th>
<th>84th Percentile</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>40 ft/inch</td>
<td></td>
</tr>
<tr>
<td>3.2 – low</td>
<td>4707.5</td>
<td>161.30%</td>
</tr>
<tr>
<td>10 – low</td>
<td>2998.2</td>
<td>66.40%</td>
</tr>
<tr>
<td>20 – low</td>
<td>2480.6</td>
<td>37.70%</td>
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<tr>
<td>20 – high</td>
<td>2461.8</td>
<td>36.70%</td>
</tr>
<tr>
<td>40 – low</td>
<td>2321.1</td>
<td>28.80%</td>
</tr>
<tr>
<td>80 - high</td>
<td>2215.8</td>
<td>23.00%</td>
</tr>
<tr>
<td>Optimal level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80 – low</td>
<td>1801.5</td>
<td>0.00%</td>
</tr>
</tbody>
</table>
Results

• **Interactions:**
  - Legibility Index and Luminance was 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.
Results

- **Effect of Contrast**
  - 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 inverse effect was more prominent when text was small at 40 foot/inch legibility index,
Key Conclusions

- 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.
Discussion

- Earlier studies showed safety benefits of comprehensive sign upgrades, but the mechanism is unknown.
- Higher sign luminance reduces the time demand to acquire information, which may allow less eyes-off-the-road time.
- Reducing eyes-off-the-road time is identified as a primary characteristic of interest for safety, Dewar et al. “Human Factors in Traffic Safety”
- Although far from explaining a comprehensive mechanism, this study helped introduce a metric that may be a good surrogate for roadway safety in assessing roadway sign performance.

For automotive safety, the primary characteristic of interest is eyes-off-the-road time. This time is the sum of all of the time associated with all glances not directed towards the road (in Figure 4.1, glances 1 and 2), plus transition time from off the road to the road (the first transition of glance 3 in Figure 4.1). Except for scanning mirrors and instrumentation, driving safety is compromised if one is not looking at the road.

Sincere gratitudes to Dr. Thomas Schnell and OPL team at the University of Iowa for sharing insight, data, and the final report on the study.
Thank You!
Backup Slides
ANOVA

<table>
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<tr>
<th>Factor</th>
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<th>Levels</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject</td>
<td>random</td>
<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, 84</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>

Analysis of Variance for Time, using Adjusted SS for Tests

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Seq SS</th>
<th>Adj SS</th>
<th>Adj MS</th>
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<th>P</th>
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</thead>
<tbody>
<tr>
<td>Subject</td>
<td>18</td>
<td>278948161</td>
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<td>15497120</td>
<td>98.34</td>
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<td>Percentile</td>
<td>1</td>
<td>66528947</td>
<td>66528947</td>
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<td>93.91</td>
<td>0.000</td>
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<td>Subject*Percentile</td>
<td>18</td>
<td>12177615</td>
<td>12177615</td>
<td>676534</td>
<td>69.29</td>
<td>0.000</td>
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<tr>
<td>Index</td>
<td>1</td>
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<td>101301158</td>
<td>662464</td>
<td>0.65</td>
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<tr>
<td>Subject*Index</td>
<td>18</td>
<td>19416030</td>
<td>19416030</td>
<td>1078668</td>
<td>511840</td>
<td>0.106</td>
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<tr>
<td>Luminance</td>
<td>4</td>
<td>47697414</td>
<td>47697414</td>
<td>45904068</td>
<td>1.98</td>
<td>0.106</td>
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<tr>
<td>Subject*Luminance</td>
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<td>333059</td>
<td>333059</td>
<td>333059</td>
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<td>Percentile*Index</td>
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<td>0.27</td>
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<td>Subject<em>Percentile</em>Index</td>
<td>18</td>
<td>4162484</td>
<td>4162484</td>
<td>4162484</td>
<td>579558</td>
<td>0.898</td>
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<td>62046849</td>
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<td>Percentile<em>Index</em>Luminance</td>
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<td>72</td>
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<td>41728171</td>
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<td>0.898</td>
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<td>*</td>
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<td>881528099</td>
<td></td>
<td></td>
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### ANOVA

<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>
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</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>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>
</tr>
</tbody>
</table>
Table 1. 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>84(^{th}) percentile</th>
<th>50(^{th}) percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>33 ft/inch</td>
<td>40 ft/inch</td>
</tr>
<tr>
<td>3.2 – typical</td>
<td></td>
<td>2659.4</td>
<td>4707.5</td>
</tr>
<tr>
<td>10 – typical</td>
<td></td>
<td>1853.9</td>
<td>2998.2</td>
</tr>
<tr>
<td>20 – typical</td>
<td></td>
<td>1701.3</td>
<td>2480.6</td>
</tr>
<tr>
<td>20 – high</td>
<td></td>
<td>1656.6</td>
<td>2461.8</td>
</tr>
<tr>
<td>40 – typical</td>
<td></td>
<td>1585.5</td>
<td>2321.1</td>
</tr>
<tr>
<td>80 – typical</td>
<td></td>
<td>1397.4</td>
<td>1801.5</td>
</tr>
<tr>
<td>80 – high</td>
<td></td>
<td>1316.7</td>
<td>2215.8</td>
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## Information Acquisition Times

<table>
<thead>
<tr>
<th>Luminance and Contrast</th>
<th>84th percentile response accuracy</th>
<th>50th percentile response accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Additional Time vs. 80 cd/m²</td>
<td>Additional Time vs. 80 cd/m²</td>
</tr>
<tr>
<td>33 ft/inch</td>
<td>40 ft/inch</td>
<td>33 ft/inch</td>
</tr>
<tr>
<td>3.2 cd/m² – 6:1 contrast</td>
<td>2659.4</td>
<td>90.3%</td>
</tr>
<tr>
<td>10 cd/m² – 6:1 contrast</td>
<td>1853.9</td>
<td>32.7%</td>
</tr>
<tr>
<td>20 cd/m² – 6:1 contrast</td>
<td>1701.3</td>
<td>21.7%</td>
</tr>
<tr>
<td>20 cd/m² – 10:1 contrast</td>
<td>1656.6</td>
<td>18.5%</td>
</tr>
<tr>
<td>40 cd/m² – 6:1 contrast</td>
<td>1585.5</td>
<td>13.5%</td>
</tr>
<tr>
<td>50 cd/m² – 10:1 contrast</td>
<td>1316.7</td>
<td>-5.8%</td>
</tr>
<tr>
<td>Optimal level 80 – typical</td>
<td>1397.4</td>
<td>0.0%</td>
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