Vision Science II - Monocular Sensory Aspects of Vision

Lecture 41 –Magnitude of Sensation, Fechner's log law, neural adaptation

REVIEW OF ROC CURVES AND SIGNAL DETECTION

The theory of signal detection help us understand and analyze problems in which you must detect something that is embedded in a background that include random noise. Examples include,

1. Measuring visual thresholds. In this case, both background neural noise and the visual stimulus will cause neural activation.
    - How well will you be able to pick out the stimulus from the background?
    - What is the probability that you will correctly detect the stimulus (hit rate)
    - What is the probability that you miss the stimulus when it is there? (1-hit rate)
    - What is the probability that you will think it's there when it is not? (false alarm)
    - What is the probability that you will correctly say it's not there? (1-false alarm)

    The answer will depend on the **detectibly** and the **criterion**.
2. Evaluating diagnostic tests. In this case you will be measuring some parameter (such as IOP) for both healthy and diseased eyes.
    - How well will you be able to pick out the diseased eye from the normals?
    - What is the probability that you will correctly diagnose the disease (hit rate; sensitivity)
    - What is the probability that you miss the disease when it is there? (1-hit rate)
    - What is the probability that you will think it's there when it is not? (false alarm; 1-sensitivity)
    - What is the probability that you will correctly say it's not there? (specificity)

Ideally, you would like to have a diagnostic test that will

- Correctly detect the disease every time (sensitivity = 100%), and
- Correctly diagnose all healthy eyes as healthy and not diagnose them as diseased (false alarm rate = 0%). That is, you would like to have a specificity = 100%. (specificity = 1- false alarm rate)

How can you choose the best diagnostic test among several options? If you use the ROC analysis, the best test will have the highest specificity and the lowest false alarm rate. Which of the following curves indicates the best diagnostic test (A, B or C)?

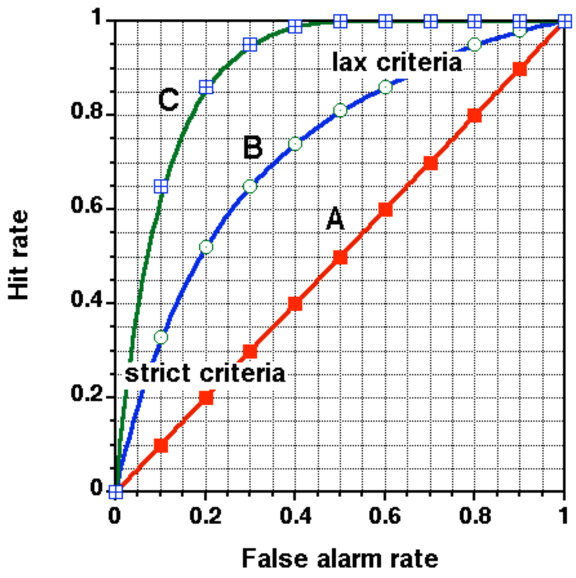

Figure 1. Three ROC curves

Q. If the ROC curve in Figure 1 referred to a visual threshold experiment, how much brighter would the stimulus be than the background if the response is described by ROC Curve A? That is, for Curve A, what is the detectability, and why?

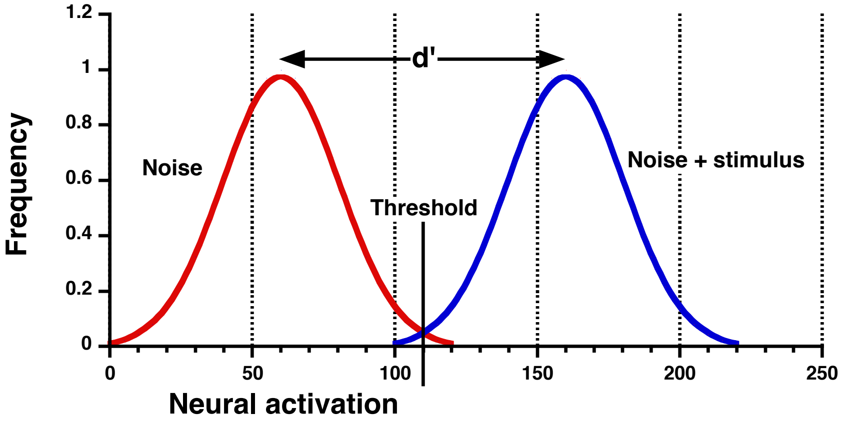

Figure 2. Detectability

Returning to the concept of a diagnostic test, we decided that ROC Curve C shows that Test C is the best diagnostic test. Recall that a good diagnostic test should have high sensitivity (a high hit rate) and a low false alarm rate.

Q. What would the hit rate (sensitivity) be for Test A?

A.

The answer is, "It depends." For any single diagnostic test, the specificity and false alarm rates will vary depending on the diagnostic criterion. This was referred to as "threshold" in the Scientific American article. For example, in the case of tonometry, if you will set your diagnostic criterion low (i.e., IOP>18 = glaucoma suspect), then you will have high sensitivity (high hit rate), but also a high false alarm rate. But if you set the criterion higher (i.e., IOP>33 = glaucoma suspect), you will decrease the false alarm rate, but you will also decrease the sensitivity (hit rate).

MAGNITUDE OF SENSATION

Previously we have been discussing thresholds; that is, stimuli which are very difficult to detect. Psychophysical experiments can also be performed to test the response to suprathreshold stimuli. That is, stimulus intensities that are well within the range of seeing. For example, how does the magnitude of sensation increase with increasing stimulus intensity above threshold? For example, is a 20/40 letter twice as easy to see as a 20/20 letter?

Perception of the value of money

In an attempt to understand perception and find a psychophysical law governing perception, mathematician Daniel Bernoulli (1738) studied how people perceive the value of money. He observed that people respond to money in proportion to its *perceived* value rather than its actual value. For example, a fixed amount of money, such as $20, has greater value to a poor person (like a child) than to a rich person (like Bill Gates). Bernoulli proposed that the perceived value of money increases as the log of the amount of money that the person owns.

Weber's law

We previously studied Weber's law in the section on light adaptation. Weber's law applies to detection of an increment threshold against a background (Schwartz Fig. 11-11). Weber developed the concept of the "**just noticeable difference**" (**JND**, which is the smallest increment that can be detected).

Recall that the JND, or the increment needed to detect a stimulus against a background, is a constant fraction of the background intensity. Schwartz Fig. 11-12 illustrates this with a case in which a subject is trying to detect a dark gray letter against a light gray background. Suppose the subject can just barely see the letter in low illumination if the background luminance is 102 and the letter's luminance is 100; that is a ΔL (JND) is 2. Weber's fraction in this case is equal to:

$$W_1 = \frac{\Delta L_1}{Background_1} = \frac{2}{102} = 0.196$$

If the illumination of the entire chart is increased by a factor of 100, the background luminance will increase to 10,200 and the letter will be barely detectable if its luminance is 10,000. In this case the ΔL (JND) is equal to 200 and Weber's fraction is:

$$W_2 = \frac{\Delta L_2}{Background_2} = \frac{200}{10{,}200} = 0.196$$

Weber's fraction says that, when detecting an increment against a background, the JND (ΔL) is a constant fraction of the background. This is closely related to contrast, so over a wide range of luminances, it is contrast, rather than the absolute luminance of a target that determines how easy it is to see.

This also means that the perceived brightness of an object is strongly influenced by its background. Figure 3 illustrates this in the phenomenon known as **simultaneous contrast**. The central square in the middle of both backgrounds have the same luminance, but the left one appears darker and the right one appears brighter. This shows that brightness ≠ luminance.

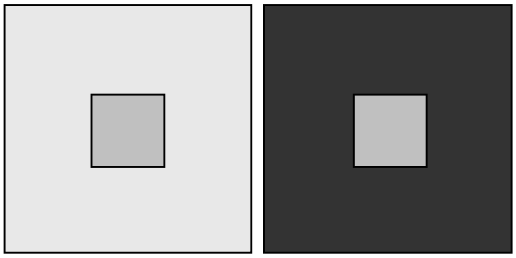

Figure 3. Simultaneous contrast.

A similar phenomenon, known as simultaneous color contrast is illustrated in Figure 4, below.

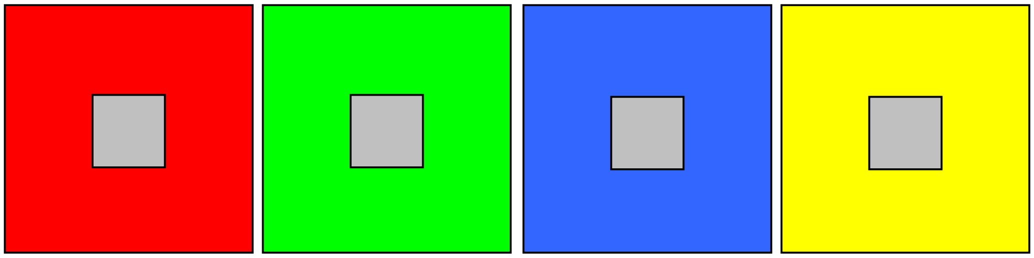

Figure 4. In simultaneous color contrast, a gray area surrounded by a colored field will appear to be slightly tinted in the complementary hue of the surround.

In **successive color contrast** - If you stare at one color, then view a white field, you should see an after-image that has the complementary hue of the color you had been staring at. We saw this in the flag illustration in lecture on color opponent theory.

Fechner's log law

Weber's work with thresholds was the background for Fechner's research on suprathreshold sensations. At what rate does the magnitude of sensation increase as the stimulus intensity increases? **Fechner's log law** states that the magnitude of sensation (S) increases in proportion to the log of stimulus intensity (I). Variable c is a constant, which is related to Weber's law.

$$S = c \cdot \log(I)$$

He used the technique of **indirect scaling** by assuming that sensations increase in the same relative step size as the threshold detection increment; that is, as a direct function of JND (or ΔL). Fechner's log law is also called the **psychophysical law**, and it has been widely accepted within the field of psychophysics. That is why many sensory (psychophysical) tests use a logarithmic or decibel scale.

- For example hearing tests use decibels. A ten-decibel increase in sound intensity is a ten-fold (one log unit) increase in sound level.
- Likewise, the letters on logMAR visual acuity charts are designed to increase in 0.1 log steps. Based on Fechner's log law, the visual difficulty on a logMAR chart will increase in equal perceptual steps. Besides visual acuity, decibel scales are also used in Humphrey Field Analyzer, the Matrix frequency doubling device and in describing stimulus brightness in electrodiagnostic tests.

Steven's' power law

Fechner's log law is well established and has been used in many fields of psychophysics for over 100 years, Steven's (1957) studied suprathreshold perception by having subjects directly assign a numerical value to their sensations (for example brightness) as the stimulus intensity was increased. This is called **direct scaling**. He concluded that the magnitude of sensation increases as a power (exponent) function (**Steven's power law**.

$$S = I^a$$

The value of exponent a varies depending on the nature of the stimulus. Examples: Loudness (0.67), smell (0.6), brightness of 5-degree patch (0.33), redness (1.7). Stephen's power law and Fechner's log law give slightly different predictions as to how the magnitude of sensation should increase with increasing stimulus intensity (Schwartz Fig. 11-13).

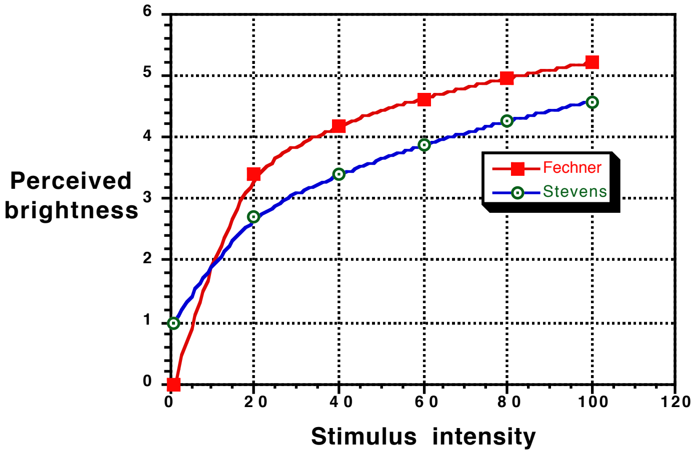

Figure 5. Example plot showing Fechner's (squares; c=2.6) and Steven's (dots; a=.33) predictions for perceived brightness as a function of stimulus intensity.

THE FOUR CONSTANCIES

For completeness, here's a few more miscellaneous terms you should know about visual perception—the four constancies.

- size constancy
- shape constancy
- brightness constancy
- color constancy

We discussed **size constancy** earlier in the course. It is also known as **distance constancy**, and is defined as "The relative apparent stability or lack of perceived change in the size of an object, despite a change in viewing distance, actual size, or other related stimulus factors." (From the Dictionary of Visual Science, 4th Edition). That is, even though retinal image size changes, it is still perceived to maintain the same size. Many illusions, including the moon illusion, are based on the principle of size constancy.

Shape constancy, also known as **form constancy** is defined as, "The relative apparent stability or lack of perceived change in the shape of an object, despite a change in the direction or angle of view." That is, even though an object's retinal image changes shape, it is perceived to still have the same shape.

The Dictionary of Visual Science defines **brightness constancy** (or **lightness constancy**) as

> *A perceptual phenomenon wherein the perceived or subjectively attributed brightness of an object or a surface tends to remain fixed at a pre-perceived or attributed brightness level, rather than in direct ratio with the actual brightness, e.g., a piece of intensely illuminated coal may continue to seem black though actually brighter than an adjacent sheet of dimly illuminated white paper.*

Color constancy, which was discussed before, is defined as the "relative apparent stability or lack of perceived change of the color of an object, despite a change in the spectral composition of incident light, or of adjacent surfaces, or of other related stimulus factors." (Dictionary of Visual Science, 4th Edition)

NEURAL ADAPTATION

Finally, I want to mention a fascinating topic I heard about at the 2009 ARVO meeting about neural mechanisms that can compensate for optical blur. The quality of a person's vision, for example, visual acuity, is strongly affected by optical blur. As optometrists, we deal with this problem everyday, and as I've stated before, the most common cause of poor vision is an uncorrected refractive error. But, it is possible that the brain can partially compensate for and improve vision in the presence of optical blur? Drs. Sabesan and Yoon (University of Rochester) studied this in a fascinating experiment, described in an ARVO 2009 poster #3048 entilted, "Neural Compensation for Asymmetric Optical Blur to Improve Visual Performance in Keratoconic Eyes.

The purpose of this study was to see if the brain compensates for optical blur caused by irregular higher order aberrations. That is, even without an optical correction, can the brain improve visual acuity by a neural mechanism? Sabesan and Yoon test this by comparing visual acuity for a group of moderate keratoconic eyes and a group of normal eyes.

- The keratoconic group consisted of 4 eyes that were corrected with a toric soft contact lenses. This corrected the lower-order aberrations, but the higher-order aberrations were not corrected.
- The control group consisted of 3 non-keratoconic emmetropic eyes whose higher-order aberrations were first corrected, and then, using an adaptive optics system, they viewed visual acuity charts through the same higher-order aberration that the keratoconus eyes had.

In theory, eyes in both groups had lower-order aberrations corrected, and also had the same higher-order aberrations. The only difference was that the keratoconic patients had long-term experience with those aberrations. Sabesan and Yoon hypothesized that the keratoconic patients may have developed neural mechanisms to compensate for the aberrations.

The normal eyes had no experience with those aberrations, and therefore could not have developed any compensatory neural mechanisms. They tested high (100%) and low (20%) contrast visual acuity and compared results for the two groups. The mean visual acuity (both high and low contrast) was about one line better for the keratoconus eyes. This was a statistically significant difference and indicated that the keratoconic eyes had developed compensatory mechanisms to improve visual acuity in the presence of irregular higher-order aberrations.

In another study, Sabesan and Yoon found that, if you perfectly correct all the refractive error of keratoconic patients, including the higher and lower order aberrations, their visual acuity is not as good that of non-keratoconic patients who had their lower and higher order aberrations corrected. This is because the neural mechanisms that partially compensated for the higher order aberrations are still working, and with the addition of a full optical correction, the keratonic eyes are, in effect, over corrected and have less-than-ideal visual acuity. The normal eyes didn't have large higher order aberrations, therefore they did not have the neural mechanisms. (Journal of Vision, 2009, Visual performance after correcting higher order aberrations in keratoconic eyes; http://journalofvision.org/9/5/6/). They found that the keratoconic patients actually had better visual acuity if their higher order aberrations were slightly undercorrected. The maximum benefit came when their aberrations were corrected to about 70% of the full correction.

This leads to some interesting questions.

- When correcting patients who has never worn glasses before, would it be better to give them a less-than-full Rx, rather than giving them perfect corrections?
- If the brain can partially compensate for optical blur, can you train the brain to see better without glasses?

This kind of neural adaptation mechanism may be the scientific basic for the NeuroVision system, which was described in an article published in the Journal of Cataract and Refractive Surgery in Aprll 2008 (Efficacy of neural vision therapy to enhance contrast sensitivity and visual acuity in low myopia.
by Donald Tan and Allan Fong, p. 570-577).

This study was conducted in Singapore to test whether NeuroVision correction technology (NVC) could improve vision in patients with low myopia. NVC aims to improve vision by training neurons in the visual cortex. Individualized, computer controlled Gabor patterns (Figure 6) were used to train the visual cortex. 20 adults with myopia between –0.50 and –1.50 D, with astigmatism less than or equal to 0.50 D participated in the vision therapy for up to 3 months, with follow-up for a year after treatment. All subjects showed an improvement in uncorrected visual acuity and contrast sensitivity. On average, the visual acuity improved 2.1 lines and contrast sensitivity improved across a wide range of spatial frequencies (1.5 to 18 c/d). They concluded that NVC treatment is safe and effective for improving the vision of low myopes.

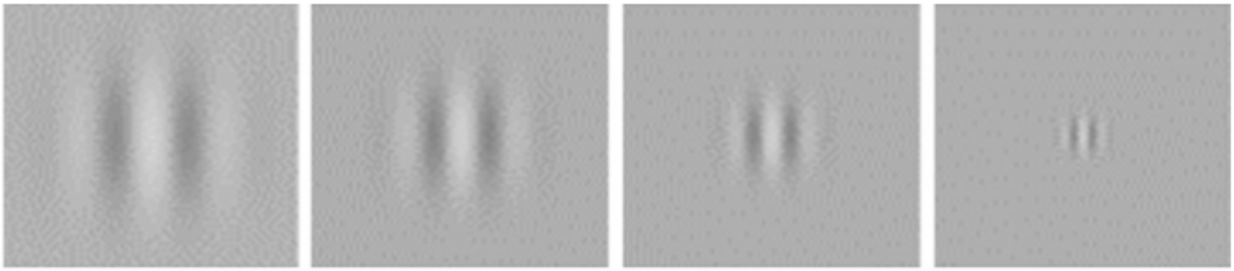

Figure 6. Examples of Gabor patches, which are used to train the visual cortex in NVC.