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2 RESEARCH METHODOLOGY

LEARNING OBJECTIVES

2.1 Explain the nature of psychophysical scales and how they measure the relations between real-world stimuli and our perceptions of them.

2.2 Demonstrate an understanding of the method of limits.

2.3 Explore the differences between the method of constant stimuli and the method of adjustment.

2.4 Think about magnitude estimation and what it tells us about perception.

2.5 Initiate an understanding of signal detection theory and how it works both in sensation and perception and other domains.

2.6 Evaluate neuroscience methods and what they tell us about sensation and perception.

INTRODUCTION

In 2019, Smith's Dragon Breath chili pepper was ranked the world's hottest chili pepper just ahead of the Carolina Reaper (Hansen, 2022). According to the *Daily Post*, the hottest peppers rate 2.5 million on the Scoville scale. That puts the Dragon Breath chili pepper in roughly the same range on the Scoville scale as law enforcement–grade pepper spray. Scotch bonnet peppers and habanero peppers, usually the hottest peppers most people eat, score from 100,000 to 300,000 Scoville units. By contrast, a green pepper has a Scoville value of 0. The first question we can ask is why would anyone ever want to eat a Smith's Dragon Breath chili pepper? And the next question we can ask is how do we determine hotness and how people experience it?

The **Scoville scale** measures our detection of the amount of an ingredient called **capsaicin** in chili peppers. Capsaicin is a chemical present in peppers that directly stimulates the somatosensory system, especially heat and pain receptors in our mouths, and our eyes (which is why pepper spray irritates the eyes). Its presence presumably evolved in wild chili peppers to prevent mammals from consuming the fruit. Capsaicin, in general, repels mammals but does not affect birds, as the birds are necessary to disperse the seeds. However, many people acquire a taste for capsaicin, as the heat and pain felt in the mouth interact with smell and taste to create interesting, if acquired, flavors, known as piquancy. Indeed, worldwide, the chili pepper has become an important ingredient in cooking. Moreover, some chili pepper enthusiasts "compete" in competitions to see who can eat the hottest pepper. For example, there is a chili pepper–eating contest at the North Carolina Hot Sauce Contest. To win, contestants must eat an entire orange habanero chili (300,000 Scoville units) (Figure 2.1). In the competition, contestants start off with milder peppers and work their way up to the really spicy stuff. To find out more about this competition, see the link on ISLE 2.1.

The Scoville scale is a psychophysical scale, meaning that it relates psychological experience to some aspect of the physical world. A **psychophysical scale** is one in which people rate their psychological experiences as a function of the level of a physical stimulus. In this case, the Scoville scale measures our experience of piquancy or "hotness" at different concentrations of capsaicin. Thus, the concentration of capsaicin in a particular food or drink is the physical dimension, whereas our experience of piquancy is the psychological correlate of that physical dimension. We will encounter numerous instances of psychophysical scales throughout this textbook. For example, the decibel scale measures the psychological construct of loudness as a function of the intensity of a sound stimulus.

The Scoville scale is named after a chemist named Wilbur Scoville, who developed the scale more than 100 years ago, in 1912. He derived the scale before chemists could accurately measure the amount of capsaicin in a particular pepper, which labs can do routinely now. In Scoville's time, having a reliable scale to measure the "hotness" of foods was important in the development of commercial foods. To measure the piquancy, Scoville recruited brave volunteers from the company he worked for to evaluate

FIGURE 2.1 ■ Eat at Your Own Risk

These are orange habaneros, which rate about 300,000 on the Scoville scale. The Scoville scale is a psychophysical scale that measures our experience of piquancy or "hotness." The more capsaicin is present in a particular food, the spicier it will taste.

Source: iStock.com/DNY59

chili peppers. Once he had willing volunteers, Scoville adjusted the level of chili peppers in a liquid solution that he had his observers taste. Obviously, the greater the concentration of chili peppers, the hotter was the taster's experience, but Scoville wanted to quantify this relation. He measured when the observers first starting experiencing heat when tasting the pepper solution and how much more capsaicin he needed to add to get people to notice a difference in the hotness of the solution. If a taster did not notice any difference as a function of more chili peppers, Scoville added more until that taster did notice the difference. In this way, Scoville was measuring a characteristic known in psychophysics as the just-noticeable difference (JND). A JND is the smallest amount of physical change observers notice as a perceptual change.

The Scoville scale, then, measures people's perceived sense of hotness as a function of the amount of capsaicin in the sample solution. This scale was critical for the development of commercial products that contained capsaicin. The production of commercial hot sauces is a worldwide business, and companies will report the Scoville ratings of their sauces. Tabasco sauce, spicy to many of us, rates only about 2,000 on the Scoville scale, far less than the piquancy of a Scotch bonnet pepper, let alone a Smith's Dragon Breath chili pepper. So, if you know that Tabasco sauce is relatively mild on the Scoville scale, you might try it on your tofu. However, if someone is offering you Smith's Dragon Breath chili pepper sauce, you might want to think twice before dousing your dinner. The scale is now widely used in the food industry. For our purposes here, the perception of piquancy and the Scoville scale serve as an excellent introduction to the research methods used in sensation and perception and in understanding the concepts of psychophysics.

This chapter covers basic questions, techniques, and research methods used by researchers to discover how human sensory systems work. This information will set the stage for later chapters that cover specific sensory systems, how they work, and what we perceive. In terms of methods, in some cases, participants are asked to rate a stimulus on a numerical scale, whereas in other situations, they may be asked to decide only whether a stimulus is present (see the various demonstrations on ISLE). In the latter case, a researcher can quantify on the basis of the percentage of correct responses at each level of the stimulus.

The study of human sensory systems starts with psychophysics, the study of the relation between physical stimuli and perception events, much as we just saw with the Scoville scale for chili pepper hotness. Psychophysical methods involve presenting a carefully controlled stimulus to a participant and asking a question directly of the participant that allows the answer to be quantified, that is, turned into a number. From these direct questions, we hope to understand the nature of sensation and perception. Thus, the psychophysical approach focuses on the relation between physical properties (e.g., the amount of capsaicin present) and perception (the experience of hotness).

However, the actual questions asked of participants may vary depending on the research focus. Participants may be asked to do a detection task ("Is there any hotness in the taste?"), a comparison task ("Which is hotter, Stimulus A or Stimulus B?"), or a magnitude task ("How hot is the stimulus?"). Moreover, the scale might be a preference scale ("Which level of hotness is preferable?"). Researchers need to be clear about which methods they use, because sometimes different methods reveal different patterns. As such, it is important to detail the research methods of sensation and perception in this chapter, before we delve into individual sensory systems in the remaining chapters.

When you go to an optometrist to get your vision tested or to an audiologist to get your hearing tested, you essentially perform a series of psychophysical tests. At the optometrist, you are asked questions such as "Can you distinguish the *d*'s from the *b*'s and the *o*'s from the *q*'s?" If you can, great; if you cannot, you may need to start wearing glasses (Figure 2.2). At the audiologist, you are asked questions such as "In which ear do you hear the tone?" If you can't identify whether the sound is coming from the left or the right, it may be time to consider hearing aids. But for our purposes, it is the basic methods of psychophysics that allow us to start studying the processes of perception. Many of the methods go back to Gustav Fechner in the 19th century.

FIGURE 2.2 ■ Woman Undergoing a Routine Eye Exam at an Optometrist's Office

People should have these exams annually to determine the health of their eyes. Many of the tests an optometrist runs are similar to psychophysical tests.

Source: iStock.com/MachineHeadz

Test Your Knowledge

1. What is the Scoville scale, and what exactly does it measure?
2. What is meant by the term *psychophysics*?

PSYCHOPHYSICS: THE METHOD OF LIMITS

In the **method of limits**, stimuli are presented on a graduated scale (i.e., a scale that varies along predictable and relatively small changes), and participants must judge the stimuli along a certain property that goes up or down. For example, a participant may be presented with an increasingly dimmer set of lights. The participant is asked to tell the experimenter when the lights are no longer visible. The researcher will then present the participant with lights so dim that they cannot be seen and then present increasingly intense lights until the participant detects them (Figure 2.3). Similarly, one could present a series of tones, starting at a volume so soft that one cannot hear them and gradually increasing the loudness until the participant can hear the tones. We illustrate the method of limits with ISLE 2.2. In the first screen of this experiment, you will find a window in which you can set up the values that will adjust how your method of limits experiment will run. The first item asks you to determine the number of levels to test. The number of levels refers to the number of intensity steps in the independent variable that will be tested. In the method of limits, the researcher hopes to pick an extreme value that is readily detected and a level that is never detected and then several levels between these.

FIGURE 2.3 ■ The Method of Limits

The participant must decide if a stimulus is present at a number of different levels of intensity. The stimulus is increased in even trials and decreased in odd trials. A *Y* indicates that the participant detects the stimulus, whereas an *N* indicates that the participant does not detect the stimulus. The estimate of the threshold is considered to be the mean crossover point.

Intensity	Trial Number								
10	Y		Y		Y		Y		Y
9	Y		Y		Y		Y		Y
8	Y		Y		Y		Y		Y
7	Y		Y		Y		Y		Y
6	Y		Y		N		Y		Y
5	Y		N	Y		Y	Y		Y
4	N	Y		N		N	Y	Y	N
3		N		N		N	N	N	
2		N		N		N		N	
1		N		N		N		N	
Crossover	4.5	3.5	5.5	4.5	6.5	4.5	3.5	3.5	4.5

Threshold = mean crossover = 4.5

The method of limits is often used to determine both absolute and difference thresholds. An **absolute threshold** is the smallest amount of a stimulus necessary to allow an observer to detect its presence. For example, the smallest amount of light energy at any particular wavelength of light that we can detect is its absolute threshold. Similarly, the least amount of sound that we can hear at any particular frequency is its absolute threshold. The smallest amount of capsaicin that we can detect as hotness is its absolute threshold. The lightest touch that we feel on our skin is its absolute threshold. For a final example, the smallest amount of salt that your taste buds can detect is also its absolute threshold.

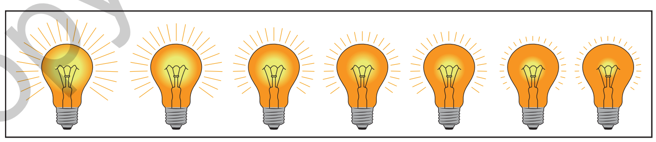
The method of limits can also be used to determine the **difference threshold (JND**, mentioned earlier), which is the smallest difference between two stimuli that can be detected. Thus, one might hold two weights and attempt to determine if their masses are the same or different. The smallest difference in weight that can be detected is the difference threshold, equal to 1 JND. Similarly, an observer might see two green lights and be asked if the lights are the same or not in terms of experienced greenness. The smallest difference in the wavelengths of the lights that can be detected is the difference threshold, or 1 JND. Similarly, the smallest increase of capsaicin that can be detected as a difference in piquancy is also a 1 JND difference.

Returning to the concept of absolute thresholds, it turns out that detecting absolute thresholds is harder than simply finding the softest sound a person can hear or the dimmest light a person can see. For example, if you are just leaving the firing range and have been hearing loud percussions for the past hour, detecting a very soft tone might be difficult. If you have been studying in the library for the past hour, that same tone might be quite audible. Similarly, it may be easier to detect a dim light in the dark of night than it is to detect the same light on a bright summer day. If you have just eaten a large and satisfying meal, the taste of another piece of lasagna may not be as satisfying as the first. That is, absolute thresholds are not so absolute—they depend on many internal and external conditions. In fact, our sensory systems are constantly adapting to local conditions. On one hand, this makes assessing absolute thresholds difficult, but on the other hand, it is an adaptive feature of our sensory systems, as it allows us to perceive under a wide range of conditions. On a bright sunny day at the beach, we want our sensitivity to light to be less than when we are trying to find our way around a forest campground on a dark, moonless night.

In assessing thresholds, we often need to estimate the threshold and try to compensate for any sensory adaptation that is occurring. Thus, to determine an absolute threshold with the method of limits, a researcher must use both an ascending series and a descending series. An **ascending series** (or an ascending staircase) is one in which a stimulus gets increasingly larger along a physical dimension. Thus, the intensity of light might increase, the amplitude of sound might increase, or the amount of capsaicin in a taste capsule might increase. By contrast, a **descending series** (or a descending staircase) is one in which the stimulus gets increasingly smaller along a physical dimension. Thus, the researcher starts with a clearly visible light and lowers the amount of light on each successive trial (Figure 2.4).

FIGURE 2.4 ■ Absolute Threshold

Illustration of the detection of absolute thresholds through the method of descending limits. Each light is dimmer than the one to its left.



Consider a light detection experiment. We want to determine a person's absolute threshold for a red light in an otherwise dark environment. In the ascending method, we start off with a level of red light that is known to be below the threshold. Participants should respond that they do not see it. The experimenter then gradually increases the intensity of the light until participants can detect the light. In the descending method, we start off with a bright level of red light that people can obviously detect and then lower the intensity of the light until they can no longer see it. The point at which people change from detecting to not detecting or vice versa is known as the **crossover point**. Typically, the threshold will be different when measured by the ascending method versus by the descending method. In general, with ascending series, people are likely to claim that they can detect a stimulus when in fact the stimulus is below the threshold. With descending series, people are likely to claim that they cannot detect a stimulus when it actually is above the threshold. Researchers will typically average over several descending and ascending series to get their best estimate of the absolute threshold (see ISLE 2.2).

Consider some common absolute thresholds in the natural world. Think of looking up at the stars on a clear night (Figure 2.5). Think of the faintest star you can possibly see—this star may be at or around your visual threshold. And for the auditory system, consider hearing the faintest drone of a conversation from an upstairs dorm room. You cannot make out the content of what they are saying, but you can just

FIGURE 2.5 ■ Stars on a Clear Night

Many stars are easy to see, but some may lie just at our thresholds. When we look at these stars straight on, we may miss them, but we see them again "out of the corner of our eye," or at our periphery, which is more light sensitive.

Source: iStock.com/Baltskars

barely hear their voices. In the domain of taste, consider how much sugar you must put in your iced tea before it has the slightest hint of sweet. And think of the faintest hint of a distant odor—perhaps a faraway smell of coffee. Thus, in real life, we do encounter at-threshold stimuli from time to time.

In Chapter 1, we mentioned the work of Ernst Heinrich Weber, who did some of the earliest work on thresholds in the 19th century. One area he investigated was threshold in touch along the surface of the skin. He was interested in the **two-point touch threshold**, which is the minimum distance along the skin at which two touches are perceived as two touches and not one. In this case, two needles can be brought gently to touch a person's skin close to one another. If a person feels only one touch, then it is below the threshold, but if the person feels two touches, then they are above the threshold. Our two-point touch thresholds vary across our skin. Our fingers can detect two touches even when the needles are extremely close to each other. However, the skin of our backs requires greater distance to feel two touches. Areas on the face and mouth have small two-point thresholds, but not as small as the fingers. Other areas, such as the arms and legs, require larger distances to perceive two touches, but not as great as distances on the skin of the back. The two-point threshold is an absolute threshold. The size of the absolute threshold differs on different parts of the body, just as acuity changes across the surface of the eye's retina. Table 2.1 lists a few everyday absolute thresholds.

TABLE 2.1 ■ Everyday Absolute Thresholds

Sense	Threshold
Vision	A candle 30 miles away on a dark night
Audition	A ticking watch 20 feet away in an otherwise silent location
Taste	A teaspoon of sugar in 2 gallons of water
Smell	A drop of perfume in three rooms

Source: Adapted from Galanter (1962).

Test Your Knowledge

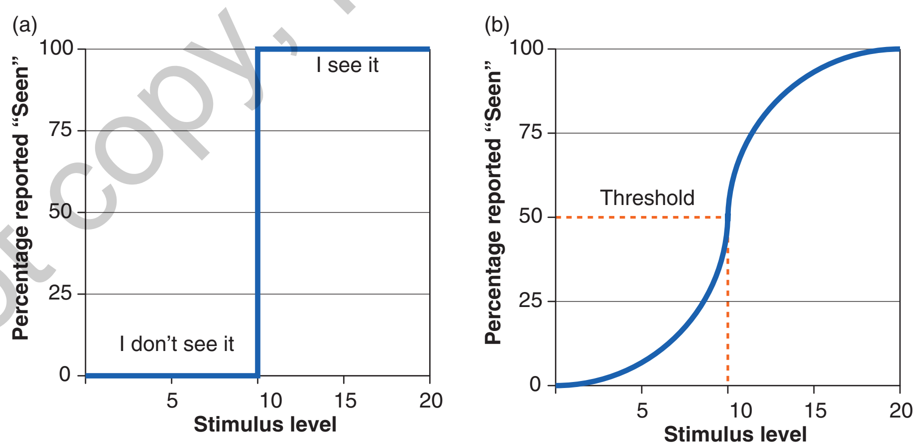
1. What is the difference between an absolute threshold and a difference threshold? When might you want to use one, and when might you want to use the other?
2. Why would the method of limits not be a good method to test piquancy of hot peppers?

THE METHOD OF CONSTANT STIMULI AND THE METHOD OF ADJUSTMENT

In the **method of constant stimuli**, the threshold is determined by presenting the observer with a set of stimuli, some of which are above the threshold and some of which are below it, but the stimuli are presented in a random order. This differs from the method of limits in which the stimuli were presented in a prescribed order. In the method of limits, the stimuli are changed to focus on a particular observer's threshold. In the method of constant stimuli, the presentation of stimuli is given in a random order rather than zeroing in on the threshold. In the method of constant stimuli, the stimuli are always presented, regardless of how people respond to them, and the stimuli are selected beforehand. This technique prevents the observer from being able to predict or anticipate what the next stimulus will be. This reduces errors that may result from habituation or fluctuations in perception due to attention or other factors. However, the method of constant stimuli is often quite time-consuming, as it requires pretesting to gauge the general region of the threshold for each participant. Moreover, it requires many trials to detect a statistically determined threshold. In the method of constant stimuli, the stimulus that is detected 50% of the time and not detected 50% of the time is considered to be the threshold (Figure 2.6). You can see a demonstration of the method of constant stimuli on ISLE 2.3.

FIGURE 2.6 ■ Measuring Threshold

These graphs illustrate how we measure the threshold in psychophysical experiments. (a) We see a hypothetical cutoff at a particular level of intensity that separates the stimulus level at which we see the stimulus and the stimulus level at which we do not see the stimulus. (b) In most cases, thresholds vary from trial to trial, and we must estimate the threshold from the point at which participants are 50% likely to say "saw it" and 50% likely to say "didn't see it."



The method of constant stimuli is used by audiologists when testing patients for hearing thresholds (Gelfand, 2009). For each frequency of sound, the audiologist will present the patient with an assortment of louder and softer tones to detect (see ISLE 2.3b). In this way, the audiologist can determine the threshold of hearing at each frequency and, in some cases, if that threshold is higher than it should be, whether the person might be a candidate for hearing aids. Typically, hearing loss varies as a function of sound frequency, meaning that for some sound frequencies, a person may be impaired but for others have normal hearing. An audiologist needs to know the profile of hearing loss to properly program a patient's hearing aids. For this reason, as we will see later in the chapter, audiology starts with psychophysics.

In the **method of adjustment**, the observer controls the level of the stimulus and "adjusts" it to be at the perceptual threshold. The participant does so by increasing or decreasing the level of the stimulus until it feels as if it is just at the detectable level. Think of it as similar to when you adjust the volume on your television to be at just the right volume for you to be able to hear comfortably. In a psychophysics experiment, the participant will set the stimuli to threshold by continuously adjusting a knob to control the level of the stimulus. This is an intuitive measure for most participants because it mirrors many normal activities, such as adjusting the volume control on a radio or a dimmer switch on a light. In a light threshold study, the method of adjustment would require the observer to adjust the light source to the dimmest light the participant can detect. Adjusting the knob any lower would render the stimulus invisible. The advantage of this technique is that it can quickly yield a threshold for each participant, but a disadvantage is that it leads to great variance from one participant to the next and between successive trials for each participant.

The method of adjustment is very useful for matching one stimulus to another to determine the **point of subjective equality (PSE)**. The PSE designates the settings of two stimuli at which the observer experiences them as identical. For example, consider a researcher who is interested in the JND in the detection of pitch differences as a function of sound frequency. The observer hears a constant sample tone at, for example, 1,000 Hz. The observer would then adjust a second tone until it matched perceptually the sample tone. The experimenter could then look at the frequency selected by the observer and see just how closely the observer actually matched the sample tone. In vision research, the experimenter may present a stimulus of particular brightness. The participant would have to adjust another stimulus to be equally bright to the first one. And, returning to our chili pepper example, an experimenter might present a chili pepper sauce as the sample taste. Then a participant would have to adjust the level of capsaicin in a second sample to match the level of hotness in the first. To see and experience an auditory example of the method of adjustment, see ISLE 2.4 and try a PSE in ISLE 2.5.

Closely related to the concept of threshold is the concept of sensitivity. **Sensitivity** is the ability to perceive a particular stimulus. It is inversely related to threshold. As the threshold goes down, the observer is deemed to be more sensitive. That is, lower thresholds mean higher sensitivity. This makes sense when one considers that *threshold* refers to the ability to perceive a stimulus at smaller and smaller levels of that quantity. Thus, a person who can hear a sound at 10 decibels (dB) is more sensitive than a person who can hear the sound only at 15 dB. A person who can smell a perfume at smaller concentrations in the air is more sensitive to that odor than someone who requires larger concentrations. Sensitivity may vary across situations. For example, one may be more sensitive to changes in the intensity of light in a room when one has just been in a dark room than when one has just come out of the brilliant sunshine.

Test Your Knowledge

1. What is meant by the point of subjective equality, and how will it differ from person to person?
2. How do the method of constant stimuli and method of adjustment differ? In what ways are they similar?

MAGNITUDE ESTIMATION

Magnitude estimation is a psychophysical method in which participants judge and assign numerical estimates to the perceived strength of a stimulus. This technique was developed by S. S. Stevens in the 1950s (e.g., Stevens, 1956). Magnitude estimation usually works in the following way. An experimenter presents a standard tone and assigns it a particular loudness value, say 20. Then the participant must judge subsequent tones and give them numerical values, in comparison with the standard. Thus, if the participant thinks the new tone is twice as loud as the standard, it should be assigned a 40. If the next tone is just a bit softer than the standard, it may be assigned a 15. If the tone is heard to be much softer than the standard, it might receive a 5 on this hypothetical scale of loudness.

Magnitude estimation can also be used for visual experiments. It follows the same principle: In brightness estimation, a sample light might be given a standard value, and then other samples are judged in relation to the standard. Magnitude estimation can be adapted to just about any perceptual dimension. Participants may be asked to judge the brightness of light, the lengths of lines, or the sizes of circles on a numerical scale. For visual and auditory examples of magnitude adjustment, go to ISLE 2.6.

As experimenters in a psychophysics experiment, we can control the stimulus. For example, we can have people taste and make judgments of the sweetness of a sample with a known quantity of sugar, say 1 teaspoon per gallon. We then present them with a sample of a solution of sugar water calibrated to 2 teaspoons per gallon. The new stimulus has twice as much sugar in it per unit of water, but is it perceived as twice as sweet? In almost all sensory systems, there is a phenomenon called response compression. **Response compression** means that as the strength of a stimulus increases, so, too, does the perceptual response, but the perceptual response does not increase by as much as the strength of the stimulus increases. That is, if you judge the first sugar-water solution as a 5 on the sweetness scale, doubling the sugar in the solution will cause an increase in your sweetness judgment but not a doubling of the perceived sweetness. In fact, you will likely judge the 2-teaspoon solution as a 7 or an 8 on the sweetness scale.

There is an exception to the response compression rule, and that involves pain perception. In pain perception, there is response expansion instead of response compression. **Response expansion** means that as the strength of a stimulus increases, the perceptual response increases even more. If a person receives an electric shock of physical intensity 10 and judges it to be 5 on a pain scale, increasing the physical intensity to 20 will lead to a more than doubling of the judgment, to perhaps 15 on the pain scale. That is, smaller increments of increase in the physical dimension (e.g., electric shock) lead to greater increments in the perception of the perceptual characteristic (e.g., the perception of pain).

Stevens (1957, 1961) developed an equation to try to encapsulate both types of data sets. (This is one of just a few mathematical equations that will be presented in this book.) It is called **Stevens's power law**, and it is as follows:

$$P = cI^b$$

In this equation, P is equal to the perceived magnitude of a stimulus, that is, how bright we perceive a light to be or how sweet we perceive a sugar solution to be. I is equal to the intensity of the actual stimulus. Thus, at the simplest level, our perception is a function of the physical intensity of the stimulus. However, there are two other parts of the equation that explain the relation between perception and the physical stimulus. The letter c represents a constant, which will be different for each sensory modality or for each sensory dimension. The constant also allows you to scale your measure appropriately. For example, both Fahrenheit and Celsius temperature scales measure the same underlying property, but they do so with different scales. The exponent b equals the power to which the intensity is raised. It is this exponent b that allows response compression and response expansion. Response compression occurs when b is less than 1, and response expansion occurs when b is greater than 1. Thus, Stevens's power law equation can account for both types of subjective responses. This is depicted in Figure 2.7. For a graphical demonstration of how this works, go to ISLE 2.7.

To give an example, let us return to the Scoville scale. We could present a chili sauce with 1 milligram of capsaicin per kilogram of other substances. We tell people that this is a 1 on the piquancy scale. We then increase the dosage to 2 mg/kg. Thus, we have doubled the active "hot" ingredient. Applying Stevens's law, we need to know the constant and the exponent to determine a person's perceptual response. Because capsaicin stimulates pain receptors, we can expect an exponent of greater than 1 (and hence response expansion). Thus, the hotness judgment should be more than double the baseline, leading to a hotness judgment of greater than 2. A few exponents for Stevens's power law are given for different sensory domains in Table 2.2. A value greater than 1 indicates response expansion, whereas a value less than 1 indicates response compression.

FIGURE 2.7 ■ Comparison of the Physical Intensity of a Stimulus and Its Perceptual Correlate

In response compression, as the physical intensity of a stimulus increases, its perceptual correlate increases as well, but not by as much. In response expansion, as the physical intensity of a stimulus increases, its perceptual correlate increases even more. The curve for brightness illustrates response compression, whereas the curve for electric shock illustrates response expansion.

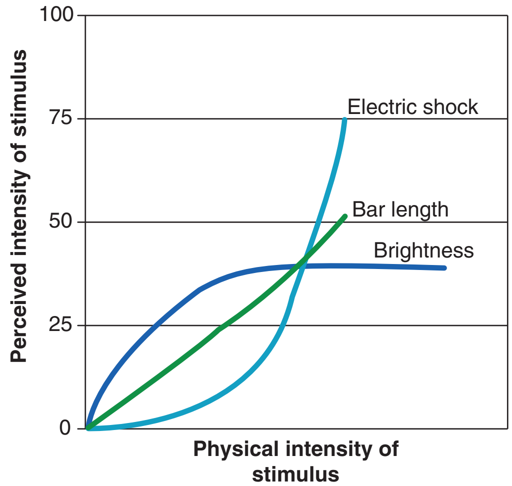


TABLE 2.2 ■ Stevens's Power Law Exponents

Sense	Perception	Exponent
Vision	Brightness	0.3
Audition	Loudness	0.5
Taste	Sweetness	0.8
Vision	Apparent length	1.0
Touch	Pain	3.5

Source: Adapted from Stevens (1961).

Catch Trials and Their Use

One of the potential difficulties that arise with the traditional methods of limits, constant stimuli, and adjustment is that the participant might be willingly or unwillingly misinforming the experimenter about perceptual experience. For example, a participant may indicate that he heard a sound when he was not sure or perhaps because he thinks a sound should have occurred even though he did not perceive one. Or worse, perhaps the participant wants to impress the experimenter with her extraordinary sensory abilities. In all of the methods described so far, it would be easy to do; you could simply report that you see or hear the stimulus when you do not. Because the stimulus is always present, even at a very soft volume or at a very low brightness, the experimenter cannot know if the participant is being truthful or not. One technique to counter this strategy is to use catch trials. A **catch trial** is a trial in which the stimulus is not presented. It is easy to insert these trials as checks on the participant's accuracy and honesty. Thus, in catch trials, the correct answer is "No, I didn't hear it" or "No, I didn't see it." If a participant reliably says that they saw the stimulus in a catch trial, we can dismiss this participant as an unreliable observer.

Another method that circumvents problems of false reporting is the **forced-choice method** (Blackwell, 1953; Jones, 1956). In every trial, the subject is asked to report either when the stimulus occurred or where it occurred. Thus, instead of determining whether a light was present or not, the participant must decide if a light was present in one location or another or at one time slot or another time slot. Instead of determining whether the participant heard a sound or not, the participant must determine in which of two intervals there was a sound or not. This technique prevents the need for catch trials because the observer cannot simply say "yes" in every trial, regardless of the presence of a stimulus in that trial. But it also allows the determination of thresholds, because if a stimulus cannot be detected, performance will be at chance (50% if there are two choices). Threshold can be determined by finding a level of performance that is significantly above chance. See ISLE 2.8 and Figure 2.8 for an illustration of the forced-choice method.

FIGURE 2.8 ■ Illustration of the Forced-Choice Method

The participant in this experiment is engaged in a psychophysical task using the forced-choice method, pressing the right or left button to indicate where a light displays on the screen.

Test Your Knowledge

1. What is the point of subjective equality (PSE)? Why is it critical when using the method of adjustment?
2. How can the equation to represent Stevens's power law explain both response compression and response expansion?

SIGNAL DETECTION THEORY

On July 3, 1988, Iran Air Flight 655 was shot down by a U.S. missile from the Navy vessel U.S.S. *Vincennes* (Figure 2.9). All 290 passengers and crew, including 66 children, were killed. Although the United States has never apologized to Iran, the U.S. government gave $61 million to the relatives of the victims of the attack. The incident took place at a time when there was heavy tension between the United States and Iran, and Iranian jets had previously attacked U.S. Navy vessels. However, in this case, the radar operators on the *Vincennes* mistakenly judged the civilian airplane, an Airbus 300, to be an incoming Iranian F-14 fighter, with horrifying consequences. How had the Navy made such a terrible mistake? We will couch an explanation of how this disaster occurred in terms of one of the most influential theories in the history of sensation and perception research, namely, **signal detection theory**.

Consider the radar specialist examining the screen that depicted incoming objects. That specialist had to decide, on the basis of the information available on the radar screen, whether the incoming object was an enemy warplane (an Iranian F-14) or a harmless jetliner (an Airbus 300). In 1988, this involved examining a radar screen and making a judgment as to the nature of the incoming airplane. The United States had (and has) complicated procedures to differentiate military and civilian airplanes on incoming radar. But in a war zone with an object approaching at 600 mph, decisions must be made quickly.

From the U.S. Navy's standpoint, there are two types of errors. The Navy could mistake a civilian airplane for a military jet, or it could mistake a military jet for a civilian airplane. Both of these errors

FIGURE 2.9 ■ The U.S.S. *Vincennes*

The U.S.S. *Vincennes*, seen here in 2005, was a guided-missile cruiser. In 1988, its crew mistakenly shot down a civilian aircraft. This error, called a false alarm in psychophysical terminology, had devastating consequences.

Source: AP Photo/Greg English

could have fatal consequences for innocent people, as indeed they did in this case. In the *Vincennes* case, the mistake that arose is called a **false alarm**. A false alarm, in psychophysical terms, occurs when the observer mistakes a nonsignal for an active signal. In this case, there was no F-14 approaching, but an error was made to expect one. The other type of error is called a **miss**, in which an incoming signal is not detected. In this military example, that would mean an F-14 is approaching, but it is not detected. In one case, the danger is to innocent civilians aboard the aircraft, whereas in the other case, the danger is to innocent personnel aboard the Navy vessel. Thus, in this situation, everything must be done to avoid both errors (Table 2.3).

TABLE 2.3 ■ Signal Detection Theory: Is It a Threat?

	Incoming Signal	
Response	Is a Fighter Jet	Is a Civilian Plane
Think it is a fighter jet	Shoot down enemy plane	Innocent civilians killed
Think it is a civilian plane	Innocent sailors killed	No hostile interactions

In such a situation, there are also two potential correct responses. A **correct rejection** occurs when a nonsignal is perceived as not occurring, and a **hit** occurs when a signal is correctly perceived as occurring. In the case of the *Vincennes*, the correct response should have been a correct rejection. The plane was a civilian jetliner that offered no threat to the Navy. In this example, a hit would have occurred if the radar had correctly identified an incoming military warplane as a threat. Military action must optimize hits and correct rejections in order to achieve strategic objectives and minimize civilian casualties. Thus, one of the goals of military surveillance equipment is to maximize hits and correct rejections while minimizing false alarms and misses.

Consider a radar operator examining the signal on the radar screen. Such an operator may be more likely to define a signal as "dangerous" if the signal is coming from an aircraft over the Strait of Hormuz, especially after recent attacks on the U.S. Navy, than if the signal is coming from an aircraft flying over the skies of central Nebraska. This differing judgment on the basis of situation is called the **criterion**. In Nebraska, the radar specialist will select a very high criterion, so as to avoid false alarms, and misses are less of a concern. However, when a Navy vessel is patrolling the Strait of Hormuz, near a highly hostile Iranian government, which has recently launched attacks against U.S. ships, the criterion will be lower, as there are more risks in the environment and the Navy does not want to miss an actual attack; thus, there is greater risk for more false alarms. This is exactly what happened off the coast of Iran in 1988. Thus, this military tragedy fits into the logic of signal detection theory, as we will shortly see (Green & Swets, 1966). See ISLE 2.9 to play such a war game yourself.

Here's another way of thinking about signal detection theory (Figure 2.10). Consider the following situation: You are driving down the road, and you think you hear a noise from the engine that sounds like a clunk. However, with your stereo playing and the sounds of the road, you are not sure exactly what the clunk is. If your car is relatively new and has a history of smooth running, perhaps you will decide that you didn't really hear anything (high criterion). Your hearing is "playing tricks" on you. However, if you are driving an old car that has a history of spending nearly as much time in the shop as on the road, you might decide that you did hear something and head to the nearest service center (low criterion). What is important in this example is that even in this basic sensory discrimination, there is a cognitive decision-making element that needs to be taken into account. This is another practical example of the situations for which signal detection accounts.

FIGURE 2.10 ■ Old Car/New Car

When we think we hear a noise associated with an engine malfunction, we adopt different criteria, depending on the situation. If we are driving the old clunker (a), we may adopt a more liberal criterion for hearing an engine problem. This will help us catch engine trouble (hits) but may also increase the rate of bringing the car to the shop when there is no problem (false alarm). If we are driving the shiny new sports car (b), we may adopt a more conservative criterion for hearing an engine problem. This will increase the likelihood of correctly dismissing a sound as noise rather than a mechanical problem (correct rejection) but may increase the likelihood that we do not hear a problem when there is one (miss).

(a)

(b)

Sources: (a) iStock.com/nwinter; (b) iStock.com/Rawpixel

So, let us look at a model of signal detection starting with a visual detection example (Table 2.4). Signal detection assumes that there is "noise" in any system. On occasion, this noise may be mistaken for an actual signal. In these examples, what should have been seen as noise, in the military sense, was mistaken for a military signal by the crew of the *Vincennes*. This noise may occur because

TABLE 2.4A ■ Signal Detection Theory: Possible Situations

	The Signal Is	
Response	Present	Absent
Perceived it	Hit	False alarm
Did not perceive it	Miss	Correct rejection

TABLE 2.4B ■ Signal Detection Theory: Possible Situations

	The Clunk	
Response	Actual	Did Not Happen
Think it happened	You get needed service	You make an unneeded service visit
Think it did not happen	You break down	You go happily on your way

of distortion on the screen or a wobble on the radar caused by atmospheric conditions. Similarly, if we have an old car, we may hear "clunks" even when the car is operating effectively. This noise in the system may be other sounds from the road, tinnitus in our ear, or something rustling in the trunk. Thus, the task for the observer is to distinguish an actual signal from the background noise. In a vision threshold experiment, this might be the actual dim light in the noise produced by random firing of retinal receptors.

Consider first the case in which there is a faint signal. We can detect it (hit) or not detect it (miss). But there is also the case in which the signal is absent. In that case, we may detect something (false alarm) or correctly realize that there is no signal (correct rejection). Signal detection theory states that we must consider all four possibilities to successfully measure thresholds.

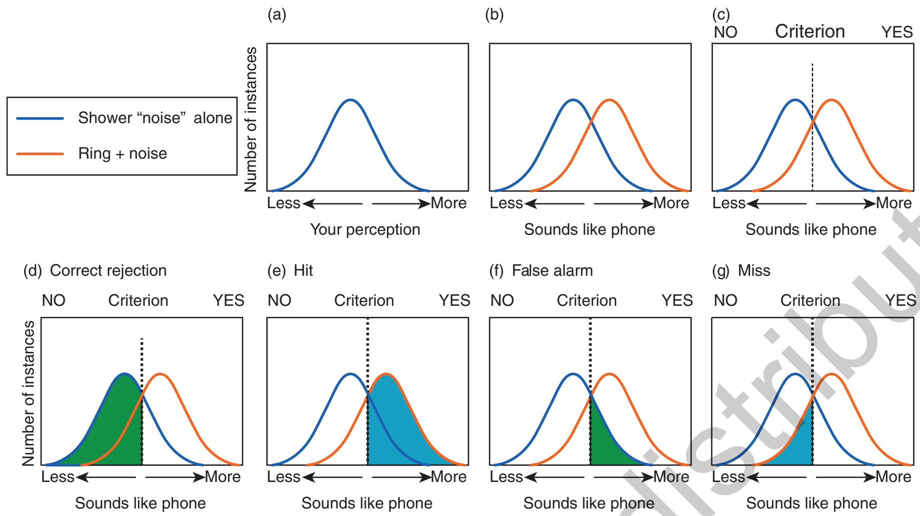
Consider a situation in which there is little noise in the system. Imagine if the captain of the *Vincennes* in 1988 had access to 2023 satellite imaging. In this case, there is little noise in the system. The captain could watch the video feed from the satellite and see that the incoming plane is an Airbus rather than an F-14. In this case, there would be few false alarms and few misses, only hits and correct rejections. But in 1988, the radar technology had noise in the system, presumably generated by any number of atmospheric conditions. Thus, the noise introduces the potential for error in the system.

These differences are represented graphically in Figure 2.11. In the figure, we consider a common psychophysical task, detecting a soft sound in a quiet environment. Noise here can be defined as random neuronal firing—think of the odd "sound" you experience but are not sure if it is real. Thus, a hit occurs when we detect a soft sound when present, and a false alarm represents when we think we heard a soft sound when one was not present. A correct rejection occurs when we say that no sound was present when no sound was present, but a miss occurs when we say that no sound was present when in fact there was a soft sound. Each of these situations is represented in the figure.

Let's return now to an idea introduced in comparing the threat in the Strait of Hormuz and the threat in Nebraska, that is, the idea of a criterion in signal detection theory. The criterion is an internal cutoff determined by the observer, above which the observer makes one response and below which the observer makes another response. Translated into technical terms, then, the criterion is a bias that can affect the rate of hits and false alarms. Thus, in the Strait of Hormuz, we adopt a criterion or an internal cutoff to respond at a lower threat level than we do in Nebraska. After all, we assume that the danger of an incoming enemy aircraft is much higher off the coast of a hostile nation than in the safety of the middle of our own. In our other example, if the clunking sound is above a certain level of loudness, we decide that there really is a clunk, and there is a problem with the car. If it is below that level of loudness, we decide that there is no reason to worry. This cutoff point may be different depending on whether we have a new car or that old clunker. Similarly, in a psychophysical study, the criterion determines the level of stimulation above which we decide a light is present and below which we decide not to indicate the presence of the light.

FIGURE 2.11 ■ Signal Detection Theory Illustrated Graphically

(a) The continuum of neurons firing in response to a soft or an absent sound. (b) A potential distribution for perceiving the soft sound or misperceiving the absent sound. (c) Addition of the criterion. (d) Correct rejection. (e) Hit. (f) False alarm. (g) Miss.



However, criteria vary depending on the situation. You might adopt a lax criterion for hearing the clunk if your car is old and has a history of engine problems. That is, you are more likely to attribute the clunk to the car than to random road sounds. This means you will risk more false alarms to catch all hits—you don't want your car to fall apart at 70 mph on the highway. But there is little cost to taking it to the shop one more time. Alternatively, if your car is new and has just been checked by a mechanic, you may adopt a stricter criterion. This means that you are more likely to attribute the noise to the road and not to the car. In signal detection terms, this means a greater desire to avoid false alarms (not paying extra money to the mechanic) and risking missing hits (i.e., a breakdown, which you think is unlikely).

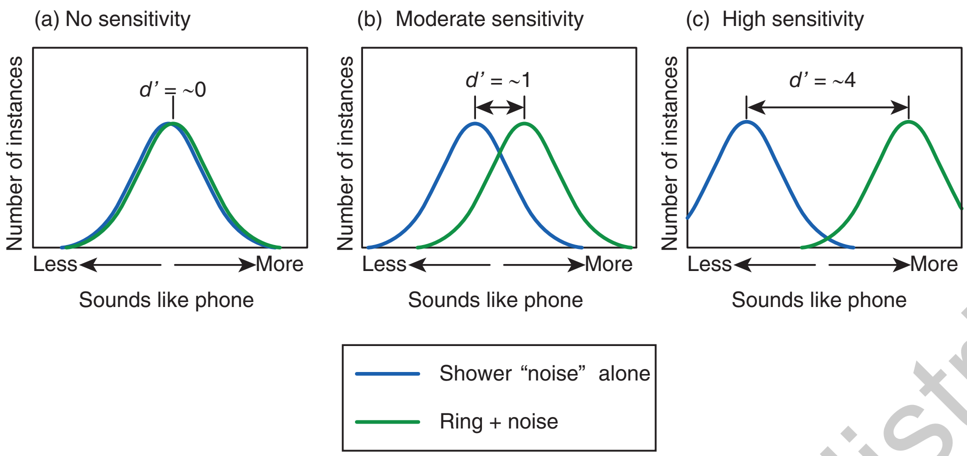
Thus, a criterion is a value set by the observer depending on circumstances known only by the observer. If the stimulus is above the criterion, the observer will say "yes" or "present," but if the stimulus is below the criterion, the observer will say "no" or "absent." Consider how the concept of a criterion might apply to real-world decisions. A radiologist screening for breast cancer must weigh the risks of unnecessary testing against the risk for cancer in evaluating a mammogram. If the woman is young and has no family history of breast cancer, the radiologist might adopt a higher (stricter) criterion, not wanting to risk a false alarm and put the woman through the pain of taking a tissue sample. However, if the woman is older or has a family history of breast cancer, the radiologist may adopt a lower (less strict) criterion, not wanting to make a miss, and recommend further testing. Mammographic screening is very effective, but there are still misses and false alarms to be concerned about.

There is one last piece to understand in signal detection theory. **Sensitivity**, as used in **signal detection theory**, is the ease or difficulty with which the observer can distinguish the signal from noise. That is, sensitivity measures how easy it is to tell if a signal is present or absent (Figure 2.12). Thus, one can imagine a radar operator with 1952 technology and one with 2022 technology. The older system has lower sensitivity, so it is harder to determine the nature of the incoming threat. The 2022 version has higher sensitivity, so it is easier to tell the difference between a harmless passenger plane and a dangerous enemy fighter jet. Similarly, if you have had a previous "clunking" problem with your car, you may know exactly what to listen for. Therefore, it will be easy to distinguish between noise and the clunk.

An observer with high sensitivity will be able to make mostly hits and correct rejections. But, as you can see in Figure 2.12, as sensitivity decreases, more false alarms and misses occur. As sensitivity increases, the observer has more hits and correct rejections. Thus, when you know what distinguishes between noise and clunks, you will make few mistakes and catch the car if it is on the brink

FIGURE 2.12 ■ Sensitivity

Sensitivity is the ability to distinguish a noise signal from an actual signal, such as the difference between random noise and the clunking sound in your car. (a) We see an example of when the perceiver has no sensitivity—it is impossible to tell the difference between signal and noise. (b) The perceiver is somewhat better at distinguishing signal from noise. (c) The perceiver shows much higher sensitivity.

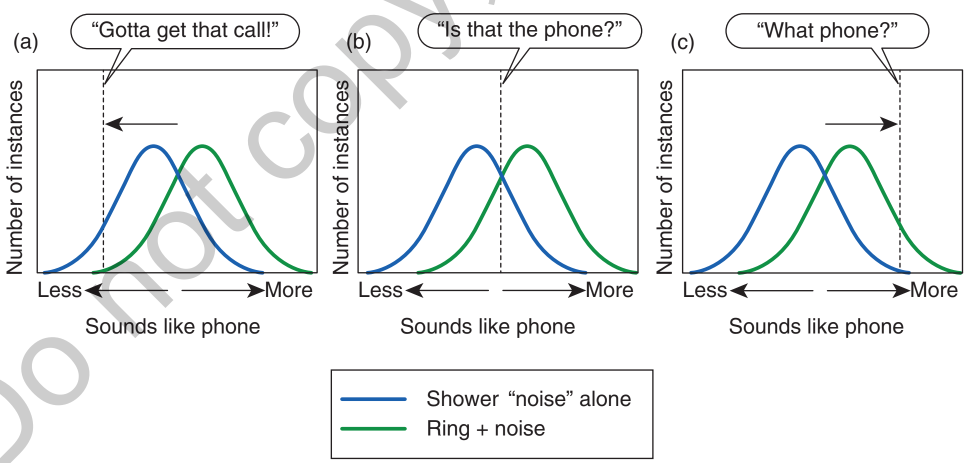


of breaking down and ignore the sound if you know that it is just random noise. In psychophysics, if you know the relation of hits to false alarms, you can determine **d′ (d-prime)**, which is a mathematical measure of sensitivity.

Sensitivity and criterion interact in interesting ways. Sensitivity may be high, but if the criterion is relatively low, there still might be many false alarms. That is, even if our radar system is very good at detecting enemy aircraft, a trigger-happy officer might still be making too many false alarms. This is illustrated in Figure 2.13. You can also review all of the issues related to signal detection theory in ISLE 2.10.

FIGURE 2.13 ■ Hits and False Alarms

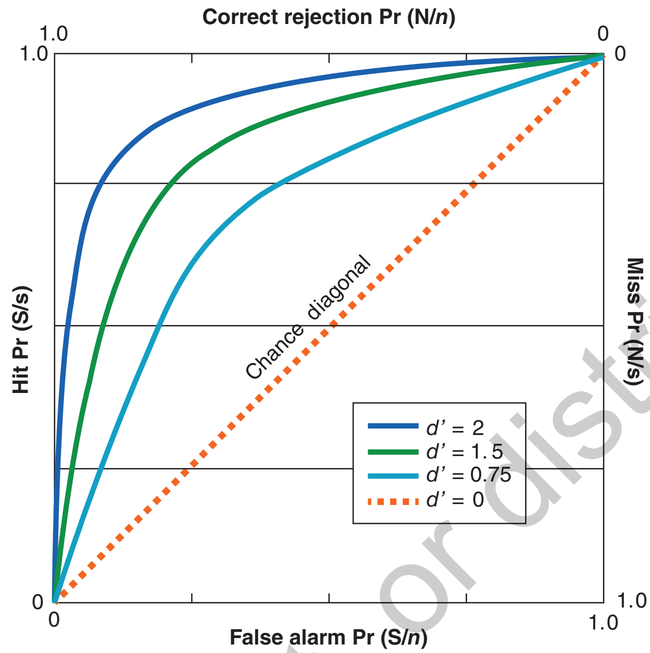
When sensitivity is kept constant, there can still be differences in the ratio of hits to false alarms, depending on the criterion. (a) Lax criterion, which allows many false alarms but maximizes hits. (b) Medium criterion. (c) Strict criterion, which minimizes false alarms but also reduces the detection of hits.



For any given sensitivity *d′*, there is a range of possible outcomes according to signal detection theory. To simplify seeing all of the possible outcomes for a given signal strength, researchers have developed a way to summarize all of the possible outcomes for this situation across all possible criteria. This summary is called the **receiver-operating characteristic (ROC) curve** (Figure 2.14). The ROC curve is a graphical plot of how often false alarms occur versus how often hits occur for any level of sensitivity. See ISLE 2.11, in which you can adjust the criterion and the sensitivity and see what the ROC curve looks like.

FIGURE 2.14 ■ Receiver-Operating Characteristic (ROC) Curves for Different Values of *d*′ (Sensitivity)

When $d' = 0$, sensitivity is zero, and the perceiver cannot discriminate between signal and noise. As d' increases, hits and correct rejections increase, and misses and false alarms decrease. If d' were perfect, we would get only hits and correct rejections, but in the real world, d' is never perfect.



The advantage of ROC curves is that they capture all aspects of signal detection theory in one graph. Sensitivity, or d', is captured by the "bow" in the curve. The more the curve bends up to the right, the better the sensitivity. Moving along the bow captures the criterion. As one moves up any individual level of sensitivity, the higher you go, the more loosely you are setting your criterion, thus opening the possibility of more hits but also more false alarms. In Figure 2.14, the line farthest to the left indicates the highest d'. This observer can set the criterion low and still catch many hits while minimizing false alarms. For the observer represented by the line second to the left to make as many hits, that observer risks more false alarms. If these two lines were radar operators, we would prefer to have the line that is farthest left making decisions, as that observer has a higher sensitivity. Depending on circumstances, this observer can set the criterion low or high and achieve the accuracies indicated on the ROC curve.

ROC curves are also important in evaluating medical decision making. Consider radiologists evaluating computerized tomographic (CT) scans looking for brain tumors. They want to be able to detect as many brain tumors as possible but also minimize the risk for false alarms, as false alarms can be quite dangerous—one does not want to initiate brain surgery if there is nothing wrong with the patient's brain. Thus, in evaluating radiologists, we want those with the highest values of d', that is, those who can best distinguish real tumors from false alarms in the CT scans. And we may also want them to set intermediate criteria, because false alarms also come with risk (Xue et al., 2013).

Test Your Knowledge

1. What is signal detection theory? How does it differentiate between accurate perception and errors?
2. What is d' in signal detection theory? Why is it important in graphing ROC curves?

NEUROIMAGING TECHNIQUES

Neuroimaging techniques are technologies that permit visual examination of living human brains. These techniques allow scientists to correlate perception with brain activity. Neuroimaging techniques are also used to investigate memory, attention, problem solving, and emotion. Two goals of neuroimaging are to reveal where perception happens in the brain and how perception unfolds through the brain over time. To reveal the particular area(s) in the brain where a specific process occurs, scientists use these methods to develop spatial maps of the brain, which show the areas that are active during perceptual tasks. To ascertain changes in activity in the brain over time, scientists use neuroimaging pictures in quick succession to find the time course of perceptual processes. The field of neuroimaging is changing quickly, but we review four of the main techniques.

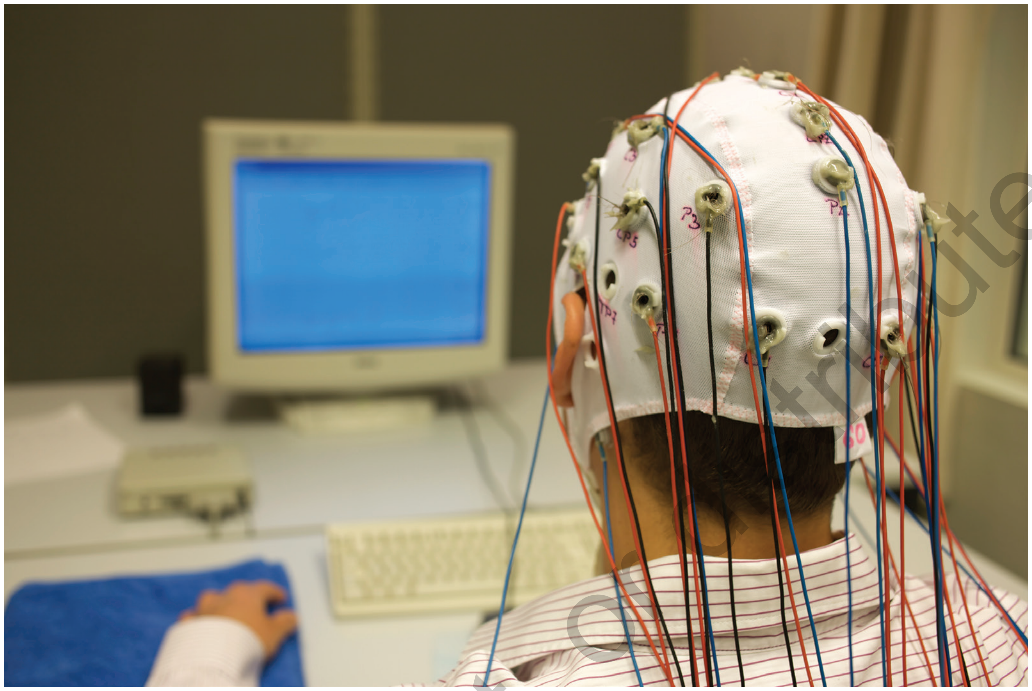
1. **Electroencephalography (EEG)**. In EEG, 256 electrodes or more are positioned on a person's scalp (Figure 2.15). The electrodes detect electrical signals created by the brain. Areas of the brain that are active generate faster changing electrical signals than those that are not active, and thus, by comparing electrical output across electrodes, we can approximate where a perceptual process is coming from in the brain. EEG picks up a continuous electric signal, which allows for measurements to be made every millisecond. Thus, EEG allows for determining the time course of perceptual processes in the brain.
2. **Magnetoencephalography (MEG)**. In MEG, magnetic sensors detect small magnetic fields produced by the electrical activity in the brain (Figure 2.16). MEG detects rapid changes in the brain, although at a less precise time scale than does EEG. However, MEG produces better spatial maps of the brain than EEG, though not as good as fMRI, discussed next.
3. **Magnetic resonance imaging (MRI) and functional magnetic resonance imaging (fMRI).** In this technique, large magnetic fields align the oxygen molecules within our brains (Figure 2.17). Then, as blood flows into areas of the brain, the molecules' organization is disrupted; this disruption can be detected by sensors in the MRI machine. The fMRI scanners take a picture approximately every 30 milliseconds, which allows scientists to pinpoint both where and over what time course perceptual processes are happening in the brain. Such fMRI scans are important for determining the areas of the brain responsible for various perceptual processes and the connections in the brain that link different areas involved in the complex process of turning sensory stimulation into experiences.
4. **Transmagnetic stimulation (TMS)**. We include a number of technologies that can be grouped together under the general label of TMS (Figure 2.18). These techniques stimulate the brain via electric current, but the specifics of the technique and what kind of current use varies from one technique to another. In TMS, researchers place a magnetic field generator (or coil) on the head of participants. The coil induces an electric current in the particular brain region beneath the coil, which induces changes in how this region functions, which may be either perceptual or behavioral. In research, these changes are temporary, but they permit the experimental analyses of brain region and function. Indeed, a TMS pulse to the occipital lobe can induce temporary blindness.

Test Your Knowledge

1. Which neuroimaging techniques are good for looking at where processes take place in the brain, and which neuroimaging techniques are good for looking at the time course of brain processes?
2. MRI scanners are important for medical use. At what point can experimental research be prioritized over the use of MRI for medical diagnoses?

FIGURE 2.15 ■ Electroencephalography (EEG)

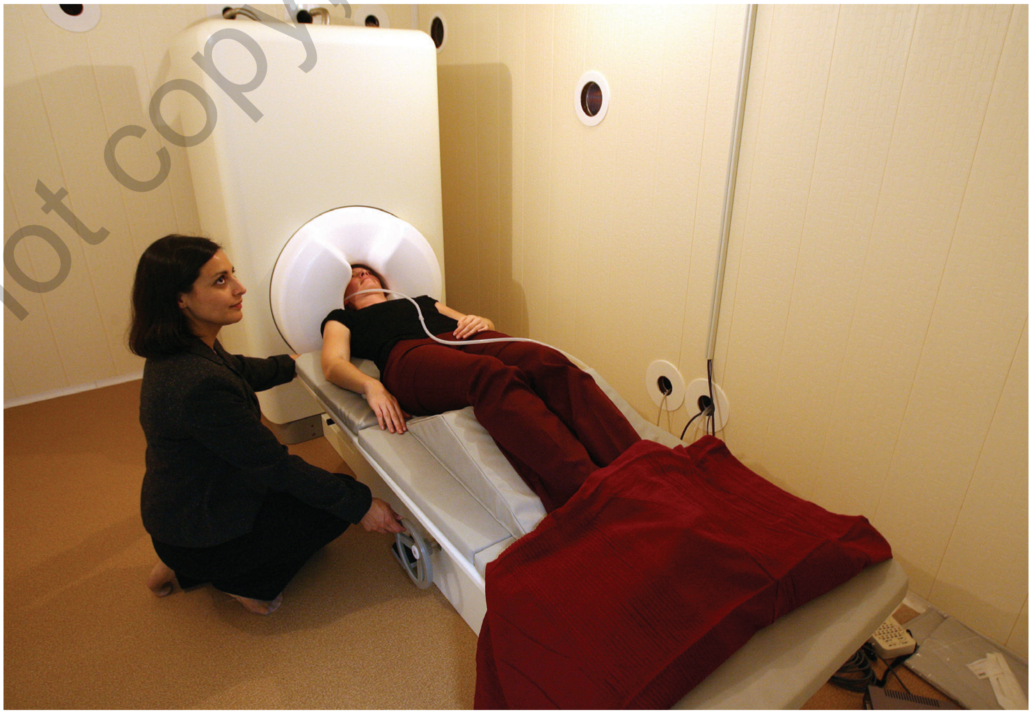
In EEG, electrodes monitor the electrical output of large numbers of neurons in the brain. The more electrodes that are placed on the scalp, the better the ability will be of the EEG to specify spatial locations in the brain.



Source: iStock.com/fotografixx

FIGURE 2.16 ■ Magnetoencephalography (MEG)

In MEG, magnetic sensors detect magnetic fields produced by the electrical activity in the brain. MEG has better spatial resolution than EEG.



Source: The Sydney Morning Herald/Fairfax Media/via Getty Images

FIGURE 2.17 ■ Magnetic Resonance Imaging (MRI)

Large magnetic fields align the oxygen molecules within our brains. Then, as blood flows into areas of the brain, the molecules' organization is disrupted; this disruption can be detected by sensors in the MRI machine.

Source: BSIP/Universal Images Group/via Getty Images

FIGURE 2.18 ■ Transmagnetic Stimulation (TMS)

TMS techniques stimulate the brain via electric current. Researchers can see if perception or behavior changes in a particular domain as a function of that stimulation, allowing researchers to draw causal relations between that brain region and perception.

Source: Garo/Phanie/Science Source

EXPLORATION: *INTERSENSORY PERCEPTION*

The chapters in this textbook cover vision, audition, the skin senses, and the chemical senses. In these chapters, we discuss the underlying neuroanatomy, the physiology, and the psychological science of each sense. However, real people moving and acting in the world are processing all of these senses simultaneously. In many domains, understanding what is going on in the world involves co-perceiving across two or more sensory modalities. For example, when we talk with someone, we both listen to their words and watch their faces. When we eat our dinner, we simultaneously taste our food, smell our food, look at our food, feel the texture of the food in our mouths, and, as discussed at the beginning of the chapter, feel the pain caused by certain chemicals that exist in our food. A natural question arises as to whether or not one sensory system affects other sensory systems, and, if so, how? This *Exploration* section looks at some research that uses psychophysical measures to address how olfaction (sense of smell) affects visual thresholds (Robinson et al., 2016).

Before discussing the work examining the effects of odor on visual thresholds, a short digression is needed concerning the nature of visual masking. **Masking** refers to the difficulty in seeing one stimulus when it is quickly replaced by a second stimulus that occupies the same or adjacent spatial locations. In masking, a briefly shown and to-be-detected stimulus that would normally be visible is rendered invisible by the presence of a second stimulus that occurs in the same location immediately after it or by stimuli that surround the test stimuli and persist after the test stimulus disappears (Enns & Di Lollo, 1997). Because masking is not easy to imagine, please take a moment to log onto ISLE and view the demonstration provided there (ISLE 2.12).

In a masking experiment, a to-be-detected stimulus is presented to participants somewhere in their visual field. The stimulus may be a simple dot, a photograph of a face, or even a word. The to-be-detected stimulus is presented for a very short time span, perhaps 50 milliseconds. This is long enough that if the stimulus is presented by itself, most people will report seeing it. However, if the stimulus is immediately replaced by another stimulus in the same area, the person will not consciously detect the to-be-detected stimulus. This is a phenomenon known as backward masking (Breitmeyer & Hanif, 2008). Masking can also occur if the to-be-detected stimulus is surrounded by other stimuli that are presented at the same time and persist a bit longer than the to-be-detected stimulus. If the masking stimuli disappear at the same time as the to-be-detected stimulus, the to-be-detected stimulus will be detected. However, if the masking stimuli persist after the to-be-detected stimulus, then it will be masked and consciously invisible. This form of masking is called object-substitution masking (Enns & Di Lollo, 1997).

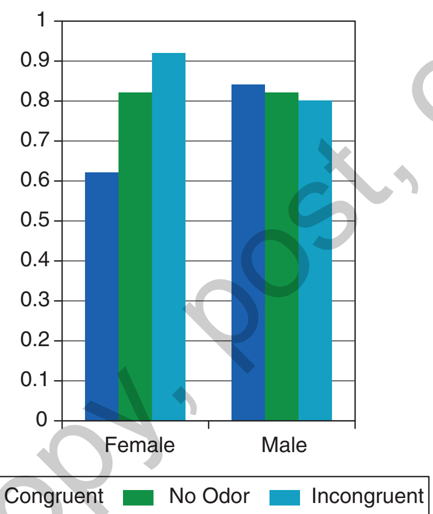
Because masking experiments require participants to make decisions about whether a visual target is present or not, they lend themselves to signal detection analyses. In signal detection analyses, how good a person is at detecting the stimuli is a measure of sensitivity. Indeed, studies using masking usually report participants' sensitivity in terms of d' analyses, which we covered in this chapter. A high d' means that participants are good at detecting the stimulus when it is present but also good at rejecting a trial when the stimulus is not present. This brings us back to the topic of this section: Does the presence of stimuli from another sensory domain affect visual sensitivity? We can answer this question by looking at the sensitivity of participants in a masking experiment when stimuli from another sensory domain are present or not. This question means presenting stimuli from another sensory domain such as audition or olfaction before or during a masking trial and determining if the presence of the second sensory modality influences the d' of the participant in the masking task.

Robinson et al. (2016) were interested in whether olfaction interacts with vision. To investigate this topic, they used object-substitution masking. In the study, participants were presented with images such as pictures of a leaf of mint, an orange, or a rose flower. These were called "target" images because, in some conditions, they would be accompanied by the odors associated with each plant. Participants were also presented with "nontarget images," which were images, such as those of a hat or a telephone, for which corresponding odors would not be presented. The odor that was presented just before each trial either corresponded to a target (i.e., the smell of a rose before an image of a rose was flashed) or did not correspond to the target (i.e., the smell of mint was presented just before an image of a rose was flashed). In some conditions, the stimulus was masked with the object-substitution masking, whereas in other conditions, the target and nontarget images were presented without masks and could be more easily seen. The question that Robinson et al. were interested in was whether or not the presence of a corresponding odor would lower the threshold (thus, raise the sensitivity) of detecting masked stimuli.

Here is a summary of Robinson and colleagues' (2016) results. (See Figure 2.19 for a graph of the results.) First, the masking manipulation worked. For the masked trials, sensitivity was higher than for the unmasked trials. On catch trials (in which no target was present), participants mostly claimed they could not see anything. Thus, these results suggest that the object-substitution masking manipulation was successful at reducing the visibility of masked trials. Having established that the masking worked, we can now look at whether the presence of odors influenced performance on the visual task. Note that if odors either strengthen the effect of the masking or make the participants more sensitive to the target stimulus, we can say that there is an odor–vision interaction. Only if the odors have no effect on masking can we reject the idea of an odor–vision interaction, at least in this type of study. The results here are mixed. For men, there was no effect of odor on the masking variable. Men showed the same sensitivity in conditions in which a congruent odor (mint–mint), an incongruent odor (mint–orange), or no odor was presented. However, there was a strong effect with women. Women showed a much stronger sensitivity to targets when there was a congruent odor but also showed a weakened sensitivity to targets when the odor was incongruent relative to the no-odor condition. Thus, for women, smelling the same odor as the masked stimulus made that stimulus easier to visually detect. But also, for women, when they smelled an odor that did not match the visual stimulus, detecting the stimulus was harder.

FIGURE 2.19 ■ Sensitivity of Detection

The *y*-axis represents sensitivity. Lower values represent better detection of the masked stimulus. Sensitivity in females was helped by congruent odors, but sensitivity was also hurt by incongruent odors. In men, however, odor had no effect at all, either positive or negative.



These results are consistent with the general advantage women have over men with respect to their sense of smell (Zucco et al., 2012). However, beyond that, Robinson et al. (2016) show a greater integration between vision and olfaction in women than in men. This greater integration helps women, relative to men, when the odor and the image match but hurts women, relative to men, when there is a mismatch. If you are interested, you can look up and read Robinson and colleagues' paper to explore neurological explanations for the effect. We present their results here to show you that psychophysical methods such as threshold detection, sensitivity, and the signal detection approach are alive and well in the contemporary field of sensation and perception.

APPLICATION: *PSYCHOPHYSICS IN ASSESSMENT: HEARING TESTS AND VISION TESTS*

Our sensory capabilities are critical to living our lives in the manner that we choose. One's ability to make a livelihood, attend school, and enjoy various recreational opportunities is directly related to one's ability to perceive the world accurately. Take, for example, the everyday activity of driving a car. Many of us have to drive to work or school. Driving is completely dependent on being visually competent. If you become visually impaired, your ability to drive safely decreases, and if you lose your eyesight altogether, driving is no longer an option. Once you get to school, you are also dependent on your senses. You have to read a textbook and listen to lectures. These require both vision and audition. Having a conversation with anyone requires that your hearing allow you to understand what others are saying. Even pain allows us to recognize health issues that threaten us. Many people will endorse the statement that eating delicious food is one of life's great pleasures.

But now, consider a student who is visually impaired or has a hearing deficit. If you do not think you know any, you are not paying attention. These impairments can range from mild nearsightedness, requiring glasses or contact lenses, to much more severe impairments. Being visually impaired presents a number of obstacles that a sighted person cannot even imagine. Even in a technological world that can offer the visually impaired many ways of compensating for their deficit and competing against normally sighted individuals, being blind obviously creates obstacles. Blind students now can use technology that automatically reads text aloud, but text readers proceed more slowly than do sighted people who typically can read while looking at text. Blind readers who use Braille type can read silently, but this process is also typically slower than reading by vision. So even with the best technology, blind students work much harder and longer to keep up with their sighted classmates.

Auditory impairment can be equally challenging. Those of us with normal hearing take spoken language for granted. But deaf individuals rely on sign language to communicate, which renders reading and writing equivalent to a second language. Even less severe auditory impairment can be challenging. Hearing aids may amplify sounds, but it is often tricky to get them to amplify the sounds you want to hear (e.g., voices) and not the sounds you do not want to hear (e.g., traffic noise).

Assessing vision and hearing loss is an important task that is fulfilled by professional optometrists and audiologists with great competence. At the heart of each of these professions is applying the ideas of psychophysics to diagnosing visual and auditory problems. In this *Application* section, we take an in-depth look at this aspect of applied psychophysics, that is, focusing on the psychophysics tests optometrists and audiologists typically perform.

According to the National Institute on Deafness and Other Communication Disorders, there are 35 million people in the United States alone with some form of hearing impairment. That's roughly 10% of the nation's population. In adults 65 years and older, the percentage exceeds 33% (National Institutes of Health, 2023). Hearing loss can be caused by any number of factors, including genetic disposition, age, disease, and exposure to noise. Hearing loss in children and younger adults is usually due to genetic conditions. But among older adults, hearing loss is just as likely to be caused by environmental conditions. Hearing loss is particularly common among those who work in professions in which exposure to loud noise (or music) is chronic. This includes airport employees, police officers, DJs and bartenders at nightclubs, and, yes, rock musicians. Indeed, many older rock musicians have serious hearing loss, including Ozzy Osbourne, Phil Collins, and Pete Townshend.

Hearing loss can be divided into two broad categories, sensorineural hearing loss and conductive hearing loss. Sensorineural hearing loss refers to permanent hearing loss caused by damage to the cochlea or auditory nerve. This means that the hearing loss is due to problems in the transduction of the physical sound waves into a neural signal. Sensorineural hearing loss can result either from genetic causes or from damage to hair cells or auditory nerve fibers. Conductive hearing loss refers to the inability of sound to be transmitted to the cochlea. This means that the problem is that inadequate levels of sound reach the cochlea to be transduced into a neural signal. Some conductive hearing loss may be as simple as clogged pathways, but conductive hearing loss may also be permanent. In many cases, medical treatment can restore hearing loss caused by conductive causes, which may include earwax buildup or a punctured eardrum (tympanic membrane). Sensorineural hearing loss is seldom treatable, although in extreme cases, cochlear implants can restore some hearing lost through sensorineural damage.

The first step in assessing hearing loss is visiting a professional audiologist. An audiologist is a trained professional who specializes in diagnosing hearing impairments. Audiologists usually train to the doctoral level and obtain a degree known as a doctorate in audiology (AuD). This qualifies them to diagnose and treat hearing impairment (Figure 2.20). An audiologist can fit a patient with the appropriate hearing aids or refer the patient to a medical doctor if the audiologist thinks the situation requires medical intervention.

The audiologist uses a device called an audiometer to assess hearing loss. An audiometer can present tones of different frequencies, from low in pitch to high in pitch, at different volumes from soft to loud. A patient will listen on headphones in a soundproof room to a series of tones presented by the audiometer. Tones are presented to one ear at a time, so as to determine if there is hearing

FIGURE 2.20 ■ Audiologists

Audiologists are trained to treat hearing loss. They assess hearing loss and help fit people with hearing aids. If medical issues arise, they will forward patients to medical doctors who specialize in auditory issues.

Source: iStock.com/Fotosmurf03

loss in each ear. Typically, an audiologist will use the method of constant stimuli combined with a touch of the forced-choice method and vary the loudness of the tone among trials. The patient indicates if they heard the tone in the left or the right ear. If the patient cannot hear the tone, chance performance will occur for that frequency at that sound level. Usually, the audiologist includes catch trials in which tones are not presented. This allows the audiologist to determine the criterion at which the patient is indicating hearing a sound.

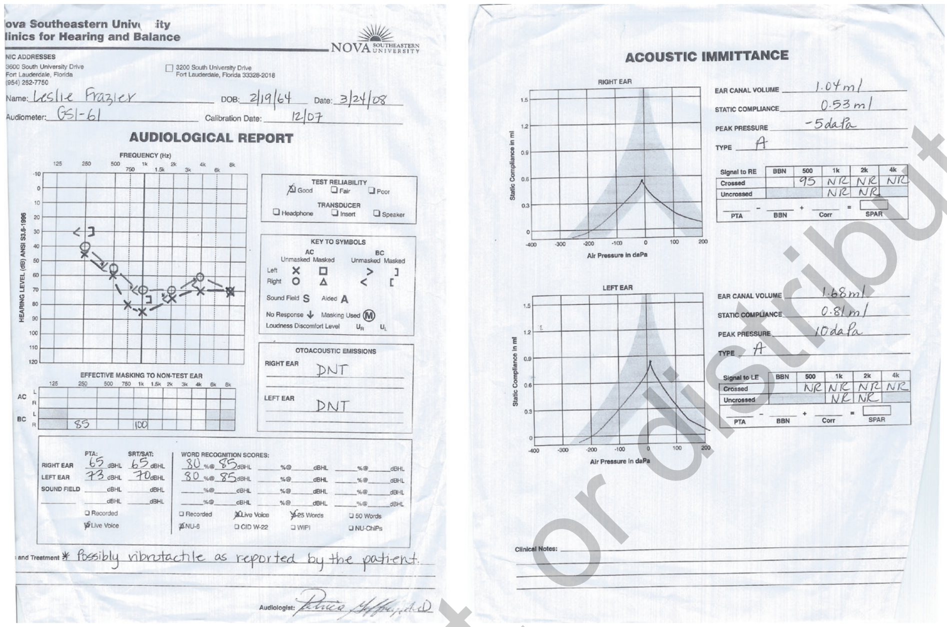
After the test is complete, the audiologist will plot the threshold for each frequency as a function of decibels. That is, the audiologist makes a graph indicating how loud each frequency needs to be in order for the patient to hear it. The audiogram is the graph that illustrates the threshold for the frequencies as measured by the audiometer (Figure 2.21). The *y*-axis represents intensity, measured in decibels, and the *x*-axis represents frequency, measured in Hertz. The threshold is then compared with a standardized curve, which represents normal or average hearing. This graph can then be used to determine if there is hearing loss at any frequency. If there is, the audiologist can help the patient with choosing hearing aids or other remedies.

Particularly important for human hearing is the ability to hear human speech sounds. Many hearing-impaired people can detect sounds but have difficulty hearing words, especially if there is background noise. A deficit in hearing the voices of family members is often what brings a patient to an audiologist in the first place. Thus, audiologists will assess patients' ability to hear speech sounds against background noise. Specialized tests have been developed to allow audiologists to check for speech recognition in hearing-impaired individuals in many different languages (Zokoll et al., 2012). In setting up hearing aids for patients, audiologists can program the hearing aids to filter out sounds that are not likely to be voices and amplify sounds that are likely to be human voices. When programmed correctly, hearing aids can selectively filter out noise and increase the volume of human voices.

Turning now to vision, most of us may be more experienced with optometry, as minor visual problems are more frequently corrected with eyeglasses than minor auditory problems are corrected with hearing aids. Optometrists have a similar job to audiologists but with respect to vision. Optometrists provide most people's primary eye care. Optometrists have doctoral degrees in

FIGURE 2.21 ■ Audiology Report

This audiology report concerns an individual with moderate sensorineural hearing loss. In the graph on the left, the *y*-axis indicates how loud in decibel units a tone must be presented in order for the patient to hear it. The *x*-axis indicates frequency, from low frequency (low notes) to high frequency (high notes). This patient shows maximum hearing loss for medium frequencies, unfortunately in the range of human voices.



optometry and are licensed to diagnose and give prescriptions for many eye-related problems. But the most common task they do is an eye examination, in which they run a patient through a battery of tests, some to look for diseases of the eye and others to look at basic psychophysical properties of the vision of each patient. Like audiologists, if an optometrist detects a medical problem, that patient will be directed to an ophthalmologist, that is, a medical doctor who specializes in care and diseases of the eye.

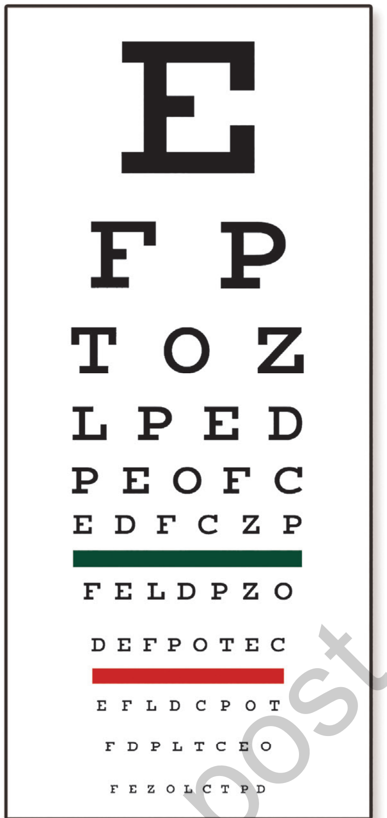
Included in the eye exam is a test of visual acuity. The test of visual acuity measures a person's ability to resolve an object in focus at a particular distance. An individual person's acuity is then compared with a "standard" or normal reference. The most common form of the test of visual acuity is the ubiquitous Snellen chart (Figure 2.22). Using a Snellen chart, an optometrist will ask a patient to read off the chart each line until the letters become difficult to resolve. Typically, this is done one eye at a time, as one eye may be normal but the other may need to be corrected. Results from the Snellen chart yield the typical measure of visual acuity that most people are familiar with. A person of normal vision is said to have 20/20 vision, or what a normal person can distinguish at 20 feet. If a person sees at 20 feet what a normal person sees at 60 feet, then that person has 20/60 vision. If so, the optometrist would prescribe corrective lenses, either glasses or contact lenses. In other countries, these tests are done in meters, so 6/6 would be the standard for 6 meters (6 meters = 19.7 feet).

Someone who has trouble seeing distant objects is said to have myopia. Myopia is a condition in which incoming light does not focus directly on the retina but in front of it. An optometrist can easily treat myopia by prescribing glasses or contact lenses. In older adults, presbyopia becomes more frequent. Presbyopia is a condition in which incoming light focuses behind the retina, leading to difficulty focusing on close-up objects. People with presbyopia need glasses to read small print. Even adults who have had 20/20 vision their entire lives are likely to develop presbyopia as they age into their 40s and 50s. To see what it would be like to have these conditions, go to ISLE 2.13.

Optometrists serve as initial screeners and diagnosticians of a number of diseases that affect the eye, including glaucoma, macular degeneration, diabetic retinopathy, and conjunctivitis. However, these diagnoses do not require psychophysical testing, and therefore we do not consider them here. The American Optometric Association has valuable educational resources on its website. If you are interested, go to http://www.aoa.org/patients-and-public/eye-and-vision-problems?sso=y.

FIGURE 2.22 ■ The Snellen Chart

Patients are asked to read the lowest line that they can. This measures visual acuity and is the first test for myopia (nearsightedness). Normal vision is considered 20/20. Anyone who cannot see what a normal person can see at 20 feet may be myopic.



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CHAPTER SUMMARY

2.1 Explain the nature of psychophysical scales and how they measure the relations between real-world stimuli and our perceptions of them.

In this chapter, we covered the basics of psychophysics. A psychophysical scale is one in which people rate their psychological experiences as a function of the level of a physical stimulus. Psychophysical methods involve presenting a carefully controlled stimulus to a participant and asking a question directly of the participant that allows the answer to be quantified, that is, turned into a number. In the case of the Scoville scale it measures our experience of piquancy or "hotness" at different concentrations of capsaicin.

2.2 Demonstrate an understanding of the method of limits.

The method of limits is used to determine psychophysical properties of the observer, including the observer's thresholds, or ability to detect differences between stimuli along a particular dimension. In the method of limits, stimuli are presented on a graduated scale (i.e., a scale that varies along predictable and relatively small changes), and participants must judge the stimuli along a certain property that goes up or down. Absolute thresholds are the smallest amount of a stimulus necessary for an observer to detect its presence, whereas a difference threshold (also known as a JND) is the smallest difference between two stimuli that can be detected. Closely and inversely related to the concept of threshold is the idea of sensitivity. Sensitivity is the ability to perceive a stimulus.

2.3 Explore the differences between the method of constant stimuli and the method of adjustment.
The method of constant stimuli and the method of adjustment are used to determine psychophysical properties of the observer, including the observer's thresholds, or ability to detect differences between stimuli along a particular dimension. In the method of constant stimuli, the threshold is determined by presenting the observer with a set of stimuli, some of which are above the threshold and some of which are below it, but the stimuli are presented in a random order.

2.4 Think about magnitude estimation and what it tells us about perception.
Magnitude estimation is a psychophysical method in which participants judge and assign numerical estimates to the perceived strength of a stimulus. Magnitude estimation fits Stevens's power law, a mathematical formula that describes the relation between the intensity of physical stimuli and the magnitude of the perceptual response.

2.5 Initiate an understanding of signal detection theory and how it works both in sensation and perception and other domains.
Signal detection theory is the theory that in every sensory detection or discrimination, there is both sensory sensitivity to the stimulus and a criterion used to make a cognitive decision. In signal detection theory, there is a trade-off between successful detection of the target (e.g., a hit) and a detection response when there is no stimulus (e.g., a false alarm). An observer wants to maximize hits and correct rejections (saying "no stimulus" when none is present) and minimize false alarms and misses (saying "no stimulus" when a stimulus is actually present). Critical in signal detection theory is the idea of sensitivity but also criterion, an internal threshold, determined by the observer, above which the observer makes one response and below which the observer makes another response. Mathematically using signal detection theory allows researchers to determine the ROC curve, which is usually a plot of hits as a function of false alarms.

2.6 Evaluate neuroscience methods and what they tell us about sensation and perception.
Neuroimaging techniques are technologies that permit visual examination of living human brains. These techniques allow scientists to correlate perception with brain activity. Two goals of neuroimaging are to reveal where perception happens in the brain and how perception unfolds through the brain over time. A number of different neuroimaging techniques are reviewed in this chapter. EEG measures electrical output of the brain. Although EEG provides good temporal resolution of the brain, it lacks the spatial resolution of other methods. MEG measures the brain's magnetic fields. MEG provides good temporal resolution and better spatial resolution than does EEG. In fMRI, magnetic fields create a three-dimensional image that can capture both the structure and the function of the brain. This technique allows for good imaging of the brain in both time and space. Finally, TMS is a procedure in which a magnetic coil is used to stimulate electrically a specific region of the brain. This allows one to probe the brain to see which areas produce which kinds of perceptions.

REVIEW QUESTIONS

1. What does the Scoville scale measure? Why is it considered to be a psychophysical scale?
2. What is the method of limits? How is it used to determine absolute thresholds?
3. What is the method of adjustment? How is it used to determine the point of subjective equality?

4. What is the two-point touch threshold? How does it illustrate the concept of a JND? How do two-point touch thresholds differ across the human body?
5. What is the difference between response expansion and response compression? How do both relate to Stevens's power law?
6. What is signal detection theory? How is it used to predict performance on perception tests?
7. Define the terms *criterion* and *sensitivity*. How do they interact in signal detection theory?
8. What are the neuroimaging techniques? How does each one allow the brain to be examined in terms of both space and time?
9. What is visual masking? How is it affected by consistent and inconsistent odors?
10. How is an audiogram used to assess hearing loss? How might an audiogram help an audiologist program a hearing aid?

PONDER FURTHER

1. Why are the methods of psychophysics still relevant and important when we have neuroimaging techniques at our disposal? What information might we still gather from psychophysics that we would not be able to know by observing neuroimaging results?
2. Signal detection theory applies some basic mathematics to understanding perceptual thresholds. But we have also seen how it might apply in other situations, from military applications to deciding whether your car needs to go to the shop. What other domains of psychology or life in general might signal detection analyses be good for? If you cannot think of any, try to apply signal detection analysis to surfing!

KEY TERMS

Absolute threshold
Ascending series
Capsaicin
Catch trial
Correct rejection
Criterion
Crossover point
d′ (d-prime)
Descending series
Difference threshold (JND)
Electroencephalography (EEG)
False alarm
Forced-choice method
Hit
Magnetoencephalography (MEG)
Magnitude estimation
Masking
Method of adjustment
Method of constant stimuli
Method of limits
Miss
Point of subjective equality (PSE)
Psychophysical scale
Receiver-operating characteristic (ROC) curve
Response compression
Response expansion
Scoville scale
Sensitivity
Sensitivity (signal detection theory)
Signal detection theory
Stevens's power law
Transmagnetic stimulation (TMS)
Two-point touch threshold