Recommended Display Qualities for Optimal Visual Performance and Comfort

Shun-nan Yang
James Sheedy
Vision Performance Institute
Pacific University College of Optometry
Visual Performance/Comfort Triangle

Visual Abilities
- Visual acuity
- Accommodation
- Vergence
- Stereoacuity

Ergonomic Factors
- Display Type
- Luminance & Contrast
- Reflection (glare)
- Resolution & size

Text Rendering
- Font size
- Inter-letter spacing
- Width-to-height ratio
- Text rendering
## Visual Abilities and Usage

<table>
<thead>
<tr>
<th>Age</th>
<th>Ocular Physiology</th>
<th>Reading Skills</th>
<th>Strategic Skills</th>
<th>Usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 to 9</td>
<td>Good</td>
<td>Poor</td>
<td>Poor</td>
<td>Limited</td>
</tr>
<tr>
<td>10 to 14</td>
<td>Good</td>
<td>Improving</td>
<td>Improving</td>
<td>Increasing</td>
</tr>
<tr>
<td>15 to 45</td>
<td>Stable</td>
<td>Well-developed</td>
<td>Good</td>
<td>Extensive</td>
</tr>
<tr>
<td>46 to 65</td>
<td>Presbyopic</td>
<td>Slightly degraded</td>
<td>Good</td>
<td>Extensive</td>
</tr>
<tr>
<td>&gt; 65</td>
<td>Absolute presbyopic</td>
<td>Degraded</td>
<td>Degraded</td>
<td>Reduced</td>
</tr>
</tbody>
</table>
Visual Ergonomic Factors

- **Luminance**: retinal intensity of light from a given area of a visual target.
- **Contrast**: luminance difference between two adjacent stimuli \( \left( \frac{l_f-l_b}{l_f+l_b} \right) \)
- **Reflective glare**: veiling luminance from room lighting that decreases image contrast.
- **Image aspect**: spatial properties of the image as defined by size, width/height ratio, and spacing.
- **Spatial resolution**: number of pixels within a display unit and its effect on image legibility.
- **Screen size**: screen width/height that affects how individuals view its content with eye/head movements.
Display Media

- **Comfort**
  - Typical illumination: Paper and E-ink > LCD
  - Bright outdoor: Paper & E-ink > LCD
  - Dim light: LCD > E-ink and paper

- **Visual performance**
  - Typical: same
  - Outdoor: same
  - Dim light: LCD > E-ink

- **User preference:**
  - Typical: LCD
  - Outdoor: E-ink
  - Dim light: LCD

* Tai et al. (this conference); Yang et al. (2010a)
Luminance & Contrast

• **Comfort:**
  - 1:3/3:1 ratio for display and background.
  - Luminance: 50 nit < 100 nit = 200 nit *
  - Contrast: 65% < 80% = 95%

• **Performance:**
  - Luminance: 50 nits < 100 nits < 200 nits (with 80%)
  - Contrast: 65% < 80% < 95% (with 100 nits)

* Yang et al. (2010b)
**Display size and Viewing Distance**

- Desktop displays: 19” / 75 cm VD (.64).
- Laptop: 10” / 48 cm (.53).
- Cell phone: 4” / 25 cm (.41).

* Yang et al. (2010a, 2010b); Tai et al. (2008)
Display Resolution/Viewing Distance

- Desktop displays: ~ 100 ppi / 75cm (51 ppd*).
- Laptop: 110 - 150 ppi / 48cm (49 ppd).
- Cell phone: 300 ppi / 25 cm (51 ppd).
- 50 ppd allows
  - 6-7 characters for foveal identification
  - 18 characters for letter locations
  - 7 character saccade amplitude

* ppd: pixel per degree;  
Legge et al. (2007)
Screen Reflection (glare)

- **Glare type:**
  - Specular: mirror-like, narrowed (< 5°) reflection
  - Diffusive: broad, even reflection

- **Screen finish:**
  - Matte: Diffusive reflection, reduced contrast
  - Glossy: specular reflection, high contrast
Image/Text Rendering

- **Character height**: 20 arcmin for reading.
- **Character width/height ratio**: 9 x 7 (.77) for x height; 7 x 5 (.71) for H height.
- **Stroke width**: 8% to 16% of H height.
- **Letter spacing**: 20% to 60% of H height.
- **Word spacing**: 50% of H height.
- **Line spacing**: 15% of H height.
- **Anti-aliasing rendering**: reduced horizontal spacing in some conditions.

* ISO 9241.303 & ANSI HFES 100
Effects of Viewing Angle

- Viewing angle has following effects:
  - Reduced luminance.
  - Different subpixel luminance.
  - Greater oblique than cardinal reduction.
  - Foreshortened image size and space.
Liquid Crystal Alignment and Viewing Angle

- Twisted nematic (perpendicular)
- In-plane switch (parallel)
- Multi-domain vertical alignment (MVA)
- Current improvements ...
Optimizing LCD Display

- Backlight/black level.
- Brightness/Luminance.
- Contrast.
- Color balance/fidelity
- Bandwidth/Sharpness
- Phase/timing/refresh rate
- Screen uniformity
Display Evaluation

- Maximize visual performance and comfort
- Cover a reasonable range of environment illuminance (500 to 1500 lux).
- Specify acceptable ranges of luminance and contrast.
- Make adjustments based on technological, physiological, and cognitive limitations.
- Identify improvements having the greatest impact.
## Illuminance @ 500 Lux

<table>
<thead>
<tr>
<th>Age Factor</th>
<th>5 - 9</th>
<th>10 - 14</th>
<th>15 - 45</th>
<th>45 - 60</th>
<th>&gt; 60</th>
<th>Confid. Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal Screen Luminance</td>
<td>100 (cd/m²) low 29 &amp; high 325 for all ages</td>
<td>100</td>
<td>100</td>
<td>130</td>
<td>170</td>
<td>7</td>
</tr>
<tr>
<td>Minimal and Actual Contrast</td>
<td>80 (84) % (108:8.5)</td>
<td>80 (84) (108:8.5)</td>
<td>80 (84) (108:8.5)</td>
<td>80 (85) (138:8.5)</td>
<td>80 (90.1) (178:8.5)</td>
<td>7</td>
</tr>
</tbody>
</table>
## Illuminance @ 750 Lux

<table>
<thead>
<tr>
<th>Age Factor</th>
<th>5 - 9</th>
<th>10 - 14</th>
<th>15 - 45</th>
<th>45 – 60</th>
<th>&gt; 60</th>
<th>Confid. Level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Optimal Screen Luminance</strong></td>
<td>155 (cd/m²) low 46 &amp; high 489 for all ages</td>
<td>155</td>
<td>155</td>
<td>207</td>
<td>267</td>
<td>1–lowest</td>
</tr>
<tr>
<td><strong>Minimal and Actual Contrast</strong></td>
<td>80 (85.6)% (161:12.5)</td>
<td>80 (85.6) (161:12.5)</td>
<td>80 (85.6) (161:12.5)</td>
<td>80 (88.9) (213:12.5)</td>
<td>80 (91.2) (273:12.5)</td>
<td>10–highest</td>
</tr>
</tbody>
</table>
## Illuminance @ 1000 Lux

<table>
<thead>
<tr>
<th>Age Factor</th>
<th>5 - 9</th>
<th>10 - 14</th>
<th>15 - 45</th>
<th>45 – 60</th>
<th>&gt; 60</th>
<th>Confid. Level</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Optimal Screen Luminance</strong></td>
<td>207 (cd/m²) low 58 &amp; high 653 for all ages</td>
<td>207</td>
<td>207</td>
<td>276</td>
<td>357</td>
<td>7</td>
</tr>
<tr>
<td><strong>Minimal and Actual Contrast</strong></td>
<td>80 (85.7)% (215:16.5)</td>
<td>80 (85.7) (215:16.5)</td>
<td>80 (85.7) (215:16.5)</td>
<td>80 (89.0) (284:16.5)</td>
<td>80 (91.3) (365:16.5)</td>
<td>7</td>
</tr>
</tbody>
</table>
# Illuminance @ 1500 Lux

<table>
<thead>
<tr>
<th>Age Factor</th>
<th>5 - 9</th>
<th>10 - 14</th>
<th>15 - 45</th>
<th>45 – 60</th>
<th>&gt; 60</th>
<th>Confid. Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optimal Screen Luminance</td>
<td>310 (cd/m²) low 58 &amp; high 653 for all ages</td>
<td>310</td>
<td>310</td>
<td>413</td>
<td>534</td>
<td>7</td>
</tr>
<tr>
<td>Minimal and Actual Contrast</td>
<td>80 (85.9) % (322:24.5)</td>
<td>80 (85.9) (322:24.5)</td>
<td>80 (85.9) (322:24.5)</td>
<td>80 (89.1 ) (425:24.5 )</td>
<td>80 (91.6) (546:16.5 )</td>
<td>7</td>
</tr>
</tbody>
</table>
# All Illuminance Levels

<table>
<thead>
<tr>
<th>Factor</th>
<th>5 - 9</th>
<th>10 - 14</th>
<th>15 - 45</th>
<th>45 - 60</th>
<th>&gt; 60</th>
<th>Confid. level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximal and Assumed Screen Reflectance</td>
<td>7.5%* (5%)</td>
<td>7.5</td>
<td>7.5</td>
<td>9.7</td>
<td>12.4</td>
<td>7</td>
</tr>
<tr>
<td>Optimal Screen Size (diagonal inches)</td>
<td>11”</td>
<td>14</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td>4</td>
</tr>
<tr>
<td>Minimal Screen Resolution (ppd)</td>
<td>= 50</td>
<td>= 50</td>
<td>= 50</td>
<td>&gt; 50</td>
<td>&gt; 50</td>
<td>3</td>
</tr>
<tr>
<td>Optimal Font Size and Spacing</td>
<td>14 point (+30% spacing)</td>
<td>12 (+30%)</td>
<td>12 (+30%)</td>
<td>14 (+30%)</td>
<td>14 (+30%)</td>
<td>6</td>
</tr>
</tbody>
</table>

* 45deg. angle with 50% reduction in luminance
Recommendations

- LCDs perform better in dim light, slightly poorer at outdoor and well light room compared to paper and E-ink.
- LCDs with > 350 nit and < 5% reflectancy work well in regular light (< 1500 lux).
- Text with > 80% contrast and 50 ppd works for those with normal vision.
- Letter size and spacing should be adaptive to viewing angle.
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Vision Performance Institute
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