Useful quantities in Vision Science

(from Wandell's *Foundations of Vision*)

Units

1. *Radiometric units* represent a physical measurement (e.g., radiance has units of watts $sr^{-1}m^{-2}$).
2. *Colorimetric units* adjust radiometric units for visual wavelength sensitivity (e.g. luminance has units of cd/m^2). Scotopic luminance units are proportional to the number of rod absorptions; photopic luminance units are proportional to a weighted sum of the L- and M-cone absorptions.
3. *Typical ambient luminance levels* (in cd/m^2): starlight, 10^{-3}; moonlight 10^{-1}; indoor lighting 10^2; sunlight 10^5; maximum intensity of common CRT monitors, 10^2.
4. One *Troland* (Td) of retinal illumination is produced on the retina when an eye with a pupil size of 1 mm^2 looks at a surface whose luminance is 1 cd/m^2.
5. *Lens focal length*: *f* (meters); lens power = 1/*f* (diopters)
6. Conversion of linear units (X) to decibels (Y): $Y = 20 \log_{10}(X)$; a change of 0.3 $\log_{10}$ units is a factor of 2, or 6 dB.

Image Formation

1. *The eyes* are 6 cm apart and halfway down the head.
2. *Visual angle of common objects* (degrees): the sun or moon = 0.5; (at arm's length) thumbnail = 1.5; thumb joint= 2.0; fist = 8-10.
3. *Monocular visual field* measured from central fixation: 160 deg (w) x 135 deg (h).
4. *Binocular visual field* measured from central fixation: 200 deg (w) x 135 deg (h).
5. *Region of binocular overlap*: 120 deg (w) x 135 deg (h).
6. Range of *pupil diameters*: 1-8mm.
7. *Refractive indices*: air 1.000; glass 1.520; water 1.333; cornea 1.376.
8. *Optical power* (diopters): cornea, 43; lens (relaxed), 20; whole eye, 60.
9. Change in power due to *accommodation*, 8 diopters.
10. *Axial chromatic aberration* over the visible spectrum: 2 diopters.

Retina

1. *Retinal area*: 5 cm x 5 cm; *Retinal thickness*: 0.4 mm.
2. One degree of *visual angle on the retina* = 0.3 mm.
3. *Number of cones* in each retina: 5×10^6; *number of rods* in each retina: 10^8.
4. *Diameter of the fovea*: 1.5 mm (5.2 deg); rod-free fovea: 0.5 mm (1.7 deg); foveola (rod-free, capillary-free fovea): 0.3 mm (1 deg).
5. *Size of the optic nerve head*: 1.5 mm x 2.1 mm (5 deg (w) x 7 deg (h)); *location of the optic nerve head*: 15 deg nasal.
6. *Peak cone density*: 1.6×10^5 cones/mm^2.
7. *Foveal cone size*: 1-4 μ (diameter) x 50-80 μ (length); *extrafoveal cone size*: 4-10 μ (diameter) x 40 μ (length).
8. *Rod size* near fovea: 1 μ (diameter) x 60 μ (length).
9. *S cone spacing* (foveal): 10 arc min; *L and M cone spacing* (foveal): 0.5 arc min.
10. Number of (L + M) cones / Number of S cones = 14 (though the ratio may be higher in the foveola).
11. Number of optic nerve fibers form each retina: 1.8×10^6 (monkey); 1.2×10^6 (human).
12. Ratio of receptors to ganglion cells: in fovea, 1:3; for whole retina, 125:1.

Cortex

1. Total cortical area: 1.3×10^5 mm^2 (human); cortical thickness: 1.7 mm (monkey), 4.0 mm (human).
2. Total number of *cortical neurons*: 10^{10}; average density: 10^5 neurons / mm^3.
3. *Synapses*: average density, 5×10^8 synapses / mm^3; 4×10^3 synapses/neuron.
4. Axons: 3 kilometers / mm^3.
5. Number of corpus callosum fibers: 5×10^8.
6. Number of macaque visual areas: 30.
7. Size of each area V1 (each hemisphere): 3cm by 8 cm. Half of area V1 represents the central 10 deg (2% of the visual field)
8. Width of ocular dominance columns: human, 0.5-1.0 mm; macaque, 0.3 mm.

Sensitivity

1. Minimum number of absorptions: detectable electrical excitation of a rod, 1; scotopic detection, 1-5; photopic detection, 10-15.
2. Following exposure to a sunny day, *dark adaptation* to a moonless night requires: 10 minutes (photopic); 40 minutes (scotopic); change in visual sensitivity: 6 $\log_{10}$ units.
3. *Highest detectable spatial frequency*: at high ambient light levels, 50-60 cpd; at low ambient light levels, 20-30 cpd.
4. *Contrast threshold* ($\Delta L / L$) for a static edge at photopic luminances: 1%.
5. *Highest detectable temporal frequency*: high ambient light, large field, 80 Hz; low ambient light, large field, 40 Hz.
6. Typical *localization threshold*: 6 arc sec (0.5 μ on the retina).
7. *Minimum temporal separation* needed to discriminate two small, brief light pulses from a single equal-energy pulse: 15-20 ms.
8. *Stereoscopic depth discrimination thresholds*: step threshold, 3 arc sec; point threshold, 30 arc sec.

Color

1. Visible spectrum: 370-730 nm.
2. Peak wavelength sensitivity: 507 nm (scotopic) and 555 nm (photopic).
3. Spectral equilibrium hues: 475 nm (blue), 500 nm (green), 575 nm (yellow), no spectral equilibrium red.
4. Number of basic English color names: 11.
5. *Incidence of color deficiencies*: anomalous trichromacy, 6×10^{-2} (male), 4×10^{-3} (female); protanopia and deuteranopia, 10^{-2} (male), 3×10^{-4} (female); tritanopia, 10^{-4}; rod monochromacy, 10^{-4}; cone monochromacy, 10^{-5}.