Detectability and Acceptability of Illuminance Reduction for Load Shedding

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August 5th, 2003
IESNA 2003 Conference, Chicago
Acknowledgements

Connecticut Light and Power sponsored this study.

Technical support
• Andrew Bierman
• Peter Boyce
• Lei Deng
• Jean-Paul Freyssinier
• Francisco Garza
• Claudia Hunter
• Russell Leslie
• Peter Morante
• Mark Rea
What is Load Shedding?
Why is Load Shedding Important?

The diagram illustrates the demand for electricity throughout the day. Peak load generators are used during the highest demand of the day, while intermediate and base load generators are used during the rest of the time. This helps manage the power grid and prevent power outages.
Why is load shedding important?

(Source: Peter Morante, Lighting Research Center, 2003)
Why load-shed lighting?

- Other loads cannot be “dimmed.”
- Dimmed lighting can give immediate energy savings that is predictable and repeatable.
- VP studies showed that a small decrease in illuminance did not greatly affect visual performance for a task of medium to high contrast.
- How much illuminance can be reduced without being noticed?
How do we detect illuminance changes?

- Detection of change in illuminance may be governed by neural detectors that sense:
  - Dynamic stimuli—rate of change triggers detection (transient mechanism)
  - Sustained stimuli—absolute level of change triggers detection (memory mechanism)
- Detectors may engage in “detector race”
  - Depending on rate of change, either the transient or memory detector may “fire,” resulting in the perception of the illuminance variation.
• Investigated sensitivity to sine wave “flicker” for a uniform visual field.
• Measured human sensitivity to temporal changes in light levels, but at a fairly high frequency of modulation.
• Transient mechanism
Kryszczuk & Boyce, 2001 & 2002

- Lower frequency
- Investigated how fast illuminance could be reduced before change is noticed.

![Graph showing the percentage of subjects who detected the illuminance decrement vs. percentage reduction in illuminance.](image)
Kryszczuk & Boyce, 2001 & 2002

- Detection threshold for slow light level reduction is independent of the rate of change.
- Once the frequency of change exceeds the threshold of transient detector’s response, the memory mechanism dominates.
- Found about 15-20% reduction in illuminance is undetectable regardless of the rate of change.
Other recent studies

Shikakura et al., 2001:
- Detectability study similar to Kryszczuk’s.
- Eight-sec dimming period condition confirmed Kryszczuk’s study—about 20% reduction in illuminance is undetectable.

Newsham et al., 2002:
- Slower reduction (0.5%/min)
- Let subjects increase illuminance when the illuminance becomes too low.
- Subjects allowed illuminance to fall by 40-50% before choosing to increase the light level.
Previous studies

Kryszczuk & Boyce (2001); Shikakura (2001)
• Focused only on detectability and didn’t include acceptability.
• Used only linear dimming functions.

Newsham (2002)
• The effect of inertia on illuminance choices was unknown.
• Used only a linear dimming function.
Goals of this study

• Maximize the energy savings through load shedding,
• Identify mechanisms of illuminance change detection
• Minimize detectability of dimming process,
• Maximize acceptability of dimming process,
• Create dimming recommendations for a load shedding ballast.
Objectives

Memory study:
• Investigate mechanisms of detecting illuminance change—whether ones can memorize the initial illuminance and how long the memory is sustained.

Dimming curvature study:
• Identify detectable and acceptable ranges of illuminance change
• Investigate how dimming curvatures and task types affect detectability and acceptability.
Memory study
Memory study

Experimental conditions

Independent Variables:
- Target illuminance (lx): 976, 781, 625, 500, 400, 320, 256
- Eye closure period (s): 3, 100

Dependent Variables
- Subjective judgment: down / same / up
Experimental Setup

Memory study

- Monitor
- Receiver
- Pico ammeter
- DC power supply
- Camera and transmitter
- Pendant luminaire (Mounting height: 2,413 mm)
- Illuminance meter
- Ceiling height: 3,505 mm

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Memory study

Procedure

• Twelve subjects, ranging from 23 to 41 in age.
• Subjects adapted to the initial illuminance of 500 lx for 5 minutes.
• Subjects closed their eyes and wore an eye mask for either 3 or 100 seconds.
• Subjects opened their eyes and answered whether the lighting had become brighter, darker, or remained unchanged.
• Illuminance was reset to 500 lx, the initial level.
• Approximately 20-30 seconds separated conditions.
Memory study

Results

Decrement Detectability

- % of subjects who detected the illuminance decrement
- target illuminance (lux)
- 3-sec.
- 100-sec.
## Two-way ANOVA

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target E</td>
<td>24.79</td>
<td>6</td>
<td>4.13</td>
<td>184.20</td>
<td>0.000*</td>
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<tr>
<td>Period</td>
<td>0.29</td>
<td>1</td>
<td>0.29</td>
<td>13.01</td>
<td>0.000*</td>
</tr>
<tr>
<td>Interaction</td>
<td>0.5</td>
<td>6</td>
<td>0.08</td>
<td>3.71</td>
<td>0.001*</td>
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<tr>
<td>Within</td>
<td>3.45</td>
<td>154</td>
<td>0.02</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>29.0</td>
<td>167</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* p<0.01
Conclusions

• Proved previous study results—20% of illuminance reduction is undetectable—even if subjects close their eyes.
• Memory of initial illuminance may be affected by longer dimming periods.
  – Confound was introduced through subjects dark-adapting when closing their eyes for 100 seconds, but not after 3 seconds.
  – Dark adaptation might have influenced the sensitivity of subjects to illuminance changes.
Curvature study
Curvature study

Experimental conditions

Independent variables
- Dimming curvature: Linear, 0.4, 0.2, 0.1
- Target illuminance (lx): 833, 752, 679, 613, 554, 500, 451, 408, 368, 332, 300
- Task condition: Paper task (word puzzle), No task (free gaze)

Dependent Variables
- Detectability: down / same / up
- Acceptability: yes / no and rating (0 -10)
Memory study

Experimental Setup

- 2,286 mm
- 2,896 mm
- Pendant luminaire (Mounting height: 2,413 mm)
- Illuminance meter
- Camera and transmitter
- Ceiling height: 3,505 mm
- Monitor
- Receiver
- Pico ammeter
- DC power supply

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Curvature study

Dimming Curvatures (10 sec):

\[ E = a \times e^{\frac{-t}{c \times b}} + b \]

- **E**: illuminance (lx)
- **a, b**: constants
- **c**: curvature constant
- **p**: dimming period (sec)
- **t**: time (sec)

**c** = 0.1, 0.2, and 0.4 from the bottom

Linear
Curvature study

Paper task (word puzzle)
Curvature study

Procedure

- Twenty subjects, ranging from 22 to 41 in age.
- Subjects seated themselves in the office and adapted to the initial illuminance of 500 lx for five minutes.
- Subject started performing either the paper task or free gaze under the initial illuminance.
- After a short time (5 to 10 seconds) the illuminance was or was not gradually dimmed according to one of the four dimming functions for 10 seconds.
- Illuminance was reset at 500 lx, the initial level.
- Approximately 20-30 seconds separated conditions.
Curvature study

Procedure

After each 10-second presentation, the experimenter asked the subject the following three questions:

1. Whether the illuminance was changed—up, down, or no change.
2. Whether the illuminance change, if the subject detected, was acceptable—yes or no.
3. How acceptable was the illuminance change, if detected—0=very unacceptable, 5=neutral, 10=very acceptable
Curvature study

Results: detectability

Free gaze

Paper puzzle
Curvature study

Acceptability: yes or no

Free gaze

Paper puzzle
Curvature study

Acceptability: 0-10 rating

- Free gaze
- Paper puzzle
Curvature study

Acceptability Correlation

\[ y = 0.1454x - 0.1115 \]

\[ R^2 = 0.8271 \]

Acceptance evaluation (0-10)

% of subjects who accept the illuminance change
Conclusions

• Dimming curvature little affected the **detectability** and **acceptability** of illuminance change.

• Regardless of task, 50% of subjects could detect illuminance change after about 15% reduction from the initial illuminance.

• Regardless of task, 50% and 80% of subjects accepted illuminance reduction up to about 40% and 20% respectively.
Update to Kelly’s 1961 model
**Detectability: Illuminance increase**

- **Overall Discussion**

- **Free gaze**

- **Paper puzzle**
Limitedations and future research

• Lack of windows
• Lighting distribution
• Reflectance of surfaces
• Undetectable reductions beyond 20% with extended dimming (10 minutes, or 1 hour)
• Extended dimming periods and acceptability