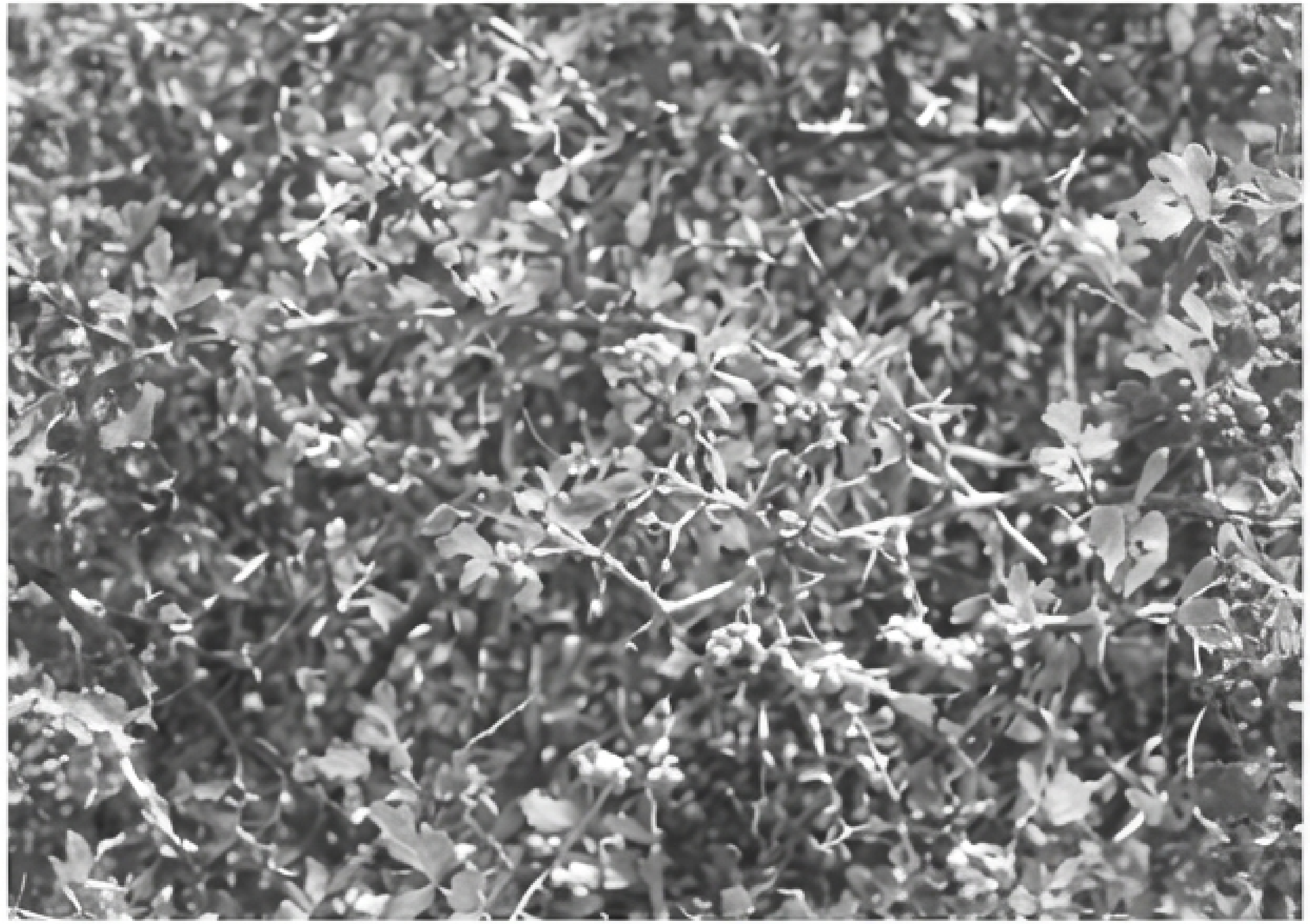
Perceiving Color: Constructing Reality

From Physical Wavelengths to Mental Experience

We tend to think of color as a physical property of the world. In reality, it is a psychological property of our visual system—a sophisticated construction used to interpret light signals.

“Based on Chapter 9: Perceiving Color" in Inter

The Function of Color: Signaling & Survival



Perceptual Organization

Color facilitates the segregation of objects from their backgrounds, **breaking camouflage**.

Evolutionary Advantage

Primates likely evolved color vision for **foraging**. Without color, a monkey must “grope among leaves” to find fruit by shape alone.

The Case of Mr. I

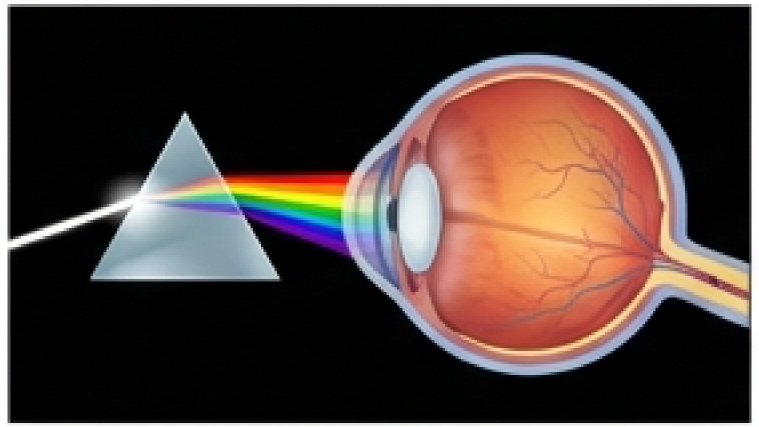
After an accident caused **cerebral achromatopsia**, the artist Mr. I described his world as “drab” and “meaningless,” with tomato juice appearing black.

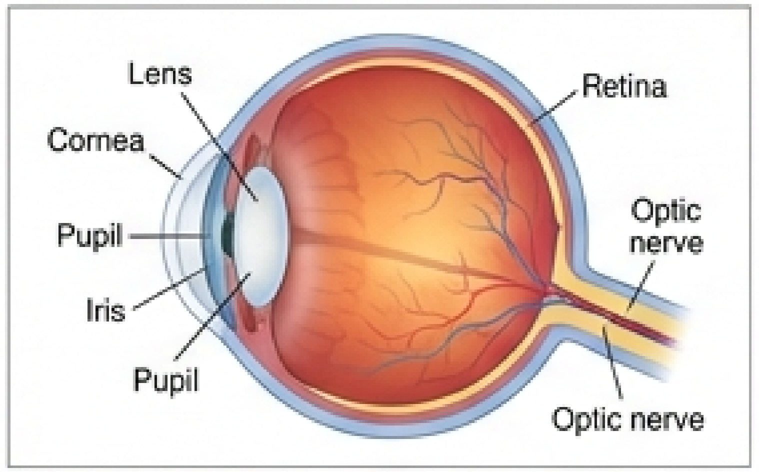
Facilitating Recognition and Emotion

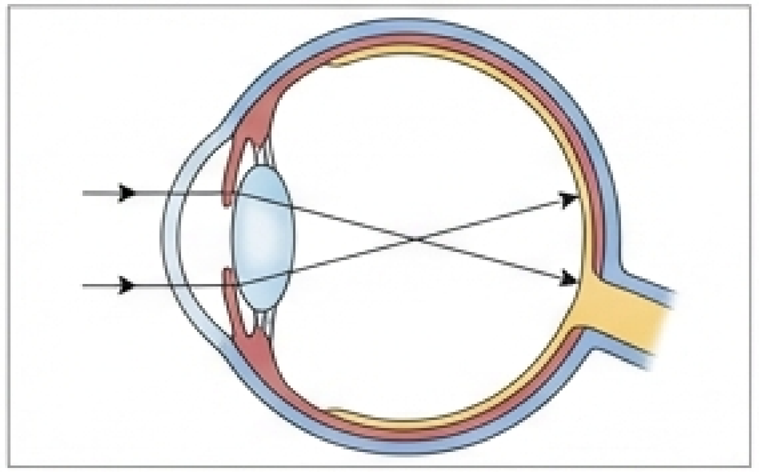
Processing Speed
We identify objects more rapidly and accurately when they are **appropriately colored**. Color allows us to instantly grasp the **‘gist’ of a scene**.

Emotional Signaling
Color cues influence emotional interpretation. Identical facial expressions are rated differently based on tint: **Red** is associated with anger, while **Green** is associated with disgust.

The Physics: Light as Wavelength







Newton's Insight

"The Rays to speak properly are not coloured."
White light is a mixture. Prisms do not add color; they separate the mixture into components.

The Visible Spectrum

Color is our perception of wavelength energy:

- 400–450 nm: **Violet**
- 500–575 nm: **Green**
- 620–700 nm: **Red**

The Mechanism

Light enters the eye, focusing on the retina where the translation from energy to neural signal begins.

Selective Reflection & Subtractive Mixing

Reflectance

Solid objects are colored by the wavelengths they reflect. A **red** apple reflects **long wavelengths** and absorbs the rest.

Transmission

Transparent liquids are colored by the wavelengths they transmit (e.g., cranberry juice transmits **long** waves).

Subtractive Mixing

Mixing pigments subtracts wavelengths. **Blue** paint absorbs **long** waves; **Yellow** paint absorbs **short** waves.

The only wavelength reflected by *both* is medium (**Green**).

Additive Color Mixing: Mixing Lights

The Process
Unlike paint, mixing lights *adds wavelengths* to the total combination reaching the eye.

The Surprise
Superimposing Blue light + Yellow light = White light.

Why?
The mixture contains short, medium, and long wavelengths. The eye perceives this full-spectrum stimulation as white, just as it does with sunlight.

The Trichromatic Theory

Young-Helmholtz Theory

Color vision depends on the activity of three distinct receptor mechanisms (**Cones**).

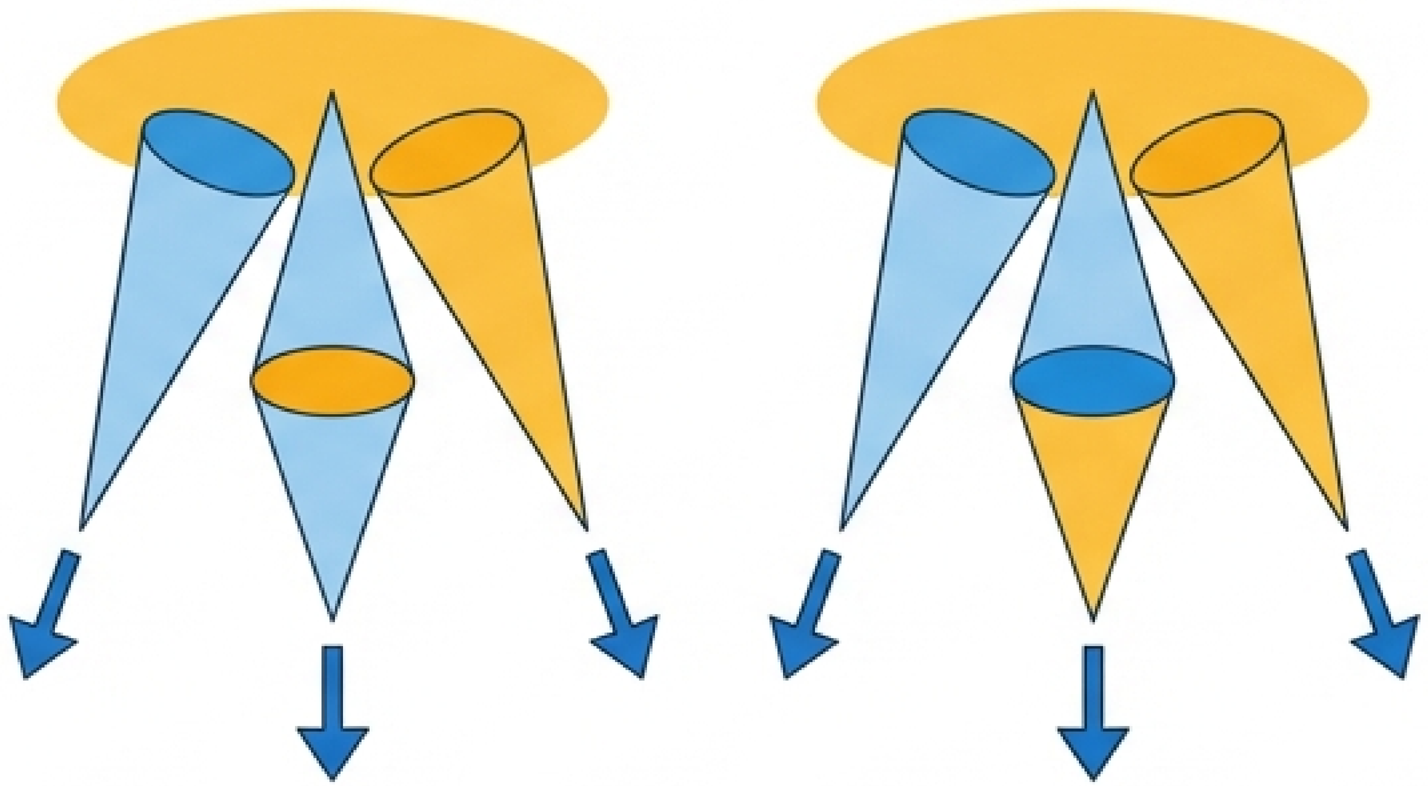
Evidence

Maxwell's color-matching experiments showed that any reference color can be matched by mixing just three wavelengths.

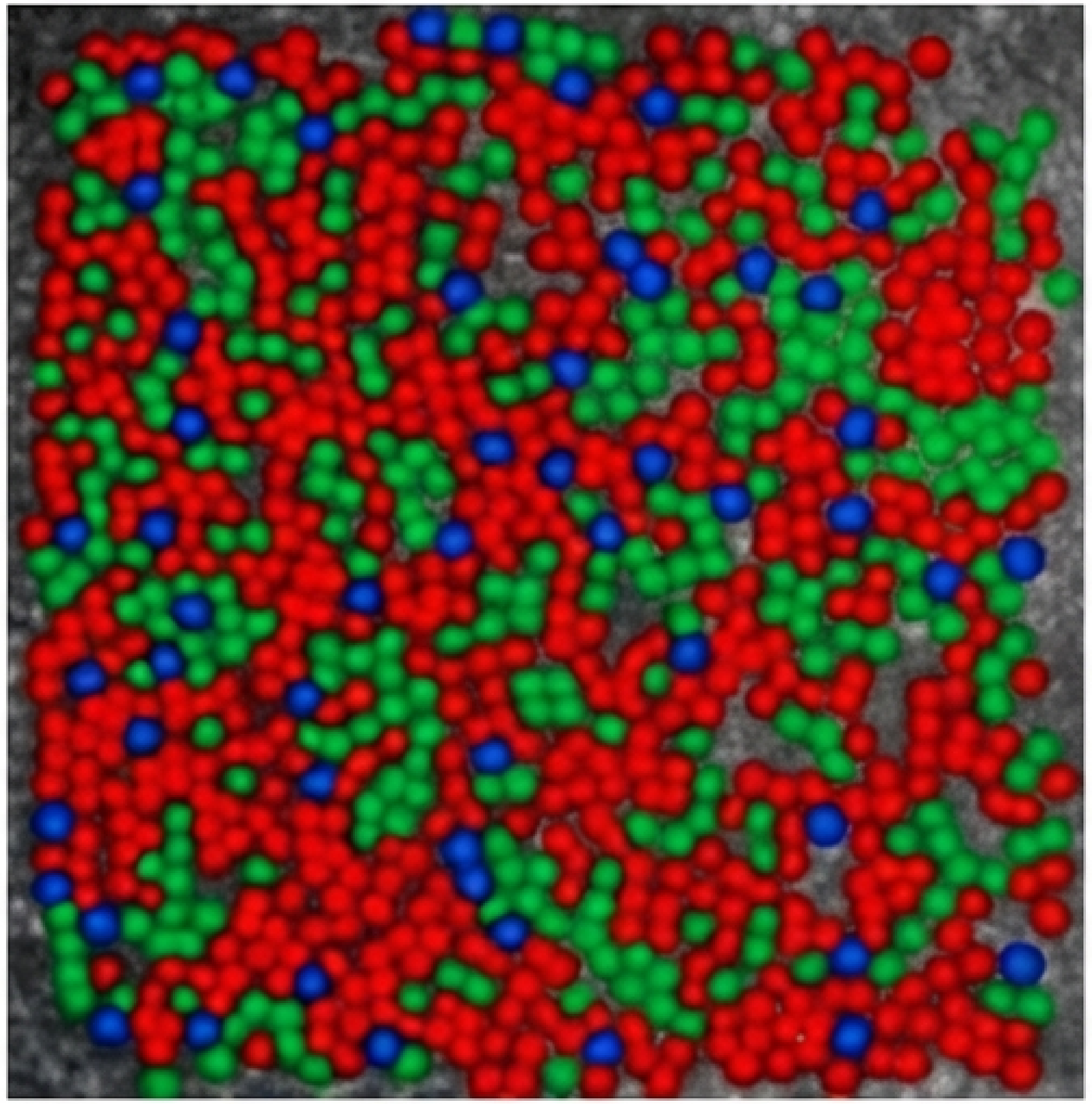
Physiology

Three cone types confirmed by microspectrophotometry:

- **S-Cone**: Short wavelengths (419 nm)
- **M-Cone**: Medium wavelengths (531 nm)
- **L-Cone**: Long wavelengths (558 nm)



The Retinal Mosaic & Metamerism



The Mosaic

The fovea contains a dense array of cones. Note the scarcity of S-cones (blue) compared to L (red) and M (green).

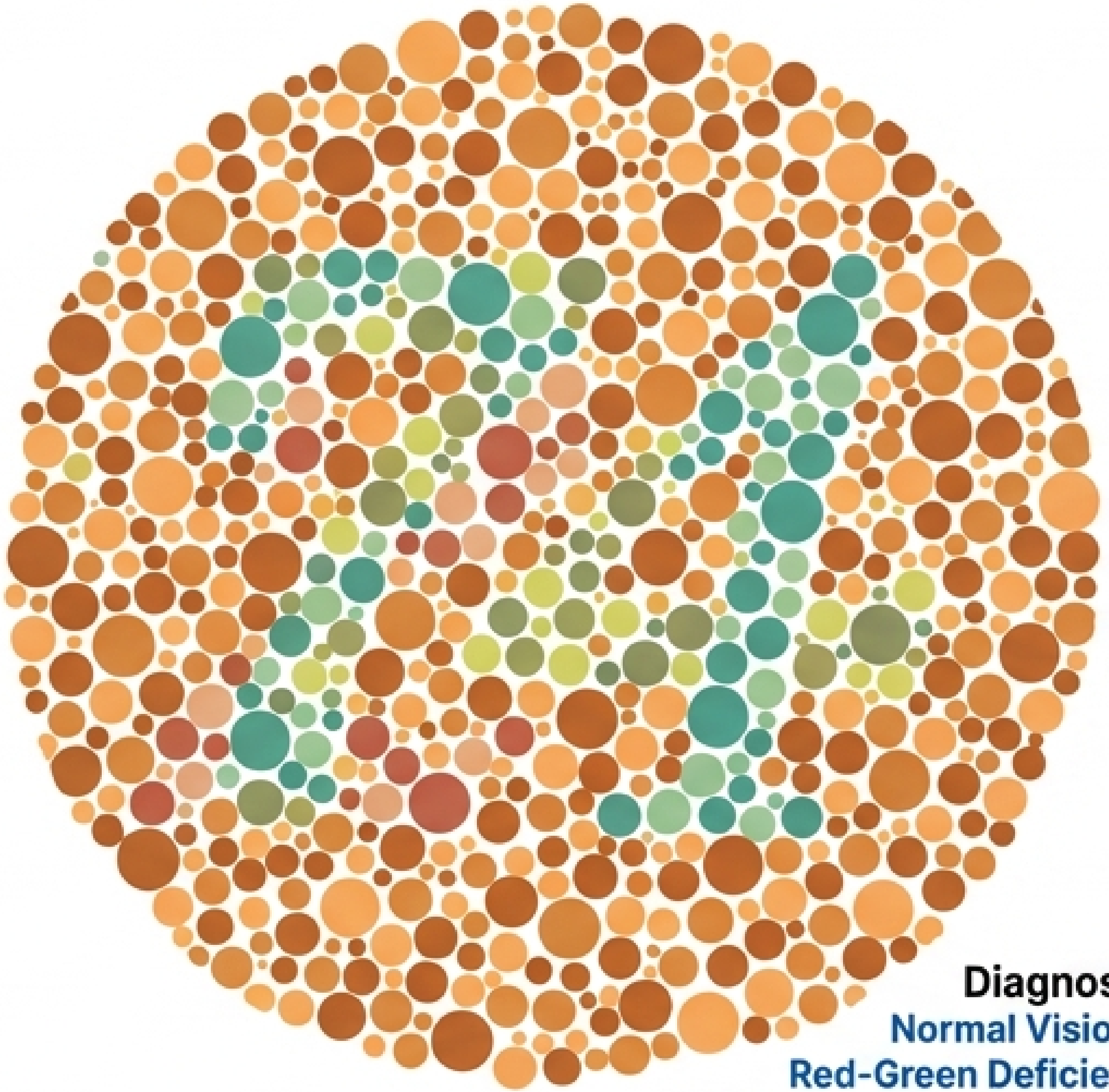
Metamerism

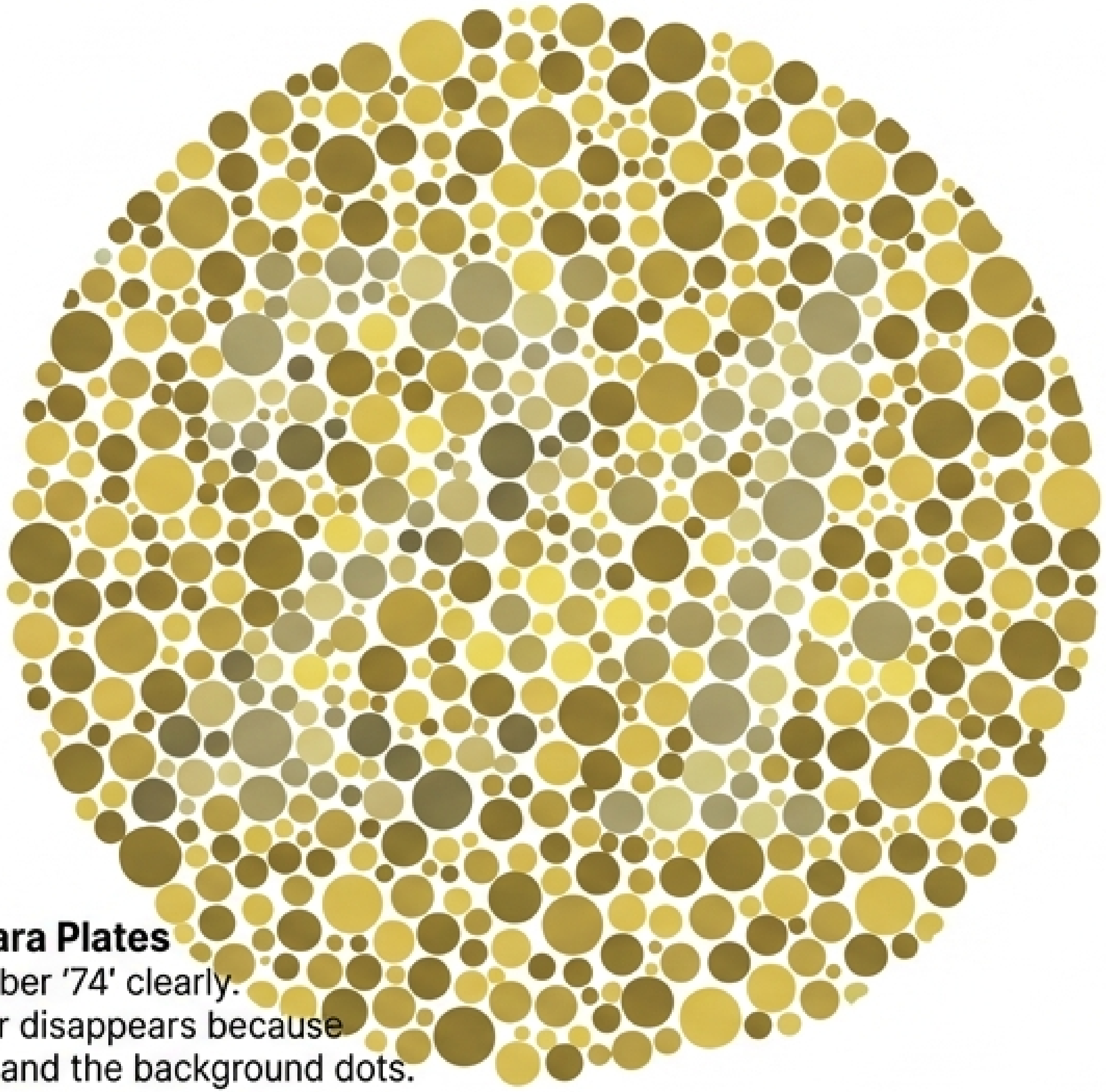
Two physically different lights (e.g., a single 580nm yellow light vs. a mix of 530nm green + 620nm red) can result in the ***identical*** pattern of cone firing.

Result

If the cone response is the same, the perception is identical. The brain cannot distinguish the difference.

Color Deficiency: When Hardware Fails





Diagnosing with Ishihara Plates

Normal Vision: Sees the number '74' clearly.

Red-Green Deficiency: The number disappears because chromatic contrast between the number and the background dots.

Types of Deficiency

Monochromats: See only shades of gray (1 pigment).

Dichromats: Confuse some hues (2 pigments).

Simulating Dichromacy

Trichromat (Normal)

Protanope (Missing L-Cones)

Deuteranope (Missing M-Cones)

Tritanope (Missing S-Cones)

Protanopes and Deuteranopes perceive a world primarily of blues and yellows, with neutral points (grey) appearing in the blue-green spectrum.

Opponent-Process Theory

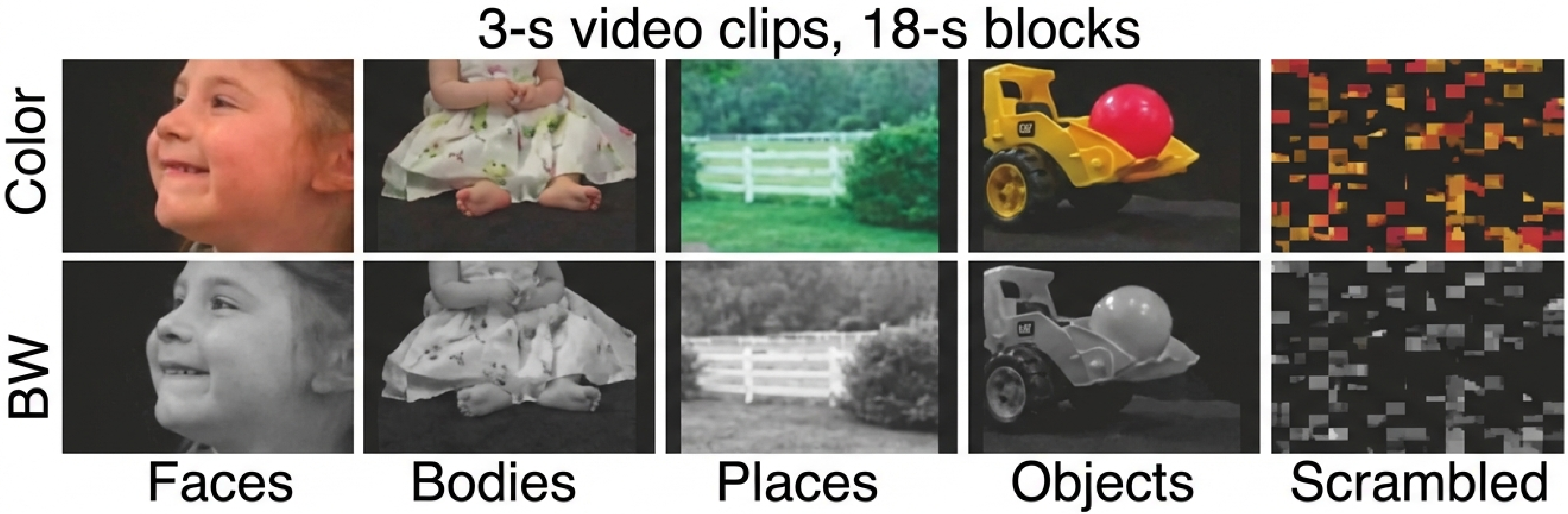
Hering's Observation:
We never see "reddish-green" or "yellowish-blue".

The Mechanism:
Neurons are wired in opponent pairs:

- **Red** vs. **Green**
- **Blue** vs. **Yellow**

Afterimages: Neurons respond with excitation to one color and inhibition to its opposite. Staring at red fatigues the mechanism; looking at white afterwards triggers a green rebound.

Distributed Processing in the Cortex



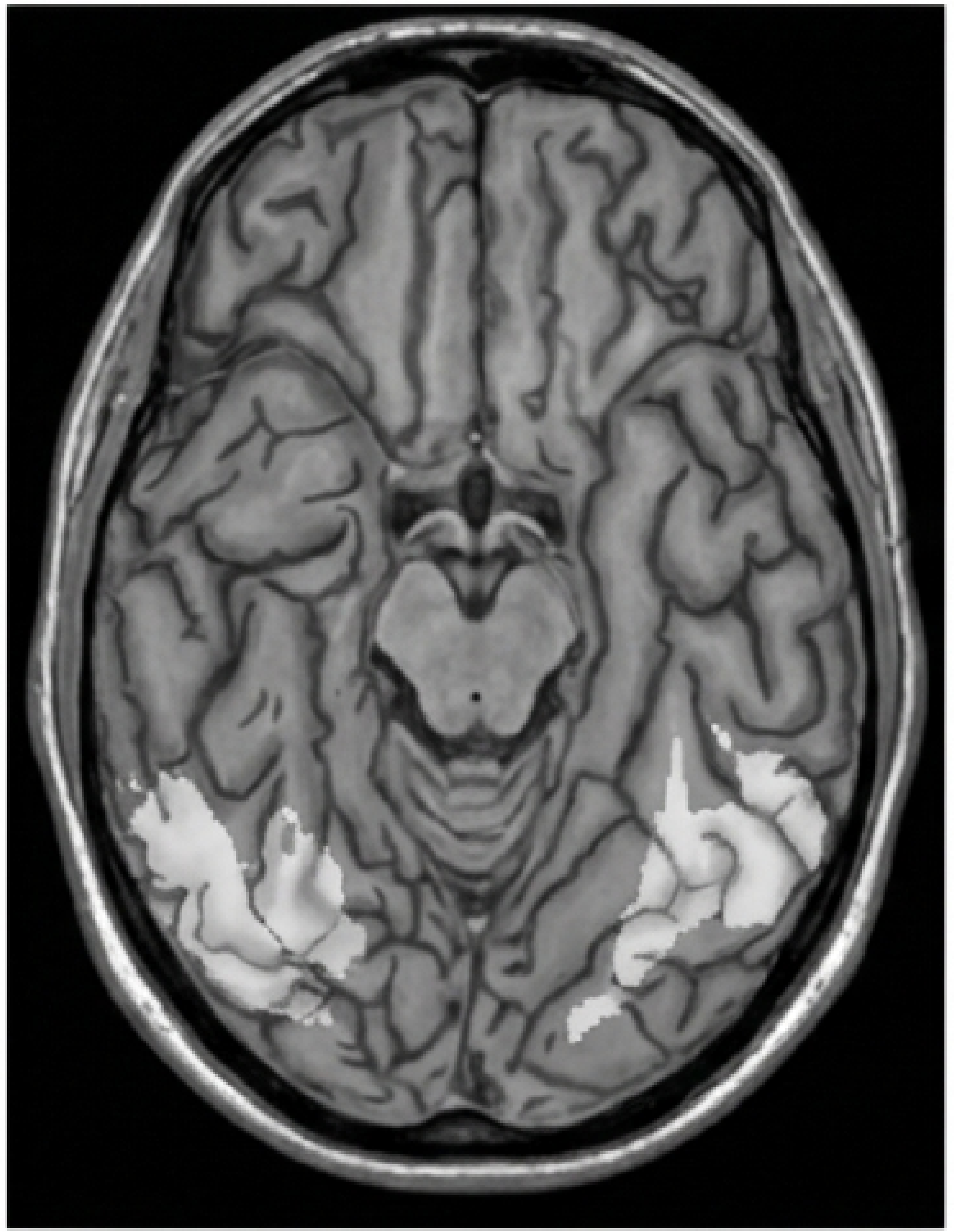
No Single 'Color Center'

Color processing is distributed across multiple cortical areas rather than a single location.

Linking Cues

Research using these video clips demonstrates that color processing is tightly coupled with **form** and **motion**. Color helps define edges and shapes, acting as a bridge between low-level vision and high-level object recognition.

The Cortical 'Sandwich'



Ventral View

Alternate View

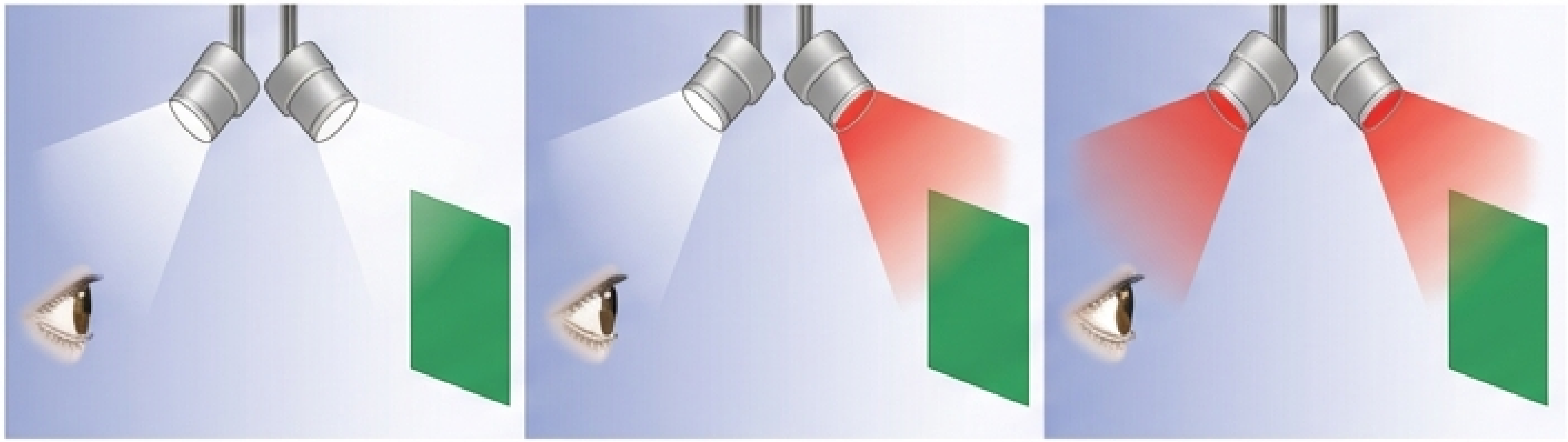
Mapping the Brain

MRI scans reveal that color-selective areas are often located immediately between face-selective (FFA) and place-selective (PPA) areas.

Clinical Implications

This physical adjacency explains why patients with brain damage in this region often suffer from both **Prosopagnosia** (face blindness) and **Achromatopsia** (color blindness) simultaneously.

Color Constancy: Stability in Change



White Light

Red & White Light

Red Light

The Phenomenon

Objects appear the **same color** even under different lighting (sunlight vs. tungsten), despite the physical light reflecting off them changing.

Mechanism: Chromatic Adaptation

The eye adapts to the dominant illuminant. Prolonged exposure to red light decreases sensitivity to red, shifting the perception of the scene back toward “normal”.

Computation

The brain effectively “**discounts**” the illuminant to deduce the object’s true color.

Environmental Adaptation

Physical Input (Season)

Perceived / Adapted View

The visual system adapts to the mean color of the environment. By filtering out the dominant lush green or arid yellow, the brain emphasizes **novel** colors to aid in detection.

Memory Color & Context

The Illusion

The camera captures the siding as green in one light and yellow in another. However, a human observer on-site sees “yellow” both times.

Memory Color

Our knowledge of familiar objects affects color perception. We perceive familiar objects (like bananas or stop signs) as having richer, more saturated colors because our brain imposes its “known” color onto the sensory input.

Case Study: #TheDress

Perceiving White & Gold
If your brain assumes the dress is in **cool shadow** (#0055AA, Inter Medium) (blue light), it subtracts blue wavelengths to correct for the shadow, leaving White and Gold.

Perceiving Blue & Black
If your brain assumes the dress is under **warm artificial light** (#0055AA, Inter Medium) (yellow light), it subtracts yellow wavelengths, leaving Blue and Black.

A viral example of color constancy failure due to ambiguous lighting cues.

Lightness Constancy: The Ratio Principle

The Problem

A shadow drastically reduces the light reflecting off a wall. Why doesn't the wall look like it changed color to dark red?

Reflectance vs. Illumination

The brain must distinguish between a change in paint (Reflectance Edge) and a shadow (Illumination Edge).

The Ratio Principle

We perceive lightness based on the *ratio* of reflectance between an object and its surroundings. Since the ratio stays constant whether in sun or shade, the perception of the object's color remains stable.

The Penumbra Effect

The Penumbra

The fuzzy, **gradient edge** of a shadow is a critical cue. It tells the brain, "This darkness is just a **lack of light**, not a dark surface."

The Illusion

If you hide the penumbra (make the edge sharp), the brain may mistake the shadow for a **dark stain** or a **different surface color**.

Conclusion

Accurate perception requires context. Remove the context (the penumbra), and the **constancy mechanism fails**.

Conclusion: Color is a Construction

- **Physics:** Light is colorless wavelength.
- **Physiology:** Cones sample the light (Trichromacy).
- **Processing:** Neurons compare the signals (Opponency).
- **Perception:** The cortex interprets the signals based on context, memory, and illumination (Constancy).

"The Rays to speak properly are not coloured. In them there is nothing else than a certain Power and Disposition to stir up a Sensation of this or that Colour." — Isaac Newton