Visual Acuity

Excerpts from a lecture by:
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Visual acuity

Visual acuity is the smallest spatial detail that can be detected or identified.

Types of acuity tasks:
- Detection acuity
- Resolution acuity
- Localization acuity
- Identification (letter or optotype) acuity
Detection acuity: bright targets

The retinal image size of a bright point is constrained by the point spread function (PSF) of the eye. Optimal width of PSF ≈ 1 arc min.
Detection acuity: bright targets

Detection “acuity” for a bright point or line does *not* depend on its angular size, but on the number of photons in the target’s image.

A bright target on a dark background (e.g., a star at night) is detected when its energy exceeds the retinal light threshold, despite an angular size < 1 sec arc.
Detection acuity: dark targets

Smallest detectable line ≈ 0.5 - 1 arc sec. Smallest detectable dot ≈ 15 arc sec.

Threshold size depends on retinal contrast threshold ≈ 1 - 2% after image spread due to retinal PSF or LSF.
Resolution acuity: two lines

Two lines can be resolved when their images fall on non-adjacent cones with a relatively unstimulated cone in between. Cone separation (or “sampling”) places a potential limit on acuity.
Resolution acuity: gratings

High SF cut-off of CSF = grating resolution.

Photopic grating acuity ≈ 40 c/deg, i.e., each light or dark bar is about 0.75 arc min.
Localization acuity

Vernier & spatial interval acuity: the precision of judging spatial location for one target with respect to one or more other targets.
Hyperacuities

Under optimal conditions, localization acuities reach a few arc sec, much finer than the separation between adjacent cones. These very fine spatial thresholds are designated as hyperacuities.
Identification acuity

Letter targets most often used:

- Sloan letters (5 x 5 matrix)
- British letters (4 x 5 matrix)
- Others: Landolt Cs, tumbling Es, etc.
A “standard” observer can just read letters with stroke width = 1 arc min.
Normal corrected acuity is better than 20/20

Normal corrected adult acuity ≈ 20/16 (-0.09 log MAR).

Based on Weymouth, 1960
## Comparisons among acuity tasks

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<tr>
<th>Acuity Task</th>
<th>Typical Stimulus</th>
<th>Optimal Threshold</th>
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</thead>
<tbody>
<tr>
<td>Detection</td>
<td>Bright line or spot</td>
<td>ca. 0 sec arc</td>
</tr>
<tr>
<td>Single dark line</td>
<td>0.5 - 1.0 sec arc</td>
<td></td>
</tr>
<tr>
<td>Single dark spot</td>
<td>15 - 20 sec arc</td>
<td></td>
</tr>
<tr>
<td>Resolution</td>
<td>Two bright lines/spots</td>
<td>40 - 60 sec arc</td>
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<tr>
<td>Two dark lines/spots</td>
<td>30 - 40 sec arc</td>
<td></td>
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<tr>
<td>Grating</td>
<td>30 - 40 sec arc</td>
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<tr>
<td>Localization</td>
<td>Spatial interval</td>
<td>2 - 4 sec arc</td>
</tr>
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<td>Vernier lines</td>
<td>3 - 6 sec arc</td>
<td></td>
</tr>
<tr>
<td>Identification</td>
<td>Letters or numerals</td>
<td>30 - 40 sec arc</td>
</tr>
</tbody>
</table>
CSF and Acuity

Contrast Sensitivity

Spatial Frequency (c/deg)

high SF cut-off (lo-C acuity)

high CS = low contrast

low CS = high contrast

high SF cut-off (hi-C acuity)
Acuity and contrast

Acuity improves gradually with contrast, as predicted by the high-SF limb of the CSF. Consequently, small changes in chart contrast should not affect clinical acuity measurements.
SF and Acuity

• If each spatial detail subtends an angle of 1 arc min, the whole letter subtends 5 arc min.

• There are 60 arc min in a degree. Therefore 2.5 cycles / 5 arc min = 30 cpd

• To convert to Snellen: 600/cpd = Snellen Denominator
  Thus 30 cpd letter = 20/20
More Examples

What is the Snellen equivalent size of a letter ‘E’ with total overall size of 10 arcmin?

- Each bar = (10arcmin/5) = 2arcmin
- 1 cycle = 2 bars = 4arcmin
- If 1 cycle = 4 arcmin, how many cycles (x) per degree?
- 1 degree = 60 arcmin, so
  \[ \frac{1 \text{ cycle}}{4 \text{ arcmin}} = \frac{x \text{ cycles}}{60 \text{ arcmin}} \]
- \( x = 15 \) cycles/degree
- Convert to snellen denominator by \( 600/15\text{cpd} = 40 \)
More Examples

What is the Snellen equivalent size of a letter ‘E’ with total overall size of 20 arcmin?

- Each bar = \( \frac{20 \text{ arcmin}}{5} = 4 \text{ arcmin} \)
- 1 cycle = 2 bars = 8 arcmin
- If 1 cycle = 8 arcmin, how many cycles (x) per degree?
- 1 degree = 60 arcmin, so

\[
\frac{1 \text{ cycle}}{8 \text{ arcmin}} = \frac{x \text{ cycles}}{60 \text{ arcmin}}
\]

- \( X = 7.5 \text{ cycles/degree} \)
- Convert to snellen denominator by \( \frac{600}{7.5 \text{ cpd}} = 80 \)
Common Visual Acuity Scales

• MAR = stroke width of threshold sized acuity letter in arcmin
• Snellen = \( \frac{20}{20 \times \text{MAR}} \)
• Decimal = \( \frac{1}{\text{MAR}} \)
• LogMAR = \( \log(\text{MAR}) \)
## Scales for Visual Acuity

<table>
<thead>
<tr>
<th>Scale Definition</th>
<th>Snellen 20/</th>
<th>Decimal (min arc)^{-1}</th>
<th>MAR min arc</th>
<th>Visual Efficiency per cent</th>
<th>LogMAR log (min arc)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Performance Criterion</strong></td>
<td>Snellen 20/</td>
<td>Decimal (min arc)^{-1}</td>
<td>MAR min arc</td>
<td>Visual Efficiency per cent</td>
<td>LogMAR log (min arc)</td>
</tr>
<tr>
<td>Normal Adult estimated inverse slope</td>
<td>16.4</td>
<td>1.22</td>
<td>0.82</td>
<td>103.3</td>
<td>-0.09</td>
</tr>
<tr>
<td>Standard estimated inverse slope</td>
<td>20</td>
<td>1.00</td>
<td>1.00</td>
<td>100.0</td>
<td>0.00</td>
</tr>
<tr>
<td>Unrestricted Driving estimated inverse slope</td>
<td>40</td>
<td>0.50</td>
<td>2.00</td>
<td>83.6</td>
<td>0.30</td>
</tr>
<tr>
<td>Moderate Visual Impairment estimated inverse slope</td>
<td>70</td>
<td>0.29</td>
<td>3.50</td>
<td>64.0</td>
<td>0.54</td>
</tr>
<tr>
<td>Legal Blindness estimated inverse slope</td>
<td>200</td>
<td>0.10</td>
<td>10.00</td>
<td>20.0</td>
<td>1.00</td>
</tr>
<tr>
<td>Profound Visual Impairment estimated inverse slope</td>
<td>500</td>
<td>0.04</td>
<td>25.00</td>
<td>1.4</td>
<td>1.40</td>
</tr>
</tbody>
</table>

*MAR = the stroke width of the threshold-sized acuity letter, in min arc.
Acuity and luminance

Acuity improves with both scotopic and photopic target luminance.

Clinically, acuity is assessed at about 100 cd/m$^2$ (approximately 3 trolands here), where small luminance changes have little effect.
Acuity and luminance

The improvement of letter acuity with luminance is consistent with luminance-dependent changes in the spatial CSF.

DeValois & DeValois, 1980
Acuity and retinal eccentricity

Photopic acuity is best at the fovea and declines steadily with increasing retinal eccentricity.

Virsu & Rovamo, 1979
Myths Regarding Acuity

High contrast acuity is the best way to test everyday vision.

A patient who has 20/20 acuity has perfect vision.