Contrast Sensitivity

Performance in a vision based task, such as reading text, recognizing faces, or operating a vehicle, is limited by the overall quality of the image. Image quality depends on many factors, in particular:

- Light level - are there enough photons to overcome the inherent "Poisson noise" of light?
- Spatial scale - can features be resolved by our optics and our receptors?
- Contrast - is there enough brightness difference between parts of the image for us to discriminate features?
- Duration - is the image stable for long enough to see the features?

Contrast Sensitivity is a measure of how much contrast is needed to perform a particular visual task. “Sensitivity” in vision science always means the reciprocal of threshold for a task. Therefore,

\[ \text{Contrast Sensitivity} = \frac{1}{\text{contrast threshold}} \]

Definitions of Contrast

The definition of image contrast depends on the type of image being described! There are three commonly used definitions in vision science:

- **Weber Contrast** $C_W$ -- used for isolated features against a larger background. EX: A letter on a chart, a single line or spot on a screen.

- **Michelson Contrast** $C_M$ -- used for repeating patterns. EX: sine wave or square wave grating.

- **RMS Contrast** $C_{\text{RMS}}$ -- used for more complex patterns. EX: random dot patterns, natural images.
Weber Contrast

Weber Contrast for a feature such as a letter, spot or line, is the difference in luminance between the feature and background divided by the luminance of the background, or “Delta L over L”:

\[
\frac{(L_{\text{target}} - L_{\text{background}})}{L_{\text{background}}} = \Delta L / L
\]

Weber contrast can vary between -100% (black on white) and +infinity (white on black).

Michelson Contrast

Michelson Contrast for a pattern such as a sine or square wave grating is the difference between highest (Lmax) and lowest (Lmin) luminance divided by the sum of the highest and lowest luminance (Lmax + Lmin):

\[
\frac{(L_{\text{max}} - L_{\text{min}})}{(L_{\text{max}} + L_{\text{min}})}
\]

Michelson Contrast can vary from zero (no pattern) to 100% (dark bars completely black).
RMS (Root Mean Square) Contrast

RMS contrast is the standard deviation (Root Mean Square) of pixel luminance in an image, divided by the average luminance of the whole image. It is used for patterns that do not fit well with either Weber or Michelson contrast, such as natural images of grass, trees or clouds, or computer generated images such as random dot stereograms ("Magic Eye" images). If $L_i$ is the luminance of pixel number $i$, and there are $N$ pixels, then

$$L_{\text{mean}} = \frac{\sum L_i}{N}$$

and

$$\text{Contrast}_{\text{RMS}} = \frac{\{\sqrt{\sum (L_i - L_{\text{mean}})^2}/N\}}{L_{\text{mean}}}$$

RMS contrast can vary from zero (blank image) to very high (one very bright "outlier" spot) but is usually less than one.

A cloud image

Luminance across cloud image in two places

A "Magic Eye" Picture
Contrast in printed and projected images

For printed figures, the contrast of a feature does not change when illumination is increased or decreased because it is based on reflectance. Percentages in the figure at right refer to proportion of light reflected by each part of the image.

-90%  
Contrast = $L_b - L_i = 90\%$  
$L_i = 3 \text{ cd/m}^2$  
$L_b = 30 \text{ cd/m}^2$

-80%  
Contrast = $L_b - L_i = 80\%$  
$L_i = (33 + 4) \text{ cd/m}^2$  
$L_b = (33 + 4) \text{ cd/m}^2$

For projected features, like a slide image, contrast is reduced if more light is added to the screen.

Weber’s Law: Contrast Threshold is Constant

For a large range of luminance levels, our ability to detect a spot added to a background follows “Weber’s Law.” This law says that the just detectable (threshold) increment of light is proportional to the background light, so $\Delta L / L$ is a constant.

Another way to say this is that our Weber contrast threshold is constant over a large range of luminance. This is true for spots and for low spatial frequency gratings, especially.

Figure 12. Schematic of the increment threshold curve of the rod system. Agular and Stiles’ data from Davison (Davison’s Physiology of the Eye, 5th ed. London: Macmillan Academic and Professional Ltd. 1990).
Spatial vs. Temporal Contrast

Luminance Contrast describes a ratio between a change in luminance and a background or average luminance. So far we have described the difference between one part of an image and another, which is Spatial Contrast. We can also describe the difference between one point in time and another, which is Temporal Contrast. The same definitions can be used, Weber, Michelson, or RMS Contrast, but the comparison is over time instead of space.

For example, a square wave grating varies over space, and we describe its spatial contrast. A flashing light varies over time and we describe its temporal contrast. A flashing grating varies over both, and we can describe both its spatial and temporal contrast.

![Lum changes across space](image1)

![Lum changes across time](image2)

![L changes across both](image3)