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About Science—Hypothesis

THE QUESTION

All scientific research begins with a question. A researcher wants to know why something happens, or how something works. Questions however are often vague and general, and may not be useful scientifically. The process of “doing science” begins when the question is stated so that it can be answered using the **scientific method** - by doing experiments or making careful observations. A question stated in this way is called an **hypothesis**. Forming an hypothesis is the first, and probably the most important, step in the scientific process. Well-designed experiments, and good research in general, grow from the hypothesis.

THE HYPOTHESIS

So, you might ask, what makes a hypothesis good? First, the hypothesis should be **specific** and **clearly state your question(s)**. For example, “How do we see brightness?” is not very specific. It is a very general question that could not be answered with a single experiment. “What is the dimmest light we can see?” is much more specific and could easily be tested. Second, the question should be stated so that **there are only two possible answers**. Either the hypothesis is confirmed or it isn’t (this is not as easy as it sounds—more on this in the “Experiment” section). Third, in addition to stating a question, you must make a **reasonable prediction** about the answer to your question—what you expect and why you expect it. This means that if your answer is what you expected, you have an understanding of and an explanation for your results. Finally, in order to ask a meaningful question and make a reasonable guess as to its answer, you must be familiar with what is already known about the subject. This means doing **background research**—finding out everything you can about what other researchers have done and what is already known. You may even discover that someone else has already asked and attempted to answer your question.

In general, you should state your question in terms of the underlying process which is being measured, and your prediction should be stated in terms of the experimental procedure used to measure that process. This difference is important because in measuring perception, we can only use indirect measurement techniques and must infer from their outcome what is “really” going on in the brain. The question must be asked in such a way that the answer can be inferred from the measurement technique that is used.

As an example, let’s say we want to find out how the brain processes information about brightness. In particular, let’s say we already know that the brain processes some types of visual information faster than others, and other research suggests that brighter stimuli might be processed faster than dimmer stimuli. So our question would be, “Does the brain process information about brighter stimuli faster than information about dimmer stimuli?” If we find that it does, then our result would be consistent with what we already know about speed differences in the brain. We also know that a common method used by vision scientists to (indirectly) measure the speed at which the brain processes information is the reaction-time procedure. If the time it takes an observer to respond to a stimulus is shorter, we can infer that the brain processed information about that stimulus faster. The hypothesis should therefore include a statement of the problem in terms of the known differences in the brain’s processing speed (the underlying process) and the expected outcome in terms of reaction times (the experimental procedure). For example we might state our hypothesis: “It is known that the brain processes some types of visual information faster than other types. Based on previous research, it is expected that

reaction times, which reflect processing speed in the brain, should be shorter for brighter than for dimmer stimuli.”

About Science—Experiment

THE PROCESS OF DOING SCIENCE

For most questions there are many different ways to find an answer, but not all are “scientific.” Although there are many different kinds of methods used by scientists to answer questions, they all share some things in common. The scientific process revolves around hypothesis testing. To test the validity of an hypothesis, objective methods are used to collect data. Data can be collected by observation or by performing experiments. When the data are analyzed, the results can be used to decide if the hypothesis is supported. (Actually, the best that can be done using the scientific method is to decide how **likely** it is that the hypothesis is correct. The scientific method does not let us “prove” anything with complete certainty.)

Vision scientists usually use experiments to test their hypotheses, rather than observations. Observation is a passive method of collecting data. That means that the researcher just watches and makes measurements—they do not interfere with what is being observed. An experiment is just the opposite—it is an active method of collecting data. The researcher manipulates certain conditions and then observes what the results are.

DESIGNING EXPERIMENTS

Once you have stated your hypothesis and decided that you will do an experiment to test it, you must design an experiment that will answer the question asked by your hypothesis. There are two things to consider when designing an experiment: the condition(s) you will manipulate—the **independent variable(s)**—and the behavior(s) you will measure—the **dependent variable(s)**. The independent variable must be something that you can accurately control and easily present to the observer, and the dependent variable must be something that you can objectively and consistently measure. It is also important to keep in mind how the results of your experiment will answer your question. In other words, be sure to think about how you will analyze and present the data you collect.

For example, let’s design an experiment to test the hypothesis stated in the “Hypothesis” section: “It is known that the brain processes some types of visual information faster than other types. Based on previous research, it is expected that reaction times, which reflect processing speed in the brain, should be shorter for brighter than for dimmer stimuli.” The **independent variable** in this case is the brightness of the stimuli. A good way to present this type of stimulus to an observer would be to create spots of light on a computer monitor. The brightness of any point on a monitor can be easily controlled and you can accurately measure the brightness of different spots with a photometer. The **dependent variable** in this case is the reaction times of the observers. Since we can’t directly measure the speed at which the brain processes information, we use reaction times to infer how fast the brain is. The time it takes an observer to make a response is an objective measure that can be made consistently on different trials. If you are presenting your stimuli on a computer, it is a simple matter to use the same computer to record responses. You can use the computer’s clock to measure the time it takes an observer to respond to a stimulus, and then record that time. When you have recorded reaction times to several stimuli that are of different brightnesses from several observers, you can prepare a graph to show how (or if) reaction times change with changes in brightness. (It is important in vision research to use more than one observer in your

experiments—it's possible that any one observer might not be "typical," and then your results would be incorrect. If you use more than one observer—usually 3 to 5—your results are more likely to be accurate.) If the reaction times got shorter as the stimuli got brighter, then your hypothesis is supported. If the reaction times got longer or stayed about the same, then your hypothesis is not supported.

The best kind of experiments will have only two possible outcomes: either the results support your hypothesis (your hypothesis is correct) or they do not (your hypothesis is incorrect). Often however, just because your results do not support your hypothesis, that does not necessarily mean that your hypothesis is wrong (we say the results are **inconclusive**). If this happens, you need to think about either your hypothesis, your experimental design, or both, and possibly restate your hypothesis and/or redesign your experiment. It's really pretty unusual that the first experiment you do will give you a definite answer to your question. Usually, several short **pilot experiments** are done to find out exactly what independent variables should be used and exactly how to manipulate those variables. In pilot experiments, you would typically use only one or two observers and only run a few trials to get a quick idea of whether or not you are asking the right question and using the best method to answer that question.

The remaining sections describe what to do with the data you have collected—how to analyze and present your results.

About Science—Data Analysis

DATA ANALYSIS

Once you've finished collecting your data, it's time to figure out what they mean. But it's pretty much impossible to do this with just the **raw data** (the list of numbers generated by the experiment). In order to interpret your data, you need to do some statistical analyses and, usually, plot the results of your analyses in graphs.

DESCRIPTIVE STATISTICS—MEAN

The most commonly used statistic is the **mean** (sometimes called the **average**). The mean lets you summarize groups of raw data and find out how they are similar or different. This is especially important in vision research because you never record just one response. Because peoples' responses are a little different each time, you need to record many responses and then average them to see trends in the responses. The mean is one of the most useful statistics for comparing trends between groups of data, and it is also one of the easiest statistics to calculate.

To calculate the mean, you add up the group of numbers and then divide by the number of members in the group. For example, say your group of data was: 105, 114, 93, 112, 110, 98. The mean of these numbers would be 105.33. That's

$$105 + 114 + 93 + 112 + 110 + 98 = 632 \quad 632 / 6 = 105.33$$

In the experiments in iNSIGHT, means will be calculated for you. However, you may need to group the data differently to answer certain questions. You can do this in one of two ways. If you want to combine groups for which the means have already been calculated, you can just calculate the mean of the means. In other words, add up the means and then divide by the number of means. If you want to group the data differently, you can calculate new means from the raw data.

DESCRIPTIVE STATISTICS—STANDARD ERROR

It was mentioned above that peoples' responses are little different each time, even if they are responding to the same stimulus. That's why we do several trials in each condition. The mean gives us an estimate of the **middle** of a group of numbers. But we also need to know the **range** of the group of numbers, or how different two groups of numbers really are from each other. This is important when we compare two groups of numbers and the two groups overlap. How do we know if the two groups are really different?

For example, say we have two groups of numbers:

$$105, 114, 93, 112, 110, 98 - \text{mean} = 105.33$$

$$74, 102, 85, 94, 82, 90 - \text{mean} = 87.83$$

The means of the two groups are different, but there is some overlap between the two groups. Are they different or not? In science, we can never really be 100% sure (we can never **prove** anything). The best we can do is do statistical analyses, and based on the results of those analyses, be **reasonably** sure. The statistic we use together with the mean to tell if two groups of data are different is the **standard error (SE)**. The standard error gives us an measure of how **spread out** the data are, and that tells us how likely it is that two groups are different. For example, for the two groups of data above:

$$\text{mean} = 105.33, \text{ standard error} = 3.40$$

$$\text{mean} = 87.83, \text{ standard error} = 3.99$$

To quickly see if they are really different, we add the SE to the smaller mean and subtract the SE from the larger mean. If the results overlap we can be reasonably sure that the two groups are **not** different. If they do not overlap, we can be reasonably sure that the two groups really are different. So, for the groups of data above:

$$105.33 - 3.73 = 101.60$$

$$87.33 + 4.37 = 92.20$$

92.20 is still less than 101.60, so we would tentatively conclude that the two groups of data really are different (you would need to do inferential statistics to confirm your conclusion). If you would like to know how to calculate SEs, take a look at the last part of this section, **Calculating the Standard Error** (it's really pretty easy!), but you don't need to know how to calculate SEs to complete these experiments—this will be done for you. You just need to understand their meaning.

CALCULATING THE STANDARD ERROR

- (1) Make a table with two columns: in the first column put the scores, and in the second column put the scores squared (multiply each score by itself). Add up each column to get a sum of scores (A) and a sum of squared scores (B).

	Scores	Squared Scores
	105	11025
	114	12996
	93	8649
	112	12544
	110	12100
	98	9604
Sums	632 (A)	66918 (B)

- (2) Take the sum of scores (A) and square it to get C.

$$\text{Sum of Scores Squared} = 632 * 632 = 399424 \text{ (C)}$$

- (3) Take the number of scores, 6, (N) and square it to get N².

$$\text{Number of Scores Squared} = 6 * 6 = 36 \text{ (N}^2\text{)}$$

- (4) Take the values you calculated in Steps 1-3 and plug them into the following formula:

$$\frac{(N * B) - C}{N^2 * (N - 1)} = \frac{(6 * 66918) - 399424}{36 * (6 - 1)} = 11.58$$

- (5) Take the square root of the value you calculated in Step 4 to get the standard error, 3.40. That's it!

About Science—Data Presentation**PRESENTING YOUR DATA**

Once you've finished with your analyses, you need to put the summary of your results into a form that makes it easy for you (and others) to tell what your results mean. Sometimes, if you have only a very few numbers and the differences between groups is very obvious, you can present your results in the form of a **table**. A table is just a list of numbers. But most of the time, it is much easier to see what your results mean when they are plotted in a **graph**. Graphs make it very easy to compare differences (or see if there are no differences) between groups.

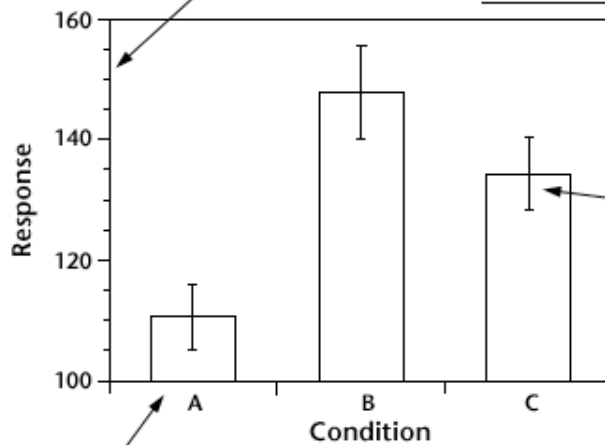
GRAPHING BASICS

There are basically two type of graphs—**bar graphs** and **line graphs**. The kind of graph you use to present your data depends on your data. **Bar graphs** are best when you are making a simple comparison between two or more groups or conditions, or if one of the experimental variables is categorical. **Line graphs** are used when the variables are represented on an interval or ratio scale, in particular when the X-axis variable is continuous. See below for examples of a bar graph and a line graph.

The Basic Parts of a Bar Graph

The Y axis (vertical) is where you represent the data values.

Data	SE
110.6	5.84
147.8	7.85
134.8	6.11



The X axis (horizontal) is where you represent the different conditions.

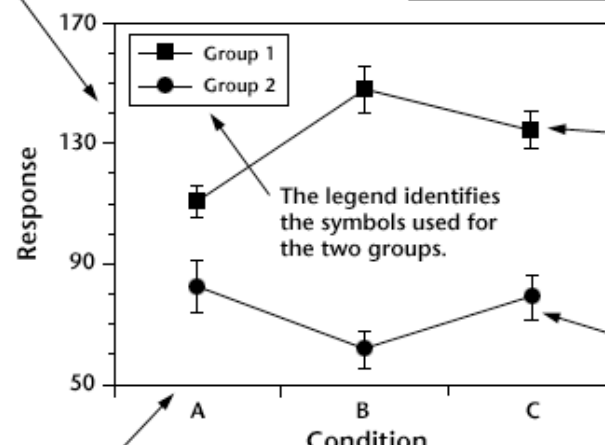
A graph should be wider than it is tall, and you should not put more than 5-7 numbers on a side. Use the little "tick marks" to show in-between values. The tops of the bars represent the means for each group.

The lines in the middle of the bars show standard errors. The top is the mean + 1 SE and the bottom is the mean - 1 SE. If the error bars in the two groups do not overlap then the two groups of data are significantly different. In this example, conditions A and B are different, conditions A and C are different, but conditions B and C are not.

The Basic Parts of a Line Graph

The Y axis (vertical) is where you represent the data values.

Group 1		Group 2	
Data	SE	Data	SE
110.6	5.34	82.5	8.65
147.8	7.85	61.6	6.33
134.3	6.11	78.9	7.21



The X axis (horizontal) is where you represent the different conditions.

A graph should be wider than it is tall, and you should not put more than 5 - 7 numbers on a side. Use the little "tick marks" to show in-between values.

There are two groups of data and each one has a value in each of three conditions. It is best to use different shaped symbols rather than different colors, so you can tell the difference if you print the graph in black and white.

The bars show standard errors. The top is the mean + 1 SE and the bottom is the mean - 1 SE. If the error bars in the two groups do not overlap then the two groups of data are significantly different.

The following are some general guidelines for making graphs:

Graphs should generally be wider than they are tall, and should not be too crowded or cluttered. That means that if you need to plot lots of data points, use a line graph, and if there are *really* a lot of data points, just connect the points and do not draw

the symbols at all. You should also not try to put too many labels on an axis—no more than about 6 or 7. For example, if the range of values you are plotting is 100 – 200, put the labels every 20 (6 labels at 100, 120, 140, 160, 180, 200) rather than every ten (11 labels), and use small lines on the axis (tick marks) to show the in-between values.

The horizontal axis in a graph is called the **X axis**, and the vertical axis is the **Y axis**. The X axis is where you plot the different conditions or groups in your experiment. You plot the results of your measurements (i.e., the independent variable) on the Y axis. The labels on the X axis are usually names that represent groups, and the labels on the Y axis are usually numbers (although sometimes you want to plot two sets of numbers). It is very important to label your graph, so people that look at it can figure out what is being plotted. Each axis should have a label showing what is being plotted (for example the X axis might be labeled “Condition”), and each unit on the axis should also have a label. For example, if the Y axis is showing the number of correct responses, the unit labels would be the actual numbers, 2, 4, 6, etc.

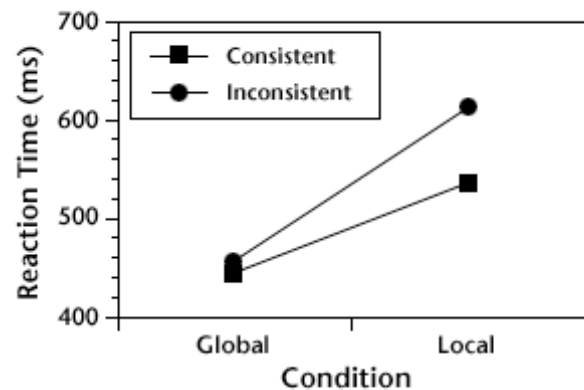


Figure 3. Reaction times (in milliseconds) are plotted for both the global and local conditions and for the consistent and inconsistent conditions.

It’s usually a good idea to design your graph so that it can be understood if it is printed in black and white. In a line graph you should choose symbols that are different shapes (squares and circles) instead of different colors. If you need to show different conditions in a bar graph you can fill the bars with stripes of different widths or at different angles.

About Science—Research Report

PRESENTING YOUR RESULTS

The final step in the research process is sharing your results and conclusions with your peers and with the world. Scientists usually do this in two different ways, by writing a research report or by making an oral presentation. We will talk here about preparing a written report, but you should use the same outline if you are making an oral presentation. The general idea is to provide enough information so that anyone can replicate your experiment just from reading your report. A research report is usually divided into four parts and each of these parts contains certain types of information.

INTRODUCTION

The **Introduction** has two main topics. First, you introduce the reader to the subject of the experiment. This means that you have to do some background research to learn about your topic (i.e., a **literature review**). You should provide enough information so that the reader will also understand your topic. The second thing that is included in the Introduction is a statement of the question(s) you are

trying to answer with your experiments. Explain briefly what you are asking, why you are asking it, what answers you expect to find, and why you expect these findings. In other words, clearly state your **hypothesis**, and try to convince the reader that it is a good hypothesis.

METHODS

The **Methods** section is usually divided into several subsections, **Observers**, **Apparatus**, and **Procedure**. You can add other sections if what you are describing does not fit into these categories. In the **Observers** section (subjects in a vision experiment are called **observers**), describe all relevant details about the subjects of your experiment—their age, if they were wearing glasses, how many were involved in the experiment, and so on. Different types of information might be important for different experiments. For example, if you were studying color vision, it would be important to know if any of your observers were color blind. In the **Apparatus** section, describe the equipment you used to conduct your experiment. This might include the kind of computer you are using, the kind of monitor it has, any special equipment or additional materials that are needed—whatever is important to know for the particular experiment. The **Procedure** section is usually the longest part of the Methods section. This is where you describe **in detail** exactly what you did. This would include a description of the different conditions, the stimuli (and their size), the viewing distance, the number of trials in each condition, and what happened on each trial. Feel free to include drawings or pictures if it helps to explain what you did or how you did it. The procedure section is one place where you can't provide too much information.

RESULTS

The **Results** section is where you present your data—not the raw data (raw data are generally not included, but in **RARE** cases may be appropriate), but the results of your statistical analyses and your graphs. The Results section should be just long enough to explain what you found, without explaining what it means (that comes later). Graphs are almost always the best way to present summaries of your data, but they aren't enough by themselves. For each graph that you include you should describe it and explain what it means. Each graph should be labeled with a number, for example "Figure 3", and should have a brief caption explaining what is plotted (what the axes represent). Explain in more detail in the body of your report what the graph shows and point out any important comparisons. For example, "Figure 1 shows the difference in reaction times between conditions A, B, and C. You can see that reaction times were longer in condition B than in A and C, but conditions A and C were about the same." **NEVER** include a graph without discussing it! Also, any graphs, pictures, or drawings you include in your report should be numbered and referred to as "Figures", for example, Figure 1, Figure 2. Anything that's not a Table (a list of numbers is called a Table), is called a Figure.

DISCUSSION

This is probably the most important part of your report—the **Discussion** section is where you explain the meaning of your results. For example, in the Results section you might have shown that reaction times were longer for one condition than for another. In the Discussion section you interpret that result. You might explain what a difference in reaction times reveals about the way the brain works. In other words, this section is where you try to answer the questions you asked in the Introduction. Did your results support or refute your hypothesis? If the results were not what you expected, you should try to think of reasons why they weren't. It might also be that your results did not really answer your question one way or the other. You can also include suggestions for future research in the Discussion section. Sometimes when

you answer one question, you think of several new questions that you would like to investigate.

GENERAL SUGGESTIONS

Most scientists have a pretty unique way of writing—some things about their style would not be considered “good form” for writing in other subject areas (like English class). For example, you should try to avoid using the **first person** (“I” or “me” or “we”). Instead of saying “I designed the experiment...”, it would be better to say “The experiment was designed...” As you may have noticed, this means that you tend to use **passive** phrases quite a bit. Although this is generally considered not to be very good if you are writing an essay, it is perfectly OK when you are writing a scientific report.

Another thing you should keep in mind when writing a report is that you are describing things that have already happened. That means that you should use the **past tense**, especially in the Methods and Results sections. For example, instead of saying “the scores in condition A **are** different than the scores in condition B,” you should say “the scores in condition A **were** different than the scores in condition B.”

Finally, probably the most important rule of all—be **brief**. That doesn’t mean that you should leave anything out. But, it does mean that you should not include any unnecessary information. When people read a research report they want just the important information—they do not want to waste their time reading about things that have nothing to do with the research. If you want to discuss your theories on the meaning of life or the nature of the universe, save it for another paper.

About Vision—Light and Color

LIGHT

To help us understand how we see, we need to know a little about light. Light is a type of energy called **electromagnetic**, or **EM**, radiation. It is the only kind of EM radiation that we can see. One thing about light that is unusual is that it can behave in two completely different ways. Sometimes it appears to be made up of waves, and other times it appears to be made up of little “packets” of energy called **particles**. Depending on how we choose to measure light, it “appears” to be either one or the other. It is similar to measuring your height with a yard stick and a meter stick: If you measure with one you will describe your height in feet and inches, and if you use the other you will describe it in meters and centimeters. There can be two different ways of measuring and describing the same thing. To keep things as simple as possible, light will be described here as waves.

We are all familiar with waves in our daily lives. We see waves at the beach and in our bathtub, and sound is another, special type of wave. Another type of wave with which we are all familiar is the electromagnetic wave (EM wave). Some examples of EM waves are X-rays, microwaves, radio waves, and visible light. We refer to the set of electromagnetic waves as the electromagnetic spectrum (EM spectrum).

A wave must have something “waving”, or moving back and forth. For waves in water, it is the water moving up and down. For EM waves, it is the electromagnetic field that is moving. One way to describe waves, EM or any other type, is to measure their **wavelength**. Wavelength is a measure of how often the pattern of the wave repeats itself. Wavelength measures the distance between two successive peaks or troughs in the wave.

MEASURING LIGHT

For convenience, the EM spectrum has been divided into several sub-groups according to wavelength. It is important to remember that the only difference between waves in these different groups is wavelength—in all other respects, the different groups are the same. The groups are: radio, microwave, infrared, visible light, ultraviolet, X-rays, and gamma rays.

Many of these groups might already be familiar to you. The only group that is important when talking about vision is visible light, because that is the only part of the spectrum that we can see. Visible light can be further divided in sub-groups, according to wavelength, and we call these sub-groups “colors.” If you shine white light through a prism, the different wavelengths will be separated, making a rainbow of colors. The order of the colors is always the same because the color we see depends on the wavelength of the light—each wavelength is bent by a different amount by the prism. The order of the colors can be recalled from the familiar ROY G BIV: **R**ed, **O**range, **Y**ellow, **G**reen, **B**lue, **I**ndigo, **V**iolet.

The wavelengths of visible light are in the middle of the range of the known EM spectrum, measured in billionths of a meter (approximately 400 to 700 billionths of a meter, or **nanometers**). This is about the size of a small dust particle in the air. At longer wavelengths is infrared, then microwave, then radio, which can be measured in centimeters and even meters. At shorter wavelengths there is ultraviolet, X-rays, and finally gamma rays, which are measured in hundredths of a nanometer.

COLORS AND COLOR SPACES

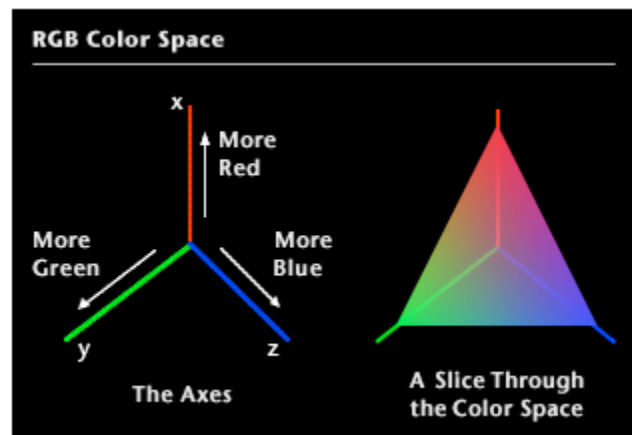
Vision scientists and others who deal with colors (like artists, photographers, or printers) often use a “color space” to describe and compare colors. A color space is a way of plotting some measure of color in a 3D space—in other words, **it’s a graph**.

There are several different types of color spaces in common use, each one being appropriate for different purposes. Two common color spaces, the RGB color space and the HSB color space, will be described here.

RGB Color Space. The RGB system (**R**ed, **G**reen, **B**lue) is normally used when making colors on computers and when mixing colored lights. Red, green, and blue are the **primary colors**. This means that any color can be made by mixing these three colors together. When using the RGB system, we plot the amount of each primary needed to make a certain color in the RGB color space. Like all three-

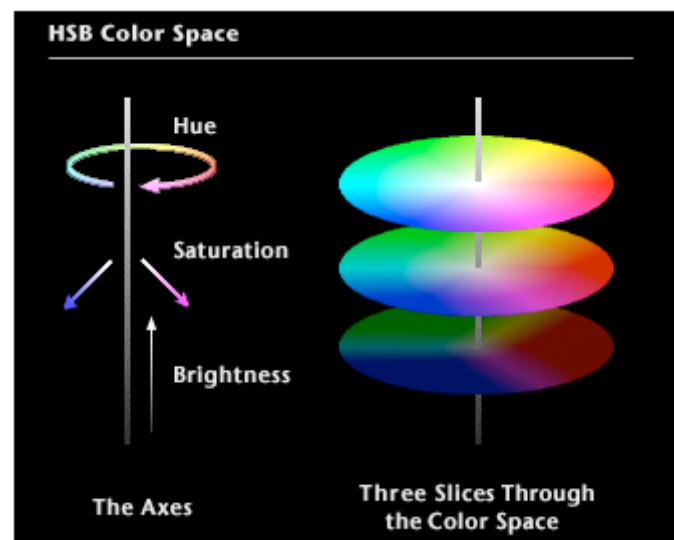
dimensional graphs, the RGB color space has three axes (that's plural for axis)—the *x* axis (red), the *y* axis (green), and the *z* axis (blue). When you plot a point on the RGB color space graph, it's position tells how much of each of the three primary colors is in the mixture. In these exercises, we will indicate the amount of

a color with the numbers 0 – 255, where 0 means no color and 255 is the maximum amount of the color. For example, if we mixed RGB values of 0, 0, 0, we would have black and it would be plotted at the point where the three axes meet. If we mixed RGB values of 0, 0, 255, we would have a bright blue and it would be plotted right on the blue axis at the very end. The “Color Mixing” demonstration will let you experiment with changing the RGB values of a mixture and show you how they are plotted in an RGB color space.



HSB Color Space. Another system that can be used to describe colors is the HSB system, where “H” stands for **hue**, “S” stands for **saturation**, and “B” stands for **brightness**. “Hue” refers to the shade, or tint, of a color mixture, for example, how red-ish or green-ish or yellow-ish the color is.

“Saturation” refers to how much of a particular hue is present, or how “pure” the color is. Another way of saying this, is that it refers to how much white is in the mixture. For example, a saturated red would be a very deep shade of red, and a desaturated



red would be a pink. “Brightness,” as you might expect, refers to how bright or dark a color is. As brightness decreases, a color gets darker and eventually becomes black.

When using the HSB system, we plot colors in the HSB color space. When plotting colors in the HSB color space, we do not use a standard “xyz” graph, but instead we use what is called a “polar” coordinate system. You can see what this color space looks like in the diagram below. As you can see in the diagram, the polar coordinate system is circular. Saturation values increase as you move out from the center, and brightness values increase as you go from bottom to top. Hue values are arranged in a circle and increase as you move around the edge. Hues are arranged in this way so that similar colors are near each other—the greens are near the blues, the yellows near the oranges, and the purples are between the reds and blues (remember, reds are at one end of the spectrum and blues at the other end).

About Vision—Measuring Vision

PSYCHOPHYSICAL METHODS

Psychophysics (not to be confused with metaphysics) is the science of measuring perception. The term perception includes all our senses—vision, hearing, taste, touch, and smell. Here, we will only talk about vision, but the principles apply to measuring any of the senses. **Psychophysical methods** are the procedures used by vision scientists to measure vision in an objective way. In one way or another, all psychophysical methods involve showing a stimulus to an observer and asking them to respond in some way to indicate what they see. It sounds pretty easy, but the tricky part is choosing the stimulus and the response so that your measurements are objective. Say for example, you wanted to study how people can tell the difference between shapes. You might show observers pictures of different shapes and ask them to describe the shapes. The problem with this method is that everyone might describe the same shape a little differently and it would be impossible to compare the responses of the different observers. A more objective method would be to show observers two shapes at a time and ask them to say whether the shapes are the same or different. That way you have only two possible responses and everybody’s responses would be the same. Over the past 100 years, vision scientists have created several such methods that can be used to measure perception objectively. The following is a description of some of those methods.

REACTION TIME PROCEDURES

Sometimes vision scientists want to find out how long it takes the brain to do or see something. You may think that you “see” something as soon as it appears, but there is actually a slight delay while the brain gathers information and creates an image for you to “see.” This delay is longer than you might think, and can often be hundreds of milliseconds long (a millisecond is one 1000th of a second). It is very difficult to measure what’s going on in the brain directly, but we can estimate how fast things happen with a psychophysical method called **reaction time**. In a reaction-time procedure the observer is shown a stimulus and asked to make a response as fast as they can. By comparing how long it takes to respond to different stimuli, we can estimate how long it takes the visual part of the brain to “see” them. There are two types of reaction-time procedures: simple reaction times and choice reaction times. In a **simple reaction-time procedure** all the observer has to do is make a response. For example, you might ask an observer to press a button as soon as they see something appear on the screen. In a **choice reaction-time procedure** the observer has to make a decision before responding. For example, we might show them either an “X” or an “O” (they don’t know which), and they have

to press one button if they see an “X” or another button if they see an “O.”

YES/NO PROCEDURES

The **Yes/No procedure** is one of the simplest and most direct methods used by vision scientists to measure perceptions. Yes/No procedures can be used in a wide variety of circumstances. For example, a Yes/No procedure could be used to measure the least amount of light that can be seen. Or, it might be used to find out how different two stimuli must be in order for them to be perceived as being different. On each trial in a Yes-No procedure the observer is shown a stimulus and asked to respond to a question in one of two ways. For example, if you were measuring the least amount of light that can be seen, you might show the observer spots of light (one at a time) at different brightnesses and ask the observer on each trial, “Do you see it?”. The response in a Yes/No procedure doesn’t have to be “Yes” or “No”—any question that has only two answers would still be called a Yes-No procedure. It just means that no in-between answers (maybe’s) are allowed.

Usually in a Yes/No procedure, the observer is shown a range of stimuli. For example, if you were trying to find out how different two stimuli must be in order for them to be perceived as being different, you would show the observer several pairs of stimuli. Some pairs would clearly look different, other pairs would clearly look the same, and still others would be somewhere in between. One method used to arrange the order of the stimuli is called the **Method of Limits**. In the method of limits, the first stimulus is chosen so that the observer will make a particular response. In the example above, you might pick a pair of stimuli that were clearly different, so the observer’s response to “Are they different?” would be “Yes.” On the next trial they would be a little less different, and would continue to be less and less different on each trial until the observer responded “No.” On the next trial, the stimuli would be the same, so the observer’s response would be “No” again. After that, the stimuli would continue to be more and more different on each trial until the observer responded “Yes” again. Each time the observer changes their response from “Yes” to “No” or “No” to “Yes,” it is called a **reversal**, and the trials would continue (going back and forth) until the observer makes a certain number of reversals.

MAGNITUDE ESTIMATION PROCEDURES

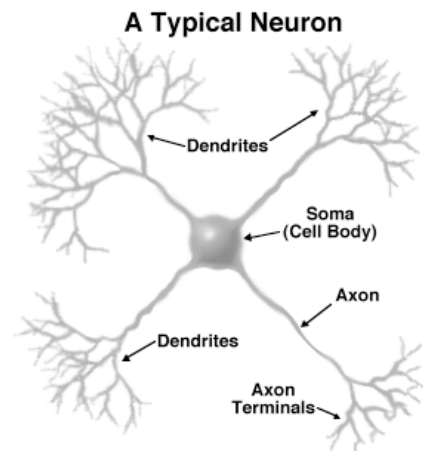
Vision scientists often like to create scales for different parts of vision. A scale is something that is used to compare or measure things. In vision science, scales are used to measure how our perceptions change when things that we see change. For example, we might want to measure how our perception of “brightness” changes when the intensity of an object changes. Scales have been created for perceptions such as size, length, color, speed of movement, among others. One of the simplest and most direct procedures vision scientists use to create perceptual scales is called **magnitude estimation**. In a magnitude estimation procedure an observer assigns numbers to a group of stimuli so that the numbers represent how the stimuli are different. When the observer has assigned numbers to a range of stimuli, a scale can be created that measures the observer’s perception of those stimuli. Usually, the observer uses a stimulus called the **standard** to compare to other stimuli. The standard is assigned a number by the experimenter (this number is called the **modulus**), then observers assign numbers to the other stimuli to show how they compare to the standard. For example, say you are scaling speed and the standard speed has a value of 100. If another stimulus looks like it’s moving twice as fast as the standard, the observer would assign the value 200 to it. If another stimulus looks like it’s moving half as fast, the observer would assign the value 50 to it. This may sound like it’s a difficult task for the observer —keeping track of all the values and

keeping them straight, but it turns out to be pretty easy. Not only are observers consistent with the same stimuli, for example if they scale the same stimulus more than once, but they also create scales that are very similar for all different kinds of stimuli.

About Vision—The Brain

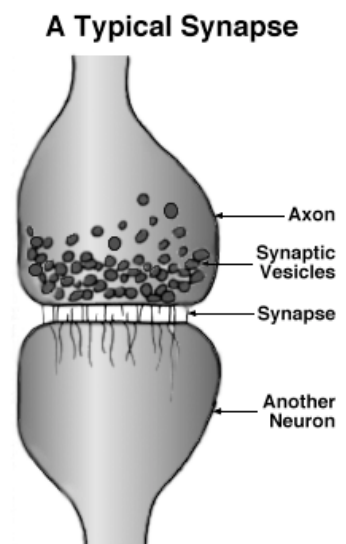
THE NEURON

Like the rest of the body, the brain is made up of cells. Unlike other cells in the body however, the cells in the brain and other parts of the nervous system—called **neurons**—can process information and transmit signals. One other difference between neurons and other cells is that, after we are born, neurons do not divide—if a neuron dies it is not replaced (with the exception of some receptors in the gustatory and olfactory systems). With somewhere between 10 billion and 100 billion neurons, the human brain is capable of doing some very complex information processing. The neurons in the human brain however are basically the same as those in the brains of all other animals. Even very primitive animals, such as jellyfish, worms, or snails, have neurons that work in the same way as the neurons in the human brain. There are many different types, sizes and shapes of neurons in our brain, but most of them have the same basic parts. The cell body of a neuron, called the **soma**, contains the cell's nucleus and other parts that work to keep the cell alive. Branching out from the soma are the **dendrites**—some cells have only one while others have many dendrites (some neurons, like the rods and cones in the retina, have no dendrites). The dendrites are the parts of a neuron that **receive** information from other neurons. Also branching out of the soma of every neuron is the **axon**—all neurons have only one axon. The axon is the part of a neuron that **sends** information to other neurons. Both the axon and the dendrites branch out at their ends so that they can make contact with many other neurons.



THE SYNAPSE

The **axon terminals**, at the tips of the axon, are where signals are passed from one neuron to another. The axon terminals come close to other neurons, but they don't actually touch one another. The small gap where one neuron comes close to another is called the **synapse**. A neuron passes signals along its own dendrites and axon electrically, but it passes signals to other neurons chemically. The dendrites gather signals from many other neurons, the neuron processes the information contained in those signals, then it responds by sending an electrical pulse out along its axon. When the pulse reaches the end of the axon, the neuron releases a chemical messenger that



crosses the synapse and starts the process over again in the next neuron. These chemicals that act as messengers are called **neurotransmitters** and they are held in containers inside the axon terminals called **vesicles**. When an electrical pulse reaches an axon terminal, the vesicles open up and dump their contents into the synapse. The neurotransmitters diffuse across the synapse, and when they come into contact with another neuron, the other neuron begins its response. This may sound like a very slow and messy process but it really isn't. Electrical pulses travel down the axon at speeds between 1 and 120 meters per second, and it only takes a few milliseconds for the neurotransmitter to cross the synapse (the space between neurons is very, very small).

About Vision—The Visual System

ANATOMY OF THE EYE

The clear front surface of the eye, where light enters, is called the **cornea**. The cornea does not have blood vessels in it, because blood vessels would block the light entering the eye. Without blood vessels, the cornea can't receive nourishment in the normal way, so it receives nutrients from the tears that are spread across it when we blink. Behind the cornea, light passes through a dark hole in the center of the eye. This dark hole, called the **pupil**, is formed by a round muscle called the **iris**, which gives the eye its color. The iris changes the size of the pupil to control the amount of light that enters the eye, much like a camera controls the amount of light so that the film is exposed correctly. Behind the pupil is a transparent **lens**. Unlike the lens of a camera which moves in and out to focus light on the film, the lens of the eye changes its shape to focus light on the back of the eye.

The **retina**, which is the "film" of the eye, is made up of millions of tiny light cells (they're actually specialized **neurons**—for more information about neurons, take a look at the topic "The Brain") that convert light into electrical and chemical signals. These signals are sent to the brain.

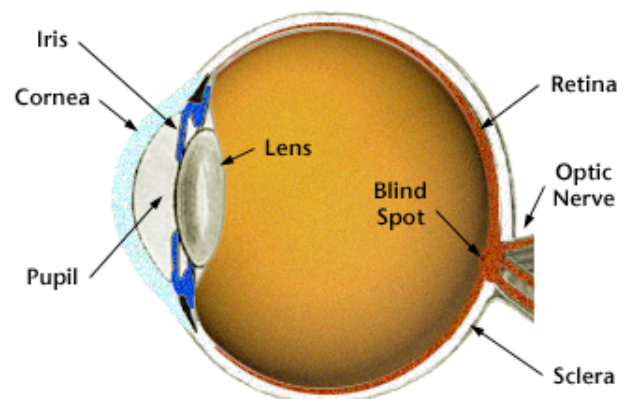
(For more information

about the cells in the retina, take a look at the topic "Color Vision".) The retina receives its nourishment from a web of blood vessels. All the blood vessels in the retina come together and exit the back of the eye at a single place called the **optic disk**. The optic disk also contains the **optic nerve**, which is the bundle of nerve fibers that carry the signals generated in the retina to the brain.

There are no cells that detect light among the blood vessels and nerves that leave the eye at the optic disk. The result is a small "**blind spot**" in each eye. Normally, we don't notice this hole in our visual world because our brain does an excellent job in "filling in."

VISUAL SYSTEM ANATOMY

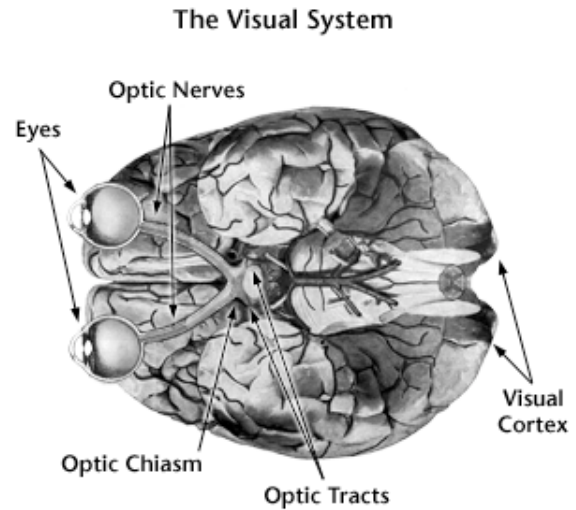
Although it is natural to assume that we use our eyes to see, we really "see" with our brain. The eyes' main job is to gather and focus light, change the light into electrical



and chemical signals that the brain can understand, and send the signals to brain. The brain interprets these signals and produces sight. Because “seeing” is such a complex process, the brain uses nearly half of all its machinery to allow us to see.

The **optic nerves** (the bundles of nerve fibers that exit the back of each eye) carry information from the eyes on the first part of its journey to the brain. Along the way, the two optic nerves cross, and half the fibers from each eye cross over to the other side of the brain. After they cross (at a place called the **optic chiasm**, which means “crossing”), the fiber

bundles are called the **optic tracts**. These fibers make their first synapse with cells in the middle of the brain. These cells send out their own bundles of nerve fibers, called the **optic radiations**, that carry the information from the eyes the rest of the way to the brain. The fibers in the optic radiations make their connections (synapses) at the very back of the brain in a place called the **visual cortex**. The visual cortex is the first of many places within the brain where information about our visual world is processed and turned into our perceptions.



About Vision—Color Vision

HOW WE SEE COLOR

The inside surface of the back of the eye is covered with several layers of special cells that make up what is called the **retina**. They are actually specialized **neurons**—instead of dendrites, one end of these cells contains pigments. (For more information about neurons, take a look at the topic “The Brain”.) Much like the film in a camera, the retina is the part of the eye that is sensitive to light. When light strikes the retina, pigments in the ends of the cells respond, and convert the light energy to electro-chemical signals that are sent on to the brain. There are two types of cells in the retina that respond to light—the **rods** and the **cones**. The rods respond to dim light and are not sensitive to color. They are used for our nighttime vision. The cones respond to brighter light and they are sensitive to color. They are used for our daytime/color vision.

We see the world in color because our retina contains three different types of cones. One type responds best to red-ish light, a second type responds best to green-ish light, and a third type responds best to blue-ish light. Signals from each of these sets of cones tell the brain how much of the three primary colors (red, green, and blue) is present in the image on the retina. The brain combines these signals to color our sight with all the colors of the rainbow. This is why a TV, which displays only red, green, and blue dots, can fool the brain into seeing full-color pictures.

COLOR VISION PROBLEMS

A person with normal color vision has three different types of cones in their retina,

and all three types function properly. A person is said to be “color blind” when one type of cone does not produce a strong enough signal, or in some cases, one type of cone is missing completely. Most color blind people do see in color, they just can’t tell the difference between certain sets of colors—so saying someone is color blind is usually not really true.

Many more men than women have a problem with color vision—overall, about 6-7 percent of men and only a small fraction of a percent of women have a color-vision defect. Most have a red-green defect—they have trouble telling the difference between shades of red, green, yellow, and orange. For some of these people, the problem is with the cones that are sensitive to red light (about 2.2 percent of men have this problem). For others, the problem is with the cones that are sensitive to green light (about 5 percent of men have this problem). Although the cause is different, and they probably see colors in very different ways, both types of people have trouble telling the difference between the same sets of colors. Very few people have a blue-yellow defect, in which blue and yellow, and violet and pink are confused. Another very rare type of color-vision defect occurs in people who are without any color vision. This happens when a person has only one type of cone. These people confuse any two colors that differ in brightness - their perception of the world is like watching a black and white TV.

Most color vision disorders are inherited and sex-linked. This means that parents pass on the disorder to their children, and the way they pass it on depends on whether their children are male or female. Women tend to pass the disorder on to their male children without having any color vision problems themselves.

Scaling Vision

OBJECTIVES

By completing this exercise, you will learn:

- that our perception of magnitude is not necessarily the same as the actual magnitude of objects.
- that the visual system uses different kinds of scales to measure the magnitude of different kinds of stimuli.
- about using a magnitude estimation procedure to create a scale of visual perception.
- about collecting, analyzing, interpreting, and presenting scientific data.

QUICK START

The following is a brief summary of the app instructions:

- Before beginning the experiment for the first time select **Practice** to become familiar with the experimental procedure.
- To begin a block of trials select **Experiment**.
- After you finish each block of trials you will be taken to the **Results** screen. After viewing your results select **Experiment** to begin another block of trials.
- On the **Results** screen tap the **Data Suggestions** button for suggestions on how to interpret or present your data.

EXERCISE

You can complete this exercise in any of three ways:

- answer each question listed below, one at a time as you go,
- use the questions as a guide to prepare a written research report, or
- use the questions as a guide to prepare an oral presentation.

INTRODUCTION

After you have finished reading the *Background* section, you should be familiar with what scales are, using a magnitude estimation procedure to create a scale, and the different types of visual scales. Before beginning an experiment it is important to understand the question(s) you are trying to answer and what the most likely answers will be.

In this experiment you will be investigating how consistent visual scales are across different types of stimuli. In other words, does the visual system use a different kind of scale for different stimuli, or does the visual system use a similar scale for many different kinds of stimuli? You will be comparing two different kinds of stimuli—**Brightness** (brightness of a spot) and **Dots** (“whiteness” of a random-dot pattern)—and the way the visual system scales each.

Before you begin a trial block, set the following experimental parameters:

Stimulus Range: Long

Stimulus Spacing: Linear


Standard Position: Middle

Standard Value: 100

You will be running two blocks of trials, one for each of the two different stimuli. Linear spacing means that there is the same distance between each of the stimuli. For example, if you were estimating line length, the test stimuli might be 10, 20, 30, 40 and 50 cm. In this example, a middle standard would mean that the standard stimulus is 30 cm. A high standard might be 50 cm.


The *Background* section discusses the different types of scales that the visual system might potentially use. In this experiment the stimuli will be spaced linearly—that means that there is an equal amount of distance between the magnitude of each of the test stimuli. If the visual system scales these stimuli according to their actual magnitudes, you would expect to create a linear scale with this procedure. If your

perception of the magnitudes of the stimuli is not the same as their actual magnitudes, you would expect to create a log or a power function scale.

-  State briefly, and in your own words, what question(s) you will be investigating, how you will do the experiment, and what you expect to find in your experiment.


COLLECTING DATA

To complete your data collection, you must complete two blocks of 40 trials each. The parameter settings will be the same for each trial block, but the stimulus will be different. You will select two of the three available stimuli, **Dots** and **Brightness**—one in each trial block. Be sure to read the instructions carefully so you understand what you will be estimating for each of the different types of stimulus.

-  Describe the experimental procedure that you used. Be sure to include a description of the stimuli and how you responded to the stimuli. The general rule is to describe the procedure in enough detail so someone who is unfamiliar with the procedure could do the exact same experiment just from reading your description.





ANALYZING YOUR DATA

When you have finished data collection, the program will present a summary of your results. This summary includes three graphs for each condition. These graphs plot your estimates (on the vertical axes) versus the actual stimulus magnitudes (on the horizontal axes) on linear, semi-log, and log scales. The data are the same in each plot, only the way the graph axes are scaled is different. Also shown in the lower-right corner of each graph is the correlation coefficient, r^2 . If all points in the plot fell exactly along a straight line, this value would be 1.00. If these points were arranged randomly, this value would be 0.00. The closer these values are to 1.00, the straighter the line. *(If any of these values is negative, or less than zero, it means that the line is upside down—review the instructions to make sure you were estimating the magnitude of the stimuli correctly.)* Tap the **Suggestions** button for more information about interpreting your results.

-  Prepare three graphs for each stimulus condition—plot the data for each condition on linear, semi-log and log graphs (or save the **Results** panel). Remember, the **correlation coefficient** (the statistic displayed in the lower-right of each graph) tells you how straight the functions are.

INTERPRETING YOUR DATA

The final step is to make sense out of your results. The numbers and graphs by themselves don't mean anything until you interpret them.

-  Explain your results. Are your data best described by a linear, a semi-log, or a power (log-log) function? Did the two different stimuli produce similar results?
-  Based on your data, what type of scale would you say the visual system uses for each of the stimuli? Is it the same type of scale for each stimulus you measured? Would your conclusions be the same if you based them on all the students in your class, rather than the results of just one observer?
-  How would you go about creating a set of stimuli (for each of those you measured in the experiment) that *appeared* to all be spaced equally from one another? How would you space them so an observer would judge the difference to be the same for both large and small stimuli?
-  Good research often generates as many new questions as it answers. Are there any other questions that you could answer with this procedure or that this procedure left unanswered?

ADDITIONAL INVESTIGATIONS

- Compare the scale for the **Lines** stimulus to the **Brightness** and **Dots** scales. Does the visual system use the same type of scale for each of these stimuli?
- Pick one of the stimuli, and compare the results of the three **Stimulus Range** settings, **Short**, **Medium**, and **Long**. It has been observed for some stimuli that the scale can change at the high and/or low end of the stimulus range. Does your scale change with stimulus range?
- Pick one of the stimuli, and compare the results of the two **Stimulus Spacing** settings, **Linear** and **Log**. If the stimuli are not spaced evenly (log spacing), does that affect the kind of scale you use?
- Pick one of the stimuli, and compare the results of the three **Standard Position** settings, **Low**, **Middle**, and **High**. If the standard is high or low compared to the test stimuli, does that cause your scale to expand or contract?
- Compare the effects of **Stimulus Range**, **Stimulus Spacing**, or **Standard Position** on scales for all three stimuli.

Global Precedence

OBJECTIVES

By completing this exercise, you will learn about:

- the anatomy of the visual system and how information gets from the eyes to the brain.
- how vision scientists can measure our perceptions—psychophysical methods.
- using a simple reaction time procedure to measure the speed at which the brain processes visual information.
- collecting, analyzing, interpreting, and presenting scientific data.

QUICK START

The following is a brief summary of the app instructions:

- Before beginning the experiment for the first time select **Practice** to become familiar with the experimental procedure.
- To complete a block of trials select **Experiment** then select either **Respond to GLOBAL letters** or **Respond to LOCAL letters**, depending on which condition you would like to do.
- After you finish each block of trials you will be taken to the **Results** screen. After completing your first trial block, select **Experiment** to begin the second block of trials.
- On the **Results** screen tap the **Data Suggestions** button for suggestions on how to present your data.

EXERCISE

You can complete this exercise in any of three ways:

- answer each question listed below, one at a time as you go,
- use the questions as a guide to prepare a written research report, or
- use the questions as a guide to prepare an oral presentation.

INTRODUCTION

After you have finished reading the *Background* section, you should be familiar with the way information is transmitted through the visual system and the way in which a reaction time procedure can be used to measure the speed of this process. Before beginning an experiment it is important to understand the question(s) you are trying to answer and what the most likely answers will be.



State briefly, and in your own words, what question(s) you will be investigating, how you will do the experiment, and what you expect to find in your experiment.

COLLECTING DATA


To complete your data collection you must complete two blocks of 40 trials each in both the **Global** and **Local** conditions. Viewing distance should be about 60 cm (24 in). *Sitting at the correct viewing distance is especially important in this experiment.* It doesn't matter in what order you complete the two conditions, unless you will be summarizing the results for several observers—then you should try to have different observers complete the conditions in different orders (that way you'll know if the order had an effect).



Describe the experimental procedure that you used. Be sure to include a description of the stimuli and how you responded to the stimuli. The general rule is to describe the procedure in enough detail so that someone who is unfamiliar with the procedure could do the exact same experiment just from reading your description.



ANALYZING YOUR DATA

When you have finished data collection the program will present a summary of your results. This summary includes for each condition the number of correct responses, mean reaction times (averages), and standard errors.

-  Prepare a graph that shows the difference in reaction times to global and local stimuli. You will need to combine the data across different conditions for this graph. Calculate two means—one for the four global conditions and one for the four local conditions.

INTERPRETING YOUR DATA

The final step is to make sense out of your results. The numbers and graphs by themselves don't mean anything until you interpret them.

-  Explain your results. Did you find any differences between the global and local conditions? Was the outcome what you expected? If it wasn't, why do you think it turned out the way it did?
-  Good research often generates as many new questions as it answers. Are there any other questions that you could answer with this procedure?

ADDITIONAL INVESTIGATIONS

- Compare the **consistent** (global and local letters the same) versus the **inconsistent** (global and local letters different) trials.
- Look at the number of incorrect responses. Were there more/less for global versus local trials? Were there more/less for consistent versus inconsistent trials?

Feature Analysis

OBJECTIVES

By completing this exercise, you will learn:

- that our visual system breaks down complex textures into simple building blocks before analyzing them.
- that our visual system uses two different methods to analyze textures, serial and parallel processing.
- about using a choice reaction-time procedure to measure the speed at which the brain processes visual information.
- about collecting, analyzing, interpreting, and presenting scientific data.

QUICK START

The following is a brief summary of the app instructions:

- Before beginning the experiment for the first time select **Practice** to become familiar with the experimental procedure.
- Before beginning a block of trials select a **Target/Distracter** stimulus combination.
- To begin a block of trials select **Experiment**. A sample of the target (the stimulus you will be looking for) will be shown at the bottom of the screen.
- After you finish each block of trials you will be taken to the **Results** screen. After viewing your results, select **Experiment** to begin another block of trials.
- On the **Results** screen tap the **Data Suggestions** button for suggestions on how to interpret or present your data.

EXERCISE

You can complete this exercise in any of three ways:

- answer each question listed below, one at a time as you go,
- use the questions as a guide to prepare a written research report, or
- use the questions as a guide to prepare an oral presentation.

INTRODUCTION

After you have finished reading the *Background* section you should be familiar with the ways the visual system analyzes features and the way in which a reaction-time procedure can be used to measure the speed of this process. Before beginning an experiment it is important to understand the question(s) you are trying to answer and what the most likely answers will be.

In this investigation you will be trying to determine whether the visual system uses a parallel or a serial process to analyze different types of features. Remember, with parallel processing you can “look at” all the items in a stimulus display at once, so it shouldn’t matter how many distractor items are present. But with serial processing you need to do a visual search, and processing should be slower when there are more distractors.

You will be comparing two sets of stimuli to determine how they are processed by the visual system. One set consists of green targets (**Green/Not Green**—the target is any item that is green), and parallel lines with end lines (**Same Ends/Different Ends**—see the table below). In the second set you will be comparing the same stimuli using each one as the target and distractor (**Line-Circles/No Line-Circles** and **No Line-Circles/Line-Circles**—see the table below). You will be completing a total of four trial blocks. *When selecting stimuli, the first item (left) is the target, and the second item (right) is the distractor.*



State briefly, and in your own words, what question(s) you will be investigating, how you will do the experiment, and what you expect to find in your experiment. Based on the *Background* information, make a prediction about which of the targets will be processed pre-attentively (in parallel) and which will be processed attentively (serially).

COLLECTING DATA


To complete your data collection you must complete 4 blocks of 36 trials each. The stimulus conditions are:

Target/Distractor

 **Green/Not Green**

 **Same Ends/Different Ends**

 **Line-Circles/No Line-Circles**

 **No Line-Circles/Line-Circles**

Be sure to complete a block of practice trials before you begin, and *be sure to run the stimulus (target/distractor) conditions shown above.*

When your data are analyzed, only trials on which you made a correct response are counted, so if you make a large number of incorrect responses, run the trial block over again. It doesn't matter in what order you complete the three conditions unless you will be summarizing the results for several observers—then you should try to have different observers complete the conditions in different orders (that way you'll know if the order had an effect).



Describe the experimental procedure that you used. Be sure to include a description of the stimuli and how you responded to the stimuli. The general rule is to describe the procedure in enough detail so someone who is unfamiliar with the procedure could do the exact same experiment just from reading your description.

ANALYZING YOUR DATA

When you have finished data collection, you will be shown a summary of your results. This summary includes for each condition, mean reaction times (averages) for 2, 8, and 32 items. When you view your results, be sure you are looking at the **Plot All Trials** graph (instead of the **Plot Present vs. Absent** graph).



Prepare two graphs—one to compare the **Green/Not Green** and **Same Ends/Different Ends** conditions, and another to compare the **Line-Circles/No Line-Circles** and **No Line-Circles/Line-Circles** conditions.

INTERPRETING YOUR DATA

The final step is to make sense out of your results. The numbers and graphs by themselves don't mean anything until you interpret them.



Explain your results. Were there any differences in RTs between the two pairs of stimuli? Which of the stimuli are processed pre-attentively (in parallel) and which are processed attentively (serially)? Was the outcome what you expected? If it wasn't, why do you think it turned out the way it did?



Good research often generates as many new questions as it answers. Are there any other questions that you could answer with this procedure? Based on your results, could you make predictions about any of the other stimuli available in the experiment? For example, what do you think would happen if you reversed the roles of target and distractor in the **Green/Not Green** or in the **Same Ends/Different Ends** conditions?

ADDITIONAL INVESTIGATIONS

- There are many other target/distractor stimuli available. Pick one (or more) of the other stimuli, and predict—before you collect any data— whether the stimuli will be processed pre-attentively or attentively. Provide justification for your prediction (you can base it on your previous results). Do your experimental results support your prediction(s)? Do your predictions improve after you collect data for more stimuli?
- After you have collected data for several different stimuli, create a set of rules that you could use to predict the results for new stimuli. In other words, what generalizations could you make about the characteristics of stimuli that are processed pre-attentively versus those that are processed attentively?
- Try to come up with an explanation for why switching some target/ distractor pairs can produce completely different results. In other words, why do you think switching a stimulus from target to distractor, or vice versa, would change the way your brain processes the information.

Signal Detection

OBJECTIVES

By completing this exercise, you will learn:

- about signal detection theory and related concepts, including response criterion, signal and signal + noise distributions, and ROC curves.
- how vision scientists can measure our perceptions—psychophysical methods.
- about using two-alternative forced choice and rating-scale procedures.
- about collecting, analyzing, interpreting, and presenting scientific data.

PLEASE NOTE: You must use each rating, 1–6, at least once in each trial block in order for an ROC curve to be calculated.

QUICK START

The following is a brief summary of the app instructions:

- Before beginning the experiment for the first time, select **Practice** to become familiar with the experimental procedure.
- To complete a block of trials select **Experiment**, and select a difficulty level.
- After you finish each block of trials, you will be taken to the **Results** screen. After completing your first trial block, select **Experiment** to begin the second block of trials.
- On the **Results** screen, tap the **Data Suggestions** button for suggestions on how to present your data.

EXERCISE

You can complete this exercise in any of three ways:

- answer each question listed below, one at a time as you go,
- use the questions as a guide to prepare a written research report, or
- use the questions as a guide to prepare an oral presentation.

INTRODUCTION

After you have finished reading the **Background** information you should be familiar with the two-alternative forced choice procedure, rating scales, and the basics of signal detection theory. Before beginning an experiment, it is important to understand the question(s) you are trying to answer and what the most likely answers will be.

In this experiment you will be measuring how well you can detect differences in small gaps in rings. Two large, black rings with small gaps in the top will be presented side by side. Your task is to determine which gap is larger. You will plot your results on ROC curves and compare your sensitivity to gaps of different sizes. In the **Difficult** condition the difference between the two gaps is very small (only one pixel); in the **Not So Easy** and **Easy** conditions the difference between the gaps is larger.




State briefly, and in your own words, what question(s) you will be investigating, how you will do the experiment, and what you expect to find in your experiment.

COLLECTING DATA


To complete your data collection you must complete three blocks of 72 trials each, one block of trials for each difficulty settings—**Easy**, **Not So Easy**, and **Difficult**. Viewing distance should be about 60 cm (24 in). *It is important that you maintain the same viewing distance for all trials blocks. If you change your viewing distance during the experiment, you will not be able to compare results across trial blocks.*

It doesn't matter in what order you complete the three conditions, unless you will be summarizing the results for several observers—then you should try to have different observers complete the conditions in different orders (that way you'll know if the order had an effect).

-  Describe the experimental procedure that you used. Be sure to include a description of the stimuli and how you responded to the stimuli. The general rule is to describe the procedure in enough detail so that someone who is unfamiliar with the procedure could do the exact same experiment just from reading your description.




ANALYZING YOUR DATA

When you have finished data collection you will be shown a summary of your results. This summary includes the number of times you used each rating and an ROC curve calculated from your ratings. Tap the **Data Suggestions** button for an explanation of how the ROC curve is calculated.

-  Prepare three ROC curve graphs similar to the ones presented by the program (or save the **Results** screen by tapping **Save Data...**). Be sure to include the area under the curve for each graph. Remember, you're trying to show how the area under the curves changes with gap size (i.e., difficulty level).

INTERPRETING YOUR DATA

The final step is to make sense out of your results. The numbers and graphs by themselves don't mean anything until you interpret them.

-  Explain your results. Did the difference in gap sizes between the three conditions affect the area under the ROC curves? If so, how?
-  Explain your results within the context of the underlying signal and signal + noise distributions. In other words, how would you infer that the width and/or spacing of the two distributions changed in the three conditions.
-  Good research often generates as many new questions as it answers. Are there any new questions that the results of this experiment suggest to you?

ADDITIONAL INVESTIGATIONS

Change your viewing distance to 30 cm (12 in) (half the viewing distance), or 120 cm (48 in) (double the viewing distance). What happens to the size of the gap when you change the viewing distance? (Think about the gap size in terms of the size of its image on your retina.) How would you expect your ROC curve to change? Would the **Difficult** condition be more or less difficult when you move closer? Farther away? Does it change as expected?

Measuring Illusions

OBJECTIVES

By completing this exercise, you will learn:

- that illusions, just like most other perceptions, can be objectively measured.
- that by measuring an illusion, we can find out what part(s) of an image are responsible for “causing” the illusion.
- the definition of point of subjective equality (PSE).
- how vision scientists can measure our perceptions using Yes-No and method of limits psychophysical procedures.
- about collecting, analyzing, interpreting, and presenting scientific data.

QUICK START

The following is a brief summary of the app instructions:

- Before beginning the experiment for the first time, select **Practice** to become familiar with the experimental procedure.
- To begin a block of trials select **Experiment**.
- On each trial click the **Practice** or **No** button in response to the question about the stimuli.
- After you finish each block of trials you will be taken to the **Results** screen. After viewing your results, select **Experiment** to begin another block of trials.
- On the **Results** screen, tap the **Data Suggestions** button for suggestions on how to interpret or present your data.

EXERCISE

You can complete this exercise in any of three ways:

- answer each question listed below, one at a time as you go,
- use the questions as a guide to prepare a written research report, or
- use the questions as a guide to prepare an oral presentation.

INTRODUCTION

When you have finished reading the **Background** information, you should be familiar with the Yes-No and Method of Limits procedures, and what the point of subjective equality means with respect to measuring the magnitude of an illusion. Before beginning an experiment, it is important to understand the question(s) you are trying to answer and what the most likely answers will be.

In this investigation you will be measuring the size of the Müller-Lyer illusion. (Look at the **Illusions and Aftereffects** module if you would like to learn more about the Müller-Lyer illusion.) The measure of interest in this procedure is the *point of subjective equality*, or PSE. This will tell you how different the lines have to be for them to appear the same length. You will be measuring the PSE for three different experimental conditions—with **Short**, **Medium**, and **Long** arrowheads. When you compare these three PSEs you will be able to tell how the length of the arrowheads affects the size of the illusion (or if there is any effect at all).



State briefly, and in your own words, what question(s) you will be investigating, how you will do the experiment, and what you expect to find in your experiment. Since you have no way of knowing what to expect in this experiment, make a reasonable guess as to how you think the length of the arrowheads will affect the size of this illusion (and be prepared to defend your guess *before you complete the experiment*).

COLLECTING DATA

To complete your data collection you must complete three blocks of trials, one for each of the stimulus conditions—**Short**, **Medium**, and **Long** arrowheads. Before beginning each trial block, select **Müller-Lyer Illusion** and set the **Arrowhead Length**. It doesn't matter in what order you complete the three conditions, unless

you will be summarizing the results for several observers—then you should try to have different observers complete the conditions in different orders (that way you'll know if the order had an effect).



Describe the experimental procedure that you used. Be sure to include a description of the stimuli and how you responded to the stimuli. The general rule is to describe the procedure in enough detail so that someone who is unfamiliar with the procedure could do the exact same experiment just from reading your description.

ANALYZING YOUR DATA

When you have finished data collection the program will present a summary of your results. You will be shown the two stimuli drawn at the PSE (in other words, they should appear equal). You will also be shown the actual numbers that correspond to the standard and test stimuli. In this case it is the length of the horizontal lines, in pixels.



Prepare a graph to compare the results of the three conditions (or save the **Results** screen by tapping **Save Data...**). Remember, you are trying to show how the length of the arrowheads affects the size of the illusion, so that should be clear to someone looking at your graph.

INTERPRETING YOUR DATA

The final step is to make sense out of your results. The numbers and graphs by themselves don't mean anything until you interpret them.



Explain your results. Did you find an effect of arrowhead length on the size of the illusion? How could you explain the effect you observed? Did the experiment turn out the way you expected? If it didn't, why do you think it turned out the way it did?



Good research often generates as many new questions as it answers. Are there any other questions that you could answer with this procedure? Take a look at the Illusions and Aftereffects demonstration and see if there are any other illusions to which the results of this experiment might apply.

ADDITIONAL INVESTIGATIONS

- Compare the effects of the two **Vertical Line Position** settings—**From Top** and **From Bottom**—on the size of the **Horizontal-Vertical Illusion**. Give an explanation for your results.
- Compare the effects of three **Spot Size** settings—**Small**, **Medium**, and **Large**—on the size of the **Simultaneous Contrast effect**. Give an explanation for your results.

Depth Perception

OBJECTIVES

By completing this exercise, you will learn:

- how the visual system uses the 2D (flat) images seen by the two eyes to construct a 3D image of the world.
- the limits of our visual system in regard to seeing depth.
- how vision scientists can measure our perceptions—psychophysical methods.
- about using a magnitude estimation procedure to measure the size of a perception, in this case depth.
- about collecting, analyzing, interpreting, and presenting scientific data.

QUICK START

The following is a brief summary of the app instructions:

- Before beginning the experiment for the first time select **Practice** to become familiar with the experimental procedure.
- To complete a block of trials select **Experiment**, and select either the **Crossed** or **Uncrossed Disparity** condition.
- Wear the red/green (or red/blue) glasses when viewing the stimuli. The red lens goes over your right eye. *It is important that you do not reverse the glasses for this experiment, or the disparities will be reversed.*
- After you finish each block of trials you will be taken to the **Results** screen. After completing your first trial block select **Experiment** to begin the second block.
- On the **Results** screen, tap the **Data Suggestions** button for suggestions on how to interpret or present your data.

EXERCISE

You can complete this exercise in any of three ways:

- answer each question listed below, one at a time as you go,
- use the questions as a guide to prepare a written research report, or
- use the questions as a guide to prepare an oral presentation.

INTRODUCTION

After you have finished reading the **Background** information you should be familiar with the way in which the visual system creates our perception of a three-dimensional (3D) world. You should also be familiar with the terms **disparity**, **diplopia**, and **Panum's fusional area**. Before beginning an experiment, it is important to understand the question(s) you are trying to answer and what the most likely answers are.

In this experiment you will be measuring how the perception of depth changes with changes in the disparity of an image. You will also obtain a measure of the limits of depth perception (in other words, the size of Panum's fusional area). Beyond these limits, the visual system cannot create a good perception of depth and you see double (diplopia). You will be comparing both crossed (in front) and uncrossed (behind) disparities—in some people, Panum's fusional area is asymmetrical (not the same size in both directions).



State briefly, and in your own words, what question(s) you will be investigating, how you will do the experiment, and what you expect to find in your experiment.

COLLECTING DATA

Before beginning the experiment, be sure to complete a block of practice trials. Some people do not see the depth in these stimuli immediately—you may need to view them for a few seconds before you see anything. View them from directly in front of the screen.

To complete your data collection you must complete two blocks of 30 trials each in both the **Crossed** and **Uncrossed Disparity** conditions. Your viewing distance should be about 60 cm (24 in). *The correct viewing distance is especially important in this experiment.* If you change your viewing distance during the experiment, the disparities of the binocular images will change.

It doesn't matter in what order you complete the two conditions, unless you will be summarizing the results for several observers—then you should try to have different observers complete the conditions in different orders (that way you'll know if the order had an effect).



Describe the experimental procedure that you used. Be sure to include a description of the stimuli and how you responded to the stimuli. The general rule is to describe the procedure in enough detail so that someone who is unfamiliar with the procedure could do the exact same experiment just from reading your description.

ANALYZING YOUR DATA

When you have finished data collection, the program will present a summary of your results. If you've only completed one of the conditions, only half the graph will be filled in. This summary includes a graph that plots your estimates of the perceived depth of the stimuli versus the actual disparity of the stimuli, for both the crossed and uncrossed disparity conditions. (The disparity, or difference between the left and right eyes' views, is measured in pixels.) The points at which you reported diplopia (seeing double) are also marked on the graph. The area between these points is an estimate of your Panum's fusional area. Tap the **Data Suggestions** button for a more detailed explanation of this graph.

If your data appear to be "backwards," as compared to the sample data (tap the **Data Suggestions** button to see the sample data), it probably indicates that you were wearing the glasses backwards. If that happens, you do not need to do the experiment over—just reverse your data. The crossed disparity condition would actually be uncrossed, and vice versa.



Prepare a graph similar to the one presented by the program that shows both disparity conditions. Remember, you're trying to show (1) how your perception of depth changed with changes in disparity, and (2) the limits of Panum's fusion area.

INTERPRETING YOUR DATA

The final step is to make sense out of your results. The numbers and graphs by themselves don't mean anything until you interpret them.



Explain your results. How did your perception of depth change with the disparity of the stimulus? In other words, did the stimuli appear to have more or less depth as disparity increased? What does that tell you about the way disparity information is used by the visual system to create a perception of depth? Was the outcome what you expected? If it wasn't, why do you think it turned out the way it did?



What happened to your perception of depth beyond the limits of Panum's fusional area? Did the change in depth continue in the same direction, or did it reverse?



In some people, Panum's fusional area is asymmetrical—it is wider in one direction than the other (for crossed versus uncrossed disparity). Was your Panum's fusional area symmetrical or asymmetrical?



For some people, the stimuli in this experiment might not be beyond Panum's fusional area. These people would be able to fuse all the stimuli without ever seeing double. If this was true for you, what do you think that means?



Good research often generates as many new questions as it answers. Are there any new questions that the results of this experiment suggest to you?

ADDITIONAL INVESTIGATIONS

Change your viewing distance to 30 cm (12 in) (half the viewing distance), or 120 cm (48 in) (double the viewing distance). What happens to the disparity of the dots when you change the viewing distance? How would you expect your measure of Panum's fusional area to change? Does it change as expected?

Contrast Sensitivity—Method of Adjustment

OBJECTIVES

By completing this exercise, you will learn:

- the meaning of contrast, threshold, sensitivity, spatial frequency, and contrast sensitivity function.
- how sensitivity to contrast varies with spatial frequency.
- how vision scientists can measure our perceptions—psychophysical methods.
- about using a method of adjustment procedure to measure the contrast detection threshold.
- about collecting, analyzing, interpreting, and presenting scientific data.

Note: Both procedures in the *Contrast Sensitivity* exercises measure the same thing. It is recommended that the half the class do the method of adjustment procedure and the other half do the forced choice procedure, then compare the results of the two procedures.

QUICK START

The following is a brief summary of the app instructions:

- Before beginning the experiment for the first time select **Practice** to become familiar with the experimental procedure.
- To complete a block of trials select **Experiment**, then select **Method of Adjustment**.
- After you finish each block of trials you will be taken to the **Results** screen. After viewing your results select **Experiment** to begin another block of trials.
- On the **Results** screen, tap the **Data Suggestions** button for suggestions on how to interpret or present your data.

EXERCISE

You can complete this exercise in any of three ways:

- answer each question listed below, one at a time as you go,
- use the questions as a guide to prepare a written research report, or
- use the questions as a guide to prepare an oral presentation.

INTRODUCTION

After you have finished reading the **Background** information you should be familiar with the method of adjustment procedure and the *contrast sensitivity function (CSF)*. Before beginning an experiment, it is important to understand the question(s) you are trying to answer and what the most likely answers are.



State briefly, and in your own words, what question(s) you will be investigating, how you will do the experiment, and what you expect to find in your experiment.

COLLECTING DATA

To complete your data collection you must complete one block of 20 trials. Viewing distance should be about 57 cm (22 in) for a 9.7-inch iPad. *Sitting at the correct viewing distance is especially important in this experiment.* If you change the viewing distance, you change the spatial frequency of the stimuli.

If you are using an iPad Pro, iPad mini, or other size screen, but sure to *adjust your viewing distance accordingly*. Tap the **Calibrate** button for more information on screen size and viewing distance, refer to the **Instructions** for an explanation.



Describe the experimental procedure that you used. Be sure to include a description of the stimuli and how you responded to the stimuli. The general rule is to describe the procedure in enough detail so that someone who is unfamiliar with the procedure could do the exact same experiment just from reading your description.

ANALYZING YOUR DATA





When you have finished data collection, the program will present a summary of your results. This summary includes a contrast sensitivity function.



Prepare a graph that shows your contrast sensitivity function (or print the **Results** panel), that is, plot contrast sensitivity versus spatial frequency.

INTERPRETING YOUR DATA

The final step is to make sense out of your results. The numbers and graphs by themselves don't mean anything until you interpret them.

-  Explain your results. Did your contrast sensitivity vary with stimulus spatial frequency? If so, how?
-  Was the outcome what you expected? If it wasn't, why do you think it turned out the way it did?
-  What can you infer about vision in the "real world" from the results of this experiment?
-  Good research often generates as many new questions as it answers. Are there any new questions that the results of this experiment suggest to you?

Contrast Sensitivity—Forced Choice

OBJECTIVES

By completing this exercise, you will learn:

- the meaning of contrast, threshold, sensitivity, spatial frequency, and contrast sensitivity function.
- how sensitivity to contrast varies with spatial frequency.
- how vision scientists can measure our perceptions—psychophysical methods.
- about using a two-alternative forced-choice procedure to measure the contrast detection threshold.
- about collecting, analyzing, interpreting, and presenting scientific data.

Note: Both procedures in the *Contrast Sensitivity* exercises measure the same thing. It is recommended that the half the class do the method of adjustment procedure and the other half do the forced choice procedure, then compare the results of the two procedures.

QUICK START

The following is a brief summary of the app instructions:

- Before beginning the experiment for the first time select **Practice** to become familiar with the experimental procedure.
- To complete a block of trials select **Experiment**, then select **Forced Choice**. Before beginning a block of trials, enter the experimental parameters.
- After you finish each block of trials you will be taken to the **Results** screen. After viewing your results select **Experiment** to begin another block of trials.
- On the **Results** screen, tap the **Data Suggestions** button for suggestions on how to interpret or present your data.

EXERCISE

You can complete this exercise in any of three ways:

- answer each question listed below, one at a time as you go,
- use the questions as a guide to prepare a written research report, or
- use the questions as a guide to prepare an oral presentation.

INTRODUCTION

After you have finished reading the **Background** information you should be familiar with the forced-choice procedure and the *contrast sensitivity function (CSF)*. Before beginning an experiment it is important to understand the question(s) you are trying to answer and what the most likely answers are.



State briefly, and in your own words, what question(s) you will be investigating, how you will do the experiment, and what you expect to find in your experiment.

COLLECTING DATA

To complete your data collection you must complete four trial blocks, one at each of the four spatial frequencies—1, 2, 4, and 8 c/deg. For each trial block enter:

Starting Contrast: 64


Stimulus Diameter: Medium

Stimulus Duration: 100

Viewing distance should be about 57 cm (22 in) for a 9.7-inch iPad. *Sitting at the correct viewing distance is especially important in this experiment.* If you change the viewing distance, you change the spatial frequency of the stimuli.


If you are using an iPad Pro, iPad mini, or other size screen, but sure to *adjust your viewing distance accordingly*. Tap the **Calibrate** button for more information on screen size and viewing distance.

It doesn't matter in what order you complete the four conditions, unless you will be summarizing the results for several observers—then you should try to have different observers complete the conditions in different orders (that way you'll know if the order had an effect).

-  Describe the experimental procedure that you used. Be sure to include a description of the stimuli and how you responded to the stimuli. The general rule is to describe the procedure in enough detail so that someone who is unfamiliar with the procedure could do the exact same experiment just from reading your description.


ANALYZING YOUR DATA


When you have finished data collection, the program will present a summary of your results. This summary includes a contrast sensitivity function.


-  Prepare a graph that shows your contrast sensitivity function (or print the **Results** panel), that is, plot contrast sensitivity versus spatial frequency.


INTERPRETING YOUR DATA

The final step is to make sense out of your results. The numbers and graphs by themselves don't mean anything until you interpret them.

-  Explain your results. Did your contrast sensitivity vary with stimulus spatial frequency? If so, how?

-  Was the outcome what you expected? If it wasn't, why do you think it turned out the way it did?

-  What can you infer about vision in the "real world" from the results of this experiment?

-  Good research often generates as many new questions as it answers. Are there any new questions that the results of this experiment suggest to you?

ADDITIONAL INVESTIGATIONS

- Compare three or more different **Stimulus Diameter** settings, for example 50, 100, and 200. Does stimulus size affect the overall sensitivity values or the shape of the contrast sensitivity function? Why do you think it should or shouldn't?
- Compare two or more different **Stimulus Duration** settings, for example 100 and 500. Does stimulus duration affect the overall sensitivity values or the shape of the contrast sensitivity function? Why do you think it should or shouldn't?
- Change your viewing distance to 28 cm (11 in) (half the viewing distance), or 114 cm (44 in) (double the viewing distance). What happens to the spatial frequency of the stimuli when you change the viewing distance? How would you expect the shape of the contrast sensitivity function to change? Does it change as expected?

OBJECTIVES

By completing this exercise, you will learn:

- how important motion is to the visual system.
- how we are capable of “seeing” depth and form where none exist, based on motion alone.
- how the visual system is especially sensitive to the motion of living things—“biological motion.”

Form and Motion**QUICK START**

The following is a brief summary of the app instructions:

- Set **Object**, **Background**, and **Playback** parameters before making a random-dot movie.
- Tap the **Play** button to view a movie.
- Tap the **Parameters** button to change settings.
- Tap the **Reset** button to set all parameters to their original values.

EXERCISE**Number of Dots**

Our visual system will try to create a perception of depth and form whenever possible. In fact, our visual system is so good at it that it needs very little information to create such a perception.

Tap the **Reset** button to reset all movie settings to their original values. Select **Shape: Sphere** and **Background Type: None**. After you close the **Parameters** panel, *DO NOT* play the movie.



What did you see? In other words, what do the dots look like when they are not moving? Did you see any depth?

Now tap the **Play** button to start the movie playing.



What did you see? In other words, what do the dots look like when they are moving? Did you see any depth? Were the depth and form easy or difficult to see?

Open the **Parameters** panel, and set **Object: Number of Dots** to 50 (the first movie had 100 dots in the object). Close the **Parameters** panel, and play the movie.



Did you still see the sphere? Was it more difficult to see?

Open the **Parameters** panel, and generate and play movies with 25, 10, 5, 2, and 1 dot(s) in the object.



Did you still see the sphere in each of these movies? Did it become more difficult to see with fewer and fewer dots? Could you see a sphere shape with only 1 or 2 dots? With only a few dots, do you think it would make a difference where on the sphere the dots are located? Try making new movies with only 1 or 2 dots (each time you make a new movie, the dots will be in different, random positions).



Do you think you would be able to see the other shapes (like the barbell, the paraboloid, or the cone) with fewer than ten dots in these objects?

The Effects of Noise

Noise is anything that interferes with what we are trying to see. Our visual system is usually very good at filtering out noise (most of what we see is noise).

Open the **Parameters** panel and tap the **Reset** button to reset all parameters to their original values. Then select:

Shape: Sphere

Background Type: Stationary Background

Area: Overlaps Object

This will create a background pattern of dots that overlaps the sphere and does not move. After you close the **Parameters** panel, *DO NOT* play the movie.



What did you see? In other words, what do the dots look like when they are not moving? Did you see any depth?

Now start the movie playing.



Could you see the sphere? Were the depth and form easy or difficult to see? Did the background interfere with your perception of the sphere?

Open the **Parameters** panel and select **Background Type: Random** (the dots appear in random positions on each frame). Close the panel and play the movie. Do the same with **Background Type: Random Motion** (the dots move in random directions) and **Background Type: Drifting** (the dots drift from right to left). For the **Drifting** background, select **Drift Speed: Medium**.



Which of the four backgrounds interfered most with your perception of the sphere? Which interfered least?

Try each of the four background types with 50 dots and then with 10 dots in the **Sphere**. Select **Object: Number of Dots** to set the number of dots in the object.



Could you see the sphere with 50 and 10 dots as easily as you could when there was no background? Which of the four backgrounds interfered most with your perception of the sphere with 50 dots? Did the same background interfere most when there were only 10 dots in the sphere?



Why do you think the backgrounds make it harder to see the object? Why do some backgrounds make it harder than others? To answer this, you need to think about what the visual system has to do to “create” a sphere from a bunch of moving dots—for each dot in each frame of the movie, the visual system needs to find a match in the next frame. Then it needs to figure out in what direction each dot is moving, which dots are moving together, and if the dots are moving together, do they appear to be part of a solid object. It’s a pretty complicated process!

Biological Motion


Biological motion is the motion produced by living things. Our visual system is especially sensitive to biological motion.

Open the **Parameters** panel and tap the **Reset** button to reset all parameters to their original values. Select **Shape: Biological** and **Background Type: None**. Set **Playback Speed** to 15. After you close the **Parameters** panel, *DO NOT* play the movie.




What did you see? In other words, what do the dots look like when they are not moving? Did you see any shape?


Now start the movie playing. You may need to adjust the **Playback Speed**.

 What did you see? What was the person doing? Is there anything you can tell about the person in the movie? For example, could you tell if it is a man or a woman?


Select **Rotation Axis: Upside Down**, then play the movie.

 Does this make it harder to see what the person is doing? If so, why do you think that is? (Hint: Do you normally see people doing that particular activity upside down?)

Select **Rotation Axis: Normal**, select **Background Type: Random**, then play the movie.

 Can you still see what the person is doing?

Select **Rotation Axis: Normal**, select **Background Type: Random Motion**, and play the movie. Do the same with **Background: Drifting, Drift Speed: Medium**.


 Can you see what the person is doing with either of these backgrounds? Did adding a background have more or less of an effect on your perception of biological motion than it did on your perception of a rotating sphere? Why do you think that is?

Color & Motion

If you have completed the *Global Precedence* exercise you know that there are two pathways that carry information from the eyes to the brain. (For a review, launch the *Global Precedence* app, tap **Instructions**, and read the **Background** information.) Each pathway carries different information. For example, one pathway carries information about large objects, and the other carries information about small objects. Another difference between these pathways is that one can see color, and the other can only see differences in brightness. Most researchers agree that the “color” pathway does not “see” motion very well—the “brightness” pathway is the “motion” pathway. Some researchers have reported that if you create a random-dot pattern where the dots and background are different colors but are the same brightness (so they can only be “seen” by the “color” pathway), you cannot see the depth and form in the random-dot movies you made in this exercise. Other researchers however have not been able to replicate this finding.

See if you can create a movie in which the shape cannot be seen. Usually the colors used to make movies without brightness differences (i.e., luminance contrast) are red and green (for example, red dots on a green background).

Tap the **Reset** button to reset all parameters to their original values. Select **Shape: Sphere**, and set **Dots Color** to red and **Background Color** to green (or vice versa).

 Could you make a movie in which you could not see the shape?

ADDITIONAL INVESTIGATIONS

- Repeat the *Number of Dots* manipulations (see above) on the other, non-biological shapes. Are any of the other shapes more or less affected by fewer dots than the sphere? Why?
- Repeat the *Effects of Noise* manipulations (see above) on the other, non-biological shapes. Are any of the other shapes more or less affected by noise than the sphere? Why?
- Try the various **Correlation** settings on the non-biological shapes. Try adding the different backgrounds. Explain how the correlation settings affect the moving dots. Can you still see the shape(s) at the lowest correlation? Can you still see the

low-correlation shape(s) when a back- ground is added? Why? Are you surprised by what you saw? Why?

Illusions & Aftereffects—Illusions

OBJECTIVES

By completing this exercise, you will:

- see many different kinds of visual illusions.
- learn that sometimes by “fooling” our visual system, we can discover something about the way it works.

QUICK START

The following is a brief summary of the app instructions:

- To view an illusion tap **Motion, Depth, Contrast, Size, Shape, Orientation, Bistable, or Misc**, and select an illusion from the available options.
- For information about individual illusions tap the **Help** button (?). When help is turned on you will see information about each illusion when you select it. Reviewing this information may help you answer some of the questions below.

EXERCISE

Motion Illusions

Tap **Motion** and select **Motion Reference** from the list. You will see three dots moving back and forth. (Reviewing the information about each of these illusions may help you to answer some of the questions below.)



How would you describe the path along which the middle dot is moving?

Tap the **Hide Reference Dots** button to hide the top and bottom dots. If you want to show them again, tap **Show Reference Dots**.



Now how would you describe the path along which the middle dot is moving? Did your perception of the motion of the middle dot change when the top and bottom dots were not there.

Tap **Motion** and select **Motion in Depth**. *You will need to view this illusion with the red-green (or red-blue) glasses.*



Describe what you see. Now look at the display without the glasses, and describe what you see. Why does the dot appear to be moving in depth?

If you have access to a television set and a pair of sunglasses (or any kind of dark filter or lens), try this: Set the television to a channel with no picture, so that all you see is static (i.e., random black and white dots). Put the sunglass lens or dark filter over one eye only, and view the static.



Compare what the static looks like when viewed with and without the dark lens.

When viewing the static with the lens over one eye, you should see swirls of motion in depth. View the static first with the lens over your right eye, then with the lens over your left eye.




Did the direction of the swirls of motion change when you switched eyes? When the lens was over your right eye, did you see mostly clockwise or counterclockwise motion (if it were viewed from the top)? How about when the lens was over your left eye?


Depth—Binocular Illusions

Tap **Depth** and select **Binocular Suppression**. *You will need to view this illusion with the red-green (or red-blue) glasses—put the red lens over your right eye.* When you look at this illusion with the glasses, your right eye will see a horizontal line and your left eye will see two vertical lines. When each eye sees something completely different, it confuses your visual system—this never happens in real life. So your visual system tries to create a perception that is more realistic. Sometimes your

perception will switch between what the left eye or the right eye sees, but at other times you will see a combination of both views. (Reviewing the information—?—about each of these illusions may help you to answer some of the questions below.)


-  Describe what you see if you close your right eye or your left eye. Look at the image for a minute or two with both eyes. When the two images appear to be combined, what do you see (wearing the red-green glasses)?

Tap **Depth** and select **Binocular Rivalry**. *You will need to view this illusion with the red-green (or red-blue) glasses—put the red lens over your right eye.* When you look at this illusion with the glasses, your right and left eyes will see two different images. Sometimes you will perceive only one image or the other, but at other times you will see some combination of the two.

-  Look at the image for a minute or two with both eyes. Can you make yourself switch between the horizontal and vertical lines? When you only see one set of lines, what do you think happened to the other set? Do you sometimes see patches of vertical lines and patches of horizontal lines at the same time? Can you make yourself see both at the same place at the same time?


Size Illusions

Tap **Size** and select **Müller-Lyer Illusion**, then **Ponzo Illusion**, then **Delboeuf Illusion**. Look at each of these illusions. (Reviewing the information about each of these illusions may help you to answer some of the questions below.)

-  Describe the illusions. Think of an explanation for each of these illusions. Why do you think they fool our visual system the way they do? Can the same explanation apply to all three? Be creative—there are no right or wrong answers, because many illusions are not understood very well even by the “experts.” The only requirement for a “good” answer here is that it makes sense.


Shape Illusions

Tap **Shape** and select **Hering Illusion**, then **Converse Hering Illusion**. Look at each of these illusions.


-  Describe the illusions. Think of an explanation for these two illusions. Why do you think they fool our visual system the way they do? The same explanation should apply to both. As with those illusions above, there are no right or wrong answers.

Orientation (Tilt) Illusions

Tap **Orientation** and select **Zöllner Illusion**.


-  Describe this illusion, and think of an explanation for it. Why do you think it fools our visual system the way it does? Again, as long as your answer makes sense, it is “correct.”

Tap **Misc** and select **Illusory Contours**.

-  Describe what you see. Why do you think you see shapes where there are none?

Bistable Figures

Bistable (pronounced *buy-stable*) figures aren’t really illusions, but they are still fun to look at. They don’t “fool” the visual system in the same way most illusions do—what they do is give the visual system two possible perceptions from which it must choose one. Look at each of the figures under the **Bistable Figures** menu.

-  Describe each of the two possible perceptions in each of the figures. Is it sometimes easier to see one than the other? Can you make yourself switch between each of the

two perceptions whenever you like? Is it possible for you to see both perceptions at the same time in any of the figures?

ADDITIONAL INVESTIGATIONS

Do a search for illusions or aftereffects on the internet. You should be able to find lots of them.



Briefly describe the most interesting illusion or other sensory phenomenon that you find.

Illusions & Aftereffects—Aftereffects

OBJECTIVES

By completing this exercise, you will:

- see many different kinds of visual aftereffects.
- learn what visual aftereffects are and what they can tell us about how our visual system works.

QUICK START

The following is a brief summary of the app instructions:

- To view an aftereffect tap **Aftereffects**, and select one from the available options.
- For information about individual aftereffects tap the **Help** button (?). When help is turned on you will see information about each aftereffect when you select it. Reviewing this information may help you answer some of the questions below.

EXERCISE

Aftereffects

As the name implies, visual aftereffects are something you see after you look at something else. First you view an **adapting stimulus** for a minute or two, then you view a **test stimulus** that is similar to, but not exactly the same as, the adapting stimulus. After viewing the adapting stimulus, the test stimulus looks different than it normally would—that's the aftereffect. Most aftereffects last only a few seconds to a few minutes, but some can last hours or days. In some of these aftereffect demonstrations, you will view the test stimulus both before and after you view the adapting stimulus, so you can compare how they look before and after you adapt.

Many aftereffects are caused by fatigue. One part of the visual system is “overworked” by the adapting stimulus, and it becomes weakened. In the time before it recovers, another part of the visual system works a little harder than normal. During the time that things are out of balance, our vision is not quite normal. Usually the two parts of the visual system that are out of balance control the perception of “opposites,” so our perception of the test stimulus is the opposite of our perception of the adapting stimulus.

Motion Aftereffect

There is a part of the visual system that is used for seeing motion. This part is divided into several motion detectors, and each of these detectors sees motion in only one direction. These motion detectors are arranged in pairs so that each member of a pair sees motion in the opposite direction (e.g., one sees upward motion, and the other sees downward motion). If we fatigue, or tire out, one member of a pair, then the other takes over temporarily.

Tap **Aftereffects** and select **Motion**. If you would like to see more information about this aftereffect, tap the **Help** (?) button. First you will see the adapting stimuli, two grating patterns (take a look at the *Background* section of the *Spatial Vision* app if you would like to know what a grating pattern is). The grating on the top will drift to the left, and the grating on the bottom will drift to the right for one minute—these are the adapting stimuli. While the patterns are moving, look at the white bar in the middle—**DO NOT** move your eyes or try to follow the moving patterns. When the movement stops, the test stimuli will appear.




Describe what happens to the test stimuli after the movement stopped. Were they still, or did they appear to move? If they moved, did they move in the same direction or different directions? How was the motion of the aftereffect different from the motion of the adapting stimuli?

Size and Orientation Aftereffects

There are also parts of the visual system that are used for seeing size and orientation (tilt). These parts are also divided up into pairs of “opposite” detectors, just like the motion detectors. If we fatigue, or tire out, one member of a pair, then the other takes over temporarily.



View the **Size** and then the **Orientation** aftereffects by selecting them from the **Aftereffects** menu. They work just like the motion aftereffect. First you will see the adapting stimuli for one minute. While the adapting stimuli are being shown, look at the white bar in the middle—*DO NOT* move your eyes or try to follow the moving patterns. Finally, the test stimuli will appear.

-  Describe the size and orientation aftereffects. Compare how the test stimuli looked before and after you viewed the adapting stimuli. Also, compare the top and bottom test stimuli with the top and bottom adapting stimuli for each aftereffect.

Color Aftereffects


The part of our visual system that sees color is also divided up into pairs of “opposite” color detectors. With color detectors, red and green are opposites, and blue and yellow are opposites.

Tap **Aftereffects** and select **Negative Afterimages**. You will be asked to select a color for the adapting image— select **Red** and tap the **OK** button. The adapting image will be shown for about a minute—with this aftereffect, you can look anywhere in the colored part of the screen. The adapting image will then be replaced by the test image—a plain white screen.

-  Does the plain white test image appear to have a color tint? What color is it?
- Try **Negative Afterimages** again with a **Green**, then a **Blue**, and then a **Yellow** adapting image. It would be best if you waited a few minutes between each one, so the previous aftereffect has a chance to wear off.
-  What color is the afterimage for each of the adapting colors? Are the aftereffects equally strong for all colors? If not, which colors produce the strongest aftereffects?

The McCollough Effect

The McCollough effect is one of the strongest and longest lasting of all the aftereffects. It is a combination of the orientation and color aftereffects. Tap **Aftereffects** and select **McCollough Effect**. There are two different adapting stimuli that you will see—a set of red and black vertical bars and a set of green and black horizontal bars. The two patterns will alternate—you will see each for a few seconds at a time—for a total of *four minutes*. This aftereffect takes a long time to develop, so *please be patient*. The adapting stimuli will then be replaced by the test stimulus. The test stimulus is a pattern that has black and white bars—some are horizontal and some are vertical.

-  Describe the test stimulus. Do the horizontal parts of the test stimulus look different than the vertical parts?

If you have the opportunity, try to see how long it takes for the McCollough effect to wear off. You can go back and look at the McCollough test stimulus without viewing the adapting stimuli again. To do this, tap **Aftereffects** and select **Show McCollough Pattern**. If you can, try looking at the test stimulus a half hour after you adapted (*DO NOT adapt again*). Try again after an hour, or even a day or two later.



Some people report that the McCollough effect lasts for hours or even days. How long did it last for you? Sometimes it's hard to tell where to draw the line between an aftereffect and learning (learning is usually believed to involve a long-term change in the brain). What do you think the McCollough effect is and why?

Spatial Vision—Making Waves

OBJECTIVES

By completing this exercise, you will learn:

- what sine waves are and what they look like.
- how sine waves can differ in frequency and amplitude.
- how sine waves can be used as a graph, or luminance profile, to plot brightness in a grayscale image—what a sine wave grating is.
- how sine waves can be added together to create complex patterns (Fourier synthesis).

QUICK START

The following is a brief summary of the app instructions:

- To get to the “Making Waves” portion of the app select **Waves**.
- Use the sliders to set **Frequency** and **Amplitude** values for up to 13 sine waves, or enter values in the boxes on the right. Frequencies can be up to 250 and amplitudes up to 1000. If you don’t want a wave to be added, enter a **Frequency** or an **Amplitude** of 0.
- The **Square Wave** button fills in the frequencies and amplitudes to approximate a square wave.
- The **Clear** button erases the current sum of waves and sets the frequency and amplitude values of all waves (except the first) to zero.
- The **Plot** button adds up the sine waves, then plots the sum and draws the corresponding grating pattern.

EXERCISE

Simple Sine Waves

First you will learn about sine waves—what they look like, how changing their amplitude and frequency changes the way they look, and what a sine wave grating looks like. To do this you will only be plotting one wave at a time, so make sure that the amplitude boxes for all the waves except the first one are all set to zero (tapping **Waves** then the **Clear** button will do this for you).

Select **Waves** then set the **Frequency** to 1 and **Amplitude** to 1000 for the first wave, then tap the **Plot** button to see the result. You will see one complete cycle of a sine wave plotted on top and a sine wave grating pattern on the bottom.



What do you think “one complete cycle” means? How does the grating pattern correspond to the sine wave plot?

Set the **Frequency** to 2 for the first wave (leave its amplitude at 1000), then tap the **Plot** button to see the result. Do the same thing with **Frequencies** of 5, 10, 20, and 50.



Now what do you think a “cycle” is? In your own words, describe how changing the frequency of a sine wave affects the way the wave and the grating pattern look (that is, define “frequency”).

Set the **Frequency** to 5 and **Amplitude** to 500 for the first wave, then tap the **Plot** button to see the result. Do the same thing with **Amplitudes** of 250, 100, 50, 10, and 5.



In your own words, describe how changing the amplitude of a sine wave affects the way the wave and the grating pattern look. (that is, define “amplitude”).

Set the **Frequency** to 1 and an **Amplitude** to 10 for the first wave, then tap the **Plot** button to see the result. Do the same thing with **Frequencies** of 2, 5, 10, 20, and 50.




Can you see the grating pattern when the frequency is set to 1? At which of the frequencies can you see the grating best? Is it true that the bigger something is (the


lower the frequency), the easier it is to see? Or do we see middle frequencies better than lower frequencies?

Complex Waves


Now you will see what happens when you add sine waves together. Tap the **Square Wave** button. This will fill in the **Amplitudes** and **Frequencies** so the sum will be a square wave. (This will not be a “true” square wave, but an approximation—to make a mathematically perfect square wave you need to keep adding sine waves until the frequency reaches infinity, and we don’t have that much time.) **Tap** the **Plot** button to see the resulting sum and grating pattern.

-  Describe the wave that was plotted and the grating pattern—how is it not perfectly square? What is the relationship between the sine waves used to make a square wave? If you were going to add a 14th wave to the sum, what would its frequency and amplitude be?


Set the **Frequency** to 0 for the 13th (last) wave, and tap the **Plot** button to see the result without the highest frequency. Next set the **Frequency** of the 12th wave to 0, and tap the **Plot** button. Continue by setting the **Frequency** to 0 for each wave—except the first one—and tapping the **Plot** button after subtracting each wave from the sum. Do this one wave at a time from the bottom to the top. Leave the first wave with a **Frequency** of 1.

-  Describe how the wave that was plotted, and the corresponding grating pattern, changed as you removed more and more of the components of the square wave.


Tap the **Square Wave** button again, but this time multiply each of the frequency values by 10. You should now have **Frequency** values of 10, 30, 50, 70, etc. Tap the **Plot** button to see the result.

-  Describe this wave and the grating pattern. Does the grating pattern look more square? Does it have sharper edges? Why? In other words, what is it that makes edges “sharp”?

Tap the **Clear** button to erase everything. Set the **Frequency** of the first wave to 2 and its **Amplitude** to 500. Set the **Frequency** of the second wave to 4 and its **Amplitude** to 250 (you should now have non-zero values set for the frequency and amplitude of only the first two waves). Tap the **Plot** button to see the result.

-  Describe this wave and the grating pattern.

Set the **Frequency** to 6 and the **Amplitude** to 125 for the third wave, then tap the **Plot** button. Then set the **Frequency** to 8 and an **Amplitude** to (approximately) 62.5 for the fourth wave, then tap the **Plot** button. Continue setting values for each wave by entering the next even number for the next **Frequency**, and half the previous amplitude for the next **Amplitude**. Tap the **Plot** button after adding each wave.

-  How did the shape of this wave change as you added even frequencies?

Spatial Vision—Image Analysis

OBJECTIVES

By completing this exercise, you will learn:

- how images can be broken down into a set of sine-wave components (Fourier analysis).
- how different types of filters operate on the sine-wave components of an image.
- what the different sine-wave components of an image “look like”—how an image changes when certain components are removed or changed.
- how the world might look to people with different kinds of visual deficits.

QUICK START

The following is a brief summary of the app instructions:

- To get to the “Image Analysis” portion of the app, select **Fourier**.
- Tap on **Original Image** to select an image from the popup list.
- Select a **Filter Type—High Pass, Low Pass, Band Pass, or Notch**. To set the filter cutoff frequencies use the **slider(s)** below the **Filter Frequencies** image.
- Tap the **Filter Image** button to filter an image.

EXERCISE

Analyzing Square Waves

If you don’t already know the basics of square wave construction, now would be a good time to take a look at the *Background* section, because in this exercise you’re going to take a square wave apart. Tap **Fourier**, then **Select Image**, and select **Square Wave** from the popup menu. Then in the **Filter Settings** panel select **Low Pass**. Set the **Filter Frequency** to about 90 and set **Filter Efficiency** to 100. Tap the **Filter Image** button to perform the filtering operation.



Describe the grating pattern. Does it look like any of the gratings you created in Exercise 1?

Reduce the **Filter Frequency** to about 80, and leave the **Filter Efficiency** at 100. Tap the **Filter Image** button.



How is this grating pattern different from the previous one? (It is, so go back and re-filter it if you need to refresh your memory.) What components does it look like it’s missing?

Reduce the **Filter Frequency** to about 50, and leave the **Filter Efficiency** at 100. Tap the **Filter Image** button.



How would you describe this wave? What components does it look like it’s missing



Describe what you just did to the square wave by applying the three filters. Think about what a low-pass filter does (which frequencies it removes) and how a square wave is “made.”

Analyzing Text

Tap **Select Image**, and select **Text Small** from the popup menu. Then in the **Filter Settings** panel select **Low Pass**. Adjust the **Filter Frequency** to about 50, and set **Filter Efficiency** to 100. Tap the **Filter Image** button.



What happened to the text? Can you read it?

Select a **High Pass** filter, adjust the **Filter Frequency** to about 50, and leave the **Filter Efficiency** at 100. Tap the **Filter Image** button.




What happened to the text this time? Can you read it?

Select a **Notch** filter. Adjust the **Filter Frequencies** to about 25 and 85, and set **Filter Efficiency** to 100. Tap the **Filter Image** button.




What happened to the text this time? Can you read it?

-  What range of frequencies (high, middle, or low) do you think are used most to “build” text? Think about what each of the three filters did to the image (what frequencies did each remove). After applying which filters could you still read the text?


Filters and Vision

Some medical conditions cause people to lose their vision for only a narrow range of frequencies. For example, cataracts make it harder to see high frequencies, glaucoma and the early stages of Alzheimer’s disease make it harder to see low frequencies, and multiple sclerosis can make it harder to see middle frequencies. What do you think the world might look like if you couldn’t see high, middle or low frequencies? For this exercise, tap **Select Image**, and select any of the “face” images from the popup menu.


In the **Filter Settings** panel select **Low Pass**. Adjust the **Filter Frequency** to between 65 and 70 (so you filter out the high frequencies and leave the low and middle ones alone), and set **Filter Efficiency** to 100. Tap the **Filter Image** button.

-  What does the image look like without high frequencies? Can you see the overall shape and form (the “global” parts of the image)? Can you see the edges and fine details (the “local” parts of the image)?

Select a **High Pass** filter. Adjust the **Filter Frequency** to between 40 and 45 (so you filter out the low frequencies and leave the middle and high ones alone), and leave **Filter Efficiency** at 100. Tap the **Filter Image** button.

-  What does the image look like without low frequencies? Can you see the overall shape and form (the “global” parts of the image)? Can you see the edges and fine details (the “local” parts of the image)?

Select a **Notch** filter. Adjust the **Filter Frequencies** to about 25 and 85 (so you filter out the middle frequencies and leave the low and high ones alone), and set **Filter Efficiency** to 100. Tap the **Filter Image** button.

-  What does the image look like without middle frequencies? Can you see the overall shape and form (the “global” parts of the image)? Can you see the edges and fine details (the “local” parts of the image)?


Repeat the last three manipulations above, but this time choose one of the other photographic (“non-face”) images (e.g., **Tree, Oil Rig, Dinner, Rose or Stone Wall**).

-  What does the image look like without high frequencies?

-  What does the image look like without low frequencies?

-  What does the image look like without middle frequencies?

Think about the overall effect all these the various manipulations had on the different types of images.

-  If you had to lose vision in just one range of frequencies (low, medium, or high), which would affect your vision the most? Which do you think would affect your vision least?

ADDITIONAL INVESTIGATIONS

- Repeat the *Analyzing Square Waves* manipulations (see above) on two or more of the sine wave images. What happens to the sine waves as you change the filter

frequency? How is the change with different cutoff frequencies different than what happens with the square wave? Why?

- Compare the effects of various filters (low pass, high pass, etc.) and filter settings on vertical, horizontal, and orthogonal (two perpendicular) sine waves. How does the FFT output change? Why?
- Try various settings of the **Subsample** filter on some of the images. Explain what subsampling is. Explain its effect on images in terms of spatial frequency. Compare and contrast it to the other types of filters (low pass, high pass, etc.). Try squinting when you look at a subsampled image. Does it look less “filtered?” Why? (Think about the effect that squinting has on the spatial frequencies you see—it’s sort of like applying a filter to your vision.)

Stereograms

OBJECTIVES

By completing this exercise, you will learn about:

- how stereograms can “fool” our visual system into seeing depth.
- what random-dot stereograms are and how they create a perception of form and depth.

QUICK START

The following is a brief summary of the app instructions:

- To view a stereogram select **Random Dots**, **Outlines**, or **Pictures**, and then select one of the available stereograms.
- For some stereograms you can set various parameters. To generate and display a stereogram, set the parameters (if they are available) and tap the **Draw It** button.
- View the stereograms with the red-green (or red/blue) glasses. The *red* lens goes over your *right* eye.

EXERCISE

Random Dot—Density

Random-dot stereograms are a very special kind of stereogram because we can not only see depth in them, but we also see solid shapes where none exist. Each eye views only a pattern of random dots that has no shape or form (there are no edges). Our brain “creates” the shape by comparing and matching up the dots seen by each eye. There are no monocular cues to depth in a random-dot stereogram—the only depth cue is the disparity of the dots.

Select **Random Dots** and then select **Square**. Set **Dot Density** to 98 (that means that, on the average, about half of the dots will be colored), and **Disparity** to 5 (that means that the difference in the position of the square seen by the left and right eye will be 5 pixels). Set **Object Size** (how big the square is) to 100. Tap **Draw It** to generate and draw the stereogram. When the stereogram is finished drawing, view it with the red-green (or red-blue) glasses (the *red* lens over your *right* eye). You may need to view these random-dot stereograms for a minute or two before you see anything. View them from directly in front of the display at about arm’s length, about 55–60 cm (20–24 in).



Describe what you see. Is the object in front of or behind the screen? Does the object really look like a square? Does it have sharp, distinct edges?

Reversing the glasses (the *red* lens over your *left* eye) reverses the disparity (objects shifted to the right are shifted to the left, and vice-versa). Reverse the glasses, and view the stereogram again.



How does the appearance of the stereogram change when you reverse the glasses?

Select **Random Dots**, and then select **Square**. Set **Dot Density** to 50— don’t change the disparity or object size. Tap **Draw It** to generate and draw the stereogram. When the stereogram is finished drawing, switch the glasses back (the *red* lens over your *right* eye), and view it.



Can you see the square? Does it have sharp, distinct edges?

Try the same thing with **Dot Densities** of 25, 10, and 5. You may need to look at these for a minute or two to get the full effect.



Can you see the square at each of these densities? Does it always have sharp, distinct edges? Do you think it should? Why or why not? Are you surprised by what you see?

Select **Random Dots**, and then select **Steps**. Set **Dot Density** to 98 and **Disparity** to 5. Tap **Draw It** to generate and draw the stereogram. When the stereogram is finished drawing, view it with the red-green (or red-blue) glasses (the *red* lens over your *right* eye).



Describe what you see.

Reverse the glasses (the *red* lens over your *left* eye), and view the stereogram again.



What does the stereogram look like when you reverse the glasses?

Select **Random Dots**, and then select **Steps**. Set **Dot Density** to 1. **Tap Draw It** to generate and draw the stereogram. When the stereogram is finished drawing, switch the glasses back (the *red* lens over your *right* eye) and view it. You may need to look at this one for a minute or two to get the full effect.



Can you see the steps? Are the black spaces between the dots without depth, or do they appear to have the same depth as the neighboring dots? Do you think these blank areas should have depth? Why or why not?

Random Dot—Disparity

Select **Random Dots**, and then select **Square**. Set **Dot Density** to 98, **Disparity** to 5, and **Object Size** to 100. **Tap Draw It** to generate and draw the stereogram. When the stereogram is finished drawing, view it with the red-green (or red-blue) glasses (the *red* lens over your *right* eye) at a distance of about 55–60 cm (20–24 in). Do the same with a **Disparity** of 3 and then 1 (that means that the difference in the position of the square seen by the left and right eye will be 3 pixels and 1 pixel). *It is important for this part of the exercise that your viewing distance is the same for each disparity.*



Compare what you see with different disparities? What happened to the square? What is the relation between the depth you perceive and the disparity of the images?

Set **Disparity** to 10 (don't change the dot density or object size). Tap **Draw It** to generate and draw the stereogram. When the stereogram is finished drawing, view it with the red-green (or red-blue) glasses (the *red* lens over your *right* eye). Do the same with a **Disparity** of 15. *It is important for this part of the exercise that your viewing distance is the same for each disparity.*



What happened to the square? Can you clearly see the depth? There is a limit to the amount of disparity the visual system can use to perceive depth. If the two eyes' views are too different, the visual system cannot combine the images, and we see double (diplopia). Did disparities of 10 or 15 exceed this limit?

Stereo Photographs

Stereo photographs are taken with a special camera that has two lenses and takes two pictures at the same time. The lenses are side by side, about the same distance apart as our eyes. As a result, each of the pictures is slightly different, just like the difference between the images seen by our two eyes. Because these pictures are of objects in the "real world," they contain both monocular depth cues and disparity.

Select **Pictures: Vatican** and then **Pictures: On Duty**. (You can look at the other stereo photos too, but these two show depth especially well.) View these stereo photos with the red-green (or red-blue) glasses (the *red* lens over your *right* eye) and without the glasses.



Describe the difference between viewing the stereo photos with and without the glasses.

Reversing the glasses reverses the disparity but not the monocular depth cues. In other words, you are sending your brain mixed signals about depth. Reverse the glasses (the *red* lens over your *left* eye), and view the stereo photos again.



Does the depth reverse in the stereo photos in the same way it does in the random-dot stereograms when you reverse the glasses? Describe how they look with the glasses reversed. Which depth cue(s) “win out”—monocular cues, disparity, or neither?

Color Vision Test

OBJECTIVES

By completing this exercise, you will learn about:

- taking and scoring a common test for color vision deficiencies.
- normal color vision and color vision deficiencies.

QUICK START

The following is a brief summary of the app instructions:

- Drag the **colored discs** to the row of dark spots in the middle, arranging them so that the most similar discs are next to each other.
- To reposition a **colored disc**, drag it to a new, empty position or drag it out of the middle row.
- When you have arranged the discs to your satisfaction, tap the **Score Test** button.

EXERCISE

Taking the Test

The object of this test is to arrange the colored discs so that the most similar discs are closest to one another. When you begin, the first colored disc is already placed at the far left of the center row. From the other colored discs select the one most similar to the one already in position, and drag it to the second position in the center row. Next, find the colored disc most similar to the second disc in the center row. Continue dragging discs to the center row until you have arranged all of the colored discs in order.



Review both the graphical and numerical results of your test.



Based on your test results, how would you describe your color vision?

Receptive Field Mapping

OBJECTIVES

By completing this exercise, you will learn about:

- the concept of visual receptive fields.
- how receptive fields differ in different parts of the visual system; how different types of cells respond to different types of stimuli.
- the technique used to identify and map receptive fields.

QUICK START

The following is a brief summary of the app instructions:

- Select a cell type—**Ganglion, LGN, or Cortex**.
- Select a stimulus—a **large spot**, a **small spot**, or one of several **bars** at different orientations.
- *To turn the stimulus on and off*, touch and release the crosshair cursor. Drag the cursor to move the stimulus.
- *To mark a receptive field*, tap **Pencil** to show the pencil. Tap the crosshair cursor to make a mark. Touch and drag the cursor to move the pencil.
- When you are satisfied that you have mapped both receptive fields on a screen, tap **Show Fields**. Once you show the receptive fields, you can not longer map them.
- For stimulus suggestions specific to a cell type, look at the *Background* section.

EXERCISE

For this exercise, work in groups to map the receptive fields of four cells—two **Ganglion or LGN** cells, *and* two **Cortical** cells. There are two of each cell type on each screen. Each individual should do the mapping for at least one cell. If there are two students in your group, each should map two cells. If there are three students in your group, two students should map one cell, and one student should map two cells.



Each student should save the screen (**Send Data**) showing the receptive fields they mapped.

Mach Bands and Simultaneous Contrast

OBJECTIVES

By completing this exercise, you will learn about:

- the concepts of brightness and luminance, and that the two are not always the same.
- what Mach bands are and what they tell us about the visual system.
- the concept of lateral inhibition and how neighboring cells communicate with one another.

QUICK START

The following is a brief summary of the app instructions:

Simultaneous Contrast

- To view an illusion tap **Motion, Depth, Contrast, Size, Shape, Orientation, Bistable, or Misc**, and select an illusion from the available options.
- For information about individual illusions tap the **Help** button (?). When help is turned on you will see information about each illusion when you select it. Reviewing this information may help you answer some of the questions below.

Mach Bands

- Use the **Arrow** buttons to draw and erase the luminance profile. A *plot* of the **Grayscale Values** is shown at the top of the screen and the *grayscale Luminance Profile* is shown below it. You can also tap in the grayscale plot area to draw and erase the profile. Tap the **Clear** button to erase the luminance profile.
- Enter values for **Amplitude** and **Space Constant** to set the amount and spread of inhibition.
- Tap the **Calculate** button to show the perceptual equivalent of the luminance profile that you have plotted.

EXERCISE

Simultaneous Contrast

Use the **Illusions and Aftereffects** app for this part of the exercise. Tap **Contrast** then select **Simultaneous Contrast—Static** from the popup menu.



Describe the brightness of the gray spot on the left compared to the brightness of the gray spot on the right.

Tap **Contrast** then select **Simultaneous Contrast—Dynamic** from the popup menu. This illustrates the same concept as the previous illusion, but the effect is much more dramatic.



Does the brightness of the spot change as it moves across the background? If so, describe how it changes.

The change in the spot's brightness is an illusion—the spot doesn't really change. To demonstrate this select **Black Background** or **White Background** to show the spot on a solid background. Select **Shaded Background** to show the spot on a shaded background.



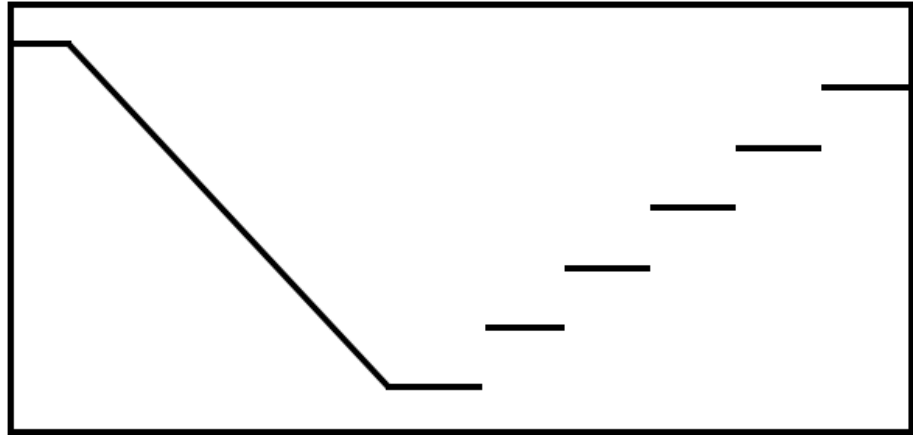
Based on the demonstrations of static and dynamic simultaneous contrast, describe a general rule that relates the brightness of an object to the brightness of the background on which it is viewed.



Based on the simultaneous contrast effect, which type of information would appear to be most relevant to our perception, absolute brightness or relative brightness?

Mach Bands

Use the **Mach Bands** app for this part of the exercise. A *plot* of the luminance profile is shown in a graph at the top of the screen and a *grayscale* luminance profile is shown below it. Plot a **Luminance Profile** that contains both a smooth



gradient and sharp steps—something like that shown below.

- ✎ Compare the plot of the luminance profile to the grayscale luminance profile. Are they the same? In other words, does the grayscale luminance profile look like you would expect based on its graph?

Mach Bands are areas that seem brighter or darker than they really are. They are caused by a phenomenon called **lateral inhibition**.

- ✎ Do you find any bright Mach Bands in the luminance profile? Where are they located?
- ✎ Do you find any dark Mach Bands in the luminance profile? Where are they located?

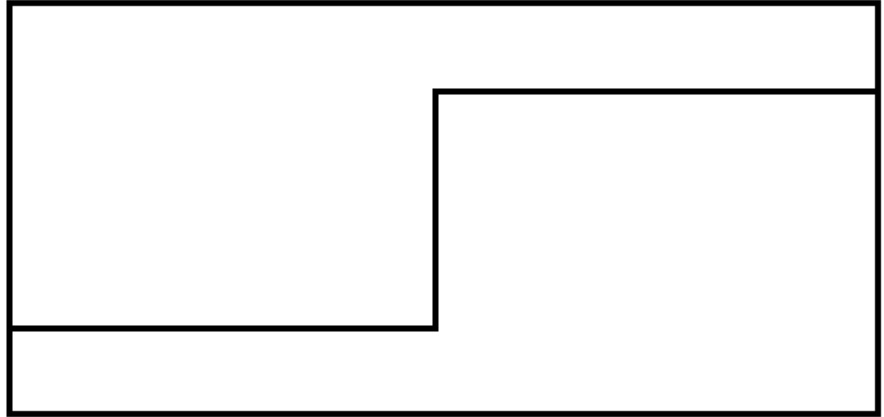
Make sure that the **Amplitude** of inhibition is set to 0.90 and tap the **Calculate** button. The white line is a graphical representation of how the luminance profile would appear to a visual system with lateral inhibition.




- ✎ Is the plot of the luminance profile shown by the white line similar to your perception of the grayscale luminance profile?

Now set the **Amplitude** of inhibition to 0 (no lateral inhibition). Tap the **Calculate** button, and compare the plot of the luminance profile (white line) to the grayscale luminance profile.

- ✎ What amount of lateral inhibition generates a plot of the luminance profile that most closely approximates the grayscale luminance profile— 0 or 0.90?
- ✎ Based on your observations, did your visual system demonstrate lateral inhibition?

Clear the display by tapping the **Clear** button and plot a **Luminance Profile** with one large step, as shown below. Enter an **Amplitude** of inhibition of 0.90 and tap the **Calculate** button.



-  When a light area is next to a dark area, where do the bright Mach Bands appear, on the light area or the dark area?
-  What aspect of a luminance profile is most affected by lateral inhibition, sharp edges or gradual gradients?
-  Describe the perceptual function served by lateral inhibition? In other words, how does lateral inhibition help us see?

ADDITIONAL INVESTIGATIONS

Create other **Luminance Profiles** that demonstrate Mach bands. Can you create any that work better than the examples in this exercise? If so, describe it/them. What characteristic(s) should be part of the profile to get the best Mach band effect?

Color Mixing

OBJECTIVES

By completing this exercise, you will learn about:

- the principles of additive color mixing, in other words, the mixing of colored lights.
- the principles of subtractive color mixing, in other words, the mixing of colored paints.
- “plotting” colors in 3D color spaces.

QUICK START

The following is a brief summary of the app instructions:

- Use the sliders labeled **Adjust Colors** to change the amounts of each primary color added to the color mixture. The numbers on the left show the amounts of each of the primary colors in the mixture—0 is none and 100 is the maximum amount.
- When you define a color, it will appear in the **Color Mixture** patches. It will also be plotted as a point in the **Color Space**.
- If you tap the **Save Color** button after you define a color, the point that is plotted in the **Color Space** will stay there after you define a new color. To delete the last saved color, tap the **Delete Last** button.
- You can rotate the **Color Space** to any orientation you like by touching and dragging it. Pinch to zoom. To reset the **Color Space** to its original position, tap the **Reset** button.

EXERCISE

Color Mixtures

When printing or painting, the primary colors are **cyan, magenta, and yellow**. With lights, the primary colors are **red, green, and blue**. A color is called a **primary color** because it cannot be made from any combination or mixture of colors. Because colors on the computer screen are produced by light coming from the display, and not by reflected light (like print or paint), we can make cyan, magenta, and yellow by mixing red, green, and blue. When mixing colored lights, cyan, magenta, and yellow are called the **secondary colors**.

To make the three secondary colors, begin by selecting the **RGB** color space. Set the amounts of **Red** and **Green** to 100 and the amount of **Blue** to 0.



What color do you get?

Next, set **Red** and **Blue** to 100 and set **Green** to 0. (Be sure you are still viewing the **RGB** color space.)



What color do you get?

Finally, set **Green** and **Blue** to 100 and set **Red** to 0. (Be sure you are still viewing the **RGB** color space.)



What color do you get?



Describe the general rule for making the three secondary colors from the three primary colors. Where are the three secondary colors plotted in RGB color space?

Be sure you are still viewing the **RGB** color space, and adjust the color mixture to make shades of gray. Make a light gray, a medium gray and a dark gray.



Describe the general rule for making grays. How does this compare to making white? Where are the grays plotted in the **RGB** color space?


Brightness

Select the **RGB** color space. Pick one of the primaries (**Red, Green, or Blue**), set its value to 100 and set the values of the other two primaries to 0. Tap the **Save Color**


button to save this color. Now decrease the amount of the primary you picked to 80, and tap the **Save Color** button again. Continue decreasing the amount of the primary you picked by 20, tapping the **Save Color** button each time, until you reach zero. For example, if you picked Red, your color settings would be as follows:

Red: 100	Red: 80	Red: 60	Red: 40	Red: 20	Red: 0
Green: 0	Green: 0	Green: 0	Green: 0	Green: 0	Green: 0
Blue: 0	Blue: 0	Blue: 0	Blue: 0	Blue: 0	Blue: 0
Save	Save	Save	Save	Save	Save

Repeat this entire process for each of the other two primary colors.

 Describe how brightness is plotted in the RGB color space (it may help to rotate the **Color Space** to get a view from different angles).


Now select the **HSB** color space.

 Describe how brightness is plotted in the HSB color space.


Tap the **Delete Last** button several times to delete all your saved colors, and be sure you are still viewing the **HSB** color space. Set **Red** to 100 (its maximum) and set **Green** and **Blue** to 0. Tap the **Save Color** button. Now do the same for **Green**, then **Blue**, tapping the **Save Color** button each time. Your settings should be as follows:

Red: 100	Red: 0	Red: 0
Green: 0	Green: 100	Green: 0
Blue: 0	Blue: 0	Blue: 100
Save	Save	Save

You will have three bright, pure primaries plotted in the **Color Space**.


 Where are these three points located relative to the height of the axis? Are they in the white, gray, or black zone?

Now rotate the Color Space to view it from the top (the axis should be a small point).

 Describe the location of the three primaries in the color space, relative to each other and to the axis.

Saturation

Tap the **Delete Last** button several times to delete all your saved colors, and select the **HSB** color space. Pick one of the primaries (**Red**, **Green**, or **Blue**), set its value to 100, and set the values of the other two primaries to 0. This creates a saturated, or pure, color. Tap the **Save Color** button to save this color. Now adjust the amounts of the other two colors to 16, and tap the **Save Color** button to save this new color. Continue adding to the other two colors in equal amounts (add about 16 or 17) and saving each setting until you reach 100. So, while one of the colors stays set at 100, the other two colors should be set to about 16, 32, 50, 66, 83, and 100. It is not important to use these exact values—it *IS important to set the values for each of the other two colors the same*.

 How did the appearance of the color mixture change as it became less and less saturated? How did the position of the colors in the **HSB** color space change? Describe in your own words what is meant by saturation.

Hue

Tap the **Delete Last** button several times to delete all your saved colors, and select the **HSB** color space. Create and **Save** the three primary colors (red, green, and blue) by setting one color's value to 100 and the other two colors' values to 0 for each primary color. Next, create and **Save** the three secondary colors (cyan, magenta, and yellow). Your settings should be done as follows:

Red: 100	Red: 0	Red: 0	Red: 0	Red: 100	Red: 100
Green: 0	Green: 100	Green: 0	Green: 100	Green: 0	Green: 100
Blue: 0	Blue: 0	Blue: 100	Blue: 100	Blue: 100	Blue: 0
Save	Save	Save	Save	Save	Save

You should now have six colors plotted in the **HSB** color space.



Describe the positions of the three secondary colors relative to the three primary colors. (It would probably be best to view the color space from the top to see the positions of these colors.) Are they located where you would expect them to be? Why or why not? Describe in your own words how hue is represented in the **HSB** color space.

Hue, Saturation & Brightness

Tap the **Delete Last** button several times to delete all your saved colors, and select the **HSB** color space. Adjust the color settings to make black.



What are the red, green, and blue settings you used to make black? Where is black in the **HSB** color space?

Adjust the color settings to make an orange color.



What are the red, green, and blue settings you used to make orange?

Adjust the color settings to make a pink color.



What are the red, green, and blue settings you used to make pink? Is your pink created with only one primary color, only one secondary color, or a combination of colors? Which hues did you use? Is your pink saturated or desaturated? Is it bright or dark?

Brown is a tricky color to make. Adjust the color settings to make a brown color. (Be sure you are still viewing the **HSB** color space.)



What are the red, green, and blue settings you used to make brown? Where is your brown in the **HSB** color space? Is it a bright or a dark color?





Some colors are difficult to make, especially colors that we say are "metallic." Adjust the color settings to make a gold color.



Is it possible to make the color gold? If so, what are the red, green, and blue settings you used to make gold? If not, what other factors might contribute to our perception of the color gold?

Subtractive Color Mixing

Tap the **Delete Last** button several times to delete all your saved colors, and select the **CMY** color space. This will change the primary colors to **Cyan**, **Magenta**, and **Yellow**, the colors used in subtractive color mixing. Adjust the color settings to make black.

-  What are the cyan, magenta, and yellow settings you used to make black? Where is black in the **CMY** color space?
- Adjust the color settings to make white.
-  What are the cyan, magenta, and yellow settings you used to make white? Where is white in the **CMY** color space?
- Adjust the color settings to make the three secondary colors. (Be sure you are still viewing the **CMY** color space.)
-  Is the relationship between primary and secondary colors the same for additive and subtractive color mixing?
-  Compare the mixtures that make black and white in additive color mixing to the mixtures that make black and white in subtractive color mixing. Describe the most significant difference between additive and subtractive color mixing.