Lecture 38 – Measuring Psychophysical Thresholds

PSYCHOPHYSICAL METHODOLOGY

Why should optometry students study and understand the basic principles of psychophysical methodology? Consider the following questions.

- How important is vision testing to optometry?
- How many of our patients do we perform vision tests on?
- How many of the tests that we do in a typical exam test vision?
- How much of our decision making is based on the results of vision tests?
- What vision tests have you learned to do so far?
- Of all the vision tests that we do, how many of them are psychophysical tests?

Psychophysics refers to psychological effects, namely perceptions that arise from some physical stimulus. Vision is a sensory perception—in fact our most important sensory perception—of light (the physical stimulus). Therefore vision is a psychophysical phenomenon, and all tests of vision are psychophysical tests. The psychophysical methods that have been developed to study perception are what we use in clinical optometry and eye research to measure visual performance, so psychophysical methodology is at the very heart of optometry.

Many vision tests attempt to measure some sort of **threshold**; that is the limit for being able to see something. For example, the smallest letter, dimmest light or lowest contrast visible. Thresholds can be very difficult to *accurately* and *precisely* measure, but we need both **accuracy** and **precision** if we are to make correct decisions in managing our patients.

- Accuracy – correctly measuring the value. For example, if the person's exact IOP is 12 mm Hg, a measurement of 13 is more accurate that a measurement of 15.
- Precision – repeatability of measurement. Using the IOP example, three repeated measurements of 15, 14, 16 are more repeatable than three measurements of 9, 12, 17. Better repeatability means better precision

Dr. Christopher Tyler, researcher at the Smith-Kettlewell Eye Research Institute (http://www.ski.org/) once said, "things get messy when you approach the threshold." Therefore special techniques have been developed to measure sensory thresholds. Many of these methods were developed by the famous German scientist **Gustav Fechner** (1801-1887), who is known as the father of modern psychophysics. Today we'll study three methods he developed for measuring thresholds.

- Method of constant stimuli
- Method of limits
- Method of adjustment

METHOD OF CONSTANT STIMULI

This consists of both a specific testing procedure, and analysis method.

Procedure

Prior to testing for a threshold, such as the contrast threshold for detecting a sine wave grating, you must have an **estimate** of the threshold value. You can determine this by doing a **pilot study** prior to a formal experiment using the method of constant stimuli. For example, to estimate the contrast threshold, you might just look at the grating and adjust the contrast until you yourself can barely see it.

Next, select 5-9 levels of stimulus intensity (in this case, contrast) around the estimated threshold, including some values below and some values above it. This should include one setting that is so low that it will never be detected, and one that is so high that it will always be detected. Between these extremes, the magnitude of other settings should be equally spaced.

For example, if you believe that the threshold contrast is about 2%, you might select contrast levels for testing such as, 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0 percent contrast.

In random order, present the stimulus at one of the intensities, and record if the subject sees it or not (yes or no). Repeat until you have tested at each level many times. For example, you might make a total of ten presentations at each level. Compute the % of detection (yes responses) for each stimulus level. Table 1 organizes the hypothetical responses to such an experiment. Note that this allows you to measure one threshold, such as the contrast threshold for an 18 cycle-per-degree sine-wave grating. If you wanted to plot a person's contrast sensitivity function for a range of spatial frequencies, you would have to repeat the entire procedure to measure the threshold at each of the other spatial frequencies.

Contrast	% Detected
0.0	0.0
0.5	2.0
1.0	10
1.5	35
2.0	60
2.5	75
3.0	85
3.5	98
4.0	100

Table 1. Example of data collected in a constant stimuli experiment.

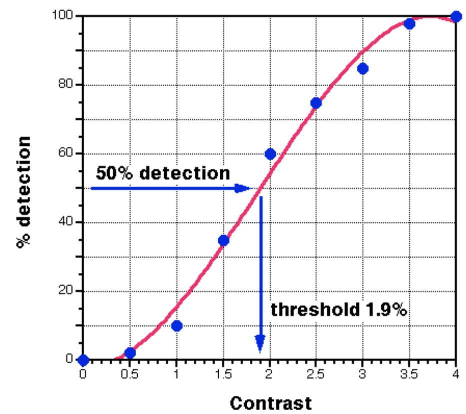

Figure 1. This graph plots the results of a constant-stimulus-type experiment. This psychometric function (perceptual response plotted as a function of physical stimulus intensity) takes the form of an ogive curve.

Analysis

For each level, plot the percent detection (perception; y-axis) as a function of contrast (intensity of the physical stimulus; x-axis) to plot what's known as a **psychometric function.** A psychometric function is a plot of measurements of a perceptual phenomenon. Fit the data points with some curve. Interpolate from the curve to determine the stimulus level (contrast) that corresponds to **50% detection**. This is taken as the threshold.

Note that, because stimuli are presented randomly, the subject cannot anticipate when it will be seen. This method is called a constant-stimulus method, not because the stimuli intensities are kept constant, but because *the subject's level of expectation is kept constant*.

In this example, the measured threshold is 1.9% contrast. Above this level the person should detect the grating at least 50% of the time. Below this level he should detect it less than 50% of the time. The constant-stimulus technique is a valuable laboratory method, but it is time consuming.

METHOD OF LIMITS

A less meticulous but faster way to estimate thresholds is to use the method of limits. It has three basic strategies:

- Ascending limits
- Descending limits
- Staircase method

Ascending limits method

Set the stimulus intensity well below threshold and increase intensity until the stimulus is seen. Record this value and repeat the procedure numerous times to obtain several estimates of the threshold. Finally compute the mean of these estimates.

Descending limits method
Start with a stimulus intensity above threshold and decrease the intensity until the stimulus is not seen. Repeat the procedure and compute the mean value as the threshold. We often test clinical visual acuity with a descending limit's method.

Q. Why would the method of ascending limits be more appropriate for a dark adaptation experiment than descending limits?

A.

While the methods of ascending and descending limits have the advantage of being fast and relatively easy to administer, they have some inherent disadvantages. These include **errors of habituation** and **errors of expectation**.

- *Errors of habituation*. If the same steps are used in either the ascending or descending sequence, the subject may fall into the habit of saying, "yes" after the same number of presentations. For example, in an ascending series, he may say, "yes" on about the fifth presentation in the first few trials. Even if he doesn't see on subsequent trials, he may still continue to say, "yes" because he thinks he should to stay consistent with his earlier responses.

  Have you have noticed how easy it is to fall into a rhythm for pressing the button when doing a threshold visual fields test? This is an example of an error of habituation.

- *Error of expectation*. The subject may start to anticipate "seeing" the stimulus and respond prematurely. This can also be a problem in clinical visual fields testing. The patient can hear the machine adjusting, then stop immediately prior to presenting the stimulus. From the sound alone, you can anticipate when the projector will project the light onto the background.

Staircase method
The staircase strategy is a modification of the ascending and descending methods. It begins with either an ascending or descending series. When you reach the endpoint, you reverse the direction until the opposite endpoint is found. Continue up and down for several reversals. The mean of several reversals is taken as the threshold. (See Schwartz Fig. 11-2)

This is a fast and popular way to locate the threshold and is used to determine the visual field thresholds in the Humphrey Visual Field Analyzer.

Quoting from the Humphrey book, "The Field Analyzer Primer" p. 23

> *The Humphrey Field Analyzer measures the threshold at a given point by a bracketing, or stairstep, process. It presents the initial stimulus at an intensity slightly brighter than the patient's expected threshold. If the patient sees the spot, the Analyzer decreases the intensity of the stimulus in 4 dB steps in subsequent presentations until the patient does not see it. Then the intensity is increased again in 2 dB steps until the patient sees the stimulus. If, on the other hand, the patient did not see the first stimulus, the same process is performed in reverse. In any case, the last seen value is identified as the patient's threshold at that point.*

Method of adjustment
In this method, you allow the observer to adjust the intensity setting himself until he finds his own threshold. This is a fast method, but among the different techniques, it is most susceptible to variations in the subject's own threshold criteria, motivation, understanding, etc. It is a useful way to quickly estimate the threshold prior to doing more formal testing. Most vision scientists, however, do not use the method of adjustment to obtain their best data.

FORCED CHOICE
The method of constant stimuli and method of limits can be further refined to improve accuracy by using the principle of **forced choice**. This is designed to reduce variance in the test results caused by changing subjective criteria for seeing or non-seeing.

Inter-subject variability in threshold criteria is expected. Intra-subject criteria may also vary. The same subject may apply different criteria depending on the time, nature of the task, test conditions, level of fatigue, motivation, understanding, confidence, etc.

By a **strict criterion**, we mean that the subject does not report seeing unless he is absolutely sure he sees the stimulus. This can cause too high an estimate of the threshold. If the subject uses a **lax criterion**, he will be quick to say he sees the stimulus, even if he is unsure. This leads to low thresholds.

The forced choice methodology is designed to minimize criteria fluctuations by encouraging the subject to always make his best guess.

Schwartz Fig. 11-4 illustrates how a constant-stimulus experiment can be modified to include forced choice. Rather than looking at one target and saying whether or not he sees the stimulus (detected/not detected), the subject looks at two targets (Fig. 11-4A) and is required to say which one contains the stimulus. One of the two sides will always contain the stimulus and the other will be blank. The subject is forced to make his best guess, no matter what his criterion. Even if he can't see it, he still must guess. You then record whether or not his guess is correct or incorrect.

If the subject is forced to choose between two alternatives, this design is call a **two-alternative forced choice** (**2AFC**) experiment. Using this procedure, a large number of trials are performed at each intensity level, and you record the *percent correct* (not percent detected) at each level (Fig. 11-4A graph). Notice that the y-axis has a different label from before. In Schwartz Fig. 11-1C, the label was "percent detected." In a forced choice experiment, the y-axis is labeled "percent correct."

Threshold is taken as the intensity associated with a percent correct response that is midway between guessing and 100% detection.

For two alternatives, the person should get 50% correct just from guessing, even when he cannot see the stimulus. A percent correct value of 100% means that he correctly identified the stimulus every time. Halfway between these two (75%) is taken as the threshold in a 2AFC experiment.

It is possible to design an experiment with more than two alternatives. Figure 11-4 also shows a **4AFC** design. In the 4AFC case, even when the stimulus cannot be seen, the subject should get 25% correct just from guessing. The threshold is therefore taken as the intensity associated with 62.5% correct (half-way between 25% and 100%).

If we test visual acuity using the Sloan letter set, as is done in the ETDRS LogMAR chart, we would be using a 10AFC technique.

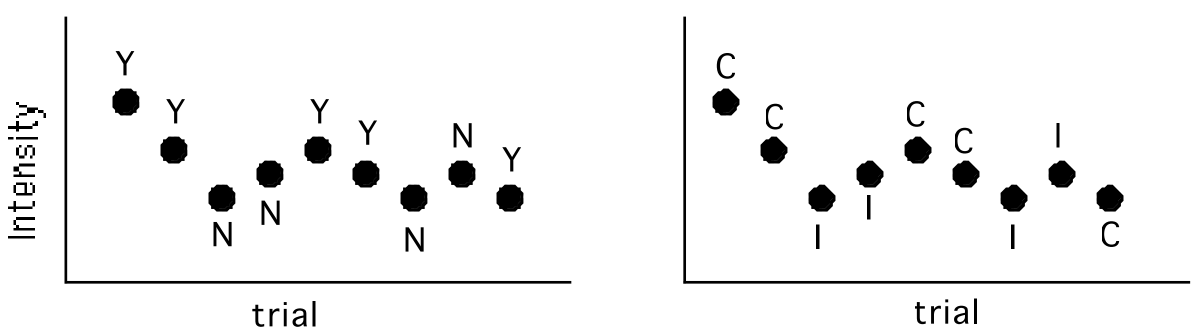

Figure 2. Comparison of responses to Y/N and 2AFC staircase experiments.

Forced Choice Staircase Methods

The forced choice design can also be used with the staircase method. You could present the stimulus in one of two positions, or you might present it in one of two intervals. The observer must watch and tell you if the stimulus was seen in the first or second interval. Then, rather than recording “yes” or “no” as in a regular staircase, the experimenter would record, “correct” or “incorrect” and adjust the staircase accordingly (Figure 2). Most subjects and patients can see better than they think, so forced choice experiments often result in lower thresholds than if they were not used.