

## Chapter 2

# Psychophysics

### Chapter Outline:

- I. What is Psychophysics
  - a. Basic Questions
    - i. Detection
    - ii. Discrimination
  - b. General Approach to Psychophysics
    - i. What is an experiment
    - ii. How psychophysics does experiments.
- II. Classical Psychophysical Methods
  - a. Method of Limits
  - b. Method of Constant Stimuli
  - c. Method of Adjustment
- III. Modern Methods
  - a. Forced Choice Techniques
  - b. Signal Detection Theory
- IV. Psychophysical Laws
  - a. Webers Law
  - b. Fechner's Law
  - c. Stevens' Law
    - i. Magnitude Estimation
    - ii. The Law that arises.

## Chapter 2 Psychophysics What is Psychophysics

Before a researcher can begin to study sensation and perception, the researcher must examine several important questions about how one goes about doing research in this area. Some of these questions might be:

- What are important research questions?
- What questions do you ask the participants so that the results will make sense?
- What research techniques do you use?

In sensation and perception, like many areas of psychology, the researcher does not have direct access to what is being studied, because most sensation and perception is an activity that occurs in the mind. You have probably heard or asked the question “Is what I describe as the color green the same green that other people see as green?” This question is important and even daunting but it does not preclude our ability to do research. Since Fechner (1860/1966), as was noted in Chapter 1, researchers have been developing ways to learn about how our sensory systems operate. Some important answers to the questions listed at the beginning of this chapter have been found that have granted researchers many sensitive techniques to investigate our sensory and perceptual systems.

This chapter covers basic questions and techniques used by researchers to discover how human sensory systems work, thus focusing on the second and third of those questions. When a researcher refers to their techniques, they usually use the term “research method” and for sensation and perception the methods used to study normally behaving humans fall under the heading of **psychophysics [to glossary]**. Simply psychophysical methods involve presenting a carefully controlled stimulus to a participant, and asking a question directly of the participant that allows the answer to be quantified; that is, turned into a number. From these direct questions, it is hoped to indirectly understand the way the mind works to accomplish sensation and perception. These methods will be used throughout the book, as you will use them in many of the demonstrations and experiments that are contained in the media portion of this book.

It is important to note that these are not the only methods used in sensation and perception. Researchers also use methods from neuroscience (see Appendix) and other areas of psychology. However, psychophysics is given special attention here for several reasons: (1) much of what is known and is covered in this book has been discovered using this method, (2) it is a major methodological contribution by sensation and perception to psychology, and (3) these methods are distinctly different from other methods in psychology.

### **Basic Questions and Measures**

To begin the discussion of psychophysics, a concrete example will be used so that the discussion does not get too abstract and ethereal and thus make no sense whatsoever. Now it is important to realize that no single experiment can study all aspects of any topic. In fact, experiments ask very focused questions to go along with their tendency to try to simplify any problem to make it easier to understand. Especially at first, start with the most basic question about what you are studying. Based on what is learned from the simple situations, more complex situations can be studied using what has already been uncovered. These simple situations are the keys to understanding more complex situations. As the first step in focusing, the research question will be narrowed to a question about motion. To assist with the discussion and to keep it concrete bring up [Interactive Illustration 2.x, Basic Ideas \[link to media\]](#). You will see a fuzzy region covering most of the screen. This fuzzy region is a **grating [to glossary]** which will be described in more detail later and it is a common type of visual pattern or stimulus used in vision research. This grating is what is going to move in this example to help make sense of psychophysics. So to start an experiment, the researcher begins with a stimulus. The next step is to determine the question to be asked using the stimulus in question.

**Detection.** One of the most basic questions concerning any stimulus that might be asked is, “how strong does the stimulus have to be for a person to be able to perceive the stimulus?” This is the question of **detection [to glossary]**. Click on the **Move** button that is at the top of the screen. Make sure the **Movement Size** slider is at the bottom of the screen in his place at **1**. One half of the times you press the **Move** button, the grating will move on your screen to either the right or the left. The other half of the time it will not move at all. After the grating moves a small window will pop-up asking you if you have seen it move. Answer the question and it will give you feedback on if you were correct or not. Try it 10 to 20 times and see if you can consistently determine if the grating moved.

If you are like most people that have tried this little demonstration, you will not be consistently correct. You are not consistent because you are not able to detect the movement of this grating that is this small. Now move the **Movement Size** slider to 51. This slider adjusts the size that the pattern on the screen will shift when it moves. The movement is now much larger when you press the **Move** button. Now try the little experiment again and see if you are more accurate in noticing when the grating moved. You should find that this task is a great deal easier.

So the detection question about motion could be phrased, “how big does the stimulus motion have to be for a person to be able to reliably detect that the stimulus has moved?” To make the answer more meaningful we want to assign a number, in our example somewhere between **1** and **51** that will give us our answer for how big of a motion it takes consistently to perceive that motion has occurred.

This process of assigning numbers to the outcome of an experiment refers to the process of measurement. This use of quantitative measures greatly facilitates the comparison of results from different situations and researchers. In this case, the measurement that is wanted is a measure of the smallest movement that can be reliably detected. This particular measurement is called the **absolute threshold [to glossary]**. The absolute threshold is one type of sensory **threshold [to glossary]**. A threshold is a type of sensory limit which draws on the analogy of the threshold to a room. As you enter a room you cross the room’s threshold, e.g., the tradition of the groom carrying the bride across the threshold. Once you cross the threshold you are in the room. On the other side of the threshold you are outside of the room. So depending on which side of the threshold you are on you are either in or out of the room. In a sensory threshold, if the stimulus is too weak it is below threshold and not perceived. If it is strong enough it is above threshold and can be perceived.

Let us examine this issue of the absolute threshold a little more closely. Go to [Experiment 2.x, Absolute Threshold \[link to media\]](#). You will see the same grating again but there will not be the slider as the bottom of the screen but the button now says **Start Experiment**. When you press this button, the button will disappear, and about a second later the grating will move some distance and then a box will appear that will ask **“Did you see the grating move?”** Click on the **Yes** button if you saw it move or on the **No** button if you did not see it move. This is one trial in the experiment. There will be 25 trials total, five trials for each of five movement sizes. After you are done, the results of your experiment will be presented on a graph. On the x-axis of the graph will be the sizes of the movements in pixels (screen dots) and on the y-axis will be the percentage of times you were able to detect that movement. **[Note to media development, I would like to have this data collected in a central database]**. Go run the experiment at this time and come back to the book when you have your data.

If your results are like most people who have run this experiment, you will find that the smaller movements were not detected as often as the larger movements. It is possible that you did not see the smallest movement at all and saw the largest movement all of the time and there may be some movement sizes you saw some but not all of the times. You can see an idealized version of the graph in Figure 2.x. Your graph may have more bumps in it than the idealized graph but then you did not do many trials and this is one of your very first times collecting data in a psychophysical experiment. *[It would be appreciated if you would share your data with other students. If you are online you can press the “Send” button at the bottom of the data page. After you have done that the button will change to “View All Data”. If you click on that button you will be taken to a web page which will have the all the data from all of the people that have done this study. Here you will see a curve that is much more like the idealized curve. Only if I get the submit button to work]*

There are some important conclusions that can be made based upon these data. One important observation from your data and the idealized data is that sensory thresholds are not quite like doorways. It is not the case that there is a stimulus intensity where suddenly you can perceive the stimulus all of the time. As intensity increases the ability of a person to detect a stimulus grows gradually and not in a sudden step. Thus, researchers have to make a decision. In this case, the decision is what percentage of times that a stimulus is detected constitutes reliable detection. The exact percentage of the time that a stimulus can be perceived for it to be considered at threshold depends on the method as discussed later in this chapter, but in this case, it is often taken as the point where the stimulus can be perceived 50% of the time. To be concrete, the size of movement in our experiment where you could detect the movement 50% of the time would be the absolute threshold for movement perception for this stimulus.

There are lots of different types of absolute thresholds. Researchers have determined many different types of absolute thresholds for each of our senses; for example, there can be absolute thresholds for the intensity of a stimulus. That would be the absolute dimmest light, softest sound, lightest pressure, smallest amount of odor that could be detected reliably. In addition, as in [Experiment 2.x, Absolute Threshold](#), where we collected the data to demonstrate an absolute threshold, there is an absolute threshold for the degree of movement. There are several types of thresholds for every sense, and throughout the course of the book you will encounter many of them as they reveal something about how that sensory system works.

**Discrimination.** The ability to detect the presence of a stimulus is an important ability but it represents only the first step in a useful sensory system. Moreover, most stimuli are sufficiently above our absolute thresholds that they are easy to detect, so understanding the limits such as described in absolute threshold does not necessarily help us in understanding much about these more intense stimuli. A much more common perceptual task is that of **discrimination [to glossary]**. In discrimination, the person's task is to determine if two stimuli are the same or different. For example, determining if two colors of paint or fabric are identical or not is a discrimination task. Thus, it becomes important to determine the **discrimination threshold [to glossary]**. Just as the absolute threshold is the minimum level of a stimulus that can be detected reliably, so the discrimination threshold is the minimum difference between two stimuli that can be detected reliably. Another name for this threshold is the **Just Noticeable Difference** or **JND [to glossary]**. Try an example using [Experiment 2.x, Discrimination Threshold or JND \[link to media figure\]](#). This is an experiment very much like the experiment for the absolute threshold, only for each trial there will be two movements, not one. Your task is now to determine if the second movement is larger than the first movement. Press **Start Experiment** and give it a try. The results will be plotted in an identical fashion to the data from the absolute threshold experiment.

There are several observations to be made about these data. First, you should see a curve much the same shape as you did last time, a gradual increase in the percentage of times that you saw the movement. From preliminary trials with this data, it appears that this slope is probably more gradual than that for the absolute threshold experiment but the general shape is the same. However, just as with the data from the absolute threshold experiment, researchers need to take a point on this curve to determine the discrimination threshold. Using this method as with the absolute threshold experiment, the 50% value is often taken to be the JND. Second, most of you will find this task more difficult than the previous task. Look at the values on the x-axis. In the absolute threshold case, the x axis represented the size of the movement. In this case, it represents how much larger the second movement was than the first movement. So in some way these values can be compared to each other. In the discrimination experiment, these x axis values are much larger than they were for the absolute threshold experiment. If you have the data from the absolute threshold experiment handy, notice that the data from the discrimination threshold experiment crosses the 50% line at a much larger value than for the absolute threshold experiment. Just use your eye for now, that will be good enough for the point I am trying to make. The most important point for now is that it is not possible to predict a discrimination threshold directly from a detection threshold. Thus, it is important to measure both types of thresholds.

There are many other types of questions than can be asked in research, and several will be encountered in this text. However, with these two questions we can begin to discuss the methods used to measure absolute and discrimination thresholds.

### **General Approach to Psychophysics**

There is a fundamental problem in doing an experiment in sensation and perception. We want to ask the participant what is going on in their head. What are they experiencing? The researcher does not have any direct access to what the participant's experience so it takes clever, and often time-consuming, methods to conduct experiments that allow researchers to gather information about human senses that can be interpreted in a meaningful way. This section of the chapter will first review the general concept of what an experiment is and then how an experiment is carried out in psychophysics.

**What is an experiment?** You may recall some of the basic facts about what makes a research study an experiment from your introductory psychology course. An experiment is the most important of all of the research methods in science because, when done precisely, it allows the necessary control of a situation to determine exactly why an observed phenomenon happens. In other words, an experiment allows researchers to determine causation. In sensation and perception, it is the goal of researcher ultimately to know why people perceive the world in the way that they do. So researchers seek to

understand what features of the physical world cause what sensory and perceptual experiences in human minds.

Let us use a simple example to review the parts of an experiment and the logic of an experiment. In order clearly to say what it is that causes us to experience, for example, the color red, the researcher needs to carefully construct the experiment. The most important feature of an experiment is the **independent variable [to glossary]**. The independent variable, often abbreviated IV, is the variable that is controlled or manipulated by the researcher. Simply put, the researcher sets the level of this variable for the experiment. In the example experiment, the independent variable might be the different wavelengths of light that can be gotten by passing white light through a prism as Newton did (see Chapter 3).

There can be any number of values or levels of the independent variable used in an experiment. In introductory psychology you were probably taught that there were two conditions of an experiment, either the independent variable was present or it was not. However, it is possible to have many different levels of the independent variable and compare them to each other. It is even possible to have more than one independent variable in an experiment. It is the presence of the independent variable that is the defining feature of an experiment.

The second feature of the experiment is the **dependent variable [to glossary]**, often abbreviated DV. The dependent variable is the variable that is measured and is based on the participant's responses. This is the variable that will be used to determine the effects of the independent variable. In this little example, our dependent variable might be the number of times that the word red is said by the participants in response to each of the different wavelengths that is presented to the participant.

The third and vital element of an experiment is the control over all other factors in the environment where the experiment is taking place. It is vital that the only difference between two conditions of an experiment is the level of the IV. Consider this situation: the researcher is changing the wavelengths for the different conditions, but the intensity of the different wavelengths also change. How can the experimenter know whether it is the intensity or the wavelength that caused the responses of red from the participant? The experimenter cannot be sure. Without control, the whole purpose of the experiment is lost. Any other variable that varies with the independent variable, in this case the intensity of the light, is called a **confound variable [to glossary]**.

**How Psychophysical Experiment are Done.** Science proceeds by having data that can be agreed upon by all of the scientific community. This fact does not require that all scientists from all places and times have to be present at the experiment, but it does mean that different scientists doing the same study at different times and locations have to be able to get comparable results. As an example, consider a device from the study of learning you probably have heard about. Part of the importance of the piece of equipment we now call the Skinner box is that it is easy to obtain results that other researchers can also find (REF). If a rat is used, researchers merely record when each bar press occurs. The patterns of data observed are easily compared with the patterns of bar presses that other researchers found. The data has been made objective and reliable.

Remember that in sensation and perception, we are interested in psychological experiences that are not directly observable. So how can we develop data that can be agreed upon by different scientists? The basic approach used by psychophysical methods has three elements that are key to understanding: 1) simple responses by the subject, 2) extensive data collection from each subject, and 3) the independent variables come from precise manipulations of the stimuli.

The use of simple responses is especially important to develop objective measures that other scientists can agree upon. Let me be very specific about what it means to ask a simple question. Try **Interactive Illustration 2.x, Asking Questions [link to media]**. This simple demonstration is a slight modification of the very first illustration that was used in this chapter. When you press the button that says **Move** at the top of the screen, you will be asked two different types of questions. The first time you press the button you will be asked a very generic **What did you see?** type of question and given a box to type your answer in. The grating will always move before the question is asked. The next time you press the **Move** button, the grating has a 50% chance of moving. You will be asked if the grating moved or not. Try both types of questions and respond as well as you can to each.

The first question is rather like the type of introspective questions asked by Wundt and his followers in the early days of psychology as a formal discipline (Bringmann, Bringmann, & Ungerer, 1980). Wundt asked questions somewhat like this one. The questions and situations were more structured and he trained his subjects. Using these techniques he hoped to get the objective and repeatable data

needed by science. However, his questions were open ended like this example. **[to development: can I collect some answers to this question and have the students refer to some sample answers?]** As you can imagine, the answers by different participants to these open ended questions can be quite varied. It would be hard to reach agreement regarding any research question except in the simplest kind of situation.

The second question “Did the grating move” is very basic and simple. The only possible answers are “Yes” and “No”. It can be very clear to the researcher what the answers to those questions mean. While that may seem an obvious statement, it is precisely this feature of the question that makes it so good for getting objective results. In addition, it can be very easy to get agreement both across participants and other researchers performing like experiments. If one researcher finds that most people see this movement so should other researchers. **[to development: could I get a running percentage of all students that have reported seeing the movement in this illustration?]** With this example, if you did not change the size of the movement (using the slider at the bottom of the page like from the first figure), you will probably have been very accurate and seen it when it did occur and when it did not occur. Such agreement is necessary to be able to build upon previous findings. These simpler questions help psychophysics form a sound basis for the development of science and theories of how sensation and perception work.

While the use of simple questions allows the results to be reliable, what has been learned by this one trial? Not much. If you just use the data from this one trial, we know that for one size movement, you either saw it or you did not. Even if we repeat this trial, **[to development – can we collect summary data across students on this trial]** we have not learned much. We probably would not even be able to determine the absolute threshold unless it just happened that the movement size fell on the point where you were able to detect the stimulus 50% of the time. Compare this single trial to the simple experiments we did to determine the absolute threshold and JND for motion. There you had 25 trials across five different sizes of movements. These experiments were still very brief and while the data was readable, in most cases your data is still rather hard to read. The percentages would increase and decrease only to increase again. The average data from all participants who have used this book looked a lot smoother **[to development: can there be a link here to a page with their results and the average results summarized as a figure for reference?]**. As a result, to accurately determine a single participant’s threshold often requires a lot more data than we have collected in our little studies.

Even after the threshold has been determined, there is still a lot more information about our sensory abilities that would interest a researcher. For example, how would the threshold change if the grating were darker or lighter, or in other colors, or the bars were narrower? The researcher would pick one or several of these variables, which become the independent variables of the research, and see how the threshold, either absolute or JND, changes as a results of changes in these independent variables. As you can see, a psychophysical study often requires an intensive data collection from individual subjects. Because of the intensity of the data collection on subjects, many classic studies will run only very few subjects (see Blakemore & Sutton, 1969, which only had two subjects). These studies will often appear very different from psychological studies in other areas, who emphasize using groups to get a reliable measure on the data. Not every study uses such small groups, but in many psychophysical studies, it is quite permissible.

The third feature of psychophysical research comes right out of the first two features of the study. The need for careful control of stimuli is the result of both the simple questions asked of the subjects, and the intensive studies. To be able to really understand what a subject’s set of responses means, the IV must be very carefully controlled. In these sample studies, the movement was in terms of pixels, but that really is not sufficient control. How big of a movement that 10 pixels seems to you depends upon the size of your monitor, the size of its pixels, and even how far you are from the screen. Try [Interactive Illustration 2.x, Effect of Distance \[link to media\]](#). In this simple little figure you can adjust the thickness of the bars of the grating. You could make the bars very thin. Then move away from the screen, and eventually you will reach a place where you cannot see these bars. Or you could make the bars very large; and if your screen is large, if you put your face up to the screen they will again become invisible. Here, the threshold for seeing these bars depends upon how far away you are from the screen. These issues of distance from the screen and monitor and pixel size were ignored here because these were just example studies, but in some of the studies later in the book you may be asked to be a certain distance from your screen.

### Classical Psychophysical Methods

#### Method of Limits

The **method of limits [to glossary]** is perhaps the simplest of the classical psychophysical methods developed as a result of Fechner’s book on psychophysics. To describe this method, imagine

trying to determine the threshold for detecting a dot against a light background. This is a type of JND. To try this experiment, bring up [Experiment 2.x, Method of Limits \[link media figure\]](#). The first screen of this little experiment is a window where you can set up the values that will adjust how your method of limits experiment will run. The first item asks you to determine the number of levels to test. The number of levels refers to the number of intensity steps in the independent variable that will be tested. In the method of limits, the researcher hopes to pick an extreme value that is readily detected and a level that is never detected and then several levels between. For this experiment, do not adjust the slider but just use the default values.

The next question is the number of staircases to run. A staircase is the term I am using in this text, another common term is series, to refer to how the levels of the independent variable is presented to the subject. In a **descending staircase [to glossary]**, the experimenter presents the most intense level that is easily seen and asks the subject if they can see the stimulus. If the subject can see this stimulus, and the researcher fervently hopes that the subject can, then the next, less intense level of the stimulus is presented. After each stimulus is presented, the subject is asked if they can see the stimulus. In a properly designed descending staircase, the subject starts by reporting that they can see the stimulus. The staircase continues until the participant reports that they cannot see the stimulus. This value where they changed their response from “Yes, I can see the stimulus” to “No, I cannot see the stimulus” is recorded and will be used to calculate the threshold. The descending staircase is then followed by an **ascending staircase [to glossary]**. In the ascending staircase, the lowest intensity is presented first, and again the participant is asked if they can see the stimulus. Here, if the staircase is designed correctly, the subject should not be able to see the stimulus. Then the next least intense stimulus is presented until the participant can see the stimulus. Again, this lowest intensity where the participant reports seeing the stimulus is recorded and used to determine the threshold. The “number of staircases” question asks the number of these descending/ascending pairs of staircases to run. Leave it at 5 for this example. The third question asks about the type of Method of Limits to run. Leave it at traditional, which is what has been described so far. If you have shifted values click on the **Restore Defaults** button to go to the values that were present when you first entered this window.

In this experiment, a red cross will be present in the middle of the screen. This is a fixation mark. You are to stare at the cross the entire time. There will be a dim flash above that cross. After the flash has appeared you will be asked at the bottom of the page if you saw the flash. If you saw the flash, press the **Yes** button and, if you did not see the flash, press the **No** button. With these instructions you are now ready to run this experiment, so now click on the **Done** button at the bottom of the page. After you are done your results will be displayed and then refer back to this page.

The graph of your results is a plot intensity displayed as a function of the trial. By that I mean that the intensity of the flashes is plotted on the y-axis and the trial number is plotted on the x-axis. So on the first trial the most intense stimulus (**25**) was displayed. Since that stimulus is easily seen, your response will most likely have been “Yes” and on the next trial the next less intense stimulus is presented. This is a descending staircase. Eventually, there will be a trial where you will not be able to detect the stimulus and you will respond “No”, this stimulus is indicated with a green dot. The next stimulus presented is the least intense stimulus (1) and an ascending staircase is begun. Each of the green dots indicates the end of a staircase where your response changed. The threshold is taken as the average intensity of the stimuli presented on these trials. If you press the **Show Threshold** button on the bottom of the screen, this average will be displayed to you.

Bring back up [Experiment 2.x, Method of Limits \[link to media figure\]](#). The type of Method of Limits that was run last time is a traditional version, and each staircase begins either at the beginning of the staircase or at some standard point. This method will waste a lot of trials getting responses that can easily be predicted. Try the experiment again but instead of the traditional method, change the **Type of MOL to Staircase, 1-up, 1-down** and again run the study. In the traditional method, each time your response changes, say from “Yes, I saw it” to “No, I did not see it” the next stimulus is taken from the beginning of the next staircase. In this staircase method, if the stimulus becomes so weak that a “No” response is given by the participant, the next stimulus presented is the next most intense stimulus instead of going to the beginning of the ascending staircase. This method flows in quickly on the region of the staircase and does not waste as many trials (Cornsweet, 1962). Run this experiment and examine the

results. See how the intensities tested are grouped around the threshold, and there are far fewer trials tested that are far from the threshold.

### **Method of Constant Stimuli**

The **method of constant stimuli [to glossary]** is very similar to the method of limits. Try [Experiment 2.x, Method of Constant Stimuli \[link to media figure\]](#). On the first screen you will be able to adjust the parameters of the method. Like in the method of limits, the experimenter pre-selects a number of stimulus intensities to present to the participant. However, instead of presenting the stimuli in any particular order, the stimuli are presented in a random order. Thus, the experimenter does not determine the number of staircases, to run but the number of times each stimulus is to be presented. Do not change the default values as on the last experiment, and you will have 25 trials (5 levels X 5 repetitions).

This is the first experiment that will use sound as a stimulus. To make this experiment work, you will need to adjust the volume of a **calibration [to glossary]** tone so that you can just hear it. Because we all adjust our computer speakers to our favorite intensities, the sounds from your speakers may be too loud or too soft for the purposes of this experiment. When picking the levels in a method of limits or method of constant stimuli experiment, it is best to pick values that are both below and above threshold. So if your volume is too loud our soft you might hear all or none of the tones. So this minimal calibration is necessary to make this experiment work.

The second screen of this experiment does not start the experiment, but is a calibration window. It sometimes takes this second screen awhile to appear, especially on older computers, but it will appear. When the second screen appears, you will see three buttons across the top of the window. They are **Play, Stop, Done**. Press the play button to start the sound. Adjust your volume on your speakers so that you can just hear the sound. It will keep playing until you press either **Stop** or **Done**.

When you have completed the calibration, the experiment begins. You will be asked if you heard the tones. At the end of the experiment your data will be presented. Try the experiment at this point.

You should find this experiment and the data plot very familiar. This is the same method that was used for plotting the data from the absolute and difference threshold experiments (see [Experiment 2.x: Absolute Threshold](#) and [Experiment 2x: Difference Threshold or JND](#)). That is because both of these experiments used the method of constant stimuli to collect their data. The graph should be a gradual increase of the proportion of times that you heard the tone, just as with the first two experiments. There is one new feature to the graph. There are two green lines on the graph that intersect somewhere on the red line that connects two of the dots. This point where the green lines intersect with the red line is the threshold. It is with the method of constant stimuli that the definition of a threshold as detection or discrimination of 50% arises. However, it is rare that the experimenter will pick an actual intensity of the stimulus that the participant will detect 50% of the time. So some method of estimating what the actual intensity that would give a 50% detection level is needed. There are many different ways, but a discussion of these methods is not necessary (Engen, 1971; Guilford, 1954; Luce, Bush, & Galnter, 1963). We need a simple way to illustrate the basic idea of what is being done to estimate the actual threshold. The simplest, though often not the best, way is illustrated on your graph. This method is called **linear interpolation [to glossary]**. In simple terms, this method uses the line equation you learned in Algebra I,  $y = mX + b$ , to estimate what stimulus intensity would be detected 50% of the time (Engen, 1971). That is why the intersection of the two green lines falls on the red line connecting the two points. Using this method, you can read your threshold for this experiment from where the green line intersects the X axis. **[Question for editor: I could build a small program (already in visual basic) to allow the students to make this calculation. What do you think? I could also calculate it for them and simply give it to them as in the Method of Limits.]**

### **Method of Adjustment**

The most direct of the classic psychophysical methods is the **method of adjustment [to glossary]**. In this method, either the participant or the subject directly controls the stimulus and adjusts it to the threshold level. Usually this task is repeated several times. This method can be a bit awkward to use for threshold, because manually adjusting a stimulus until you can just perceive it is a difficult task. However, it is very useful for matching one stimulus to another to determine the **point of subjective equality or PSE [to glossary]**, another psychophysical measure that you will run into in this book. The PSE is exactly as the name implies, the settings of two stimuli where the subject experiences them as identical. Finding this value may not sound very interesting, but let us try an experiment that will both illustrate the method and illustrate the PSE.



Go to [Experiment 2.x, Method of Adjustment \[link to media figure\]](#). This figure will open a window where you can set the parameters for adjusting the method of adjustment prior to running this experiment. This method has two important settings, one is the **Number of Trials** and the other is the **Range of Variation**. The number of trials is the number of times you will repeat the measurement. The range of variation refers to how much the initial value of the comparison stimulus, the one you will be adjusting, varies over the entire possible range of values for that stimulus. The reason an experimenter wants the initial value to vary from trial to trial is that the participant will have to make each judgment on their perceptions instead of simply repeating their adjustment from earlier trials. Use the default values and click on the **Done** button at the bottom of the screen.

The next screen will have two large circles, each with two smaller circles inside. The standard, or unchanging stimulus, is on the left and it is a bluish outer circle with a greenish inner circle. The comparison stimulus has a yellowish outer circle with an inner circle that will vary with how blue the stimulus is. Your task is to adjust the comparison's inner circle so that it matches the hue or color of the inner circle of the standard on the left. You use the slider on the right side of the screen. This slider will adjust how blue the comparison's inner circle is. Now the two circles may not be the same brightness, that is, one may be a bit darker than the other. Do not worry about that, concentrate on matching the color. Think of it as making the two inner circles have the same amount of blue. When you have made your match, click on the match button at the bottom of the screen.

This experiment should remind you of the very first figure in the text, [Interactive Illustration 1.x, Müller-Lyer Illusion \[link to the media\]](#) in the book. That figure used the method of adjustment as you adjusted the length of the shaft of the comparison. Since you match the length of two stimuli, you determined your PSE between the lengths of the two lines as well. It is with illusions and similar sorts of phenomena where one stimulus may appear in some way different from usual that the PSE is a good measure. Returning to the current experiment, when you have finished the experiment, two things will happen. First, the outer circles are removed and the comparison's inner circle is adjusted to your average setting. If you are typical, the two circles should not appear the same. In fact, your comparison circle on the right should be less blue than the standard circle which will make it appear a little more green. In addition, the average difference in the settings of the two circles is shown in a window in the middle of the screen. This value is the difference in the computer settings telling the monitor how much blue to have in the two circles. You should see a negative value. The method of adjustment may not be as precise as the method of constant stimuli, but it is fast and can be very reliable for determining the PSE like we did in our experiment.

### Modern Methods

While the classical methods have proven very powerful indeed, certain problems were perceived with the type of information that can be gotten from them. Some more modern methods have been developed to deal with some of these perceived difficulties.

#### **Forced Choice Techniques**

One of the potential difficulties that arise with the traditional methods is that the participant might be deceiving the experimenter. Perhaps the participant wants to impress the experimenter with their extraordinary sensory abilities. In all of the methods described so far it would be easy to do, you could simply report that you see or hear the stimulus on trials when you don't. Since the stimulus is always present, the experimenter cannot know if the participant is being truthful or not. One older technique employed was to use catch trials. A catch trial is a trial where the stimulus is not presented. It is easy to insert these trials as checks on the participant's accuracy and honesty. However, this method adds trials and is still relatively easy to get around. The **forced-choice method [to glossary]** was developed to get around this difficulty (Blackwell, 1953; Jones, 1956). On every trial the subject either has to say when the stimulus occurred or where it occurred.

To illustrate this method, open [Experiment 2.x, Forced Choice \[link to Media Figure 2.x: Forced Choice\]](#). The first thing to note about the figure is the lack of a method window. Forced-choice method is actually a different way of doing the methods we have discussed so far. In this case, the forced-choice method will have the stimuli presented in a order determined from the method of constant stimuli. Since you know how to set up a method of constant stimuli, the method window is skipped in this instance to save some time. So you start with the calibration window that you have seen before. In this method, your task will be to discriminate between two frequencies. The experiment will measure your JND for detecting the difference between two frequencies, when the standard frequency is 1200 **Hertz** or **Hz [to**

**glossary**]. A Hertz is a unit of frequency that means cycles or repetitions per second. Thus the vibrations in the air that you will be hearing for the base frequency will be going at a rate of 1200 times a second. All of the comparison or test frequencies will be higher than the standard.

In a standard method of limits experiment, the standard frequency would occur first and the higher comparison tone would occur second, and you would be asked if the second tone sounded higher. In a forced-choice experiment, the order of the two tones will be random. On half of the trials the standard will occur first and on half the standard will occur second. Your task will be to say when the comparison tone occurred. You will not be given the option of “I don’t know.” If you cannot tell the difference between the two tones you have to guess when the comparison occurred. It is this feature of the experiment that makes it a “forced-choice” experiment. In this particular case the way that the question will be phrased is “Which sound had the higher pitch?” If you heard the higher pitch first of the two tones, then press the button labeled **First** and press the button labeled **Second** otherwise. Now run the experiment and come back here when your results have been presented.

The first thing to notice about your results is that you will tend to be about 50% correct. You can do this well because when you really do not know when the comparison occurred you will be guessing, and you will have the same chance of being correct as of guessing which side of a flipped coin will come up. As the difference between the comparison and standard increases, you will be correct a greater percentage of the time. The fact that participants are correct 50% of the time when they are guessing leads to an issue that needs to be resolved. If the participant is correct 50% of the time when they are guessing, it does not seem a good idea to say that when the participant is correct 50% of the time that they have reached threshold. A new value needs to be chosen. Since 75% falls half way between guessing and perfect as 50% falls half way between never detecting a stimulus and always detecting the stimulus, the 75% point has been used.

This particular type of forced-choice method has been what is called a **temporal forced-choice [to glossary]** method. It is also possible, particularly in tactile and visual experiments, to do a **spatial forced-choice [to glossary]** method. In your experiment, the standard and comparison were presented at different times. You determined when the comparison occurred. In a spatial forced-choice method, both the standard and comparison are presented at the same time but in different locations. In this case, the decision is where the comparison was presented. See Figure 2.x for how such an experiment might be laid out.

### **Signal Detection Theory**

You have now been in several threshold type situations, and you have experienced some of the uncertainty associated with detection and discrimination at threshold. In these cases, we have found a range of stimulus values where you as the participant cannot be sure if you perceived the stimulus or not. Considerations of this situation from the perspective of **Signal Detection Theory [to glossary]** have led to an entirely different way of considering this situation (Green & Swets, 1966).

Consider the following situation: You are driving down the road and you think you heard a sound that might have come from the engine. Say it sounded kind of like a clunk. Now, you have your stereo going and there are sounds from the road so you are not sure. If your car is relatively new and has a history of smooth running, perhaps you will decide that you didn’t really hear anything. Your hearing is “playing tricks” on you. Perhaps instead of the fine automobile described above you are driving an old car that has a history of spending nearly as much time in the shop as on the road. In this case you might decide that you did hear something and head to the nearest service center. What is important in this example is that even in this very basic sensory discrimination, there is a cognitive decision making element that needs to be taken into account.

Signal detection theory attempts to understand the role that decision making plays in these situations. Examine the situation above a little more carefully. All the possible outcomes are shown in Table 1(a). In the real world, the stimulus event does not always occur. So it is possible that the clunk either occurred or did not. These two possible stimulus events are indicated across the top of the table. In either case, and to some extent independently, of whether the clunk happened or not, you can decide that you heard the clunk or not. These possible judgments on your part are shown on the left hand side of the table. The four cells of the table are the possible outcomes. For example, the clunk could have happened and you could decide that you heard the clunk and so you go get the car serviced. That outcome is in the upper left hand cell of the table. Thus, two of the outcomes, deciding the sound occurred when it did and deciding the sound did not occur when it did not, are correct responses and have positive outcomes; the

other two outcomes represent incorrect decisions and have negative outcomes. It is of course in your best interest to maximize the positive outcomes while minimizing the negative outcomes.

Table 1(a)  
Signal Detection Theory Possible Situations  
The clunk:

You decide that the clunk:	Happened	Did not happen
Happened	You get needed service	You pay an unneeded service visit
Did not happen	You break down on the road	You go happily on your way

Table 1(b)  
Signal Detection Theory Possible Situations  
The Signal is:

The Participants Judgment:	Present	Absent
Present	Hit	False Alarm
Absent	Miss	Correct Rejection

Table 1(b) gives the general terms to what has been described. The clunk in our original example is now called the signal. The signal is simply what we have been calling the stimulus in all of our earlier examples. It is the event in the world that a person is trying to detect. The reason for the different term is due to the fact that Signal Detection Theory comes to psychology from engineering, where the terminology was already established (Green & Swets, 1966). The only other new terms that are used in Table 1(b) are terms to describe the four possible outcomes. If the signal is present and you judge it to be present, it is a hit; if the signal is present but you judge it to be absent, it is a miss; if the signal is absent and you judge it to be present, that is a false alarm; finally, if the signal is absent and you judge it to be absent that is a correct rejection. Everything else from the example holds.

Now try an experiment and collect some data. Bring up [Experiment 2.x, Signal Detection Experiment \[link to the media\]](#). In this experiment, you will be searching for a **Y** among a string of **X**'s. The **Y** will not be present on every trial, only some of the time. You are to search the string and indicate whether you saw the **Y** or not. At the end of the experiment, the proportion of hits, misses, false alarms, and correct rejections will be presented to you. Go ahead and run the experiment now but do not change the default values.

The first thing to notice about the data is the way that the percentages are calculated. The hits, in the upper right hand cell of the table, are the percentage of hits out of all of the times that the stimulus was present, not the percentage of hits out of all of the trials. The misses show the percentage of misses out of all of the trials when a signal was present. Thus, the percentages of hits and misses add up to 100%. The same situation holds for false alarms and correct rejections, but in this case they refer to the trials where the signal was not present. This way of representing the data has some nice features. One of the nice features of representing the data this way is that you can reconstruct the entire table from just knowing the proportions related to hits and false alarms. Misses are equal to 100 - hits, and correct rejections are equal to 100 - false alarms. Check your table for yourself.

Now we come to how the signal detection theory tries to explain what is going on during the detection of a stimulus. First, close your eyes and keep them closed for a minute or two. If the room is dark enough you might see some small flashes of light, even though there are not any small flashes out in the real world. Even when no stimulus is present, the nervous system is still firing randomly and at a low level. This low level of firing rate constitutes part of what signal detection theory calls **noise [to glossary]**. Open the [Interactive Model 2.x, Signal Detection Theory \[link to the media\]](#). When the figure opens, the main action will take place on the graph. The x-axis of the graph is called **Sensory Signal Strength**. The x-axis of this graph indicates how strongly the nervous system is signaling to the brain. One way to think of the x-axis, is how fast neurons are firing or how many neurons are firing. Going back to the closed eye example mentioned earlier, the more flashes you noticed, the higher up on this sensory signal level axis would you be. The y-axis of the graph is the probability or likelihood of getting a given

sensory signal level. When the figure first opens up you will see one curve, drawn in red on the graph, and it is labeled the noise curve. The red curve is the probability curve referring to what happens in the sensory system when there is no signal, but only noise. The theory uses the old and should be familiar normal curve to describe how likely you are to have different sensory signal levels when no signal is present. The higher the curve, the more likely you will experience that sensory signal level when there is not a signal. To use our closed eye example, there usually are some flashes in our eye, that would be the middle of the noise curve and represent the average intensity experienced, and it is the most common signal level experienced when only noise is present. Sometimes there are fewer flashes and that would occur towards the left of the mean of the curve, closer to the y-axis, where the curve is not as tall so they would not occur as often. Sometimes there are more flashes in your eye than normal and that is to the right away from the y-axis from the mean. These also are not as common, as can be seen by the fact that that part of the curve is not as tall.

Click on the **Show Signal** and the **Remove Noise** buttons on the right hand side of the window. This action will show how the Signal Detection Theory explains what happens when the signal is present. First, notice that the curve is called **Signal+Noise** not just a **Signal** curve. That is because the noise in your nervous system does not go away. It is always there. The signal, in essence, simply moves the curve to a place where there is, overall, a higher level of activity in the sensory system. However, the level of activity is not constant. Sometimes there is more activity, and sometimes there is less. The height of the blue curve at any point indicates the likelihood of any given level of activity when the signal is present.

Now, the **Remove Noise** button has turned to a **Show Noise** button. Click on it so that both the noise alone curve and the signal plus noise curves are present. If you have moved the signal curve using the slider along the bottom of the screen, move it back to a level of about 1 on the slider's scale. Notice that the curves overlap. With this overlap, we can now begin to see how hits, misses, false alarms, and correct rejections happen. What that means is that for those values of sensory activity where the two curves overlap, during a signal detection situation or experiment, that level of sensory activity could be caused by either the signal or the noise when the signal is not present. Imagine being in a dark room and expecting a very dim and brief light. From the eyes closed example, it is clear that you will see some flashes caused by the random activity of the nervous system. If the stimulus is similar in characteristics to the flashes, then you might see the stimulus but confuse it for a flash, or see a flash from the nervous system and confuse it for the stimulus.

Click on the **Show Overlap** button along the right side of the window to see the region of overlap between these two curves. When pressed, this button will cause a square to be drawn to indicate the region along the sensory signal strength axis, to show those levels of activity that could be caused by either the noise alone or when the signal occurs. Now the degree of overlap is related to what is called by Signal Detection Theory **sensitivity [to glossary]**. The sensitivity is how far apart the signal+noise curve is from the noise curve. The most common measure of sensitivity is **d' [to glossary]**. The d' measure is the distance between the two means in the number of standard deviations. In fact, the scale labeled sensitivity on the graph is in d'. Click on the **Show d'** to graphically see d'. You can adjust the sensitivity, and as a result the d', by using the slider at the bottom of the screen. As the sensitivity is larger and d' grows, the amount of overlap is smaller. It is possible for there to be no overlap between the noise and the signal plus noise curves.

Now move the slider back to about a d' of 1 and examine the implication of the overlap for signal detection. The person detecting the signal only knows the level of sensory activity that occurred. If the activity occurred along the range of sensory activity indicated by the rectangle, then the person cannot know if the activity occurred as a result of noise or the signal. So the person will have to make a decision as to what caused that activity level.

Let us now see how the four decisions discussed earlier; hits, misses, false alarms, and correct rejections, can be represented by Signal Detection Theory. Go to [Interactive Model 2.x, Decisions in SDT \[link to the media\]](#). The figure is very similar to the last media figure in that it shows both the noise and the signal plus noise curve on the same graph as before. The sensitivity or d' is shown by the orange bar connecting the means of the two curves. You can adjust sensitivity by adjusting the slider labeled "Sensitivity-d'" below the x-axis. In addition, there is a vertical yellow line. This line is the last component of signal detection theory, the **criterion [to glossary]**. Signal Detection Theory proposes that the person chooses a level of the sensory activity; and any sensory activity above that level the person will

make the judgment that the signal was present and any activity below that level the subject will judge the signal to be absent.

Now we have the four outcomes in the theory that match the possible events from a detection experiment shown in Table 1(b). The two curves describe what is going on with the signal and with noise. If you look to the right of the figure, you will see a table that describes these outcomes. Instead of the labels hits, misses, and the rest, there are percentages of trials that will fall in that category. So how do we get from the figure to the table? The noise curve describes our experience when the signal is absent and the signal plus noise curve describes what is going on when the signal is present. The criterion now describes how we make our judgments, particularly when the two curves overlap. Press the **Show Hits** button. This and the rest of the buttons are found in a table below the outcomes table with the buttons in the corresponding cell. The portion of the signal plus noise curve above the criterion is shaded. Since the entire curve represents all of the times the signal is present, the shaded portion of the curve represents the percentage of hits, which is shown in the table at the bottom of the figure. Pressing the **Show Misses** button will shade that portion of the curve that is below the criterion. This is the region of sensory activity when the signal is present that falls below the person's criterion, and thus the person making the signal detection judgment will say the signal not present and thus miss it. Press the **Remove Hits** and **Remove Misses** buttons. Now that the figure is cleared, press the **Show False Alarms** and the **Show Correct Rejection** buttons to show how these are represented in Signal Detection Theory. For both of these decisions, referring back to Table 1(b) will show that they are the result of the signal being absent, so they refer to the noise curve. The noise only sensory activity that is above the criterion will lead the person to make a judgment that the signal is present and thus make a false alarm. The green shading under the noise curve shows the false alarms. The percentage of noise only trials that lead to false alarms is the same as the percentage of the curve above the criterion and is shown in the table below the curves. The correct rejections refer to the portion of the noise curve that is below the criterion and is shown by the dark red shading and the percentage in the table.

Now the sensitivity is determined by the subject's sensory abilities to detect that signal and the strength of the signal, but the criterion is under the person's control. Using the bottom slider, adjust the criterion to about four on the slider scale. This is a strict criterion, where the subject wants to minimize the false alarms. As a result, though, the number of hits goes way down as well, shown in the table at the bottom of the screen. However, this might at times be a good decision. Say you have just gotten into a nice warm bath and the house is cold and you think you heard the phone. You are not expecting an important call and you have an answering machine. It might be wise to stay warm instead of climbing out of the tub, getting cold, and risk slipping on the floor to get a call from what might be a telemarketer.

Now adjust the criterion to about 1 on the criterion slider. Now you have minimized the chance of a miss. This is called a lax criterion. There are times when this might be a good decision as well. Going back into the bath, now change the situation so that you are expecting an important phone call, say from a significant other or potential employer or your parents and your answering machine is broken. It might be worth the discomfort to get out of the bath and get the call. The point is that regardless of the decision, it is under the control of the observer how they place their criterion and they will adjust their criterion to work best as they see the situation.

For any given sensitivity,  $d'$ , there is a range of possible outcomes according to Signal Detection Theory. For example, set  $d'$  to 1. Now take the criterion to its lowest level and notice the level of hits and false alarms. Adjust the criterion to successively larger values and see all the different values for hits and false alarms. To simplify seeing all of the possible outcomes for a given signal strength, researchers have developed a way to summarize all of the possible outcomes for this situation across all possible criterions. This summary is called the **receiver operating characteristic** or **ROC curve [to glossary]**.

Open [Interactive Model 2.x, Receiver Operating Characteristic \[link to the media\]](#). This figure shows the noise and signal+noise curve on the same graph that was shown in the last two figures. At the bottom of the screen is a table showing the proportion of signal trials that will be hits, and the proportion of noise trials that will be false alarms. In addition, in a panel to the right is another graph that plots the proportion of false alarms on the x-axis and the proportion of hits in on the y-axis. The dull yellow curve is the receiver operating characteristic or ROC. It represents all the possible combinations of proportions of hits and false alarms for any given sensitivity for all possible values of the criterion that can be set. The bright yellow dot is the current proportions of hits and false alarms for the current criterion. Drag the criterion slider around and watch how the yellow dot moves along the ROC.

Now, how bowed the ROC is depends upon the sensitivity of the subject to the signal. Adjust the sensitivity so that it is a  $d'$  of zero. The signal plus noise curve now lies on top of the noise curve, which means that the person has no sensitivity and the ROC is now where the gray diagonal line is. For all criteria, the proportion of hits equals the proportion of false alarms. Try changing the criterion and watch the table shown in the bottom right corner. After this, change the sensitivity and watch how, as the sensitivity increases, the ROC becomes more bowed and moves towards the outer lines. As sensitivity increases, it is easier to find a criterion where you can have perfect hits and no false alarms (the upper left corner of the ROC curve). Try it.

**I need a study that uses signal detection theory and the ROC curve to illustrate why this would be a good thing to study.**

### Psychophysical Laws

Science looks for patterns in the data that it discovers. A summary of these patterns that allows one to determine one outcome from another is called a law, such as Newton's laws of motion. Using these psychophysical methods, researchers have tried to determine if there are similar patterns that can become laws in our sensory and perceptual systems. For example, you measure a JND for a sound intensity of say 10 units at it is 1 unit. Next, you measure the JND for a sound intensity of 100 units and it is 10 units. Next, you measure the JND for a sound intensity of 1000 units and it is 100 units. You keep measuring JND's and there is not apparent pattern to your results. This situation would mean an immense amount of memorization of different values that would try everyone's patience and you would probably not be reading this book. Scientists would have packed in this subject long ago. This last section will discuss some of the important laws that have been proposed for sensation and perception.

#### Weber's Law

Weber's law dates back to **DATE** (REF, XXXX), when **NAME** Weber noticed something interesting about JND's. First, he noticed that not all JND's are the same size. Let us use the same example that was to illustrate JND's above. Let us call the base movement  $I$ . The JND represents how much a movement has to be increased to be discriminated as being a larger movement. Let us call this increase in movement size  $\Delta I$  (pronounced delta I). The delta stands for the difference. One expectation that might be had about JNDs is that they might all be the same size. This statement could be written as  $k = \Delta I / I$ . The letter  $k$  represents a constant, a value that does not change. This would be a nice easy law, but as you can probably guess, it does not work that way. For different sizes of movements, the JND's are different sizes. However, they can still be described by a nice easy relationship:

$$k = \Delta I / I \quad (1)$$

This equation can be translated as follows: the JND is a constant proportion of the stimulus. So if for a movement of  $1''$ , the JND turns out to be a movement  $1.1''$ . That is a  $\Delta I$  of  $.1$  and a  $k = .1/1 = .1$ . So if the movement is increased to  $10''$  I can now predict what the size of the JND will be. The  $k$  stays the same (.1) which means I need to solve the equations  $.1 = x/10$  to get the increase in movement size needed to get to the JND. This  $x$  is obviously 1 and now a movement size of  $11''$  is needed to reach the discrimination threshold. One interesting implication of Weber's law is that as stimulus intensity increases, sensory systems lose sensitivity to stimulus changes.

Open up [Interactive Illustration 2.x, Weber's Law \[link to media\]](#). On the screen, there are two graphs with a slider on the right side of the screen. The left hand graph is a plot of two stimuli against a background. The x-axis is a plot of **Location** and the y-axis is a plot of **Intensity**. Imagine that the graph is a plot of two lights against a background light level. The two lights show up as the two higher points on the graph and the background is the lower level that covers the rest of the graph. The slider adjusts the intensity of the background light level. The two stimuli will behave differently as the background changes. The stimulus on the left will always be the same absolute amount more intense than the background, that is, its  $\Delta I$  will not change. For example, if the background is 50 units of light and the stimulus is 100 units of light, then when the background is 500 units of light the stimulus will be 550 units of light. The difference is always 50. The right hand stimulus is always a constant proportion of the background, that is, its  $\Delta I$  is a constant  $k$  of  $I$  like in Weber's law. If the background is 50 and the stimulus is 100, then when the background is 500, the stimulus would be 1000. The ratio would always be 2. The right hand graph is a plot of  $\Delta I / I$  for the two stimuli. The left bar is for the left hand stimulus and the right bar is for the right hand stimulus.

In this example, assume that the right hand stimulus is actually at threshold. As you increase the background intensity, the right hand bar is always the same size because the ratio of the stimulus to the

background is always the same. However, the left hand stimulus's  $\Delta I / I$  gets smaller. When it is smaller than the right hand bar, it will be below threshold and detectable for less than half of the time.

[ADD THE DISCUSSION OF THE NOW WEBER'S LAW EXPERIMENT – MAKE SURE YOU HAVE ONE THAT WORKS FIRST]

Let us make this situation concrete. Weber's Law explains why stars are not visible during the day. The stars are like the left hand stimulus on the figure. The stars are always a constant increase from the background, as their light simply adds to the light in the sky. During the night, when the background light is low, you can see the stars because they are above the threshold. Try it on the figure. Reduce the background level and watch the star stimulus, the left hand stimulus, go above threshold on the right hand graph. In the day, with the sun out, the background light level is high and we cannot see the stars because they are below our difference threshold for that light level. Try it and watch the "star" go below threshold as you increase the background light level. In this sense, it can be stated that we lose sensitivity as we are stimulated by more intense stimuli.

Weber's law has held up well since it was first introduced. While it does not work for all conditions and all stimuli, it does work for a large range of many types of stimulation as the star example illustrates (REF, XXXX).

### **Fechner's Law**

Weber's law deals with threshold stimulation, the JND in fact. However, in our world we usually are not around threshold stimulation. We are usually being stimulated by above threshold or suprathreshold stimulation. Is it possible to be able to use what is known about thresholds to determine something about this suprathreshold experience? Gustav Fechner, the developer of psychophysics if you recall, decided that thresholds could predict suprathreshold perception. He was influenced by the success of Weber's Law to develop an explanation for suprathreshold experience. His law about sensitivity to suprathreshold stimuli is:

$$S = k * \text{Log}(I) \quad (2)$$

Where S is the strength of the person's internal sensory experience, I is the actual intensity of the stimulus and k is the constant from Weber's Law. First, do you remember your logarithms? They are exponents. So the  $\text{Log}(100)$ , assuming a base of 10, is 2. The number 10 raised to the power of 2 is 100. Logarithms have an interesting behavior: they make big numbers much more manageable by making them much smaller, and the bigger the number the smaller the number is made as the **Interactive Illustration 2.x, Logarithms [NOT DONE]** shows. **[I will have more description here but would like some feedback on even if this illustration ought to be here]**

The use of the k from Weber's Law gives an interesting interpretation to the implication of Fechner's Law. Fechner's Law implies that the difference in our experience of the strength of two stimuli is the same as counting the number of JND between the two intensity levels. Try it on [Interactive Illustration 2.x, Fechner's Law and JND \[line to media\]](#). In this figure, you will see a graph of Fechner's law relating the physical intensity of a stimulus (I) to the psychological strength of the sensory experience (S). There is a slider to the right of the screen that will allow you to adjust the constant that would be obtained from Weber's Law (k). At the bottom are two sliders that will allow you to pick two points along this curve. As you adjust them, there will be a stepped line drawn on the screen. Each step is one JND; notice that they get larger as they go up in intensity (that is what we would expect from Weber's Law). The number of steps is the difference in the sensory strength of the two intensities that you have chosen. Next to the JND is the ratio of the two values (both in terms of S and in terms of I so you can see how changes in physical intensity increase much more rapidly than increases in our sensory experience).

Thus, Fechner's Law is a big step forward in trying to understand how we experience sensations beyond thresholds. However, it assumes that threshold sensory experience is the same as suprathreshold sensory experience. This law works reasonably well for many senses, such as our perception of brightness and loudness, but the question remains whether it works for all senses.

### **Stevens' Law**

While Fechner's Law seemed to work in many situations, there still appeared some situations that were not adequately explained by the law. Take our responses to painful stimuli, it seems that pain goes up very fast, and not more and more slowly as expected by Fechner's Law. It is possible that not all senses have the same law for suprathreshold experiences, but science likes generality, so the search was on for a more general law. It is into this situation that the psychologist S. S. Stevens stepped.

**Magnitude Estimation.** Stevens' work begins with the development of a new psychophysical method. Stevens' himself dates the development of the new method to a moment on an elevator with a colleague at Harvard. In his own words he describes the situation:

"It all started from a friendly argument with a colleague who said, 'You seem to maintain that each loudness has a number and that if someone sounded a tone I should be able to tell him the number.' I replied, 'That's an interesting idea. Let's try it.'" (Stevens, 1956, p. 2),

It is from this conversation that the **Magnitude Estimation [to glossary]** was developed.

The method is very simple. The participant is presented a stimulus. Then the participant simply assigns a number that indicates the strength of that stimulus. Bring up the [Experiment 2.x, Magnitude Estimation \[link to the media figure\]](#) to try a sample of a magnitude estimation experiment. First, as with the other psychophysical methods, there comes up a page where you can set the method parameters. The parameters for this method are the number of steps to be estimated, the number of repetitions, and whether or not there is a **modulus [to glossary]**. In the standard experiment the only stimulus presented is the stimulus to be judged. When a modulus is used, a second stimulus is presented that is given a standard number. The experimenter will pick one stimulus setting and assign it a number such as 100. Then the participant will assign the value to the stimuli in the experiment relative to the modulus. If the modulus appears twice as strong, then the participant should assign a number of 200. If the modulus appears half as strong, then the participant should assign a 50. The modulus is a good technique for getting participants to use the same range of values, though it is not required to get good data. There are ways of adjusting participant's data to be in the same range even if they do not use the same range.

In this experiment, you will be judging the loudness of a tone and you will have a modulus. The modulus, as will be indicated on the screen, will be assigned a value of 100. As in the other auditory experiments, you will be asked to adjust the intensity of a tone until it is a comfortable, moderate intensity. This is the same calibration step you have done before. Then on each trial you will hear the modulus followed by the tone you are to judge. There is a box where you are to enter a number that indicates your judgment. Use only whole numbers, and if you enter any character other than a number you will be asked to reenter the value. If you have changed any of the values push the **Reset** buttons at the bottom of the screen and then press the **Done** button.

Now that you have done the experiment, the data is presented on your screen. On the x-axis is the intensity of the sound plotted as the proportion of the intensity of the loudest tone. On the y-axis is the average of your magnitude estimations for each tone. You have your average of 5 magnitude estimations of 10 different intensities with the lines connecting between the dots. **[Development: can we do this]** Please submit the data so that it can be collected with the data from other students. Then run the [Experiment 2.x, Magnitude Estimation 2 \[link to the media\]](#). This experiment runs exactly the same as the last except you will be judging the length of lines. You will have a modulus again, and it will have a value of 100 as before. When you get the data from this experiment please submit it as well.

**The Law That Arises.** Now bring up [Interactive Illustration 2.x, Data from both Magnitude Estimation Experiments \[link to media figure NOT DONE\]](#). **[Development: is this figure possible?]** This figure will graph on a figure the results from all of the students who have tried this experiment. Using these data we will try to show how Fechner's Law fails and how Stevens came up with a more general law.

If you click on the checkbox on the left hand side of the screen, you will add a line representing Fechner's Law. There is a slider right below the check box that will allow you to adjust the value of k from the equation. Adjust it and see if you can get this equation to lie close to on top of the data from the loudness magnitude estimation study. It will not lie on top of it, but it should get pretty close to hitting most of the points. Thus, Fechner's Law is adequate for loudness data. Now try the same exercise with the line length data. This data looks almost like a straight line and because Fechner's Law has a logarithm in it it will never be a close fit. Fechner's Law cannot describe these results very well.

Stevens developed a new equation to try to encapsulate both types of data sets. It is called Stevens' Power Law and it is as follows:

$$S = cI^b \quad (3)$$

The S and I are the same as from Fechner's Law. The c is just a constant that is used to make the numbers come out to convenient values and as such we can ignore it for now. The b or power of the equation is the important number in the equation. When b is less than one, you get a curve that looks somewhat like Fechner's logarithm function. Click on the Stevens' Law check box on the figure. You will have a slider where you can adjust b. Make it less than one and you can make it lie pretty close to the



loudness data just like Fechner's Law. In fact, it tends to fit loudness data even a bit better than Fechner's Law (REF). Now adjust it to 1 and it will be a straight line and will fit closely to the line length data [**I may need to add a slider for c as well to adjust the fit**]. You can also make b greater than 1. Adjust it on the figure. Now our sensory experience increases in strength much faster than the physical stimulus. This pattern can also be found in nature. An example is the pain that comes from electric shock. You might consider why this would be the case.

Open **Interactive Illustration 2.x, Fechner's Law vs. Steven's Law** [[link to media](#)]. In this figure you can directly compare the possible relationships between sensory intensity and sensation described by these two laws. The figure opens with graph with one curve on it in red. The graph is a plot of **Intensity or I** for the physical domain and **Sensation or S** for the psychological domain. The first curve is a graph of Fechner's Law. On the left side of the screen are several controls and the bottom slider is the **k** slider. Adjust this slider to see the effect that k has on Fechner's Law. The shape does not change but the curve does move. No click on the **Show Example 1** check box to add one curve following Steven's Law. The curve and the labels for this line are all in cyan. If you move the **b1** slider you will change the exponent for this line and the value for this exponent is given at the end of the slider. You can adjust the b for this equation to a point less than on and then adjust the **k** slider for the Fechner's Law curve and make the two lines be very similar. This is the situation for brightness and loudness where the two laws both perform very well. But you can also adjust the **b1** slider so that the b for the Steven's Law Curve is equal to 1. Now, the cyan line is straight. This situation is like the line length judgments from the second magnitude estimation experiment. You can even make the **b1** slider greater than 1 and now the exponent is greater than 1 for the Steven's Law Curve. The function curves upward, opposite to Fechner's Law. There are a few psychological experiences that follow these types of trends. The perception of pain due to electrical shock is one of them. In this activity, you can also play with the constant for the Steven's Law curve using the **c1** slider and actually have up to 3 Steven's Law curves on the screen at one time. In this way you can more directly compare the variety of relationships of intensity to sensation that Steven's Law can describe.

Thus, Stevens' Law covers a wider range of possibilities than Fechner's and has replaced his law. The value of b has been found in a number of cases. Table 2 gives a number of representative values for b.

#### Summary

In this chapter we have covered the basic ways that sensory psychologists collect data from human subjects. Many of the studies that will be discussed in this book will use these methods or adaptations of these methods. In addition, throughout this book you will be asked to try a sample experiment and we will use these methods. These methods are grouped into the traditional methods, the modern methods, and magnitude estimation. They all require simple responses from the subject and complex manipulation of the stimulus.

The chapter also covered the standard measures such as the absolute threshold, difference threshold or JND, and the point of subjective equality. These methods allow a lot of information about the limits and behavior of our sensory systems to be uncovered.

This behavior of our sensory systems has been summarized in psychophysical laws. These laws are Weber's Law which describes the behavior of JND, Fechner's Law and Stevens' Law which attempt to describe our suprathreshold sensory abilities. With this foundation we are now ready to understand how our sensory systems work and in the next chapter we will begin the discussion of the visual system.

#### Key Terms

Figure 2.x. An idealized response curve from a threshold experiment.

Figure 2.x. A spatial forced-choice experiment.