ROC CURVES, MAGNITUDE OF SENSATION

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THIS CHAPTER WILL INCLUDE A REVIEW OF:

- ROC curves
- Example of decision theory in glaucoma
- Magnitude of sensation
- The four constancies

ROC CURVES

The subjective responses obtained for different criteria levels and different stimulus intensities (delectability, d') can be plotted on a receiver operating characteristic (ROC) curve. It plots the hit rate (true positives) as a function of false alarm (false positive) rate for many repeated trials (Figure 33-1, below and Schwartz, 2004 Fig. 11-9). Each ROC curve represents one level of detectability – that is, a level of stimulus intensity above the background. When detectability is small, the stimulus is hard to see and you get a large number of false alarms as well as hits. An extreme example is represented by ROC curve A in Figure 33-1. ROC curve A represents a detectability of d'=0.

ROC CURVES

Q. Why?

A. For higher stimulus intensities, detectability increases, and the target will become easier to see. There will be fewer false alarms and more hits, such as that shown in Curve C.

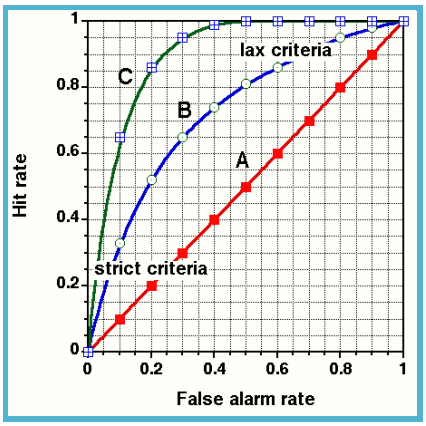

Figure 33-1: *Three ROC curves*

Within one ROC curve, the detection criterion is plotted as a single point on the curve, as shown in Schwartz, Fig.11-9 A and Fig. 33-1. This is because the criterion determines the probability of both the hits and false alarms.

EXAMPLE OF DECISION THEORY IN GLAUCOMA

The use of ROC curves and the theory of signal detection are not limited to psychophysical experiments. ROC curves are frequently used to evaluate medical diagnostics tests that are designed to detect something such as a disease in a population (like the signal+noise) from a normal population (the noise). These techniques have also been used to evaluate the GDx machine, to evaluate how good it is for diagnosing glaucoma. Sometimes the hit rate is called the **"sensitivity"** of the diagnostic test. Sensitivity of the test is the probability of correctly diagnosing the disease when it is present (a true positive). The correct rejection is also sometimes referred to as the **"specificity."** Specificity is the probability of correctly diagnosing a normal condition when it is actually normal (a true negative).

Since, (false alarm) = 1 − (correct rejection)

You can also say, (false alarm) = 1 − (specificity)

ROC curves associated with diagnostic tests may be plotted with hit rate along the y-axis and false alarm rate along the x axis, or you may see ROC curves with sensitivity plotted along the y-axis and **1-specificity** plotted along the x-axis. The example below (Fig 33-2) comes from a glaucoma research article (Johnson C, Samuels SJ. Screening for Glaucomatous Visual Field Loss With Frequency-Doubling Perimetry. Invest Ophthalmol Vis Sci. 1997; 38: 353-425).

A good diagnostic test is one that has a high detectability; that is, an ROC curve that extends closer to the upper-left corner or top of the ROC plot. Another statistic used is the area under the ROC curve. A better diagnostic test would be one that has a larger area under the ROC curve.

EXAMPLE OF DECISION THEORY IN GLAUCOMA (CONT.)

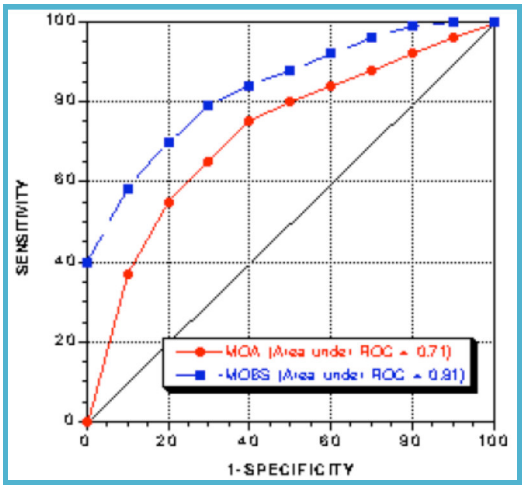

Figure 33-2a: *Use of ROC curves to compare two diagnostic tests for glaucoma, the MOA and MOBS test. The higher detectibility or greater area under the ROC curve indicates a better test. (Redrawn from: Johnson C, Samuels SJ. Screening for Glaucomatous Visual Field Loss With Frequency-Doubling Perimetry. Invest Ophthalmol Vis Sci. 1997; 38: 413-425)*

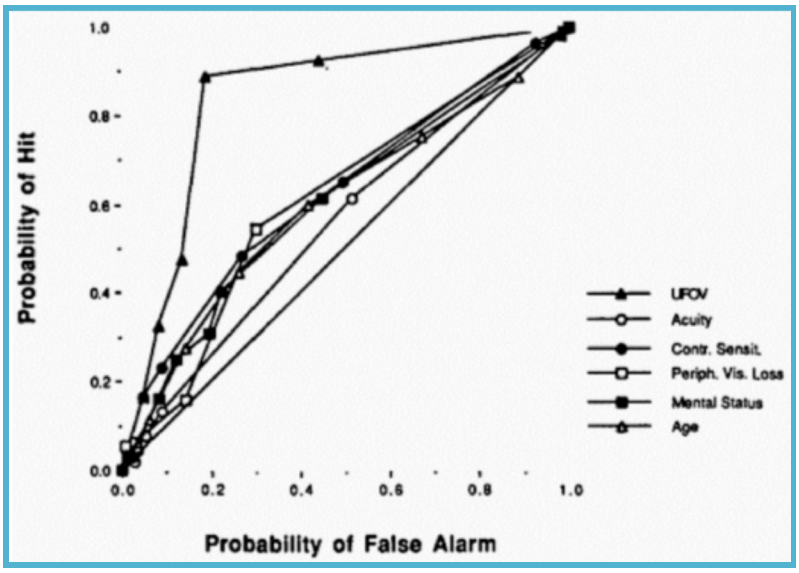

Figure 33-2b: *Example of an ROC curve from the article on the UFOV test (useful field of vision). The goal of this research was to find a vision test that could predict which elderly drivers were at risk for traffic accidents. The UFOV test was superior to visual acuity or the other tests listed in the legend. Reference: Ball K, Owsley C, Sloane ME, Roenker DL, Bruni JR. Visual Attention Problems as a Predictor of Vehicle Crashes in Older Drivers. Invest Ophthalmol Vis Sci. 1993; 34: 3110*

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. For example, how does the magnitude of sensation increase with increasing stimulus intensity above threshold? For example, is a 20/40 letter twice as difficult to see than a 20/20 letter?

In an attempt to find a 'psychophysical law', mathematician Daniel Bernoulli (1738) theorized that people respond to money in proportion to its perceived value rather than its actual value. Therefore, a fixed amount of money (i.e. $20) has greater value if the person is poor, but it becomes less valuable as the person becomes richer because the person's perception of the amount changes. Bernoulli proposed that the perceived value of money increases as the log of the amount of money that the person owns.

MAGNITUDE OF SENSATION (CONT.)

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, 2004 Fig. 11-9). 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, 2004 Fig. 11-11 illustrates this with a case in which a subject is trying to detect a dark gray letter against a light gray background. 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 an L (JND) of 2. Weber's fraction in this case is equal to:

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

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 L (JND) is equal to 200 and Weber's fraction is:

$$W_2 = \frac{\Delta L_2}{\text{Background_}L_2} = \frac{200}{10200} = 0.196$$

Weber's fraction says that, when detecting an increment against a background, the JND (L) 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 will be strongly influenced by its background. Schwartz, 2004 Fig. 11-12 illustrates this in the phenomenon known as simultaneous contrast (Fig.33-3).

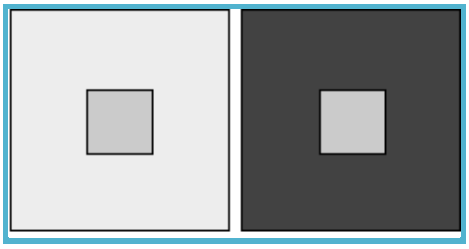

Figure 33-3: *Simultaneous contrast*

A similar phenomenon, known as **simultaneous colour contrast** is illustrated in Figure 33-4, below.

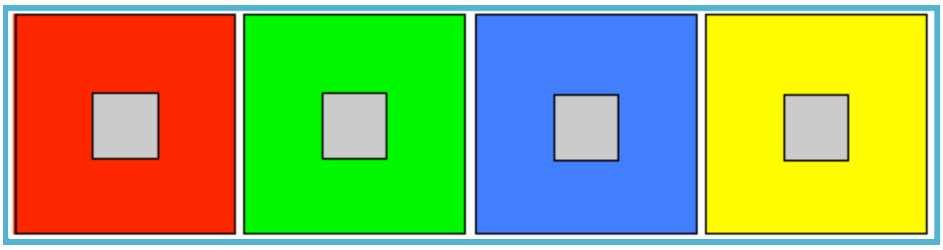

Figure 33-4: *In simultaneous colour contrast, a gray area surrounded by a coloured field will appear to take up the complementary hue of the surround*

In **successive colour contrast** – If you stare at one colour, and then view a white field, you should see an after-image that has the complementary hue of the colour you had been staring at.

MAGNITUDE OF SENSATION (CONT.)

FECHNER'S LOG LAW

Weber's work with thresholds was the background for Fechner's later theory about suprathreshold sensations. Fechner (1860) assumed that such a relationship exists, and this lead to **Fechner's log law** which states that the magnitude of sensation (S) increases in proportion to the log of the 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 step size as the threshold detection increment; that is, as a direct function of JND (or L in the examples above). Fechner's log law is also called the **psychophysical law**.

Fechner's law is widely accepted and is the reason why many sensory tests change increments in log steps. 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 steps.

STEVEN'S POWER LAW

Fechner's log law was assumed to be correct for nearly 100 years, until Steven's (1957) studied the problem if stimulus intensity was increased. This is called **direct scaling. Steven's power law** states that the magnitude of the sensation increases as a power (exponent) function:

$$S = I^a$$

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 (Fig.33-5) give slightly different predictions as to how the magnitude of sensation should increase with increasing stimulus intensity (Schwartz, 2004 Fig. 11-13).

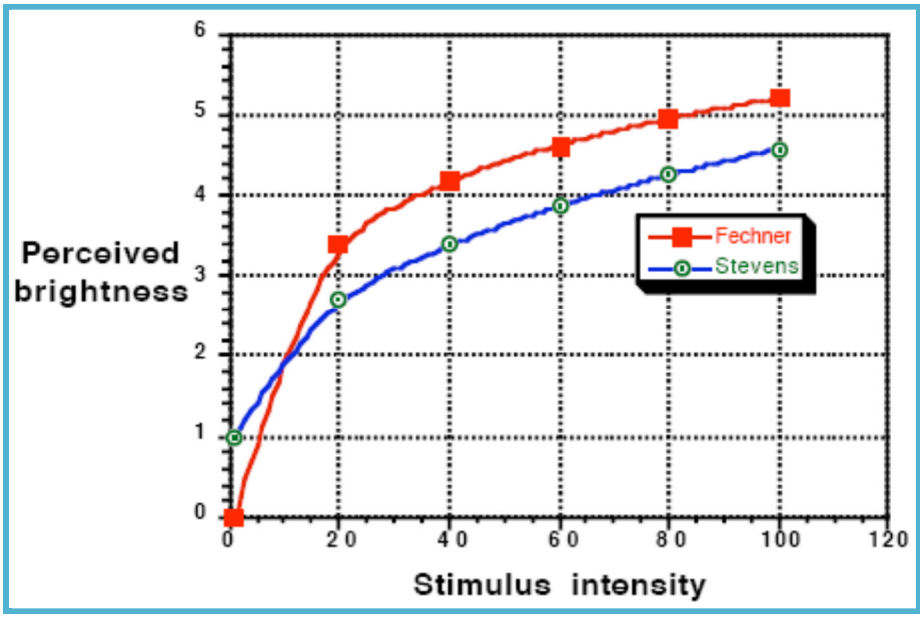

Figure 33-5: *Example plot showing Fechner's (squares; c=2.6) and Steven's (dots; a=.33) predictions for perceived brightness as a function of stimulus intensity*

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
- Colour 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, 1997). 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 indirect 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".

Colour constancy, which was discussed before, is defined as the "relative apparent stability or lack of perceived change of the colour 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, 1997)

SELECTED READING/REFERENCES

- Schwartz SH. **Visual Perception - A Clinical Orientation, 3rd Edition**. Appleton & Lange, Stamford, Connecticut, 2004
- Cline D, Hofstetter HW and Griffin JR. **Dictionary of Visual Science. 4th Edition**. Butterworth-Heinemann, Boston. 1997
- Johnson C, Samuels SJ. Screening for Glaucomatous Visual Field Loss With Frequency-Doubling Perimetry. Invest Ophthalmol Vis Sci. 1997; 38: 353-425
- Ball K, Owsley C, Sloane ME, Roenker DL, Bruni JR. Visual Attention Problems as a Predictor of Vehicle Crashes in Older Drivers. Invest Ophthalmol Vis Sci. 1993; 34: 3110