**Instructor’s Manual**

by Evan M. Palmer

to accompany

*Sensation & Perception,* Sixth Edition

Wolfe • Kluender • Levi • Bartoshuk • Herz • Klatzky • Merfeld

**Chapter 5: *The Perception of Color***

**Chapter Introduction**

Is a lemon “colored”? Yes and no.

Lemons have reflectance characteristics (a physical property) that we interpret as “yellow” (a psychological property). Color is our subjective perception of the wavelengths of light that reflect off an object and into our eyes. In this chapter, we describe how we get from wavelengths of light to the perception of colors following the three stages of color detection, color discrimination, and color appearance. We discuss the trichromatic and color opponent theories of color perception, along with additive and subtractive color mixing. We explore the causes and effects of colorblindness, discuss color and lightness *constancy*, and then close with a discussion about the usefulness of color vision in humans and animals, including how color can influence taste.

**Chapter Outline**

5.1 Basic Principles of Color Perception

*Three Steps to Color Perception*

5.2 Step 1: Color Detection

5.3 Step 2: Color Discrimination

*The Principle of Univariance*

*The Trichromatic Solution*

*Metamers*

*The History of Trichromatic Theory*

*A Brief Digression into Lights, Filters, and Finger Paints*

*From Retina to Brain: Repackaging the Information*

*Cone-Opponent Cells in the Retina and LGN*

5.4 Step 3: Color Appearance

*Three Numbers, Many Colors*

Sensation & Perception in Everyday Life: Picking Colors

*The Limits of the Rainbow*

*Opponent Colors*

*Color in the Visual Cortex*

5.5 Individual Differences in Color Perception

*Language and Color*

*Genetic Differences in Color Vision*

*Does Everyone See the Same Colors? The Special Case of Synesthesia*

5.6 From the Color of Lights to a World of Color

*Adaptation and Afterimages*

*Color Constancy*

*The Problem with the Illuminant*

*Physical Constraints Make Constancy Possible*

5.7 What Is Color Vision Good For?

Scientists at Work: Filtering Colors

**Chapter Learning Objectives**

*Upon successful completion of this chapter, students will be able to:*

**5.1 Basic Principles of Color Perception**

5.1.1 Describe the three steps to color perception: detection, discrimination, and appearance.

**5.2 Step 1: Color Detection**

5.2.1 Name the three types of cones that contribute to color vision.

5.2.2 Describe the spectral sensitivities of the three types of cones.

**5.3 Step 2: Color Discrimination**

5.3.1 Explain the principle of univariance and the related concept of metamers.

5.3.2 Describe the Young-Helmholtz trichromatic theory of color vision.

5.3.3 Define additive and subtractive color mixing and describe their differences.

5.3.4 Outline the four different ways that cone outputs are pitted against each other in cone opponent cells.

**5.4 Step 3: Color Appearance**

5.4.1 Describe the various ways that the three-dimensional color space is represented and indexed.

5.4.2 Describe opponent color theory and how it has been studied with color cancellation experiments.

5.4.3 Explain the phenomenon of achromatopsia.

**5.5 Individual Differences in Color Perception**

5.5.1 Summarize the ways in which language does or does not influence our perception of color.

5.5.2 Describe the various forms of anomalous color vision.

5.5.3 Explain the concept of synesthesia.

**5.6 From the Color of Lights to a World of Color**

5.6.1 Explain how the perception of color can be influenced by context.

5.6.2 Predict which color a negative afterimage will be depending on the color of the adapting stimulus.

5.6.3 Describe the concept of color constancy and how it is achieved by the visual system.

**5.7 What Is Color Vision Good For?**

5.7.1 Describe some of the ways that color vision is useful for humans and animals.

5.7.2 Describe some of the ways that color can influence perceived flavor.

**Chapter Summary**

1. Probably the most important fact to know about color vision is that lights and surfaces look colored because a particular distribution of wavelengths of light is being analyzed by a particular visual system. Color is a mental phenomenon, not a physical phenomenon. Many animal species have some form of color vision. It seems to be important for identifying possible mates, possible rivals, and good things to eat. Color vision has evolved several times in several different ways in the animal kingdom.

2. Rod photoreceptors are sensitive to low (scotopic) light levels. Humans have only one type of rod photoreceptor; it yields one “number” for each location in the visual field. Our rods can support only a one-dimensional representation of color, from dark to light. Thus, human scotopic vision is achromatic vision.

3. Humans have three types of cone photoreceptors, each having a different sensitivity to the wavelengths of light. Cones operate at brighter light levels than rods, producing three numbers at each location; the pattern of activity over the different cone types defines the color. Some animals have many more types of photoreceptors, but we know rather little about their color experience.

4. If two regions of an image produce the same response in the three cone types, they will look identical; that is, they will be metamers. And they will look identical even if the physical wavelengths coming from the two regions are different.

5. In additive color mixture, two or more lights are mixed. Adding a light that looks blue to a light that looks yellow will produce a light that looks white (if we pick the right blue and yellow). In subtractive color mixture, the filters, paints, or other pigments that absorb some wavelengths and reflect others are mixed. Mixing a typical blue paint and a typical yellow paint will subtract most long and short wavelengths from the light reflected by the mixture, and the result will look green.

6. Color blindness is typically caused by the congenital absence or abnormality of one cone type—usually the L- or M-cones, usually in males. Most color-blind individuals are not completely blind to differences in wavelength. Rather, their color perception is based on the outputs of two cone types instead of the normal three.

7. A single type of cone cannot be used, by itself, to discriminate between wavelengths of light. To enable discrimination, information from the three cones is combined to form three cone-opponent processes. In the first, cones sensitive to long wavelengths (L-cones) are pitted against medium-wavelength (M) cones to create an L – M process that is *roughly* sensitive to the redness or greenness of a region. In the second cone-opponent process, L- and M-cones are pitted against short-wavelength (S) cones to create an (L + M) – S process *roughly* sensitive to the blueness or yellowness of a region. The third process is sensitive to the overall brightness of a region.

8. Color appearance is arranged around opponent colors: red versus green, and blue versus yellow. This color opponency involves further reprocessing of the cone signals from cone-opponent processes into color-opponent processes.

9. The visual system tries to disentangle the properties of surfaces in the world (e.g., the “red” color of a strawberry) from the properties of the illuminants (e.g., the “golden” light of evening), even though surface and illuminant information are combined in the input to the eyes. Mechanisms of color constancy use implicit knowledge about the world to correct for the influence of different illuminants and to keep that strawberry looking red under a wide range of conditions.

**References for Lecture Development**

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Gegenfurtner, K. R., and Kiper, D. C. (2003). Color vision. *Annu Rev Neurosci* 26: 181–206.

Kaiser, P. K., and Boynton, R. M. (1996). *Human Color Vision* (2nd ed.). Washington, DC: Optical Society of America.

Shevell, S. K. (2003). Color appearance. In S. K. Shevell (Ed.), *The Science of Color* (2nd ed., pp. 149–190). Oxford, UK: Elsevier.

[The whole book is recommended.]

Stockman, A., & Brainard, D. H. (2010). Color vision mechanisms. *OSA Handbook of Optics*, 11-11.

[An advanced, technical treatment of color vision mechanisms.]

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**Video and Image Resources from the Internet**

***Color Mixing***

Color Mixing: The mystery of magenta

<https://youtu.be/iPPYGJjKVco>

Addresses color perception, color mixing, and the strange case of magenta.

How a TV Works in Slow Motion – The Slow Mo Guys

<https://youtu.be/3BJU2drrtCM>

Starting at 7:30, the host shows a close-up image of the red, green, and blue sub-pixels in a 4k television and discusses how colors are produced by lighting up different sub-pixels.

A gif of just this section of the video is available here: https://gfycat.com/EmptyBlueFairybluebird

***Qualia***

Is your red the same as my red?

<https://youtu.be/evQsOFQju08>

An exploration of color vision and the philosophical question of whether everybody perceives colors the same way. This gets into some theory of mind experiments.

***Color Afterimages***

Negative color afterimage of a courtyard

<http://i.imgur.com/I0Ox6.gif>

A particularly effective color afterimage demo.

Negative color afterimage of a stylized city scene.

<http://orig03.deviantart.net/26e2/f/2010/287/1/b/yet_another_optical_illusion_by_varuas-d30rx6p.gif>

An effective color afterimage demo.

***Color Blindness***

Colorblind—a colorful guide to colorblindness (infographic)

<http://youtu.be/8Aaivktz8G0>

This video won first prize at the 2013 Salazar Awards in the category of “Video & Animation,” as well as a 2013 Applied Arts Magazine Student Award.

Color blindness 4: Simulation

<http://youtu.be/XncZ3aPjXMY>

Simulation of color blindness. Estimate of what color scenes look like with different levels of color deficiency. Range includes: zero cones, one cone, two cones, and two normal and one hybrid cone. The latter is most common. Dalton describes his color vision.

The Origins of Human Color Vision – HHMI BioInteractive Video

<https://youtu.be/1zw2RE-PavQ>

Why do humans see in color? Around 23 million years ago, our primate ancestors were red-green colorblind. Neil Shubin asks color vision expert Jay Neitz how color vision evolved. The answer is in our DNA. This biology classroom-ready educational video allows students to experience the trichromatic theory of color vision.

***Synesthesia***

What is synesthesia?

<https://youtu.be/4upZHjZnM-0>

A quick overview of the condition of synesthesia and what may cause it.

***Color Constancy***

Incredible color constancy illusion!

<https://youtu.be/XYnqH_HHZDo>

Here’s an amazing effect called color constancy. This illusion is caused by the separate red and green illumination of the two cubes and by the apparent shadows that are cast on their front surfaces. We interpret colors as being constantly the same even if there are shadows or different illumination conditions (such as the red and green “lighting” effect). We also define/perceive colors based on their surroundings. The end result is that we see the marked square on the left cube as being light blue (cyan) and the marked square on the right cube as being red. Removing their cue-producing surroundings and placing them next to each other reveals that they are both, in fact, reddish-gray.