Traffic Sign Luminance Requirements of Nighttime Drivers

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How does better signage improve safety?

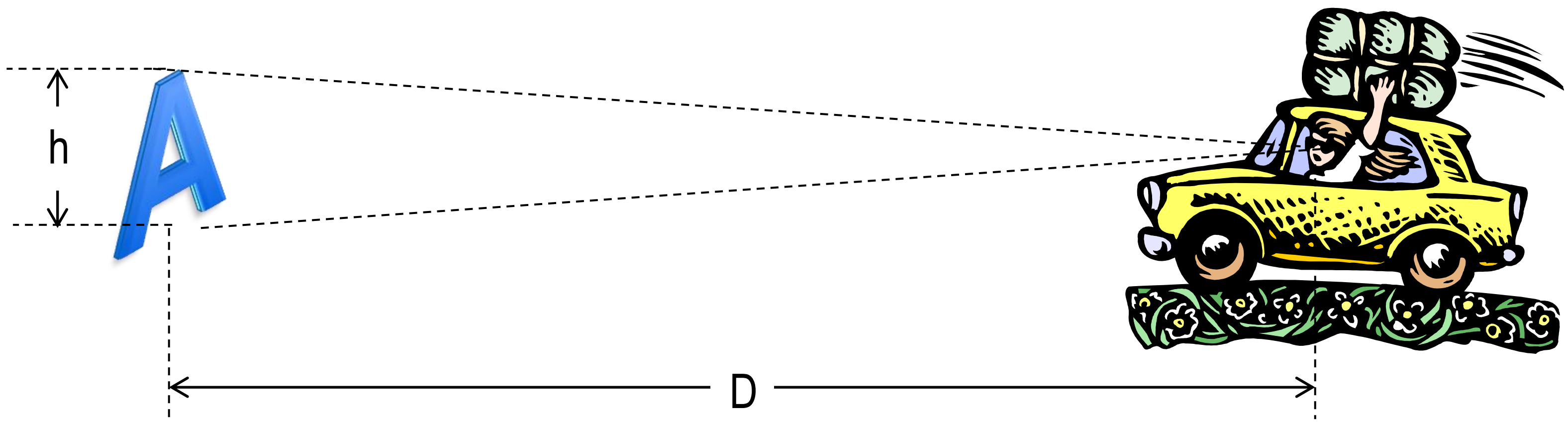
- Driving is a highly visual task (some[1] say 90%)
- Although a quarter of total miles is driven at night, about half the crashes occur at night, and fatalities are three times higher in nighttime[2]
- Decreased visibility at night is a problem, which warrants particular focus
- Signs need to "communicate" with the driver in nighttime just as in daytime
- Sign brightness (luminance) in nighttime improves "communication" with the drivers[3]

1. Kline et al, "Vision, Aging, and Driving: The Problems of Older Drivers", March 1991, The Journal of Gerontology
2. US Federal Highway Administration, http://safety.fhwa.dot.gov/roadway_dept/retro/gen/back_needs.htm
3. Schnell, T., Yekhshatyan, L., Daiker, R., Konz, J., Effect of Luminance on Information Acquisition Time and Accuracy from Traffic Signs. Paper accepted for presentation and publication, Transportation Research Record, Journal of the Transportation Research Board, 2008. Full report available at http://www.ccad.uiowa.edu/opl/projects/luminance

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)



  - D/h = 480 (or 4.8m/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.

1. Mace, D. J, "Sign Legibility and Conspicuity". In Special Report 218: Transportation in an Aging Society, vol.2, pp. 270-93
2. Schieber, F., Burns, D. M., Myers, J., Willan N., Gilland, J. Driver Eye Fixation and Reading Patterns while Using Highway Signs under Dynamic Nighttime Driving Conditions: Effects of Age, Sign Luminance and Environmental Demand. in TRB 2004 Annual Meeting. 2004. Washington, D.C.: TRB.

Luminance need in legibility range

- Minimum required brightness is around 3.2 cd/m^2 for median driver above the age of 65[1].
- 80 cd/m^2 is recommended as optimal for maximizing legibility range[2]
- 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.

1. Eugene R. Russell, M.R., Andrew Rys, and Merle Keck, *Characteristics and Needs for Overhead Guide Sign Illumination from Vehicular Headlamps, Dept of Civil Engineering,* Kansas State University. 1999, FHWA Office of Safety and Traffic Operations Research and Development, FHWA-RD-98-135.
2. Schnell, T., Aktan, F., Li, C., 2004, *Traffic Sign Luminance Requirements of Nightime Drivers for Symbolic Signs. Transportation Research Record No. 1862: Journal of the* Transportation Research Board, 2004: p. 24-35.

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

The University of Iowa
Be remarkable

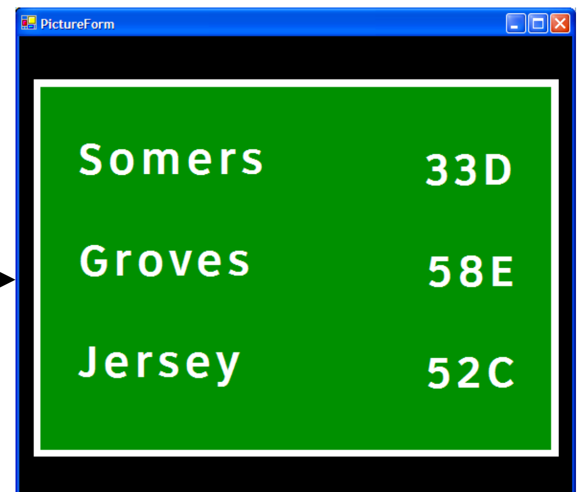
Operator Performance Laboratory

Method

- Use actual street names, guide sign, 3.2 cd/m^2 up to 80 cd/m^2
- 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?

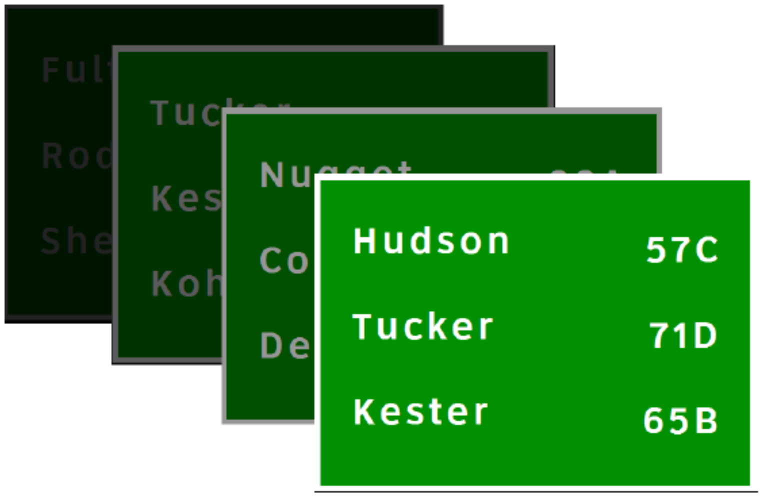


Method

- Try to determine "acquisition time" to achieve 50th percentile and 84th 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

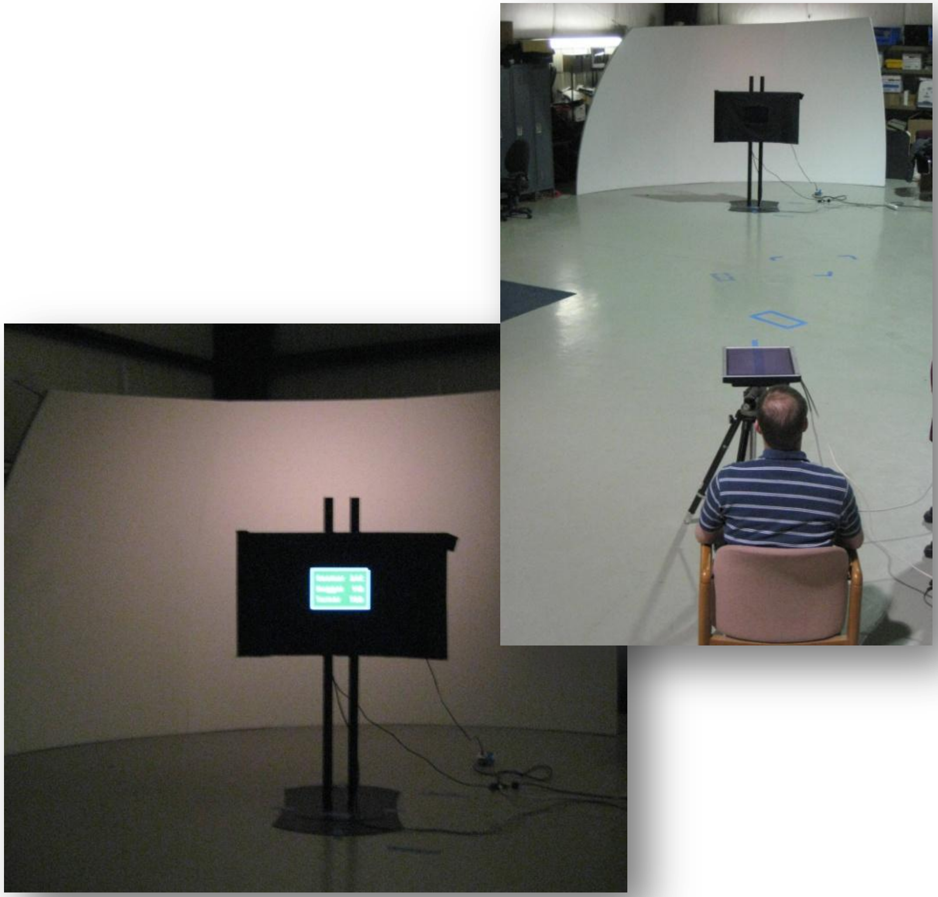
Method

- Independent Variables:
  - Luminance of legend:
    - 3.2 cd/m^2 (6:1 Contrast)
    - 10 cd/m^2 (6:1 Contrast)
    - 20 cd/m^2 (6:1 Contrast, 10:1 Contrast)
    - 40 cd/m^2 (6:1 Contrast)
    - 80 cd/m^2 (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/m^2
  - 3-5 cd/m^2 simulated roadway luminance via an adapting display

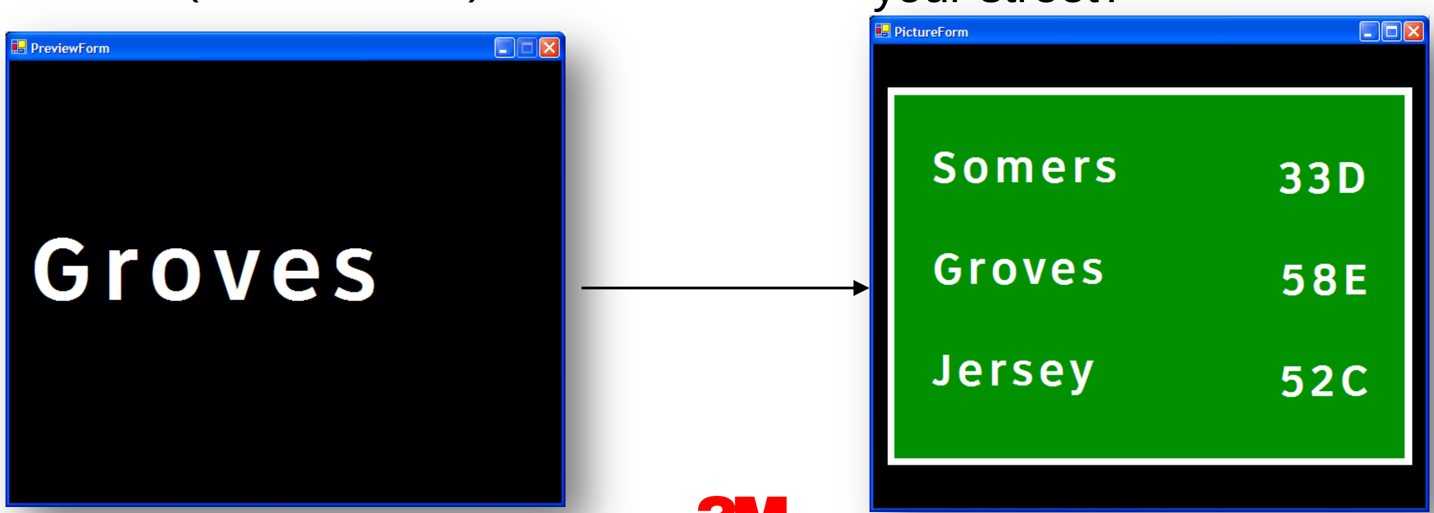


Method

- 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)

CUE (Street Name)

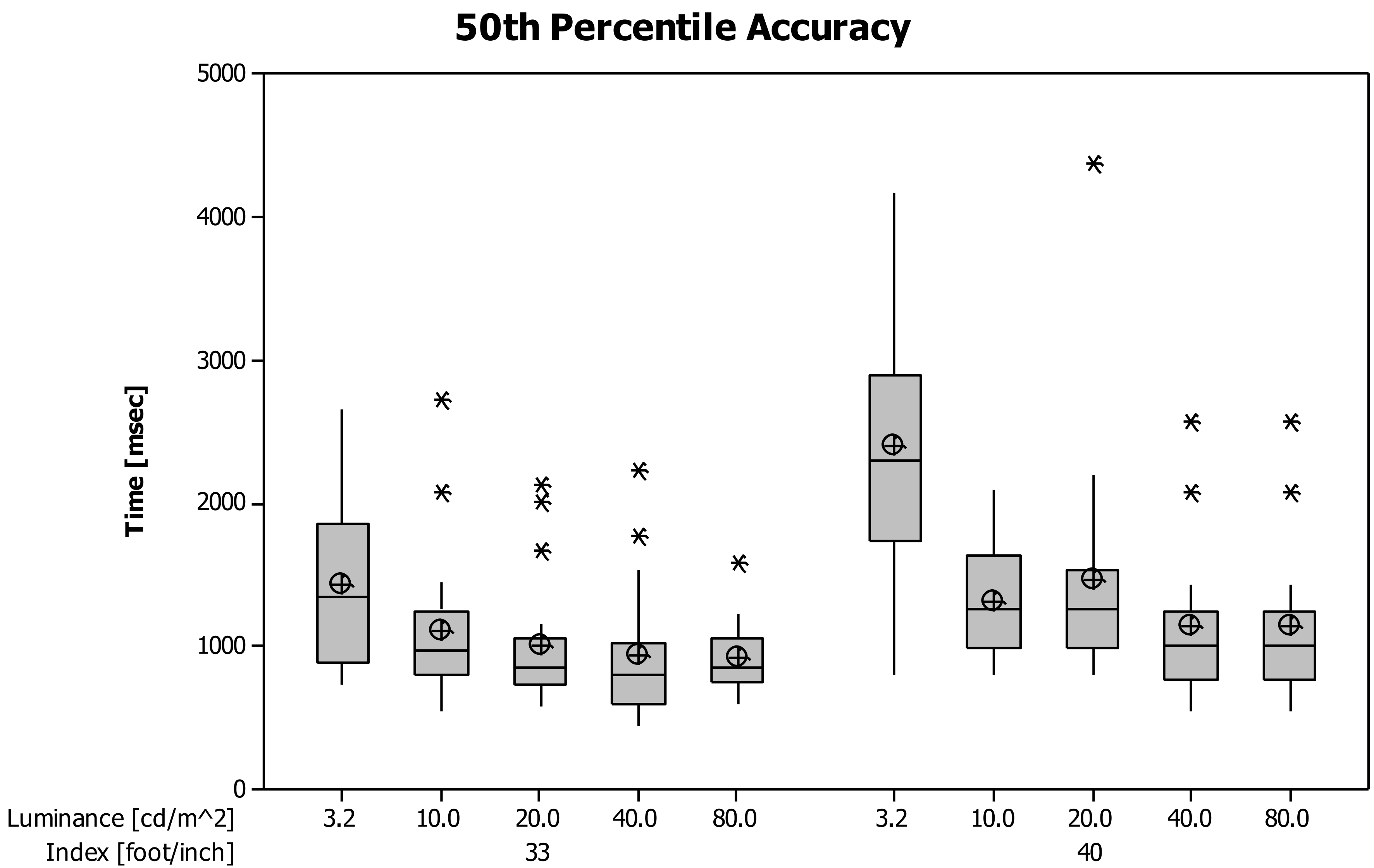
What is the exit number for your street?



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/m^2,
- 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
- 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



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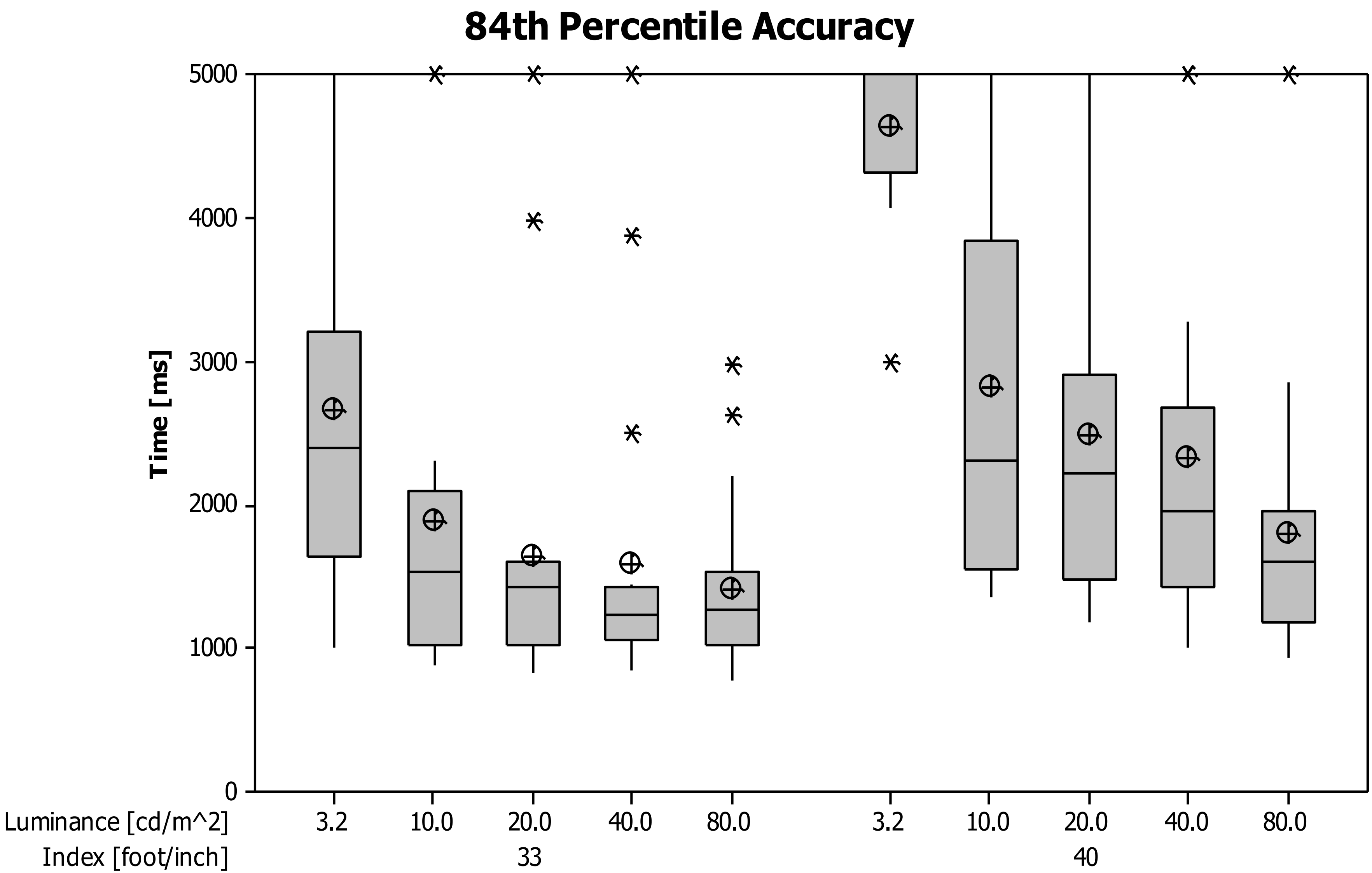
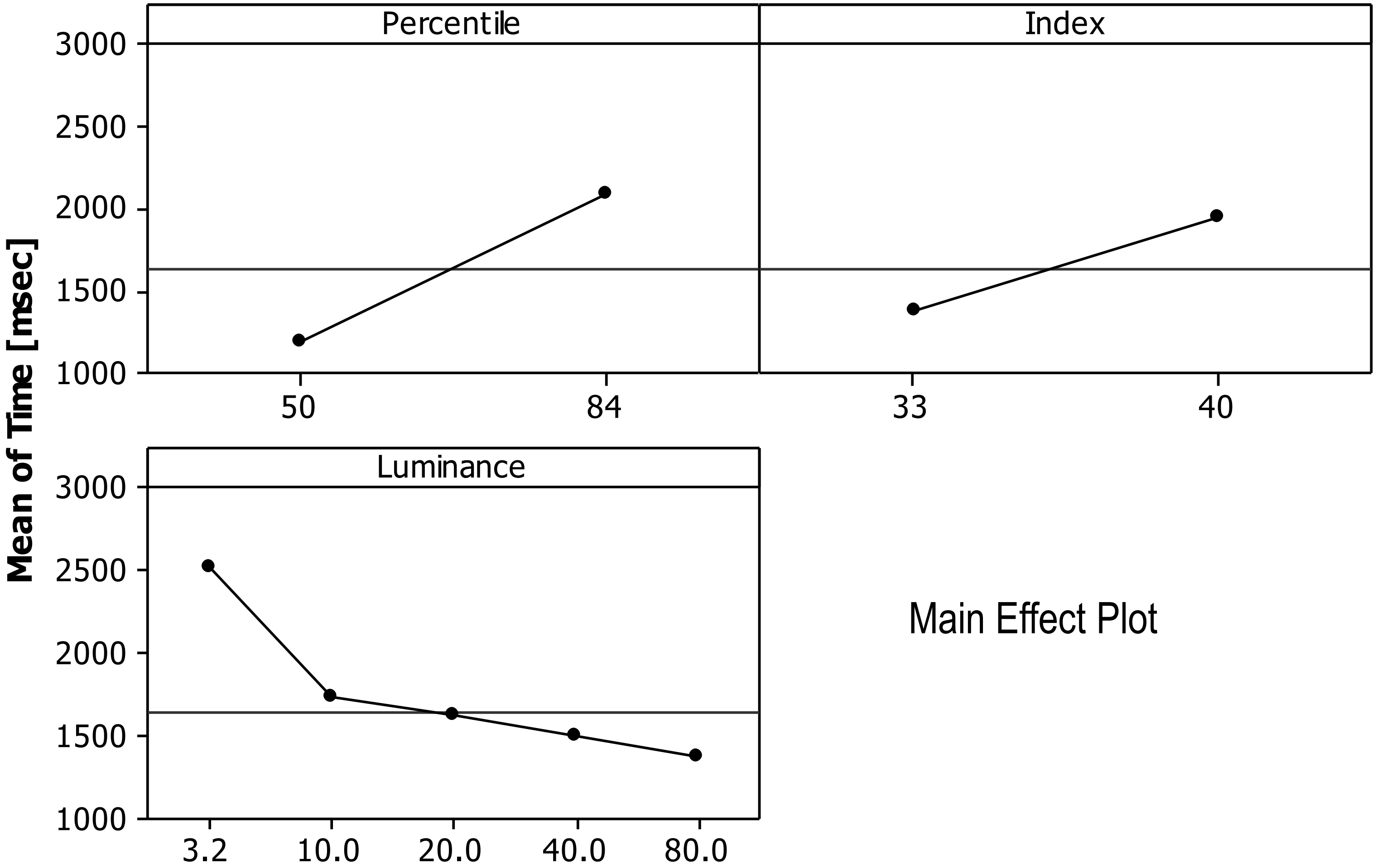
Results


84th Percentile Accuracy
5000
4000
3000
2000
1000
0
Time [ms]
Luminance [cd/m^2]
3.2
10.0
20.0
40.0
80.0
3.2
10.0
20.0
40.0
80.0
Index [foot/inch]
33
40

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 (α=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 84th percentile accuracy level ($p=0.042$) than it was for 50th percentile.

Results



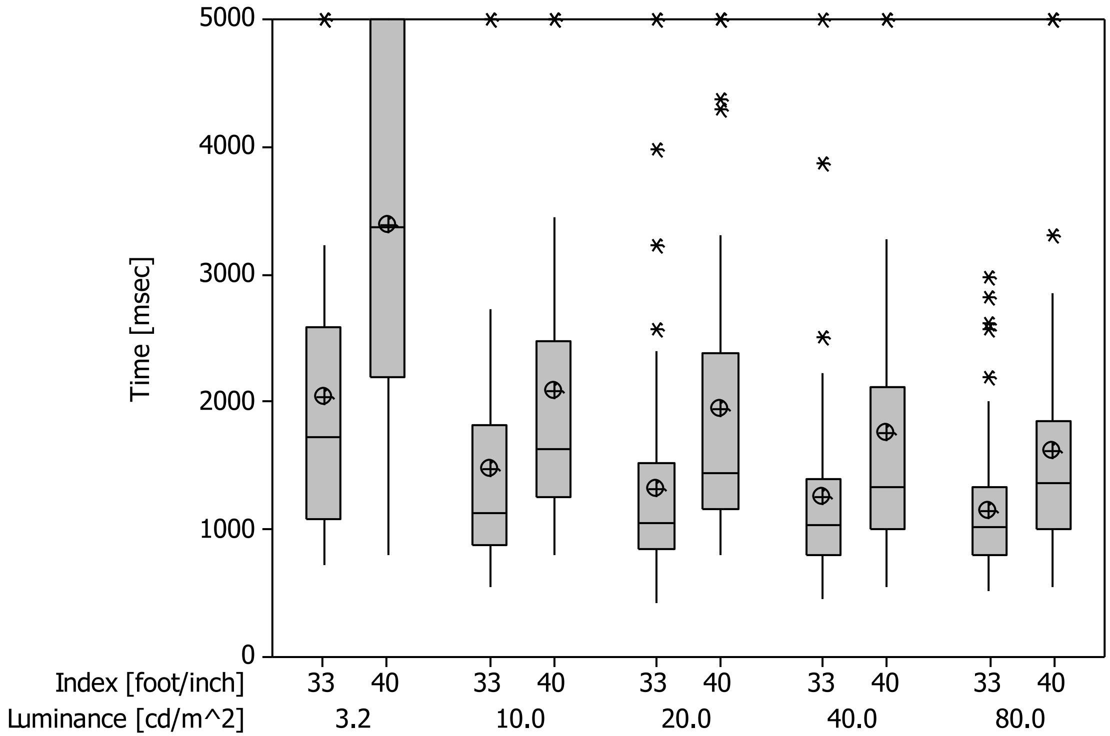
Main Effect Plot

Results

Increase in acquisition time as a function of luminance

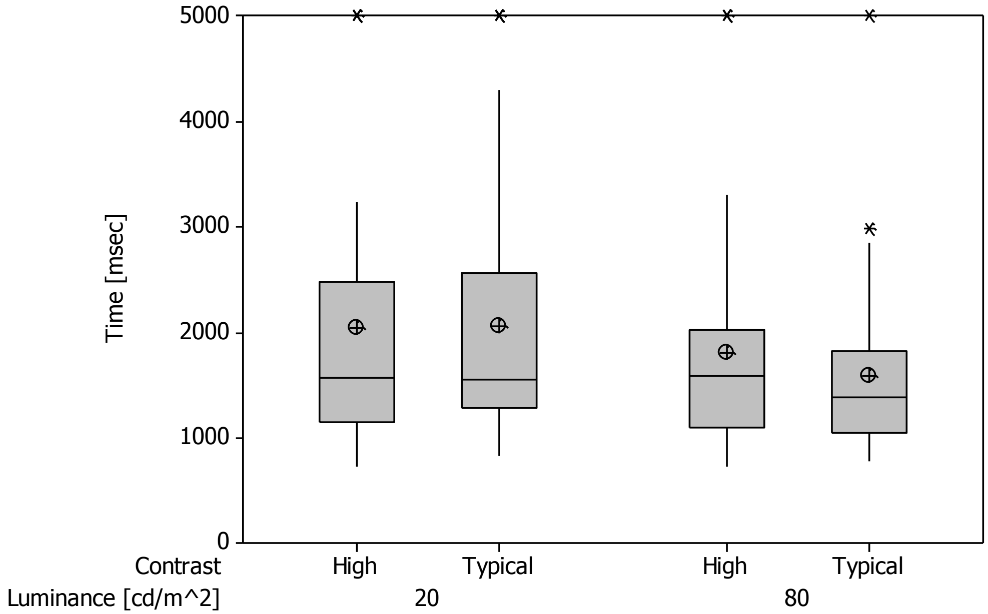
Luminance - Contrast	84th Percentile	
	40 ft/inch	Changes
3.2 – low	4707.5	161.30%
10 – low	2998.2	66.40%
20 – low	2480.6	37.70%
20 – high	2461.8	36.70%
40 – low	2321.1	28.80%
80 - high	2215.8	23.00%
Optimal level 80 – low	**1801.5**	**0.00%**

Results



- Interactions:
  - Legibility Index and Luminance was statistically significant at α=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"[1]
- 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.

1. Dewar et al, "Human Factors in Traffic Safety"

Acknowledgments

- 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

Factor	Type	Levels	Values
Subject	random	19	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19
Percentile	fixed	2	50, 84
Index	fixed	2	33, 40
Luminance	fixed	5	3.2, 10.0, 20.0, 40.0, 80.0

Analysis of Variance for Time, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Subject	18	278948161	278948161	15497120		
Percentile	1	66528947	66528947	66528947	98.34	0.000
Subject*Percentile	18	12177615	12177615	676534		
Index	1	101301158	101301158	101301158	93.91	0.000
Subject*Index	18	19416030	19416030	1078668		
Luminance	4	183616273	183616273	45904068	69.29	0.000
Subject*Luminance	72	47697414	47697414	662464		
Percentile*Index	1	333059	333059	333059	0.65	0.430
Subject*Percentile*Index	18	9213128	9213128	511840		
Percentile*Luminance	4	4162484	4162484	1040621	1.98	0.106
Subject*Percentile*Luminance	72	37794079	37794079	524918		
Index*Luminance	4	15944089	15944089	3986022	4.63	0.002
Subject*Index*Luminance	72	62046849	62046849	861762		
Percentile*Index*Luminance	4	620641	620641	155160	0.27	0.898
Subject*Percentile*Index*Luminance	72	41728171	41728171	579558	**	
Error	0	*	*	*		
Total	379	881528099				

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ANOVA

Luminance		10 cd/m^2	20 cd/m^2	40 cd/m^2	80 cd/m^2
versus	3.2 cd/m^2	$p<0.001$	$p<0.001$	$p<0.001$	$p<0.001$
	10 cd/m^2	---	$p=0.001$	$p<0.001$	$p<0.001$
	20 cd/m^2	---	---	$p=0.011$	$p=0.003$
	40 cd/m^2	---	---	---	$p=0.047$

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Information Acquisition Times

Table 1. Stimulus correct information acquisition times for the two legibility indices

Luminance (cd/m^2)-Contrast	Time of stimulus correct identification [ms]					
	84th percentile			50th percentile		
	33 ft/inch	40 ft/inch	Difference	33 ft/inch	40 ft/inch	Difference
3.2 – typical	2659.4	4707.5	77.0%	1431.3	2692.5	88.1%
10 – typical	1853.9	2998.2	61.7%	1115.8	1410.7	26.4%
20 – typical	1701.3	2480.6	45.8%	997.4	1500.0	50.4%
20 – high	1656.6	2461.8	48.6%	990.8	1388.2	40.1%
40 – typical	1585.5	2321.1	46.4%	943.4	1343.4	42.4%
80 – typical	1397.4	1801.5	28.9%	900.0	1157.4	28.6%
80 – high	1316.7	2215.8	68.3%	875.0	1309.2	49.6%

Information Acquisition Times

Luminance and Contrast	84th percentile response accuracy				50th percentile response accuracy			
	33 ft/inch [ms]	Additional Time vs. 80 cd/m^2	40 ft/inch [ms]	Additional Time vs. 80 cd/m^2	33 ft/inch [ms]	Additional Time vs. 80 cd/m^2	40 ft/inch [ms]	Additional Time vs 80 cd/m^2
3.2 cd/m^2 – 6:1 contrast	2659.4	90.3%	4707.5	161.3%	1431.3	59.0%	2692.5	132.6%
10 cd/m^2 – 6:1 contrast	1853.9	32.7%	2998.2	66.4%	1115.8	24.0%	1410.7	21.9%
20 cd/m^2 – 6:1 contrast	1701.3	21.7%	2480.6	37.7%	997.4	10.8%	1500.0	29.6%
20 cd/m^2 – 10:1 contrast	1656.6	18.5%	2461.8	36.7%	990.8	10.1%	1388.2	19.9%
40 cd/m^2 – 6:1 contrast	1585.5	13.5%	2321.1	28.8%	943.4	4.8%	1343.4	16.1%
80 cd/m^2 – 10:1 contrast	1316.7	-5.8%	2215.8	23.0%	875.0	-2.8%	1309.2	13.1%
Optimal level 80 – typical	1397.4	0.0%	1801.5	0.0%	900.0	0.0%	1157.4	0.0%

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