Rod Contributions to Color Perception

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Outline

A tutorial on color vision as requested (15 minutes)
Rod contribution to color perception (30 minutes)

Part I: A Short Tutorial On Color Vision

What is Color Vision?

Color vision refers to the ability of an organism to distinguish objects based on the variation in spectral reflectance.

This ability has two aspects:
- Color discrimination
- Color appearance appreciation

IS THE COLOR IN THE LIGHT?

Visible Spectrum

"White" Appearing light
Visual Pathways

The Magnocellular (MC) pathway
Receptive field center-surround: +(L+M); -(L+M);
Diffuse bipolar cell-parasol ganglion cell.

The Parvocellular (PC) pathway
Receptive field center-surround: (L-M); (M-L); (-L+M); (-M+L)
Midget bipolar cell-midget ganglion cell.

The Koniocellular (KC) pathway
Receptive field center-surround: (S-(L+M)); Invaginating S-cone bipolar cell-bistratified ganglion cells.

Visual Stimulus Specification
Visual Stimulus Specification

The CIE 1931 RGB Color matching functions

\[
R = \int_0^{400} I(\lambda) r(\lambda) \, d\lambda \\
G = \int_0^{400} I(\lambda) g(\lambda) \, d\lambda \\
B = \int_0^{400} I(\lambda) b(\lambda) \, d\lambda
\]

The CIE rg chromaticity space

\[
r = \frac{R}{R + G + B} \\
g = \frac{G}{R + G + B}
\]

The CIE Standard Observer Color matching functions

\[
x = \frac{X}{X + Y + Z} \\
y = \frac{Y}{X + Y + Z} \\
z = \frac{1 - X - Y}{X + Y + Z}
\]

Cone Chromaticity Space

Smith & Pokorny Judd based cone fundamentals

\[
I(\lambda) = 0.15516, 0.54308, 0.03287 \\
E(\lambda) = -0.15516, 0.45692, 0.03287 \\
S(\lambda) = 0.00000, 0.00000, 1.00000
\]

\[
l = \frac{L}{L+M} \\
x = \frac{S}{L+M} \\
Y = L+M
\]
Silent Substitution

In the example, one receptor type could be silenced using two lights.

From colorimetric theory, we can extend this:

Using three appropriately chosen lights, you can silence two receptor types

Using four appropriately chosen lights, you can silence three receptor types

Psychophysical Techniques for Color Vision
Psychophysical Techniques: Color Matching to Quantify Color Shift

Asymmetric matching, haploscopic matching, memory matching, temporal matching

Part II: Rod Contribution to Color Perception

Why Do We Care?

Humans are diurnal animals.
Anatomically, rods are in fact the predominant receptor type in the human retina.

Duplicity Theory of Vision

RODS
NIGHT VISION
HIGH SENSITIVITY
SLOW
LOW ACUITY
ACHROMATIC

CONES
DAY VISION
LOW SENSITIVITY
FAST
HIGH ACUITY
CHROMATIC

Rods and Cones are Both Active at Mesopic Light Levels

Human Retina

4-8 million cones
>100 million rods

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Rods and Cones Share the Same Pathways from Eye to Brain

(Sharpe & Stockman, 1999)

Apparatus

A 2-channel 4-primary colorimetric system that allows independent control of stimulation of the rod and 3 cone types.

CIE 10° Chromaticity Diagram

Study 1

(Cao, Pokorny & Smith, 2005)

Purpose

• Examine how rod stimulation alters color percepts at mesopic light levels.

Stimulus Pattern

Temporal Matching

Observers adjusted the cone excitations of the matching epoch to match the center color of the stimulus epoch. Observers can switch freely between the matching and the stimulus epochs.
Chromaticity & Luminance

Retinal illuminance: 1, 2, 10, 20, 40, 80, 160 td
Rod modulation contrast: 30%

Results: 2 Td

We fitted a straight line with the origin at EES L/(L+M) chromaticity. Thus the diagonal line has an intercept of 0 and a slope of 1.

L/M Results: 2 Td

1. MATCHES REQUIRED MORE M CONE CONTRIBUTION.
2. SMALLER ROD SHIFTS OCCURRED AT HIGHER LUMINANCES.
The matching L/(L+M) was lower than the stimulus L/(L+M) at light levels where hue shifts occurred.

The rod shifts decreased with increases in luminance.

The matching S/(L+M) was larger than the stimulus S/(L+M) at low light levels (1-2 td).

The matching luminance was higher than the stimulus luminance. Matching cone Weber contrast decreased exponentially with luminance level.

**Questions**

How do the rod contributions to color perception vary with rod contrast?

**Stimulus Conditions**

- Chromaticity: (0.7, 0.2)
- Retinal Illuminance: 2, 10, 100 Td
- Rod Weber Contrast: 20%-80%
At 2 Td, the \( \frac{L}{L+M} \), \( \frac{S}{L+M} \) and \( L+M \) required to match rod percept are linearly related to rod contrast.

**Summary**

Rod input to the inferred PC, KC and MC pathways was linearly related to rod contrast.

The strength of rod input weakened with increase in retinal illuminance level.