CHAPTER 3: NEURAL PROCESSING

Chapter Outline

I. Introduction
   A. Some Questions We Will Consider

II. Inhibitory Processes in the Retina
   A. Lateral Inhibition in the *Limulus*
      1. Hartline et al. (1956)
         a. Ommatidia
         b. Lateral plexus

   B. Using Lateral Inhibition to Explain Perception
      1. The Lateral Inhibition Explanation of the Chevreul (Staircase) Illusion
         a. Chevreul (Staircase) Illusion
         b. Mach Bands
      2. The Lateral Inhibition Explanation of the Hermann Grid
         a. Bipolar cells, initial response

   C. Problems with the Lateral Inhibition Explanation of the Chevreul Illusion and the Hermann Grid
      1. Chevreul Illusion
         a. Luminance Ramp
      2. Hermann Grid

III. Test Yourself 3.1

IV. Processing from Retina to Visual Cortex and Beyond
   A. Responding of Single Fibers in the Optic Nerve
      1. Receptive fields
         a. Center-surround organization
            i. Excitatory-center, inhibitory-surround
            ii. Inhibitory-center, excitatory-surround
         b. Center-surround antagonism
   B. Hubel and Wiesel's Rationale for Studying Receptive Fields
      1. Method: Presenting stimuli to determine receptive fields
      2. Visual pathway
         a. Optic Nerve
         b. Lateral Geniculate Nucleus (LGN)
         c. Superior Colliculus
         d. Occipital Lobe
         e. Visual receiving area/striate cortex
   C. Receptive Fields of Neurons in the Visual Cortex
      1. Simple cortical cells

a. Side-by-side receptive fields
b. Orientation tuning curves
2. Complex cortical cells
3. End-stopped cortical cells
4. Table: Properties of neurons in the Optic Nerve, LGN, and Cortex

V. Do Feature Detectors Play a Role in Perception?
A. Selective Adaptation
1. Method: Psychophysical Measurement of the Effect of Selective Adaptation to Orientation
a. Contrast threshold
b. Adapting stimulus
B. Selective Rearing
1. Neural plasticity

VI. Higher-Level Neurons
A. Inferotemporal (IT) cortex
B. Fusiform face area (FFA)

VII. Sensory Coding
A. Specificity Coding
B. Population Coding
C. Sparse Coding

VIII. Something to Consider: “Flexible” Receptive Fields
A. Contextual Modulation

IX. Test Yourself 3.2

X. Think About It

XI. Key Terms

Learning Objectives

At the end of the chapter, the student should be able to:

1. Define lateral inhibition, and describe research demonstrating the phenomenon.
2. Discuss lateral inhibition accounts and issues for three perceptual phenomena (Chevreul Illusion, Mach Bands, and Hermann Grid).
3. Define and identify “receptive field” and discuss techniques to map them.
4. Describe the basic function of the LGN, and differentiate among simple cortical cells, complex cortical cells, and end-stopped cortical cells.
5. Describe the method used for selective adaptation to orientation, and discuss how the phenomenon is related to feature detectors.
6. Contrast specificity coding, distributed coding, and sparse coding.
7. Discuss “flexible” receptive fields and explain context modulation.

Chapter Overview/ Summary

Chapter 3 begins with additional discussion of the neural processing of visual information from the retina to the striate cortex. At the retinal level, lateral inhibition is introduced to describe the interaction between neurons. The Chevreul Illusion, Mach Bands, and the Hermann Grid are three phenomena that can be explained by lateral inhibition; however, there are some problems with these explanations. From the retina, information travels through the optic nerve which is composed of the axons of retinal ganglion cells. Each "fiber" of the nerve is associated with a receptive field (which typically includes the information from hundreds of receptors). The receptive field is the area on the retina that influences the firing rate of the neuron. Antagonistic center-surround (excitatory vs. inhibitory) configurations are prevalent receptive field patterns. This early receptive field work lead to Hubel and Wiesel's systematic investigation of receptive fields in the visual pathway. Further neural processing occurs in the lateral geniculate nucleus, the striate cortex (containing simple, complex, and end-stopped cells), and the striate cortex. Because the different cortical neurons respond to specific features of a stimulus, these neurons are often referred to as "feature detectors." Feature detectors play a role in visual perception, as demonstrated by selective adaptation to orientation (using grating stimuli and contrast sensitivity). Research that shows selective rearing of cats in an environment that contains only vertical lines also supports the role of feature detectors in vision. The last major topic in the chapter is the sensory code: How does the firing of neurons represent various characteristics of the environment. Three theories are: (1) specificity coding; (2) population coding; and (3) sparse coding. The "Something to Consider" portion of the chapter addresses the idea that receptive fields are flexible, and firing rates can be affected by what happens outside the receptive field – contextual modulation.

Demonstrations, Activities, and Lecture Topics

(1) **<u>Create your own Hermann Grid:</u>** Students will occasionally ask about variants of the Hermann Grid, e.g., "What happens if you use colors?"; "What happens if you change the spacing between the squares?" To provide a brief answer to these questions, have the students create the "Hermann Grid" that answers the question. This is very easy using PowerPoint ™, which most students have used. Simply use the "auto-shapes", make 15 copies of the original square, and then place the squares in the appropriate pattern and the desired fill colors. (This takes about 10 minutes for even an inexperienced user). They can then answer their own questions.

(2) **<u>A different theory of brightness illusions:</u>** A review article by Purves et al. summarizes the Mach bands brightness illusions covered in Chapter 3 in addition to the Chubb-Sperling-Solomon illusion and the Craik-O'Brien-Cornsweet edge effects. The main premise of the article, however, is to propose a counterargument to the "conventional" lateral inhibition explanations (as used in Goldstein): an "empirical framework" theory. This theory is based, not on visual neural circuits, but on the probability of the source of the ambiguous stimulus. Purves, D., Williams, M., Nundy, S., & Lotto, R.B. (2004). Perceiving the intensity of light. *Psychological Review, 111*, 142-158. Corney and Lotto (2007) use computational methods to study illusory perception, with the aim to show *why* these illusions come about. They show that natural stimuli are ambiguous, and that these ambiguities are resolved by encoding the statistical relationships between images and scenes in past visual experience. Corneym D. and Lotto, R.B. (2007). What are Lightness Illusions and Why Do We See Them? *PLOS Biology*. doi: 10.1371/journal.pcbi.0030180.

(3) <u>How did they do that? Chubb-Sperling-Solomon Illusion:</u> An interesting aspect of perceptual phenomenon is how an effect is discovered. I contacted Charlie Chubb to find out the origins of the Chubb-Sperling-Solomon illusion. Chubb had been doing work on motion with George Sperling. One of the displays they were developing was to start with a visual noise stimulus and "window" the noise with a drifting sinusoidal pattern. Through brainstorming, the three authors wondered whether texture would work the same way as luminance changes in the display. To test this idea, they used simultaneous contrast displays with the visual noise. This first attempt even surprised them (it "pretty much knocked our socks off," according to Chubb), and resulted in the illusion that now bears their names. The moral: Knowledge, brainstorming, and playing with the stimuli can lead to amazing discoveries!

Chubb, C.F., Sperling, G., & Solomon, J.A. (1989). Texture interactions determine perceived contrast. *Proceedings of the National Academy of Sciences, USA, 86,* 9631-9635.

(4) <u>How did they do that? White's Illusion:</u> Michael White also graciously supplied a narrative of the creative process behind the discovery of the illusion that now bears his name. He had some setbacks in his early undergraduate and graduate career, and had doubts about his career path, when:
"… early in 1976, and Vicki and I had a two-year-old son and baby daughter, with the scholarship income available only to the end of the year. I was despondent about my prospects as a scientist.

Then, in February 1976 something wonderful happened. I had been interested in the relationships between art (particularly modern art) and illusions. I was reading O*ptical Art* by Rene Parola (1969), when I saw an astonishing picture by Susan Hirth, who was one of Parola's 11th Grade students. It was a 'busy' design with black, white and grey elements, where two wedge-shaped sets of physically identical mid-grey annular segments appeared to be very different in lightness (shade of grey). Although the new illusion was in a chapter explaining various lightness contrast and lightness assimilation (the opposite of contrast) effects, Parola offered no real explanation for it. Presumably, he assumed that it was some sort of contrast or assimilation effect, and he simply noted that "The grey wedges seem different." To me, it seemed that the illusion was not readily explicable in terms of classical lightness contrast or assimilation, and I believed that I had stumbled across a powerful new effect. The following days, weeks and months

were very exciting. I started by designing simple variants of the illusion to extract its essence. This was before image digitization was readily available, so the designs were created by cutting shapes from black, white and mid-grey paper and gluing them together. Eventually, I isolated what I considered to be the essential effect - now commonly known as ‘White’s Illusion.’ This history is described in my PhD thesis, but is absent from my journal articles. As well as producing the designs, I read the relevant research literature, and speculated about possible explanations. I would sometimes get out of bed in the middle of the night to scribble down my latest bright idea. By the end of 1976, I had produced scores of designs, and conducted some simple experiments. Progress was satisfactory, but the remainder of my PhD research would take another five years (1977-1981) during which time I was again employed as a tutor in the Psychology Department. One of my greatest thrills was to produce a ‘dotty’ version of the illusion. It had seemed to me that the illusion essentially consisted of patterned black/grey and white/grey test regions in patterned black/white surrounds. While the pattern in the original illusion was a square-wave grating, it occurred to me that the illusion might also work with regular ‘dotty’ patterns. My father and I spent many hours creating such patterns from black, white and mid-grey paper with the help of a large leather punch to make the circular holes. The results were amazing. The different combinations of test-region and surround patterns led to very different apparent shades of grey in the objectively mid-grey test regions. The difference in lightness between two particular test regions was even stronger than in the grating version of the illusion. It was an amazing feeling to be the first person ever to see the strongest effect yet produced in what is one of the most basic human capacities - the ability to perceive differences in lightness.”
Another wonderful and inspiring message for our students!

White, M. (1979). A new effect of pattern on perceived lightness. *Perception*, *8*, 413-416.

(5) Contrast sensitivity and acuity and performance: Students will be familiar with the Snellen eye chart as a measure of acuity, but will not be aware of the uses of contrast sensitivity to measure acuity. Various applications include testing jet pilots, driving, computer usage, and sports. Age-related differences (in Evans and Ginsburg) and dynamic visual acuity (in Long and Zavod) can also be discussed.

Evans, D. W., & Ginsburg, A. P. (1985). Contrast sensitivity predicts age-related differences in highway-sign discriminability. *Human Factors*, *27*, 637-642.

Grimson, J. M., Schallhorn, S. C., & Kaupp, S. E. (2002). Contrast sensitivity: Establishing normative data for use in screening prospective naval pilots. *Aviation, Space, & Environmental Medicine*, *73*, 28-35.

Jacko, J. A., Rosa, Jr., R.H., Scott, I.U., Pappas, C.J., & Dixon, M. (2000). Visual impairment: The use of visual profiles in evaluations of icon use in computer-based tasks. *International Journal of Human-Computer Interaction, 12*, 1044-1054.

Long, G. M., & Zavod, M. J. (2002). Contrast sensitivity in a dynamic environment: Effects of target conditions and visual impairment. *Human Factors*, *44*, 120-132.

Rabin, J. (1995). Small letter contrast sensitivity: An alternative measure of visual resolution for aviation candidates. *Aviation, Space, & Environmental Medicine, 66,* 56-58.

(6) Animal research ethics: The research on selective rearing will elicit some strong reactions from some students. An instructor might want to be prepared for some questions about animal research. Each instructor probably covers this at some point in his/her courses, and has appropriate references. One suggestion is:
McCarty, R. (1998). Making the case for animal research. *APA Monitor*, Nov., 18.
Bennett, A.J. (2012). Animal research: The bigger picture and why we need psychologists to speak out. Psychological Science Agenda, April 2012.

(7) Video suggestions: *"Vision and Movement"* from *"The Brain"* series (from WNET) has segments that show Hubel and Wiesel's work on discovering simple and complex cells in the cat visual cortex, and Russell DeValois' research on mapping the monkey visual cortex. The video also contains an example of how different spatial frequencies synthesize to form a complex visual image.
"Discovering Psychology" by Zimbardo contains a chapter titled "Sensation and Perception." A segment toward the beginning of this chapter also has an interview with Hubel about mapping cortical cells, as well as Misha Pavel explaining feature and edge detection.

(8) Book Recommendation: Steven Yantis's collection of important articles in visual perception is a great resource for additional readings. The readings most appropriate for this chapter are Helmholtz's "Concerning the perceptions in general"; Barlow's "Single units and perception"; and Hubel and Wiesel's "Receptive fields and functional architecture of monkey striate cortex." The whole book has other readings that could be assigned as well for later chapters.

Yantis, S. (ed.), (2001). *Visual perception: Essential readings.* Philadelphia: Psychology Press.

Suggested Websites

ePsych: An Electronic Psychology Text
The site contains many student-friendly tutorials, very readable, informative, and sprinkled with humor. Click on "The Eye" – (page 22 onwards) provides a brief overview of early visual processes and concepts and continues to a primer on receptive fields.

Lightness Perception and Lightness Illusions Interactive Movies
Ted Adelson has animated versions of numerous lightness illusions at this website. Simultaneous contrast, White's Illusion, the Koffka ring, the Knill and Kersten illusion, the Vasarely illusion, and Craik-O'Brien-Cornsweet illusion are all shown. All illusions are followed by a brief explanation of the effect.

Sandlot Science
This popular website is geared toward a general audience, but contains an interactive version of White's illusion and several other illusions. From the homepage select "The Mother of all Site Maps" and scroll down to "Contrast & Color"

David Hubel's *Eye, Brain, and Vision*
This is the website for Hubel's book *Eye, Brain, and Vision.* Chapter 4 (Primary Visual Cortex) and Chapter 5 (Architecture of the Visual Cortex) are excellent supplements to the Goldstein text material. Readable, with outstanding photos and figures.

The Primary Visual Cortex - Webvision
Matthew Schmolesky provides a biologically-oriented piece on the visual cortex on the Webvision website. The page contains great graphics and information. It also includes some historical perspectives on vision.

John Krantz Sensation and Perception Tutorials
John Krantz has created excellent tutorials for undergraduate students for Sensation & Perception. For Chapter 3, the tutorials on receptive fields are recommended. Krantz also has a model of the Retina, LGN, and Primary Visual Cortex; information is available at "Interactive Sensation Laboratory Exercises (ISLE)" link.

The Joy of Visual Perception: A Web Book
This York University website features a web book, *The Joy of Visual Perception*, that is an excellent resource for receptive fields. Be sure to check out the numerous links also.

Movie Scene – *The Matrix* (1999)
(38:38-40:38): In this famous scene, Morpheus (Laurence Fishburne) is revealing to Neo (Keanu Reeves) what the "Matrix" is. He begins by asking "What is real?" The answer relates to materialism; that is, our perceptual experience is due to neural firing. It is also related to the "easy" and "hard" problems of consciousness. This is an excellent, familiar scene to motivate students to learn about the biological approach to perception and to

encourage them to think about what is known and unknown about our conscious experience.