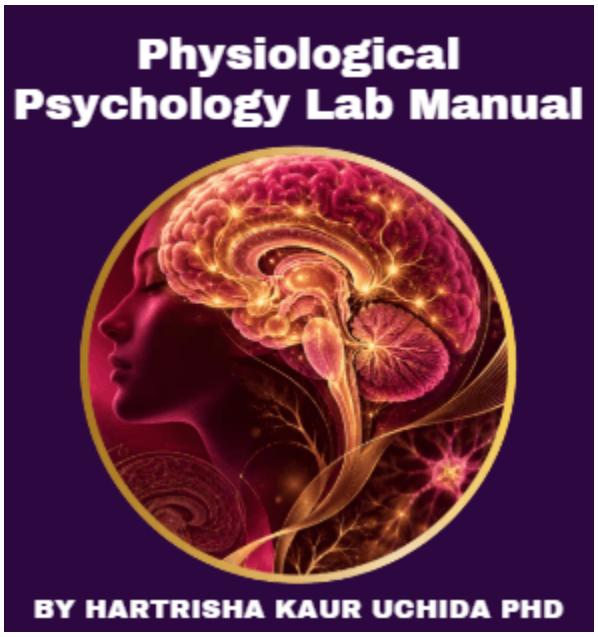
PHYSIOLOGICAL PSYCHOLOGY LAB MANUAL



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Physiological Psychology Lab Manual

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1: INTRODUCTION TO LABORATORY PSYCHOLOGY AND SENSORY SYSTEMS

1.1: Why Do Psychologists Conduct Laboratory Research?
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1.1: Why Do Psychologists Conduct Laboratory Research?

By Matthias R. Mehl

University of Arizona

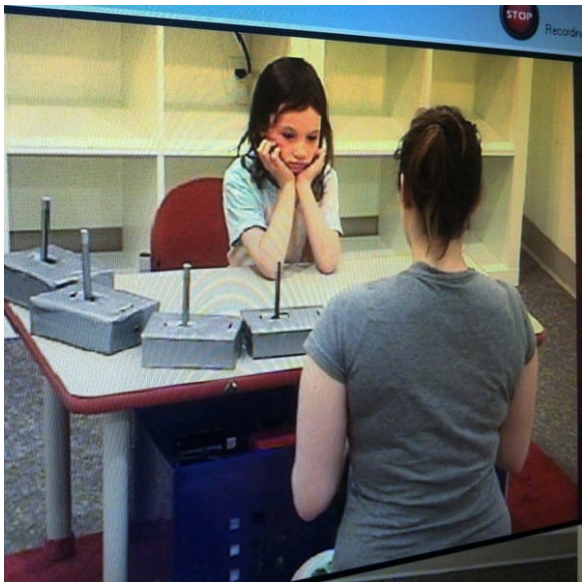
Because of its ability to determine cause-and-effect relationships, the laboratory experiment is traditionally considered the method of choice for psychological science. One downside, however, is that as it carefully controls conditions and their effects, it can yield findings that are out of touch with reality and have limited use when trying to understand real-world behavior. This module highlights the importance of also conducting research outside the psychology laboratory, within participants' natural, everyday environments, and reviews existing methodologies for studying daily life.

learning objectives

- Identify limitations of the traditional laboratory experiment.
- Explain ways in which daily life research can further psychological science.
- Know what methods exist for conducting psychological research in the real world.

Introduction

The laboratory experiment is traditionally considered the "gold standard" in psychology research. This is because only laboratory experiments can clearly separate cause from effect and therefore establish causality. Despite this unique strength, it is also clear that a scientific field that is mainly based on controlled laboratory studies ends up lopsided. Specifically, it accumulates a lot of knowledge on what *can* happen—under carefully isolated and controlled circumstances—but it has little to say about what actually *does* happen under the circumstances that people actually encounter in their daily lives.



Do the research results obtained in isolated, carefully controlled laboratory conditions generalize into the real world? [Image: Nessen Marshall, CC BY-NC-SA 2.0, goo.gl/Toc0ZF]

For example, imagine you are a participant in an experiment that looks at the effect of being in a good mood on generosity, a topic that may have a good deal of practical application. Researchers create an internally-valid, carefully-controlled experiment where they randomly assign you to watch either a happy movie or a neutral movie, and then you are given the opportunity to help the researcher out by staying longer and participating in another study. If people in a good mood are more willing to stay and help out, the researchers can feel confident that – since everything else was held constant – your positive mood led you to be more helpful. However, what does this tell us about helping behaviors in the real world? Does it **generalize** to other kinds of

helping, such as donating money to a charitable cause? Would all kinds of happy movies produce this behavior, or only this one? What about other positive experiences that might boost mood, like receiving a compliment or a good grade? And what if you were watching the movie with friends, in a crowded theatre, rather than in a sterile research lab? Taking research out into the real world can help answer some of these sorts of important questions.

As one of the founding fathers of social psychology remarked, "Experimentation in the laboratory occurs, socially speaking, on an island quite isolated from the life of society" (Lewin, 1944, p. 286). This module highlights the importance of going beyond experimentation and also conducting research outside the laboratory (Reis & Gosling, 2010), directly within participants' natural environments, and reviews existing methodologies for studying daily life.

Rationale for Conducting Psychology Research in the Real World

One important challenge researchers face when designing a study is to find the right balance between ensuring **internal validity**, or the degree to which a study allows unambiguous causal inferences, and **external validity**, or the degree to which a study ensures that potential findings apply to settings and samples other than the ones being studied (Brewer, 2000). Unfortunately, these two kinds of validity tend to be difficult to achieve at the same time, in one study. This is because creating a controlled setting, in which all potentially influential factors (other than the experimentally-manipulated variable) are controlled, is bound to create an environment that is quite different from what people naturally encounter (e.g., using a happy movie clip to promote helpful behavior). However, it is the degree to which an experimental situation is comparable to the corresponding real-world situation of interest that determines how generalizable potential findings will be. In other words, if an experiment is very far-off from what a person might normally experience in everyday life, you might reasonably question just how useful its findings are.

Because of the incompatibility of the two types of validity, one is often—by design—prioritized over the other. Due to the importance of identifying true causal relationships, psychology has traditionally emphasized internal over external validity. However, in order to make claims about human behavior that apply across populations and environments, researchers complement traditional laboratory research, where participants are brought into the lab, with field research where, in essence, the psychological laboratory is brought to participants. Field studies allow for the important test of how psychological variables and processes of interest "behave" under real-world circumstances (i.e., what *actually does happen* rather than what *can happen*). They can also facilitate "downstream" operationalizations of constructs that measure life outcomes of interest *directly* rather than indirectly.

Take, for example, the fascinating field of psychoneuroimmunology, where the goal is to understand the interplay of psychological factors - such as personality traits or one's stress level - and the immune system. Highly sophisticated and carefully controlled experiments offer ways to isolate the variety of neural, hormonal, and cellular mechanisms that link psychological variables such as chronic stress to biological outcomes such as immunosuppression (a state of impaired immune functioning; Sapolsky, 2004). Although these studies demonstrate impressively how psychological factors can affect health-relevant biological processes, they—because of their research design—remain mute about the degree to which these factors actually do undermine people's everyday health in real life. It is certainly important to show that laboratory stress can alter the number of natural killer cells in the blood. But it is equally important to test to what extent the levels of stress that people experience on a day-to-day basis result in them catching a cold more often or taking longer to recover from one. The goal for researchers, therefore, must be to complement traditional laboratory experiments with less controlled studies under real-world circumstances. The term **ecological validity** is used to refer the degree to which an effect has been obtained under conditions that are typical for what happens in everyday life (Brewer, 2000). In this example, then, people might keep a careful daily log of how much stress they are under as well as noting physical symptoms such as headaches or nausea. Although many factors beyond stress level may be responsible for these symptoms, this more correlational approach can shed light on how the relationship between stress and health plays out outside of the laboratory.

An Overview of Research Methods for Studying Daily Life

Capturing "life as it is lived" has been a strong goal for some researchers for a long time. Wilhelm and his colleagues recently published a comprehensive review of early attempts to systematically document daily life (Wilhelm, Perrez, & Pawlik, 2012). Building onto these original methods, researchers have, over the past decades, developed a broad toolbox for measuring experiences, behavior, and physiology directly in participants' daily lives (Mehl & Conner, 2012). Figure 1 provides a schematic overview of the methodologies described below.

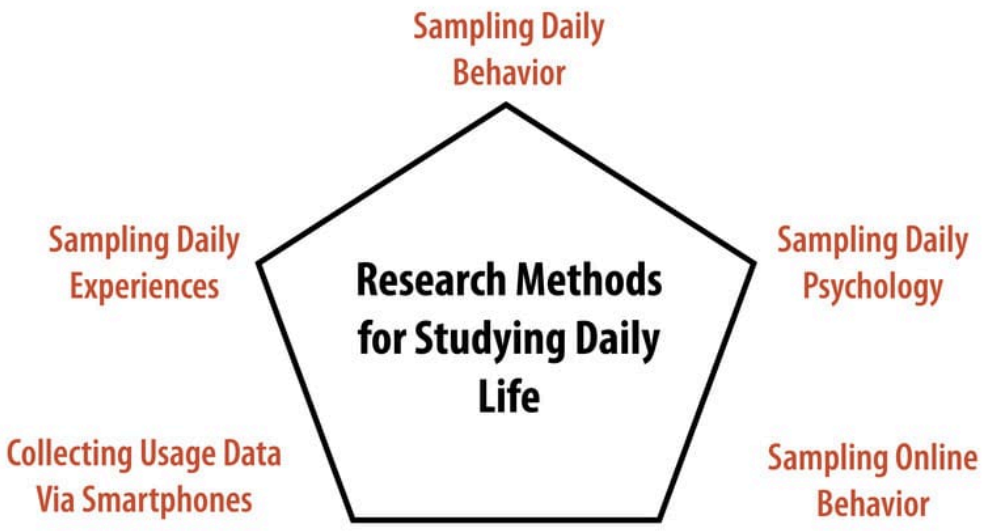


Figure 1. Schematic Overview of Research Methods for Studying Daily Life

Studying Daily Experiences

Starting in the mid-1970s, motivated by a growing skepticism toward highly-controlled laboratory studies, a few groups of researchers developed a set of new methods that are now commonly known as the **experience-sampling method** (Hektner, Schmidt, & Csikszentmihalyi, 2007), **ecological momentary assessment** (Stone & Shiffman, 1994), or the **diary method** (Bolger & Rafaeli, 2003). Although variations within this set of methods exist, the basic idea behind all of them is to collect in-the-moment (or, close-to-the-moment) self-report data directly from people as they go about their daily lives. This is typically accomplished by asking participants' repeatedly (e.g., five times per day) over a period of time (e.g., a week) to report on their current thoughts and feelings. The momentary questionnaires often ask about their location (e.g., "Where are you now?"), social environment (e.g., "With whom are you now?"), activity (e.g., "What are you currently doing?"), and experiences (e.g., "How are you feeling?"). That way, researchers get a snapshot of what was going on in participants' lives at the time at which they were asked to report.

Technology has made this sort of research possible, and recent technological advances have altered the different tools researchers are able to easily use. Initially, participants wore electronic wristwatches that beeped at preprogrammed but seemingly random times, at which they completed one of a stack of provided paper questionnaires. With the mobile computing revolution, both the prompting and the questionnaire completion were gradually replaced by handheld devices such as smartphones. Being able to collect the momentary questionnaires digitally and time-stamped (i.e., having a record of exactly when participants responded) had major methodological and practical advantages and contributed to experience sampling going mainstream (Conner, Tennen, Fleeson, & Barrett, 2009).



Using modern technology like smartphones allows for more widespread experience sampling of research participants. Whether at home, work, or just sitting in a coffee shop technology makes it easier than ever to participate in psychology research. [Image: Vladimir Yaitskiy, https://goo.gl/7sjXfq, CC BY-NC-SA 2.0, goo.gl/Toc0ZF]

Over time, experience sampling and related momentary self-report methods have become very popular, and, by now, they are effectively the gold standard for studying daily life. They have helped make progress in almost all areas of psychology (Mehl & Conner, 2012). These methods ensure receiving many measurements from many participants, and has further inspired the development of novel statistical methods (Bolger & Laurenceau, 2013). Finally, and maybe most importantly, they accomplished what they sought out to accomplish: to bring attention to what psychology ultimately wants and needs to know about, namely "what people actually do, think, and feel in the various contexts of their lives" (Funder, 2001, p. 213). In short, these approaches have allowed researchers to do research that is more externally valid, or more generalizable to real life, than the traditional laboratory experiment.

To illustrate these techniques, consider a classic study, Stone, Reed, and Neale (1987), who tracked positive and negative experiences surrounding a respiratory infection using daily experience sampling. They found that undesirable experiences peaked and desirable ones dipped about four to five days prior to participants coming down with the cold. More recently, Killingsworth and Gilbert (2010) collected momentary self-reports from more than 2,000 participants via a smartphone app. They found that participants were less happy when their mind was in an idling, mind-wandering state, such as surfing the Internet or multitasking at work, than when it was in an engaged, task-focused one, such as working diligently on a paper. These are just two examples that illustrate how experience-sampling studies have yielded findings that could not be obtained with traditional laboratory methods.

Recently, the **day reconstruction method (DRM)** (Kahneman, Krueger, Schkade, Schwarz, & Stone, 2004) has been developed to obtain information about a person's daily experiences without going through the burden of collecting momentary experience-sampling data. In the DRM, participants report their experiences of a given day retrospectively after engaging in a systematic, experiential reconstruction of the day on the following day. As a participant in this type of study, you might look back on yesterday, divide it up into a series of episodes such as "made breakfast," "drove to work," "had a meeting," etc. You might then report who you were with in each episode and how you felt in each. This approach has shed light on what situations lead to moments of positive and negative mood throughout the course of a normal day.

Studying Daily Behavior

Experience sampling is often used to study everyday behavior (i.e., daily social interactions and activities). In the laboratory, behavior is best studied using direct behavioral observation (e.g., video recordings). In the real world, this is, of course, much more difficult. As Funder put it, it seems it would require a "detective's report [that] would specify in exact detail everything the participant said and did, and with whom, in all of the contexts of the participant's life" (Funder, 2007, p. 41).

As difficult as this may seem, Mehl and colleagues have developed a naturalistic observation methodology that is similar in spirit. Rather than following participants—like a detective—with a video camera (see Craik, 2000), they equip participants with a portable audio recorder that is programmed to periodically record brief snippets of ambient sounds (e.g., 30 seconds every 12

minutes). Participants carry the recorder (originally a microcassette recorder, now a smartphone app) on them as they go about their days and return it at the end of the study. The recorder provides researchers with a series of sound bites that, together, amount to an acoustic diary of participants' days as they naturally unfold—and that constitute a representative sample of their daily activities and social encounters. Because it is somewhat similar to having the researcher's ear at the participant's lapel, they called their method the **electronically activated recorder, or EAR** (Mehl, Pennebaker, Crow, Dabbs, & Price, 2001). The ambient sound recordings can be coded for many things, including participants' locations (e.g., at school, in a coffee shop), activities (e.g., watching TV, eating), interactions (e.g., in a group, on the phone), and emotional expressions (e.g., laughing, sighing). As unnatural or intrusive as it might seem, participants report that they quickly grow accustomed to the EAR and say they soon find themselves behaving as they normally would.

In a cross-cultural study, Ramírez-Esparza and her colleagues used the EAR method to study sociability in the United States and Mexico. Interestingly, they found that although American participants rated themselves significantly higher than Mexicans on the question, "I see myself as a person who is talkative," they actually spent almost 10 percent less time talking than Mexicans did (Ramírez-Esparza, Mehl, Álvarez Bermúdez, & Pennebaker, 2009). In a similar way, Mehl and his colleagues used the EAR method to debunk the long-standing myth that women are considerably more talkative than men. Using data from six different studies, they showed that both sexes use on average about 16,000 words per day. The estimated sex difference of 546 words was trivial compared to the immense range of more than 46,000 words between the least and most talkative individual (695 versus 47,016 words; Mehl, Vazire, Ramírez-Esparza, Slatcher, & Pennebaker, 2007). Together, these studies demonstrate how naturalistic observation can be used to study objective aspects of daily behavior and how it can yield findings quite different from what other methods yield (Mehl, Robbins, & Deters, 2012).

A series of other methods and creative ways for assessing behavior directly and unobtrusively in the real world are described in a seminal book on real-world, subtle measures (Webb, Campbell, Schwartz, Sechrest, & Grove, 1981). For example, researchers have used time-lapse photography to study the flow of people and the use of space in urban public places (Whyte, 1980). More recently, they have observed people's personal (e.g., dorm rooms) and professional (e.g., offices) spaces to understand how personality is expressed and detected in everyday environments (Gosling, Ko, Mannarelli, & Morris, 2002). They have even systematically collected and analyzed people's garbage to measure what people actually consume (e.g., empty alcohol bottles or cigarette boxes) rather than what they *say* they consume (Rathje & Murphy, 2001). Because people often cannot and sometimes may not want to accurately report what they do, the direct—and ideally nonreactive—assessment of real-world behavior is of high importance for psychological research (Baumeister, Vohs, & Funder, 2007).

Studying Daily Physiology

In addition to studying how people think, feel, and behave in the real world, researchers are also interested in how our bodies respond to the fluctuating demands of our lives. What are the daily experiences that make our "blood boil"? How do our neurotransmitters and hormones respond to the stressors we encounter in our lives? What physiological reactions do we show to being loved—or getting ostracized? You can see how studying these powerful experiences in real life, as they actually happen, may provide more rich and informative data than one might obtain in an artificial laboratory setting that merely mimics these experiences.



Real world stressors may result in very different physiological responses than the same stressors simulated in a lab environment. [Image: State Farm, https://goo.gl/FGYyVz, CC BY 2.0, goo.gl/9uSnqN]

Also, in pursuing these questions, it is important to keep in mind that what is stressful, engaging, or boring for one person might not be so for another. It is, in part, for this reason that researchers have found only limited correspondence between how people respond physiologically to a standardized laboratory stressor (e.g., giving a speech) and how they respond to stressful experiences in their lives. To give an example, Wilhelm and Grossman (2010) describe a participant who showed rather minimal heart rate increases in response to a laboratory stressor (about five to 10 beats per minute) but quite dramatic increases (almost 50 beats per minute) later in the afternoon while watching a soccer game. Of course, the reverse pattern can happen as well, such as when patients have high blood pressure in the doctor's office but not in their home environment—the so-called **white coat hypertension** (White, Schulman, McCabe, & Dey, 1989).

Ambulatory physiological monitoring – that is, monitoring physiological reactions as people go about their daily lives - has a long history in biomedical research and an array of monitoring devices exist (Fahrenberg & Myrtek, 1996). Among the biological signals that can now be measured in daily life with portable signal recording devices are the electrocardiogram (ECG), blood pressure, electrodermal activity (or "sweat response"), body temperature, and even the electroencephalogram (EEG) (Wilhelm & Grossman, 2010). Most recently, researchers have added **ambulatory assessment** of hormones (e.g., cortisol) and other biomarkers (e.g., immune markers) to the list (Schlotz, 2012). The development of ever more sophisticated ways to track what goes on underneath our skins as we go about our lives is a fascinating and rapidly advancing field.

In a recent study, Lane, Zareba, Reis, Peterson, and Moss (2011) used experience sampling combined with ambulatory electrocardiography (a so-called Holter monitor) to study how emotional experiences can alter cardiac function in patients with a congenital heart abnormality (e.g., long QT syndrome). Consistent with the idea that emotions may, in some cases, be able to trigger a cardiac event, they found that typical—in most cases even relatively low intensity— daily emotions had a measurable effect on ventricular repolarization, an important cardiac indicator that, in these patients, is linked to risk of a cardiac event. In another study, Smyth and colleagues (1998) combined experience sampling with momentary assessment of cortisol, a stress hormone. They found that momentary reports of current or even anticipated stress predicted increased cortisol secretion 20 minutes later. Further, and independent of that, the experience of other kinds of negative affect (e.g., anger, frustration) also predicted higher levels of cortisol and the experience of positive affect (e.g., happy, joyful) predicted lower levels of this important stress hormone. Taken together, these studies illustrate how researchers can use ambulatory physiological monitoring to study how the little—and seemingly trivial or inconsequential—experiences in our lives leave objective, measurable traces in our bodily systems.

Conclusion

This module sought to make a case for psychology research conducted outside the lab. If the ultimate goal of the social and behavioral sciences is to explain human behavior, then researchers must also—in addition to conducting carefully controlled lab studies—deal with the "messy" real world and find ways to capture life as it naturally happens.

Mortensen and Cialdini (2010) refer to the dynamic give-and-take between laboratory and field research as "**full-cycle psychology**". Going full cycle, they suggest, means that "researchers use naturalistic observation to determine an effect's presence in the real world, theory to determine what processes underlie the effect, experimentation to verify the effect and its underlying processes, and a return to the natural environment to corroborate the experimental findings" (Mortensen & Cialdini, 2010, p. 53). To accomplish this, researchers have access to a toolbox of research methods for studying daily life that is now more diverse and more versatile than it has ever been before. So, all it takes is to go ahead and—literally—bring science to life.

Outside Resources

Website: Society for Ambulatory Assessment
http://www.ambulatory-assessment.org

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1.2: Sensory Systems - Transduction and Neural Encoding

Learning Objectives

- Explain how stimuli are converted to signals that are carried to the central nervous system

Transduction

The most fundamental function of a sensory system is the translation of a sensory signal to an electrical signal in the nervous system. This takes place at the sensory receptor. The change in electrical potential that is produced is called the receptor potential. How is sensory input, such as pressure on the skin, changed to a receptor potential? As an example, a type of receptor called a mechanoreceptor possesses specialized membranes that respond to pressure. Disturbance of these dendrites by compressing them or bending them opens gated ion channels in the plasma membrane of the sensory neuron, changing its electrical potential. In the nervous system, a positive change of a neuron's electrical potential (also called the membrane potential), depolarizes the neuron. Receptor potentials are graded potentials: the magnitude of these graded (receptor) potentials varies with the strength of the stimulus. If the magnitude of depolarization is sufficient (that is, if membrane potential reaches a threshold), the neuron will fire an action potential. In most cases, the correct stimulus impinging on a sensory receptor will drive membrane potential in a positive direction, although for some receptors, such as those in the visual system, this is not always the case.

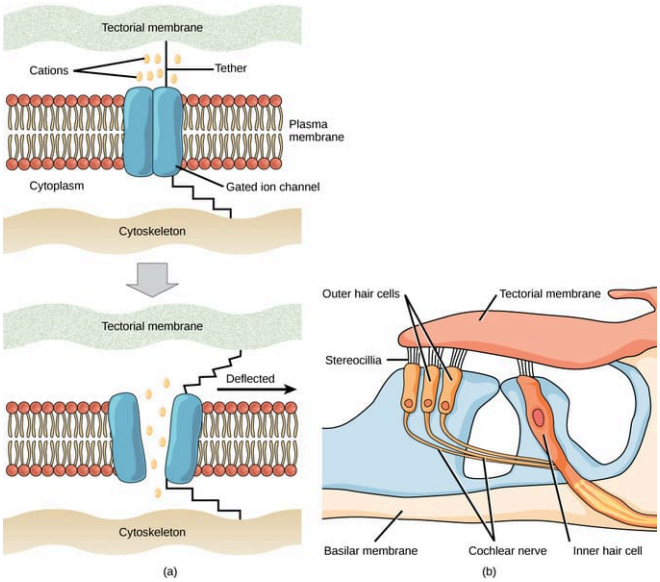


Figure 1.2.1: Mechanoreceptor activation: (a) Mechanosensitive ion channels are gated ion channels that respond to mechanical deformation of the plasma membrane. A mechanosensitive channel is connected to the plasma membrane and the cytoskeleton by hair-like tethers. When pressure causes the extracellular matrix to move, the channel opens, allowing ions to enter or exit the cell. (b) Stereocilia in the human ear are connected to mechanosensitive ion channels. When a sound causes the stereocilia to move, mechanosensitive ion channels transduce the signal to the cochlear nerve.

Sensory receptors for the various senses work differently from each other. They are specialized according to the type of stimulus they sense; thus, they have receptor specificity. For example, touch receptors, light receptors, and sound receptors are each activated by different stimuli. Touch receptors are not sensitive to light or sound; they are sensitive only to touch or pressure. However, stimuli may be combined at higher levels in the brain, as happens with olfaction, contributing to our sense of taste.

Encoding and Transmission of Sensory Information

Four aspects of sensory information are encoded by sensory systems: the type of stimulus, the location of the stimulus in the

receptive field, the duration of the stimulus, and the relative intensity of the stimulus. Thus, action potentials transmitted over a sensory receptor's afferent axons encode one type of stimulus. This segregation of the senses is preserved in other sensory circuits. For example, auditory receptors transmit signals over their own dedicated system. The electrical activity in the axons of the auditory receptors will be interpreted by the brain as an auditory stimulus: a sound.

The intensity of a stimulus is often encoded in the rate of action potentials produced by the sensory receptor. Thus, an intense stimulus will produce a more rapid train of action potentials. Reducing the stimulus will likewise slow the rate of production of action potentials. A second way in which intensity is encoded is by the number of receptors activated. An intense stimulus might initiate action potentials in a large number of adjacent receptors, while a less intense stimulus might stimulate fewer receptors. Integration of sensory information begins as soon as the information is received in the central nervous system.

Perception

Perception is an individual's interpretation of a sensation. Although perception relies on the activation of sensory receptors, perception happens, not at the level of the sensory receptor, but at the brain level. The brain distinguishes sensory stimuli through a sensory pathway: action potentials from sensory receptors travel along neurons that are dedicated to a particular stimulus.

All sensory signals, except those from the olfactory system, are transmitted though the central nervous system: they are routed to the thalamus and to the appropriate region of the cortex. The thalamus is a structure in the forebrain that serves as a clearinghouse and relay station for sensory (as well as motor) signals. When the sensory signal exits the thalamus, it is conducted to the specific area of the cortex dedicated to processing that particular sense.

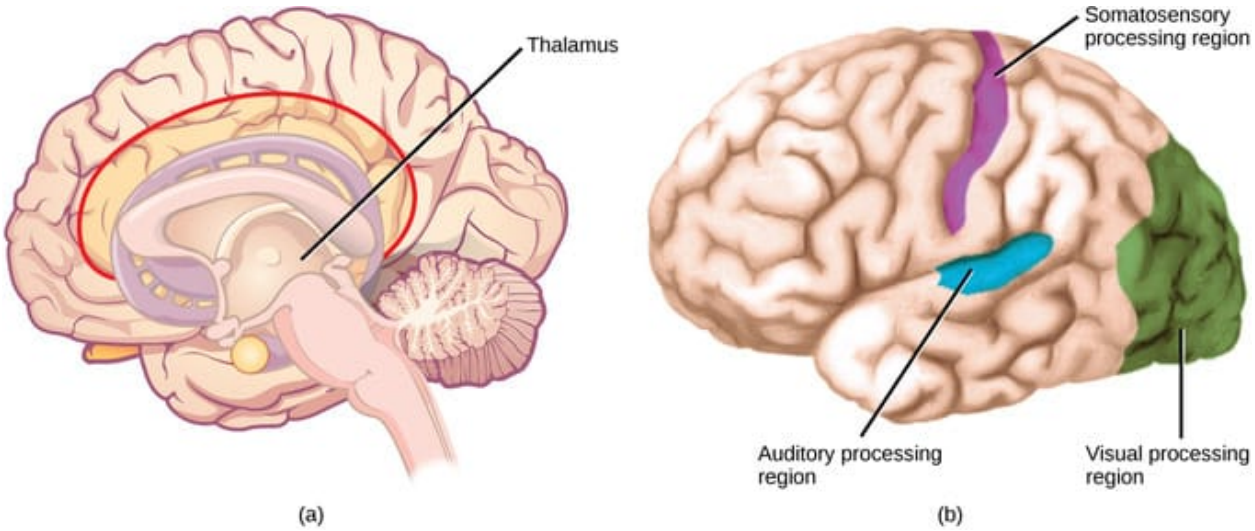


Figure 1.2.1: Sensation processing: The brain has dedicated areas to the processing of stimuli, including: (a) thalamus and (b) the auditory, visual and somatosensory processing regions.

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Key Points

- Sensory signals are converted to electrical signals via depolarization of sensory neuron membranes upon stimulus of the receptor, which causes opening of gated ion channels that cause the membrane potential to reach its threshold.
- The receptor potentials are classified as graded potentials; the magnitude of these potentials is dependent on the strength of the stimulus.
- The sensory system shows receptor specificity; although stimuli can be combined in processing regions of the brain, a specific receptor will only be activated by its specific stimulus.
- The brain contains specific processing regions (such as the somatosensory, visual, and auditory regions) that are dedicated to processing the information which has previously passed through the thalamus, the 'clearinghouse and relay station' for both sensory and motor signals.
- The four major components of encoding and transmitting sensory information include: the type of stimulus, the stimulus location within the receptive field, the duration, and the intensity of the stimulus.

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1.3: Sensory Receptors and Their Functions

Overview

Human bodies are continually exposed to an onslaught of sensory information, both externally from the environment and internally within the body. These changes in the external or internal environment are called stimuli. Our conscious awareness of incoming sensory information is called sensation. Only a stimulus that reaches the cerebral cortex of the brain results in a sensation of that stimulus. Thus, although our bodies are constantly bombarded by sensory stimuli, we are consciously aware of only a fraction of these stimuli. Stimuli are detected by receptors. This lab focuses on receptors for the general senses (temperature, pain, touch, stretch, and pressure) and receptors for the special senses (gustation, olfaction, vision, equilibrium, and hearing). There are different types of sensory receptors that respond to stimuli:

- Mechanoreceptors respond to mechanical forces such as pressure, vibration, and stretching. Examples include tactile receptors like Meissner's and Pacinian corpuscles, which detect touch and vibration, and baroreceptors, which monitor changes in blood pressure.
- Thermoreceptors detect temperature changes. Cold receptors respond to decreasing temperatures, while warm receptors respond to increasing temperatures.
- Nociceptors are responsible for detecting pain. They respond to potentially harmful stimuli—thermal, mechanical, or chemical—to alert the body to possible injury.
- Photoreceptors respond to light. Rods allow vision in low-light conditions, while cones provide color vision and visual acuity.
- Chemoreceptors detect specific chemicals. They are primarily located in taste buds on the tongue, enabling the sense of taste, and in the nasal passages, where they contribute to the sense of smell.

General Senses

General senses are all associated with touch and lack special sense organs. These receptors allow us to react to stimuli. Slowly adapting receptors continue sending impulses to the brain for a relatively long time when a constant stimulus is applied. Rapidly adapting receptors fire at the time a stimulus begins and sometimes again when it is removed, but they do not continue firing to a constant stimulus. Having receptors with different preferences and different “reporting” capabilities allows us to tune in more acutely to our environment and distinguish a wide variety of sensations.

Table 1.3.1: Overview of Skin Receptors - Types, Stimuli Detected, Sensation Types, and Adaptation Rates when Stimulated.

Receptor	Stimulus	Sens	Ada
Free nerve endings	Painful stimuli, hot and cold, light touch	Pain, thermal and light touch	Slow
Merkel disc	Vibrations at low frequencies (5 to 15 Hz), tissue displacement	Spatial details (Braille for reading)	Slow
Meissner corpuscle	Low frequency vibration	Light touch receptors	Rapi
Ruffini’s corpuscle	Rapid indentation, direction and force	Touch Skin Stretch	Slow
Pacinial corpuscle	Vibration frequency: 100 Hz to 300 Hz	Touch Vibration	Rapi

Receptor	Stimulus	Sensa	Adap
Hair receptor	Hair deflection; direction and velocity	Hair movement and skin deflection	Rapi Slow

Using our tactile sense, we detect superficial and deep pressure and sensations we describe as brushing, vibration, flutter, and indentation. As mentioned before, our skin is also sensitive to temperature and pain, which we sense with different sets of receptors. These skin senses, along with muscle/joint position awareness or proprioception, make up the somatic senses.

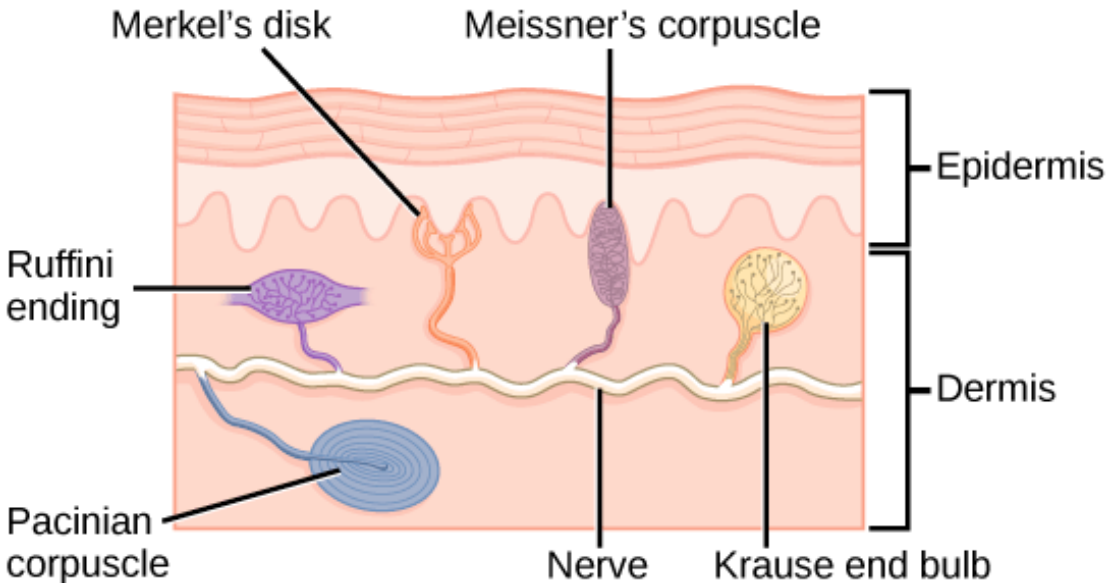


Figure 1.3.1: Distribution of major cutaneous sensory receptors within the epidermis and dermis of the skin. (CC BY-SA 4.0; via Somatosensation - Somatosensation Receptors).

Figure 1.3.1 is illustrating the four primary mechanoreceptors found in human skin. The diagram shows a cross-section of skin with two main layers labeled on the right: epidermis (outer layer) and dermis (deeper layer). Several sensory receptors are labeled to show where different touch-related receptors are located within the skin. Labeled structures:

- Merkel's disk: a touch receptor shown near the boundary between the epidermis and dermis.
- Meissner's corpuscle: a touch receptor shown in the upper dermis, close to the epidermis.
- Ruffini ending: a receptor shown deeper in the dermis.
- Pacinian corpuscle: a large, layered receptor shown deep in the dermis.
- Krause end bulb: a receptor shown in the dermis.
- Nerve: a nerve fiber shown extending through the dermis toward the receptors.

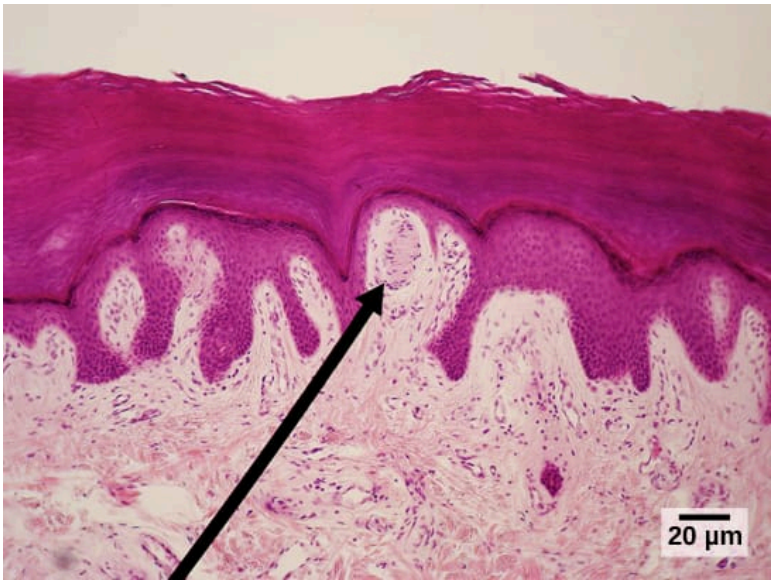


Figure 1.3.2: Meissner corpuscles: Meissner corpuscles in the fingertips, such as the one viewed here using bright field light microscopy, allow for touch discrimination of fine detail. (CC BY-SA 4.0; via Somatosensation - Somatosensation Receptors).

Figure 1.3.2 is a right field light microscopy image of Meissner corpuscles located in the fingertips. The image highlights these specialized mechanoreceptors, which are responsible for touch discrimination of fine detail. The structure of the Meissner corpuscle is visible, showcasing its encapsulated form and close association with the sensory nerve fibers, underscoring its role in tactile sensation.

Touch receptors such as Meissner's corpuscles and Pacinian corpuscles are abundant in the skin. The density of these touch receptors varies greatly over the surface of the body, giving certain areas greater ability to "feel." Note the image below that shows the areas of sensory cortex allocated to various regions of the body, and where the information is processed in the somatosensory gyrus.

There are a few main similarities and differences to be aware of regarding pain vs. touch pathways. The dorsal column terminates neuron one in the nuclei of the medulla, then separates into two component tracts, targeting specific fibers. The fasciculus gracilis (contains axons from the legs and lower body) targets the nucleus gracilis, while the fasciculus cuneatus (contains axons from the upper body and arms) targets the nucleus cuneatus.

The spinothalamic tract neurons extend their axons to the dorsal horn, where they synapse with the second neuron. Axons from these second neurons then decussate within the spinal cord and ascend to the brain and enter the thalamus, where each synapses with the third neuron in its respective pathway. In the dorsal column system, this decussation takes place in the brainstem; in the spinothalamic pathway, it takes place in the spinal cord at the same spinal cord level at which the information entered. Not only does pain projects to the contralateral primary somatosensory cortex, but it does to the limbic system as well. If you want to motivate a strong reaction from someone, the limbic system is a good target!

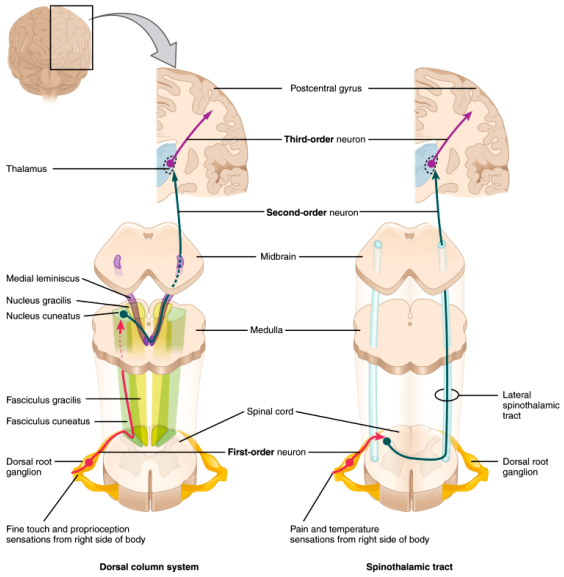


Figure 1.3.3: Ascending sensory pathways of the spinal cord. The dorsal column system and spinothalamic tract are the major ascending pathways that connect the periphery with the brain. (CC-BY 4.0; Dr.Cheryl Olman via Pain Pathways in the Brain).

Figure 1.3.3 compares two ascending sensory pathways that carry information from the body to the brain. The left side shows the dorsal column system (fine touch and proprioception). The right side shows the spinothalamic tract (pain and temperature). Both pathways are shown as a sequence of first-order, second-order, and third-order neurons projecting from the spinal cord to the thalamus and then to the postcentral gyrus (primary somatosensory cortex).

Left panel - Dorsal column system (fine touch and proprioception)

Sensory modality: fine touch and proprioception from the right side of the body.

1. First-order neuron: begins in the periphery with the cell body in the dorsal root ganglion and enters the spinal cord.
2. The axon ascends in the fasciculus gracilis and/or fasciculus cuneatus (dorsal columns).
3. Second-order neuron: synapses in the nucleus gracilis and nucleus cuneatus in the medulla.
4. The pathway continues upward through the brainstem as the medial lemniscus toward the thalamus.
5. Third-order neuron: relays from the thalamus to the postcentral gyrus.

Right panel: Spinothalamic tract (pain and temperature)

Sensory modality: pain and temperature from the right side of the body.

1. First-order neuron: begins in the periphery with the cell body in the dorsal root ganglion and enters the spinal cord.
2. Second-order neuron: synapses in the spinal cord and then ascends in the lateral spinothalamic tract through the spinal cord and brainstem.
3. The pathway projects to the thalamus.
4. Third-order neuron: relays from the thalamus to the postcentral gyrus.

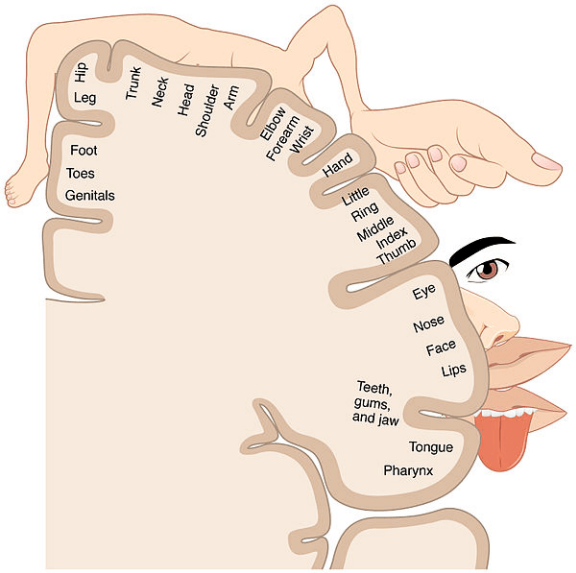


Figure 1.3.4: Homunculus (Latin for "little man" or "little person"): Image representing the cortical sensory homunculus. It shows how the anatomical portions of the body, such as the tongue, elbow, and hip, are mapped out on the homunculus. The surface area of cortex dedicated to a body part correlates with the amount of somatosensory input from that area. (CC-BY 4.0; via The Somatosensory system).

Figure 1.3.4 presents the cortical sensory homunculus, a map of body regions on the primary somatosensory cortex (postcentral gyrus), emphasizing the relationship between body part representation and sensory processing in the brain. Different body parts are represented by different amounts of cortical area, with the size of each part on the homunculus (an abstracted human body) corresponding to the amount of somatosensory input and sensitivity from that region. Areas with greater sensitivity—such as the hands, lips, and face—occupy more cortical space than less sensitive areas.

Moving from within the groove that separates the left and right hemispheres (longitudinal fissure) clockwise to the termination of the postcentral gyrus, we see ridges and folds labeled with groupings of body parts, as noted here:

- Foot, toes, genitals
- Leg, hip
- Trunk, neck, head, shoulder, arm
- Elbow, forearm, wrist
- Hand - by far the largest element on the homunculus
- Fingers and thumb, with the thumb shown as much larger than the fingers on the homunculus
- Eye, nose, face, lips. The lips are the largest part of this grouping on the homunculus.
- Teeth, gums, and jaw. These parts are labeled with a fold of the gyrus.
- Tongue, pharynx. The pharynx is not represented on the homunculus, while the tongue is shown as proportional to the lips.

Special Senses

Vision

Vision, or sight, is the ability to sense light and see. The eye is the special sensory organ that collects and focuses light and forms images. However, the eye is not sufficient for us to see. The brain also plays a necessary role in vision.

Anatomy of the Human Eye

The eye is located within the orbit and surrounded by soft tissues that protect and support its function. The orbit is surrounded by cranial bones of the skull. The human eye is a complex organ responsible for vision, which involves the reception of light and the processing of visual information. Understanding the anatomy of the eye is essential for comprehending how it functions in the visual system. The human eye's structure is intricately designed to optimize its function as a sensory organ, enabling clear vision and the ability to adapt to varying light conditions.

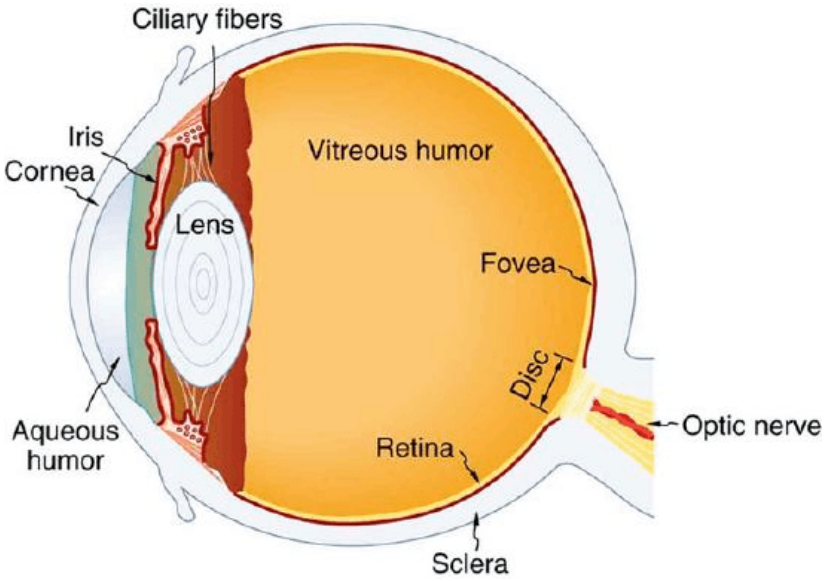


Figure 1.3.5: A simple cross-section showing how light enters through the cornea and lens, passes through the eye's fluids, and reaches the retina at the back of the eye, where visual signals are sent to the brain through the optic nerve. (CC By-SA 4.0; via The Human Eye).

Figure 1.3.5 is a diagram showing the structure of the human eye, illustrating its division into the anterior cavity, which contains aqueous humor (a clear fluid), and the posterior cavity, filled with vitreous humor (a clear gel). The wall of the eye is composed of three layers: the fibrous tunic (sclera), the vascular tunic (choroid), and the neural tunic (retina). The image highlights how the cornea and lens work together to form a real image on the retina, which has the densest concentration of photoreceptors in the fovea and a blind spot over the optic nerve.

Understanding the Design

The eye is a fluid-filled sphere enclosed by three layers of tissue. Most of the outer layer is composed of a tough white fibrous tissue, the sclera. At the front of the eye, however, this opaque outer layer is transformed into the cornea, a specialized transparent tissue that permits light rays to enter the eye. The cornea's curvature and its ability to maintain its shape are vital for proper visual acuity.

The middle layer of tissue includes three distinct but continuous structures: the iris, the ciliary body, and the choroid. The iris is the colored portion of the eye that can be seen through the cornea. It contains two sets of muscles with opposing actions, which allow the size of the pupil (the opening in its center) to be adjusted under neural control (adapting to bright and dim conditions).

The ciliary body is a ring of tissue that encircles the lens (refines the focus by changing shape, a process called accommodation) and includes a muscular component that is important for adjusting the refractive power of the lens, and a vascular component (the so-called ciliary processes) that produces the fluid that fills the front of the eye. The choroid is composed of a rich capillary bed that serves as the main source of blood supply for the photoreceptors of the retina. Only the innermost layer of the eye, the retina, contains neurons that are sensitive to light and are capable of transmitting visual signals to central targets.

En route to the retina, light passes through the cornea, the lens, and two distinct fluid environments. The anterior chamber, the space between the lens and the cornea, is filled with aqueous humor, a clear, watery liquid that supplies nutrients to these structures as well as to the lens. Aqueous humor is produced by the ciliary processes in the posterior chamber (the region between the lens and the iris) and flows into the anterior chamber through the pupil. A specialized meshwork of cells that lies at the junction of the iris and the cornea is responsible for its uptake. Under normal conditions, the rates of aqueous humor production and uptake are in equilibrium, ensuring a constant intraocular pressure. Abnormally high levels of intraocular pressure, which occur in glaucoma, can reduce the blood supply to the eye and eventually damage retinal neurons. The space between the back of the lens and the surface of the retina is filled with a thick, gelatinous substance called the vitreous humor, which accounts for about 80% of the volume of the eye. In addition to maintaining the shape of the eye, the vitreous humor contains phagocytic cells that remove blood and other debris that might otherwise interfere with light transmission.

Eyelids protect the eye from injury and help to keep the surface of the eye moist by spreading tears over the surface during blinking. The lacrimal apparatus - includes the lacrimal glands, which produce tears, and the lacrimal ducts, which drain tears into

the nasal cavity. Tears help to keep the eye lubricated and provide nutrients to the cornea.

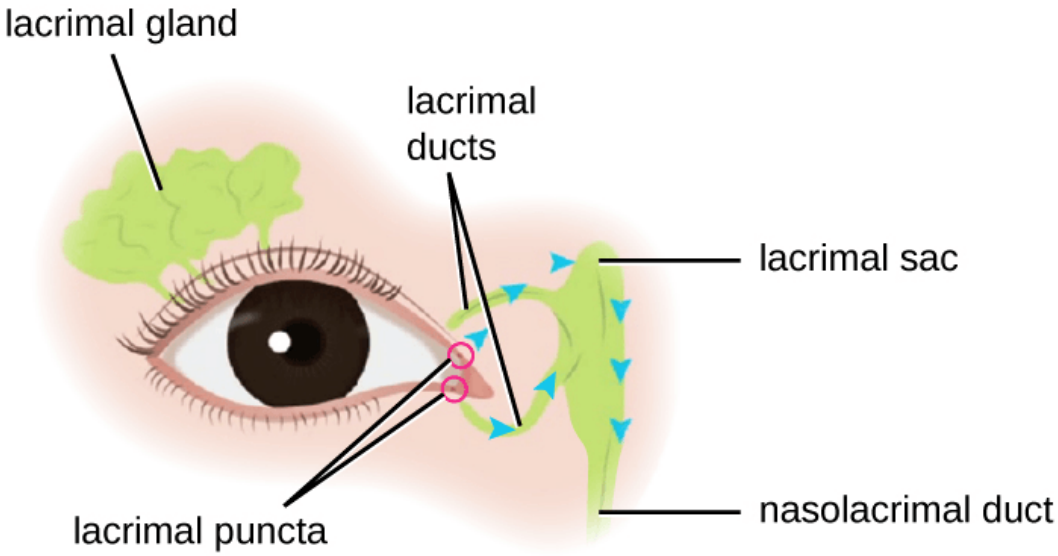


Figure 1.3.6: Frontal view of the lacrimal apparatus showing the flow of tears from the lacrimal glands to the nasolacrimal duct and nasal cavity. Note that the lacrimal canaliculi are shown as lacrimal ducts in the figure. (CC-BY 4.0; via Wikimedia Commons).

Figure 1.3.6 is a frontal view of the lacrimal apparatus illustrating the pathway of tear flow from the lacrimal glands to the nasolacrimal duct and into the nasal cavity. The diagram highlights the lacrimal canaliculi, labeled as lacrimal ducts, which collect tears from the eye. This visual representation emphasizes the anatomical relationships and functions of the various components involved in tear production and drainage that help maintain ocular health. This image is a labeled diagram of the lacrimal (tear) system, showing where tears are produced and how they drain from the eye. Labeled structures and flow:

- Lacrimal gland: produces tears.
- Lacrimal ducts: carry tears from the lacrimal gland to the surface of the eye.
- Lacrimal puncta: small openings near the inner corner of the eyelids where tears enter the drainage system.
- Lacrimal sac: collects tears after they pass through the puncta and associated drainage channels.
- Nasolacrimal duct: carries tears from the lacrimal sac downward into the nasal cavity.

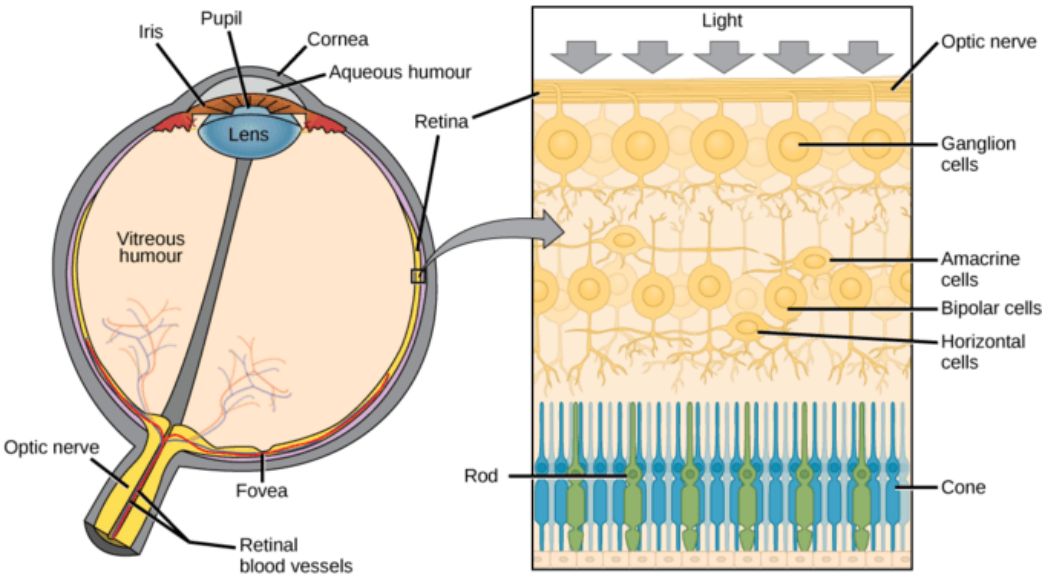


Figure 1.3.7: Retina: (a) The human eye is shown in cross section. The human eye contains structures, such as the cornea, iris, lens, and fovea, that process light so it can be deciphered by the retina. Other structures like the aqueous humor and the vitreous humor help maintain the shape of the eye. (b) A blowup shows the layers of the retina. The retina contains photoreceptive cells. In the retina, light is converted into neural signals sent to the brain. (CC BY-SA 4.0; via Anatomy of the Eye).

Figure 1.3.7 is a cross-sectional illustration of the human eye, displaying key structures such as the cornea, iris,lens, and fovea, which work together to process light for interpretation by the retina. The diagram also shows the aqueous humor and vitreous humor, which help maintain the eye's shape. Additionally, a magnified view reveals the layers of the retina, highlighting the presence of photoreceptive cells responsible for converting light into neural signals that are transmitted to the brain for visual processing.

Fovea centralis is a small depression in the retina where visual acuity is highest. It contains a high concentration of cones and is responsible for sharp central vision. Optic disc is the point where the optic nerve exits the eye. It is also known as the blind spot because it lacks photoreceptors; thus, no visual information is detected at this point.

Audition (Hearing)

Hearing, or audition, is the transduction of sound waves into a neural signal that is made possible by the structures of the ear. The large, fleshy structure on the lateral aspect of the head is known as the auricle or pinna. The C-shaped curves of the auricle direct sound waves toward the auditory canal. The canal enters the skull through the external auditory meatus of the temporal bone. At the end of the auditory canal is the tympanic membrane, or eardrum, which vibrates after it is struck by sound waves. The auricle, ear canal, and tympanic membrane are often referred to as the external ear. The middle ear consists of a space spanned by three small bones called the ossicles. The three ossicles are the malleus, incus, and stapes, which are Latin names that roughly translate to hammer, anvil, and stirrup. The malleus is attached to the tympanic membrane and articulates with the incus. The incus, in turn, articulates with the stapes. The stapes is then attached to the inner ear, where the sound waves will be transduced into a neural signal. The middle ear is connected to the pharynx through the Eustachian tube, which helps equalize air pressure across the tympanic membrane. The tube is normally closed but will pop open when the muscles of the pharynx contract during swallowing or yawning.

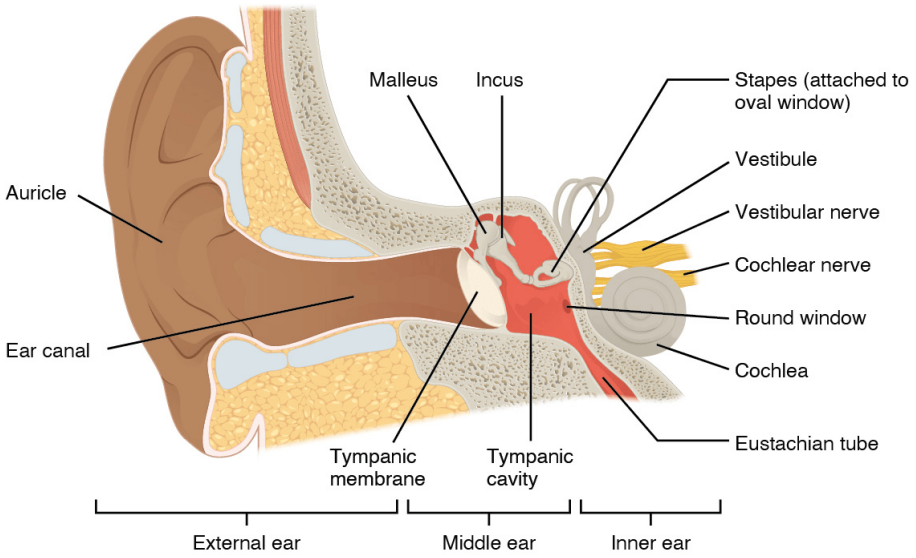


Figure 1.3.9: A simple cross-section showing how sound travels from the outer ear through the ear canal and middle-ear bones to the inner ear, where it is converted into nerve signals sent to the brain. (CC By 4.0; via Audition).

Figure 1.3.9 illustrates the structures of the ear, including the external ear, middle ear, and inner ear. The external is composed of the auricle (the visible part of the ear), the ear canal, and the tympanic membrane (eardrum) deep within the ear canal. Behind the tympanic membrane is the tympanic cavity of the middle ear. The ossicles (malleus, incus, and stapes) are within this cavity, and are described above the figure. The stapes is attached to the inner ear via the oval window, and the round window is shown just below it. The inner ear region includes, in order as shown in the diagram:

- the vestibule, with the vestibular nerve
- the cochlear nerve runs parallel to the vestibular nerve, with the cochlea just below it

The vestibule and cochlea are connected, looking somewhat like a snail, with the cochlea similar to the shell and the vestibule like the body and head - but with two delicate loops instead of eye stems. The cochlea is responsible for hearing (audition), and the vestibule is responsible for balance (equilibrium).

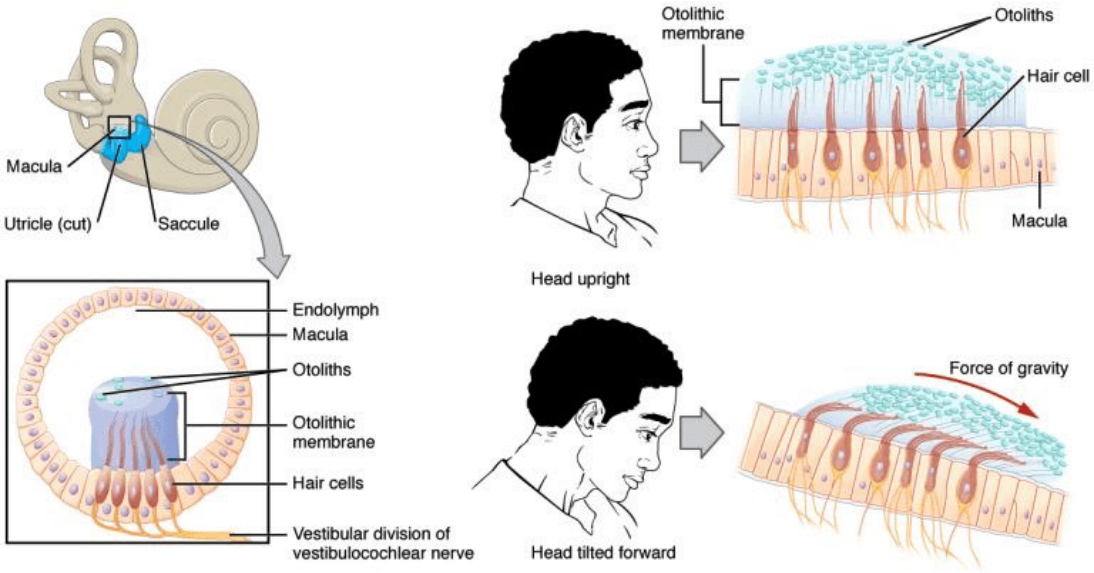


Figure 1.3.10: Linear Acceleration Coding by Maculae: The maculae are specialized for sensing linear acceleration, such as when gravity acts on the tilting head, or if the head starts moving in a straight line. The difference in inertia between the hair cell stereocilia and the otolithic membrane in which they are embedded leads to a shearing force that causes the stereocilia to bend in the direction of that linear acceleration. (CC BY-SA 4.0; via Anatomy & Physiology).

Figure 1.3.10 includes four diagrams that illustrate the vestibular system in the inner ear, which is responsible for detecting head position and maintaining balance.

Top Left: The vestibule and cochlea are shown with a region highlighted just below the loops of the vestibule. In this region we see two small structures, the utricle and saccule. They meet at the macula, a sensory region within the utricle and saccule that detects linear acceleration and head position.

Bottom Left: This simplified diagram shows a macula as a sphere filled with endolymph, a fluid that surrounds the sensory structures within. The macula is lined by the otolithic membrane, a gelatinous layer that moves in response to head tilts, stimulating hair cells beneath it. These hair cells are sensory receptors that convert mechanical movement into neural signals that are transmitted to the brain by the vestibular division of the vestibulocochlear nerve. Tiny calcium carbonate crystals called otoliths sit atop the otolithic membrane and shift with gravity or movement.

The top right and bottom right diagrams show how the otoliths within the macula shift when a man's head is moved from upright position to tilting forward. As gravity moves the otoliths, the underlying hair cells bend in response, altering the signals sent to the brain. This mechanism helps the body detect orientation and maintain equilibrium.

The diagram compares two head positions upright and tilted forward, to show how the otoliths shift, bending the hair cells differently and altering the signal sent to the brain. This mechanism helps the body detect orientation and maintain equilibrium.

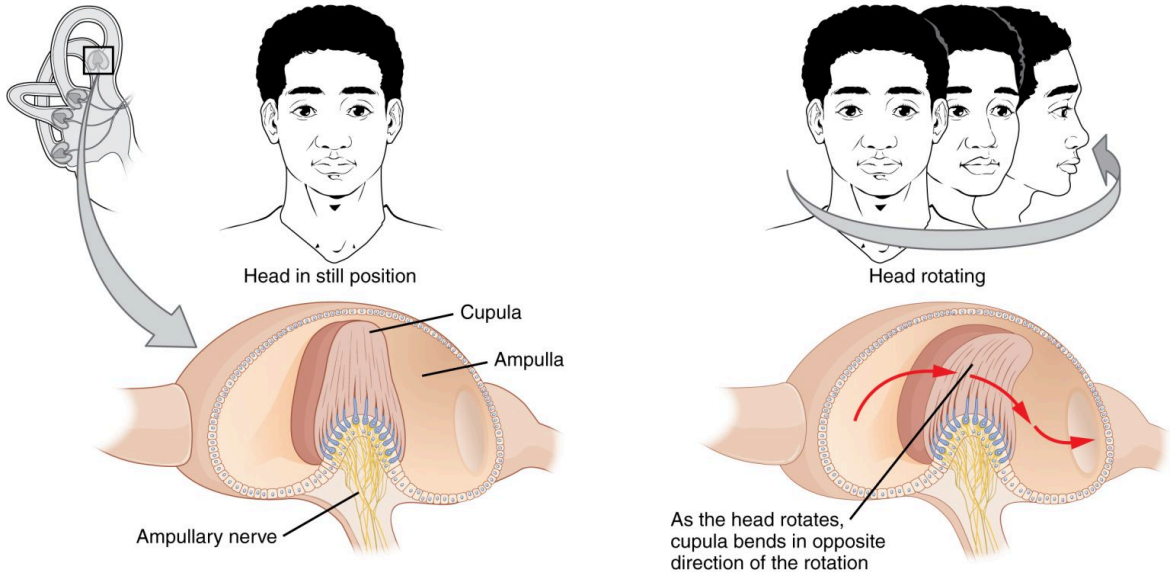


Figure 1.3.11:Semicircular canal ampulla during head rotation: cupula bends opposite rotation, stimulating the ampullary nerve. (CC BY-SA 4.0; via Anatomy & Physiology).

Figure 1.3.11 illustrates the rotational coding by semicircular canals in the inner ear. The image shows the semicircular canals and their associated hair cells located at the base, which are responsible for detecting rotational movements of the head. As the head moves in an arc, the internal fluid in the canals moves in the opposite direction, causing the cupula and stereocilia to bend. This bending indicates the direction of head movement. The diagram emphasizes that the activation of two canals within a plane provides information about head movement, while the simultaneous activation of all six canals offers precise indications of head movement in three-dimensional space. Labels highlight key structures involved in this sensory process.

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1.4: Visual Adaptation and Afterimages

Trichromatic Coding

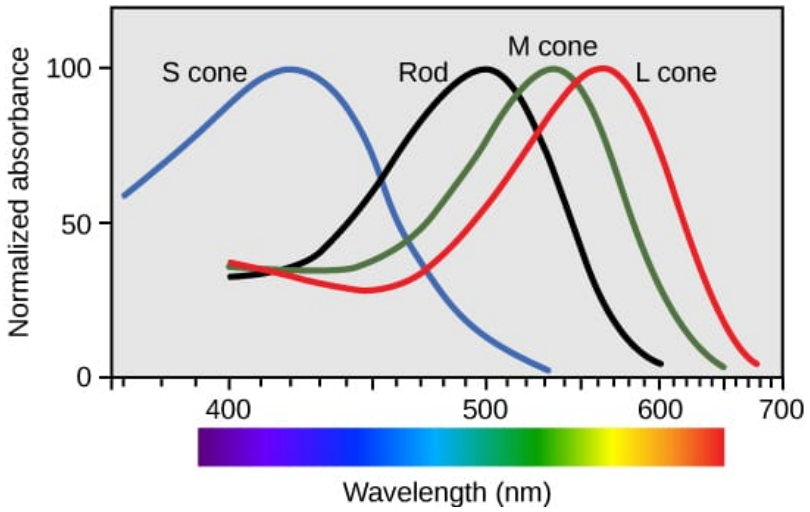


Figure 3. Human rod cells and the different types of cone cells each have an optimal wavelength. However, there is considerable overlap in the wavelengths of light detected.

There are three types of cones (with different photopsins), and they differ in the wavelength to which they are most responsive, as shown in Figure 3. Some cones are maximally responsive to short light waves of 420 nm, so they are called S cones (“S” for “short”); others respond maximally to waves of 530 nm (M cones, for “medium”); a third group responds maximally to light of longer wavelengths, at 560 nm (L, or “long” cones). With only one type of cone, color vision would not be possible, and a two-cone (dichromatic) system has limitations. Primates use a three-cone (trichromatic) system, resulting in full color vision.

The color we perceive is a result of the ratio of activity of our three types of cones. The colors of the visual spectrum, running from long-wavelength light to short, are red (700 nm), orange (600 nm), yellow (565 nm), green (497 nm), blue (470 nm), indigo (450 nm), and violet (425 nm). Humans have very sensitive perception of color and can distinguish about 500 levels of brightness, 200 different hues, and 20 steps of saturation, or about 2 million distinct colors.

Retinal Processing

Visual signals leave the cones and rods, travel to the bipolar cells, and then to ganglion cells. A large degree of processing of visual information occurs in the retina itself, before visual information is sent to the brain.

Photoreceptors in the retina continuously undergo **tonic activity**. That is, they are always slightly active even when not stimulated by light. In neurons that exhibit tonic activity, the absence of stimuli maintains a firing rate at a baseline; while some stimuli increase firing rate from the baseline, and other stimuli decrease firing rate. In the absence of light, the bipolar neurons that connect rods and cones to ganglion cells are continuously and actively inhibited by the rods and cones. Exposure of the retina to light hyperpolarizes the rods and cones and removes their inhibition of bipolar cells. The now active bipolar cells in turn stimulate the ganglion cells, which send action potentials along their axons (which leave the eye as the optic nerve). Thus, the visual system relies on change in retinal activity, rather than the absence or presence of activity, to encode visual signals for the brain. Sometimes horizontal cells carry signals from one rod or cone to other photoreceptors and to several bipolar cells. When a rod or cone stimulates a horizontal cell, the horizontal cell inhibits more distant photoreceptors and bipolar cells, creating lateral inhibition. This inhibition sharpens edges and enhances contrast in the images by making regions receiving light appear lighter and dark surroundings appear darker. Amacrine cells can distribute information from one bipolar cell to many ganglion cells.

You can demonstrate this using an easy demonstration to “trick” your retina and brain about the colors you are observing in your visual field. Look fixedly at Figure 4 for about 45 seconds. Then quickly shift your gaze to a sheet of blank white paper or a white wall. You should see an afterimage of the Norwegian flag in its correct colors. At this point, close your eyes for a moment, then

reopen them, looking again at the white paper or wall; the afterimage of the flag should continue to appear as red, white, and blue.

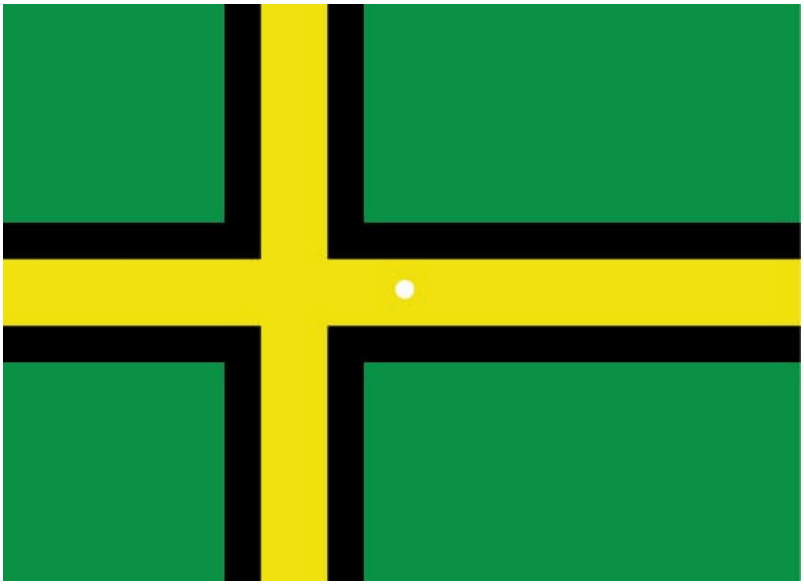


Figure 4. View this flag to understand how retinal processing works. Stare at the center of the flag (indicated by the white dot) for 45 seconds, and then quickly look at a white background, noticing how colors appear.

What causes this? According to an explanation called opponent process theory, as you gazed fixedly at the green, black, and yellow flag, your retinal ganglion cells that respond positively to green, black, and yellow increased their firing dramatically. When you shifted your gaze to the neutral white ground, these ganglion cells abruptly decreased their activity and the brain interpreted this abrupt downshift as if the ganglion cells were responding now to their "opponent" colors: red, white, and blue, respectively, in the visual field. Once the ganglion cells return to their baseline activity state, the false perception of color will disappear.

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1.5: Introduction and Sensory Systems Lab

Introduction and Sensory Systems

Throughout this course, we will explore the biological processes underlying human behavior, cognition, and physiological functioning. We will examine how the nervous system responds to different stimuli, how physiological activity can be measured, and how researchers use these measurements to better understand human behavior. Some of the topics and techniques we will explore include:

- Sensory Systems: How we detect, process, and interpret information from our environment.
- Electroencephalography (EEG) and Visual Evoked Potentials (VEP): How researchers measure electrical activity in the brain.
- Reflexes and Nerve Conduction: How electrical signals travel through the nervous system and produce responses.
- Galvanic Skin Response (GSR): How changes in skin conductance reflect physiological arousal.
- Vagal Tone: How the autonomic nervous system influences physiological functioning.
- Skin Temperature: How changes in skin temperature relate to physiological regulation.
- Heart Rate and Respiration: How cardiovascular and respiratory activity respond to different conditions.
- Electromyography (EMG): How electrical activity in muscles can be measured/analyzed.

How Will We Conduct Labs Online?

In a traditional laboratory setting, students use specialized equipment to collect physiological measurements and conduct experiments. Because this course is offered online and asynchronously, we will use a combination of at-home experiments, virtual simulations, and existing physiological datasets to explore many of the same concepts.

Although you will not have access to all the equipment used in a traditional biopsychology laboratory, you will still have opportunities to engage in the scientific process. Depending on the activity, you may:

- Conduct simple experiments using everyday household materials.
- Collect and record observations or measurements.
- Use online simulations to explore physiological processes.
- Analyze and interpret data collected from physiological experiments.
- Develop hypotheses and evaluate experimental results.
- Apply concepts from biopsychology to explain your findings.

The goal of these activities is not simply to learn about physiological psychology techniques, but to understand how researchers use these techniques to investigate questions about the brain, nervous system, and behavior.

These instructions outline the activities you will complete for this lab and include the questions you will need to answer. You will submit your work directly in Canvas, where you will have space to type or paste your responses and upload any required files, such as graphs, drawings, or images. For your convenience, spaces are provided for recording your answers in the lab instructions, but you are not *required* to fill in your answers on this document.

Lab Protocols and Safety

- Although you will be completing your laboratory activities at home, it is important to follow appropriate experimental procedures and safety guidelines.
- Read all instructions *before* beginning an activity. Make sure you understand the procedures, materials, and expectations before starting.
- Follow the procedures carefully. Accurate observations and measurements depend on consistent experimental methods.
- Use materials safely. Only use the materials specified in the instructions. Do not substitute potentially hazardous materials or attempt procedures requiring specialized equipment.
- Choose an appropriate environment. Complete your activities in a safe, comfortable space with minimal distractions.
- Be mindful of your physical well-being. Some activities may involve sensory stimulation or physical responses. If an activity causes discomfort, stop immediately.

- Record your observations accurately. Report what you actually observe, even if your results differ from what you expected. Unexpected findings are a normal part of scientific research.
- Do not fabricate data. If you are unable to complete an activity or obtain a measurement, explain the difficulty or reach out to your professor rather than inventing results.

Remember that the purpose of laboratory research is to investigate questions systematically. Following instructions, collecting accurate data, and interpreting your findings are essential components of the scientific process.

In this lab, you will investigate how your sensory systems detect and respond to information from the environment. You will conduct simple experiments to examine visual perception and sensory adaptation. Throughout these activities, you will collect observations, record measurements, and use your results to better understand how sensory information is processed. Before beginning, review the sensory systems material in your lab textbook.

Materials Needed:

- Paper and pen or pencil
- Ruler with millimeter measurements
- Timer or stopwatch (a smartphone timer is acceptable)
- Computer or tablet screen
- A quiet, comfortable workspace

In laboratory research, psychologists attempt to understand behavior by observing responses under specific conditions. Controlling variables helps researchers determine whether changes in an outcome are associated with the condition being studied. In the following activities, you will manipulate aspects of visual stimulation, record your observations, and consider how experimental conditions influence your results.

Experiment 1: Measuring Your Blind Spot

Each eye contains an area of the retina where the optic nerve exits the eye. This region lacks photoreceptors, creating a blind spot in your visual field. In this experiment, you will locate your blind spot, estimate its size, and investigate how your brain processes missing visual information.

Procedure:

1. Using a blank sheet of paper, draw an X on the left side and an O approximately 50 millimeters (5 centimeters) to its right, as illustrated below.



2. Position the paper approximately 30 centimeters in front of your face, keeping it at eye level.
3. Cover your left eye and look directly at the X with your right eye.
4. While maintaining your focus on the X, gradually adjust the distance between your face and the paper. Notice when the O disappears from your field of vision.
5. Using a ruler, measure the distance from your eye to the paper at the point where the O disappears. Record your measurement in millimeters.
6. Create additional circles with diameters of 5, 10, 15, and 20 millimeters. Test each circle using the same procedure, keeping the distance between the X and the center of each circle consistent. Identify the largest circle that disappears completely.
7. Switch eyes and repeat the experiment, placing the O to the left of the X while focusing on the X with your left eye.
8. Enter your measurements for each eye in the table below. You will use these values to estimate the size of your blind spot.

	Right Eye	Left Eye

Largest Circle that Disappeared	mm	mm
Distance from Eye to Paper	mm	mm

After identifying the largest circle that disappears, draw a straight line connecting the X to the circle and extending beyond it, as shown below.

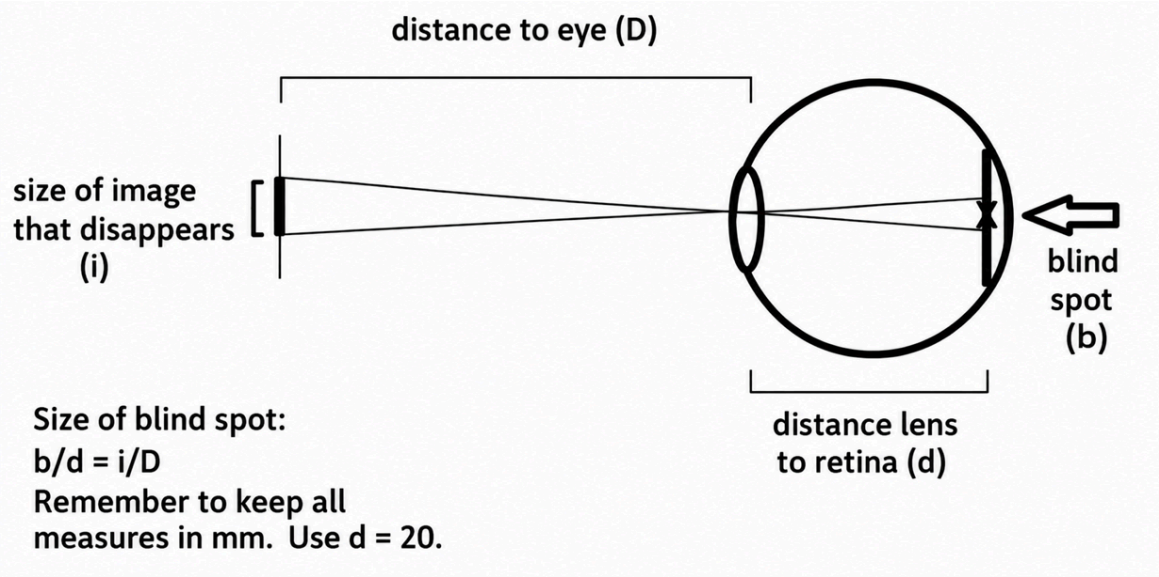


Repeat the experiment, positioning the circle within your blind spot while continuing to focus on the X.

What happens to the line when the circle disappears? You may notice that the line appears uninterrupted, even though part of it falls within your blind spot. This occurs because the optic disc contains no photoreceptors, and your visual system uses surrounding information to perceptually fill in the missing portion of the image.

Calculating the Size of Your Blind Spot:

Use the formula below to estimate the diameter of your blind spot on the retina. The calculation uses the diameter of the largest circle that disappeared and the distance between your eye and the paper.



Your calculation will look like this:

$$\text{Blind Spot (mm)} = 20 \times \frac{\text{Diameter of Largest Image that Disappears (mm)}}{\text{Distance to the Eye (mm)}} \tag{1.5.1}$$

Show your work for both calculations in your lab report assignment. The calculations must clearly show what you determine your blind spot to be on each side.

Experiment 2: Visual Afterimages

Visual afterimages occur when a visual sensation persists or changes after the original stimulus is removed. In this experiment, you will observe how the duration of exposure to a visual stimulus influences your perception of an afterimage.

For this activity, use a moderately bright colored image displayed on a computer or tablet screen. Do not use the sun, flashlights, or other intense light sources. Avoid this experiment if visual stimulation triggers migraines or other symptoms.

Procedure:

1. Create a solid-colored square (approximately 5 centimeters wide) on a white background using a drawing program or presentation slide. Choose a saturated color such as red, green, or blue. Alternatively, you can search “negative color afterimage illusion” on Google, YouTube, or another search engine.
2. Position yourself comfortably in front of the screen. Keep your viewing distance and screen brightness consistent throughout the experiment.
3. Look directly at the center of the colored square for 5 seconds.
4. Immediately shift your gaze to a blank white area of the screen or a white wall.
5. Observe any afterimage that appears. Record its color and use a timer to measure approximately how long it remains visible.
6. Rest your eyes for at least one minute, or until your vision has returned to normal.
7. Repeat the procedure using the same image, screen brightness, and viewing distance. This time, look at the colored square for 20 seconds.
8. Record the color and duration of the afterimage.

Report your findings in your lab report.

Experiment 3: Eye Dominance

Although we use both eyes to perceive the world, many people demonstrate a preference for one eye when performing certain visual tasks. This is known as ocular dominance.

Procedure:

1. Hold both hands in front of you with your arms extended.
2. Overlap your hands to create a small triangular opening between your thumbs and index fingers.
3. With both eyes open, look through the opening and center a distant object, such as a clock or picture on the wall.
4. Without moving your hands, close your left eye and observe whether the object remains centered.
5. Open your left eye and close your right eye. Again, observe whether the object remains centered.
6. Determine which eye keeps the object centered within the opening. This is your dominant eye.
7. Record your dominant eye. If the result is unclear, repeat the procedure, making sure to keep your hands stationary while alternating eyes.

Lab Report

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4. **Fill out the table below with your results from experiment 2.**

5-second exposure		20-second exposure	
Original stimulus color:		**Original stimulus color:**	
Afterimage color:		**Afterimage color:**	
Afterimage duration:		**Afterimage duration:**	

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2: MICROSCOPY AND NERVOUS TISSUE

2.1: Microscopy - Seeing Beyond the Naked Eye
2.2: Imaging the Cells of the Nervous System
2.3: Recognizing Nervous Tissue Under the Microscope
2.4: Histology Lab

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2.1: Microscopy - Seeing Beyond the Naked Eye

Learning Objectives

- Compare and contrast light and electron microscopy.

Microscopy

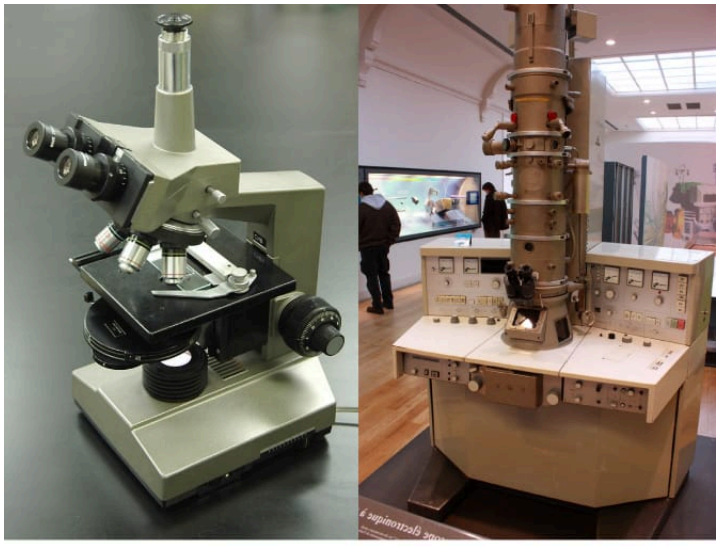
Cells vary in size. With few exceptions, individual cells cannot be seen with the naked eye, so scientists use microscopes (micro- = “small”; -scope = “to look at”) to study them. A microscope is an instrument that magnifies an object. Most photographs of cells are taken with a microscope; these images can also be called micrographs.

The optics of a microscope’s lenses change the orientation of the image that the user sees. A specimen that is right-side up and facing right on the microscope slide will appear upside-down and facing left when viewed through a microscope, and vice versa. Similarly, if the slide is moved left while looking through the microscope, it will appear to move right, and if moved down, it will seem to move up. This occurs because microscopes use two sets of lenses to magnify the image. Because of the manner by which light travels through the lenses, this system of two lenses produces an inverted image (binocular, or dissecting microscopes, work in a similar manner, but they include an additional magnification system that makes the final image appear to be upright).

Light Microscopes

To give you a sense of cell size, a typical human red blood cell is about eight millionths of a meter or eight micrometers (abbreviated as eight µm) in diameter; the head of a pin of is about two thousandths of a meter (two mm) in diameter. That means about 250 red blood cells could fit on the head of a pin.

Most student microscopes are classified as light microscopes. Visible light passes and is bent through the lens system to enable the user to see the specimen. Light microscopes are advantageous for viewing living organisms, but since individual cells are generally transparent, their components are not distinguishable unless they are colored with special stains. Staining, however, usually kills the cells.



(a) (b)

Figure 2.1.1: Light and Electron Microscopes: (a) Most light microscopes used in a college biology lab can magnify cells up to approximately 400 times and have a resolution of about 200 nanometers. (b) Electron microscopes provide a much higher magnification, 100,000x, and a have a resolution of 50 picometers.

Light microscopes, commonly used in undergraduate college laboratories, magnify up to approximately 400 times. Two parameters that are important in microscopy are magnification and resolving power. Magnification is the process of enlarging an object in appearance. Resolving power is the ability of a microscope to distinguish two adjacent structures as separate: the higher the resolution, the better the clarity and detail of the image. When oil immersion lenses are used for the study of small objects, magnification is usually increased to 1,000 times. In order to gain a better understanding of cellular structure and function, scientists typically use electron microscopes.

Electron Microscopes

In contrast to light microscopes, electron microscopes use a beam of electrons instead of a beam of light. Not only does this allow for higher magnification and, thus, more detail, it also provides higher resolving power. The method used to prepare the specimen for viewing with an electron microscope kills the specimen. Electrons have short wavelengths (shorter than photons) that move best in a vacuum, so living cells cannot be viewed with an electron microscope.

In a scanning electron microscope, a beam of electrons moves back and forth across a cell's surface, creating details of cell surface characteristics. In a transmission electron microscope, the electron beam penetrates the cell and provides details of a cell's internal structures. As you might imagine, electron microscopes are significantly more bulky and expensive than light microscopes.

Key Points

- Light microscopes allow for magnification of an object approximately up to 400-1000 times depending on whether the high power or oil immersion objective is used.
- Light microscopes use visible light which passes and bends through the lens system.
- Electron microscopes use a beam of electrons, opposed to visible light, for magnification.
- Electron microscopes allow for higher magnification in comparison to a light microscope thus, allowing for visualization of cell internal structures.

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2.2: Imaging the Cells of the Nervous System

Microscopy

Example questions answered:

> "What is the diameter of the soma of a granule cell?"
>
> "How are the retinal neurons at the fovea different from the neurons in the periphery?"

Among the techniques used for neural imaging, short of physical dissection or autopsy, microscopy may be the oldest. The Dutch scientist Antonie van Leeuwenhoek made pioneering contributions to microscopy in the late 1600s. Originally, microscopy was more of a novelty for entertainment rather than a piece of equipment fit for a laboratory. Using a series of precisely-crafted lenses and a bright source of light, Leeweunhoek was able to see tiny animals living in water.

Microscopy gives us the ability to see things at a level of resolution that would otherwise not be possible. Compared to today's microscopes, the earliest scopes provided poor magnification, able to bring us only about 40 times closer than the unaided eye (these days, a standard laboratory microscope provides a level of magnification up to 400 or 1,000 times closer). Other types of microscopes, such as the **electron microscopes** developed in the 1930s, use an electron emission device in conjunction with high speed detectors to visualize structures that are on the order of nanometers, giving us a zoom of up to a million times!

A different form of microscopy relies on the fluorescent properties of molecules such as **green fluorescent protein (GFP)**. Fluorescence microscopes use light sources such as filtered light or lasers which emit light at specific wavelengths. Photons at specific wavelengths activate the proteins, which in turn emit light at a different wavelength. The emission of this second color of light can then be detected.

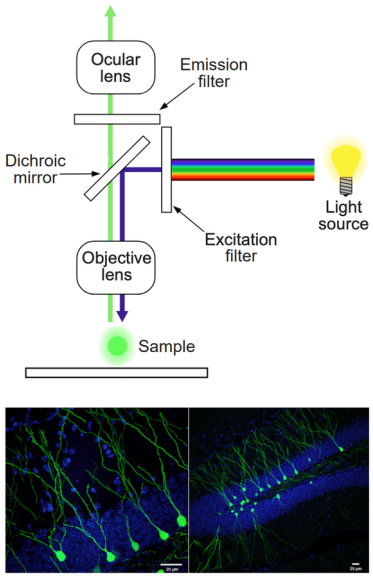


Figure 6.18 The fluorescence microscope (diagram, top) can be used to excite GFP (green) expressed in hippocampal neurons (bottom).

Microscopy is a standard part of a neuroscience research kit. Most of the techniques below will rely on microscopy to visualize some component of the nervous system.

Staining

Example questions answered:

> "Where is the white matter located in the brain stem?"

"What is the morphology of dendritic arbor of a cerebellar Purkinje cell?"

Staining is an imaging method that is often used in conjunction with microscopy. Thin slices of brain tissue are exposed to various chemical processes. The chemicals that are used for staining have different affinities for parts of cells. For example, there are stains that specifically stain myelin (Luxol Fast Blue), some that only stain neurons (cresyl violet), and some that stain only the genetic material found in cell nuclei (DAPI).

One of the most influential biological stains was developed in the late 1800s by the Italian anatomist Camillo Golgi. The **Golgi stain** is a silver-based stain that filled every single part of the neuron, from the dendrites to the axons, turning the cells black. The stain is only taken up by less than 1% of neurons, and because of the low rate of staining, individual neurons could be traced in their entirety and drawn. This stain led to a contentious battle between Golgi and a rival neuroanatomist Santiago Ramon y Cajal over the nature of the connections between neurons.

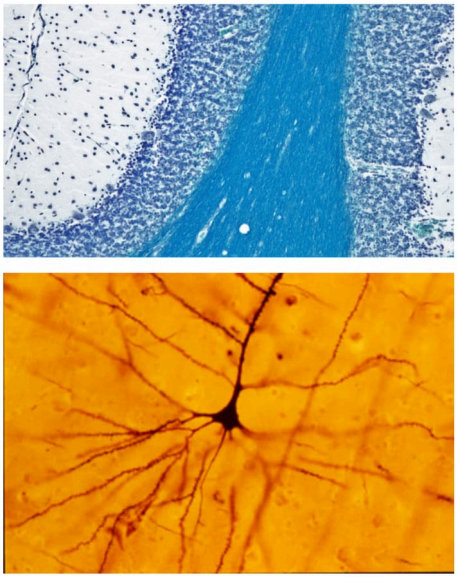


Figure 6.19 A slice of cerebellum, with the myelin stained with Luxol Fast Blue and the neurons stained with cresyl violet (top; 100x magnified). A pyramidal cell treated with a Golgi stain (bottom).

For staining to work, the tissue needs to be subjected to a series of chemical processes. First, the tissue needs to be **fixed**. Fixation is a chemical process that is accomplished by exposing the tissue to a chemical like **paraformaldehyde (PFA)**. The most effective way to expose every part of the body to fixative is to "hijack" the endogenous circulatory system by flushing fixative through the arteries, a process called **perfusion**. Chemically, fixatives cause adjacent proteins to become covalently bonded (crosslinked), a process which causes the proteins to become unchangeable - they become "fixed" in time. These fixatives are very harsh chemicals, and usually kill microorganisms and inactivate the endogenous enzymes that normally degrade biological tissue. (As a side note, fixatives are particularly nasty carcinogens that can permeate easily through latex gloves.)

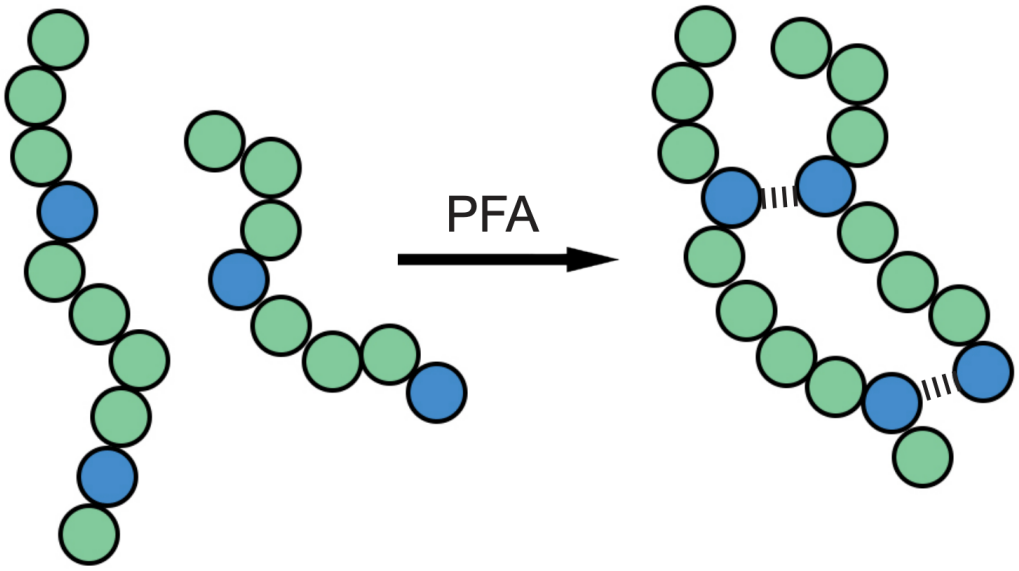


Figure 6.20 A chemical fixative such as PFA creates covalent bonds between lysine (blue) amino acid residues of proteins.

After fixation, devices such as a **microtome** or **cryostat** are used to slice the brain into sections as thin as 10 microns. Stains do not always reliably pass all the way through thick sections of tissue such as an intact brain. With thin slices, chemical stains are able to permeate through the depth of the tissue.



Figure 6.21 A microtome (left) or a cryostat (right) are devices for taking brain sections. The microtome fits on a tabletop, and cuts accurately down to 100 uM thin. The cryostat is larger, and can cut 10 uM thin slices.

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2.3: Recognizing Nervous Tissue Under the Microscope

Information

Nervous tissue is the last of the four major categories of animal tissue. Nervous tissue comprises **neuron**s, the cells specialized for the propagation of electrochemical signals, and **neuroglia**, the so-called "supporting cells" of nervous tissue. There are multiple types of neuroglia cells (sometimes called just glial cells), and most of them do assist neurons, but recent research has discovered that some of the neuroglia cells play an active role by themselves in the proper functioning of the central and peripheral nervous systems. It is turning out that neuroglia do more than just support neurons.

We will leave investigation of the neuroglia for later labs. In this lab, we will just focus on the structural features of neurons as they are visible under microscopic examination.

A neuron is typically represented as having the following features. A large cell body (sometimes known as the soma) in which the nucleus and other major organelles are found. Dendrites, which are usually represented as numerous small projections extending from the cell body. A single axon, which is usually represented as a large single projection extending from the cell body, much longer than any of the dendrites. Multiple axon terminals that branch off at the end of the axon. Figure 2.3.1 shows a typical drawn neuron showing all these features.

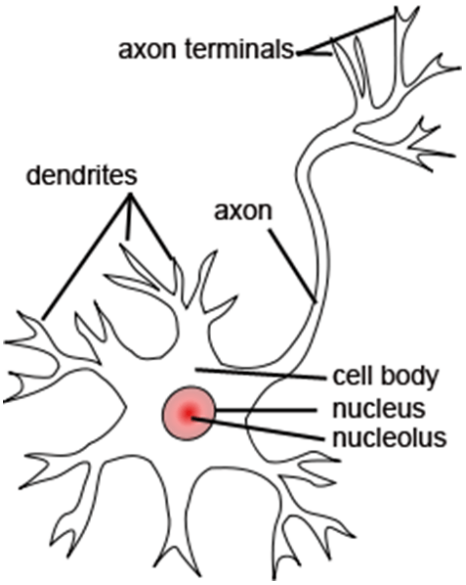


Figure 2.3.1: A typical diagrammatic representation of neuron. (CC-BY-SA, Jonathan Haas, Wikimedia)

All of these features are important to the functioning of neurons. The cell body is where most of the cellular processes of the neuron take place: protein synthesis, metabolism, etc. The dendrites contact and pick up signals coming in from other cells (other neurons or sensory cells). The axon propagates the neuron's electrical signal to its various targets. And the axon terminals actually contact (synapse with) those targets and send chemical signals to the targets to trigger changes in them. However, most neurons in the body do not look as clear-cut as the neuron in Figure 2.3.1. Some neurons have short axons. Others have dendrites that are almost as large as the axon. Others have two axons connected to the same cell body. Many have dendrites and axon terminals that are too thin and small too see clearly. Cell bodies tend to come in all sorts of sizes and shapes, and are not always bulbous lumps readily distinguished from the rest of the cell.

What's more, nervous tissue is delicate and fragile. In creating preparations for slides to viewed under a microscope, some of the cells are smushed together, damaged, truncated, or torn. Other times, the nervous tissue cells are simply too densely packed together to make out individual details. Much of what is visible is not useful to the student looking to find an intact and well-defined neuron. However, a bit of searching will often reveal some intact neurons.

Often these are found at the edges of the preparation where the material is least dense. Keep in mind, you will often see neurons

shaped distinctly different from those shown in textbooks and if Figure 2.3.1.

Figure 2.3.2 shows two different locations in the same slide. Figure 2.3.2 A shows a mass of neurons (stained black) in which it is difficult to distinguish the shape of even one neuron clearly. Figure 3.8 B shows a different area from the same slide, where the neurons are not so crowded, and where one neuron in particular (outlined in red) shows many of the structures we are interested in. So, keep in mind, it is important to know what you want to find in a particular slide, and it is important to search around the slide to find the best example of what you are looking for.

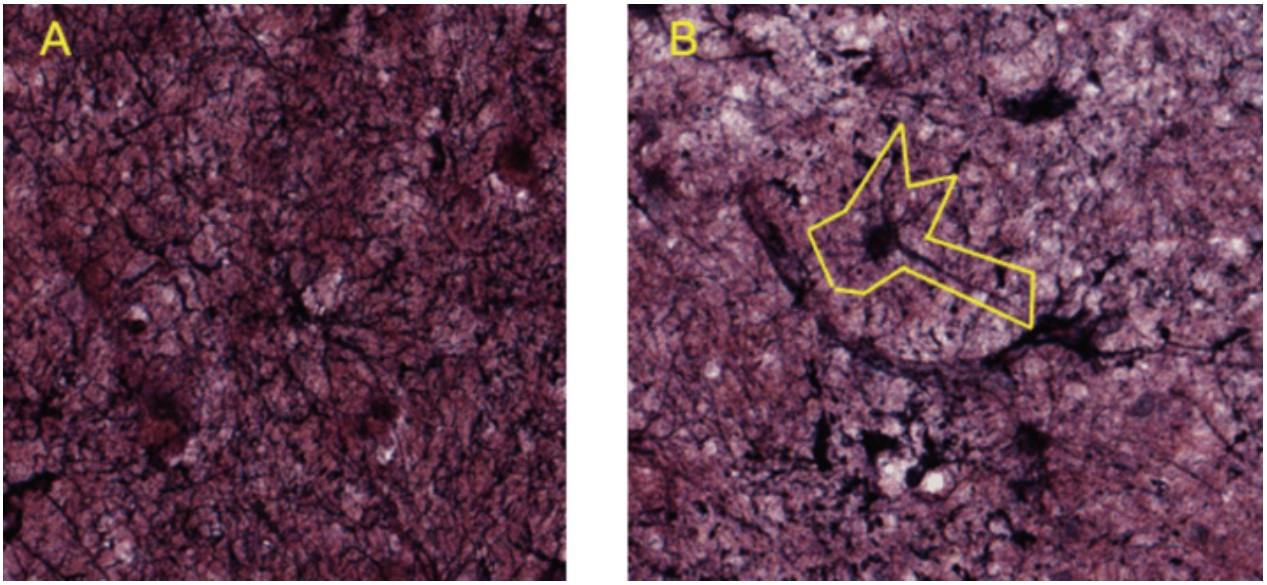
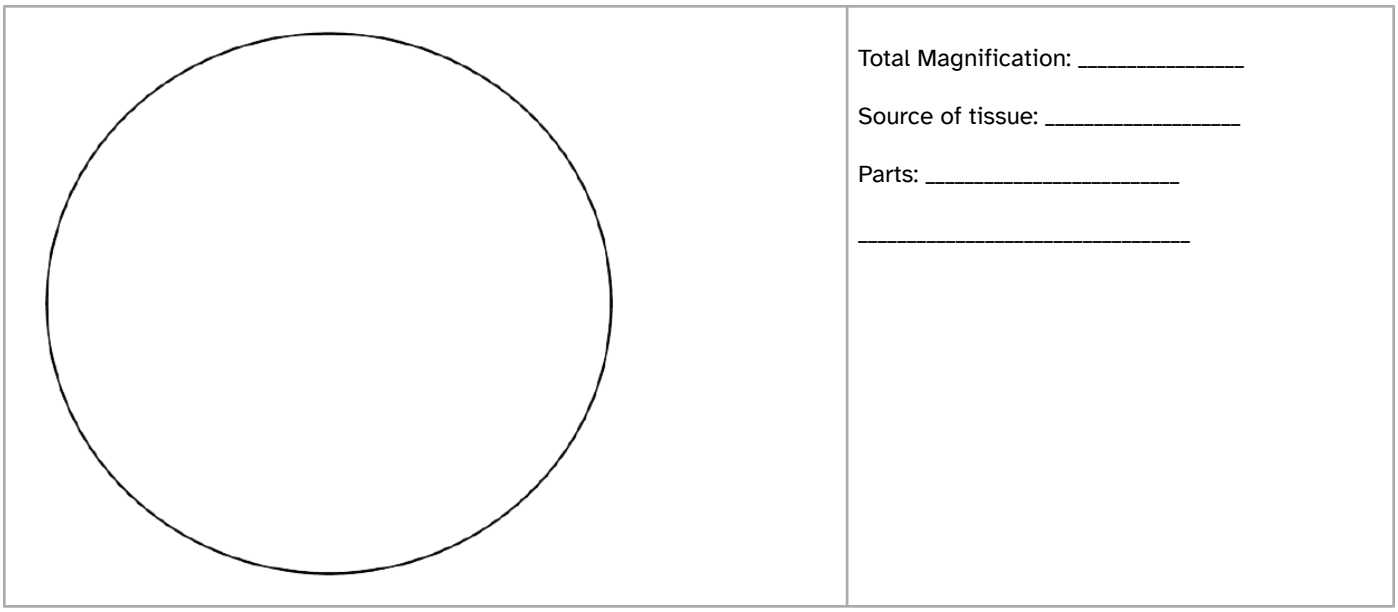


Figure 2.3.2: Two different areas from the same slide of a nervous tissue preparation. In A, the neurons are too crowded to see any one neuron clearly. In B, the neuron outlined in yellow illustrates a typical dendrite-cell body-axon arrangement. (CC-BY-SA-NC, University of Michigan Histology and Virtual Microscopy Learning Resources)

1. Obtain a slide of nervous tissue from the instructor. Use any nervous tissue except peripheral nerve, there are no nerve cell bodies in a peripheral nerve section.
2. View the slide on the second-highest objective. Search carefully until you find a clear, representative neuron in your field of view.
3. In the circle below, draw the neuron you found. Only draw the single neuron. Do not draw any of the other material. Draw your structures proportionately to their size in your microscope's field of view.
4. Label any neural parts you can clearly recognize.



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Figure 2.3.1. A typical diagrammatic representation of neuron.. **Authored by**: Jonathan Haas. **Located at**: **commons.wikimedia.org/w/inde...curid=18271454**. **License**: ***CC BY-SA: Attribution-ShareAlike***

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Figure 2.3.2. **Authored by**: Kent Christensen, Ph.D., J. Matthew Velkey, Ph.D., Lloyd M. Stoolman, M.D., Laura Hessler, and Diedra Mosley-Brower. **Provided by**: University of Michigan Histology and Virtual Microscopy Learning Resources. **Located at: 141.214.65.171/Histology/Central%20Nervous%20System/13270.svs/view.apml. License: *CC BY-SA: Attribution- ShareAlike***

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2.4: Histology Lab

Histology

Histology is the study of the microscopic structure of cells and tissues. In this lab, you will use the University of Michigan's Virtual Histology collection to examine different tissues of the nervous system. You will explore microscope slides, identify anatomical structures, and create colored drawings of your observations. The purpose of this lab is to develop your ability to recognize nervous tissue structures and connect their microscopic appearance to what you have learned about the nervous system.

Slide	Description
65-1.	Spinal cord and dorsal root ganglion, H&E stain, 20X
65-1N.	Spinal cord, trichrome stain, 40X
65-2.	Spinal cord and dorsal root ganglion, H&E stain, 40X
66a.	Thoracic spinal cord, cross section, Luxol blue stain, 40X
76.	Cerebrum, axons and neuron cell bodies stained blue, 40X
76b.	Cerebrum, TB&E stain, 40X
77 (20X).	Cerebellum (H&E stain), 20X
77 (40X).	Cerebellum (H&E stain), 40X
77a.	Cerebellum (Luxol blue stain), 40X
13270.	Astrocytes (gold stain)
NP004N.	Hippocampal region (Luxol blue stain), 40X

Source: University of Michigan Medical School. (2026). *Virtual Histology* [Digital microscope slides]. https://histology.medicine.umich.edu/

Last modified: February 13, 2026.

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The virtual histology slides are provided by the University of Michigan Medical School and are used as external educational resources. All images and associated materials remain the property of their respective copyright holders.

Materials Needed

- Computer, tablet, or other compatible device with internet access
- Access to the University of Michigan Virtual Histology slides
- Paper and colored pencils, pens, markers, crayons, etc. OR a digital drawing application
- Camera or scanner (if completing drawings by hand)

Procedure

1. Open the University of Michigan Virtual Histology slides.
2. Familiarize yourself with the virtual microscope by practicing zooming in and out and navigating around the tissue specimens.
3. Explore the available slides before selecting which ones you would like to draw. Pay attention to differences in tissue organization, staining patterns, and cellular structures.
4. Select eight different slides to examine, draw, and label. You may choose which slides to use and the magnification at which you draw them. However, your selections must represent a variety of nervous system tissues and structures. For example, you may not submit eight different views of the spinal cord.

For each of your eight selected slides:

1. Explore the specimen at different magnifications before deciding which area you would like to draw.
2. Create a colored drawing that accurately represents the tissue as it appears in the virtual microscope. You may draw by hand or use a digital drawing application.
3. Use colors that reflect the staining and appearance of the specimen. Black-and-white drawings will not be accepted.
4. Identify and label anatomical structures you recognize in your drawing. Refer to your textbook and the assigned histology tutorials to help identify structures. You are not expected to identify every structure visible in the slide.
5. Include the slide name, slide number, and magnification used with each drawing.

Your drawings should reflect what you actually observe in the virtual microscope rather than a generalized diagram of what the tissue is supposed to look like.
If you completed your drawings by hand, take clear photographs or scan them. Make sure the entire drawing and its labels are visible and legible.

Upload or paste all eight drawings according to your professor's instructions. Each drawing must include the slide name, slide number, magnification, and anatomical labels.

All drawings must be your own original work. AI-generated images, copied illustrations, and screenshots of the virtual microscope submitted in place of drawings will not be accepted.

You will be evaluated on the following:

- Completion of eight original, colored drawings.
- Selection of a variety of nervous system tissues and structures.
- Accuracy of your observations, including the general organization, shapes, and colors of the tissues.
- Appropriate identification and labeling of recognizable anatomical structures.
- Completeness and clarity of your submitted work.
- Completeness and quality of responses to the lab report questions, including the use of specific observations and connections to course concepts.

You are not being graded on artistic ability. Your drawings do not need to be perfect or professionally rendered. The goal is to demonstrate careful observation and an understanding of the anatomical structures you are examining.

Lab Report

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6. **Upload your 8 drawings according to your professor's instructions.**

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3: NEURONS AND NEURAL COMMUNICATION

3.1: Neuron Anatomy and Neural Communication
3.2: Action Potentials and Neural Communication Lab

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3.1: Neuron Anatomy and Neural Communication

As you read this, your nervous system is performing several functions simultaneously. The visual system is processing what is seen on the page; the motor system controls your eye movements and the turn of the pages (or click of the mouse); the prefrontal cortex maintains attention. Even fundamental functions, like breathing and regulation of body temperature, are controlled by the nervous system. The nervous system is one of two systems that exert control over all the organ systems of the body; the other is the endocrine system. The nervous system's control is much more specific and rapid than the hormonal system. It communicates signals through cells and the tiny gaps between them rather than through the circulatory system as in the endocrine system. It uses a combination of chemical and electrochemical signals, rather than purely chemical signals used by the endocrine system to cover long distances quickly. The nervous system acquires information from sensory organs, processes it and then may initiate a response either through motor function, leading to movement, or in a change in the organism's physiological state.

Nervous systems throughout the animal kingdom vary in structure and complexity. Some organisms, like sea sponges, lack a true nervous system. Others, like jellyfish, lack a true brain and instead have a system of separate but connected nerve cells (neurons) called a "nerve net." Flatworms have both a central nervous system (CNS), made up of a ganglion (clusters of connected neurons) and two nerve cords, and a peripheral nervous system (PNS) containing a system of nerves that extend throughout the body. The insect nervous system is more complex but also fairly decentralized. It contains a brain, ventral nerve cord, and ganglia. These ganglia can control movements and behaviors without input from the brain.

Compared to invertebrates, vertebrate nervous systems are more complex, centralized, and specialized. While there is great diversity among different vertebrate nervous systems, they all share a basic structure: a CNS that contains a brain and spinal cord and a PNS made up of peripheral sensory and motor nerves. One interesting difference between the nervous systems of invertebrates and vertebrates is that the nerve cords of many invertebrates are located ventrally (toward the stomach) whereas the vertebrate spinal cords are located dorsally (toward the back). There is debate among evolutionary biologists as to whether these different nervous system plans evolved separately or whether the invertebrate body plan arrangement somehow "flipped" during the evolution of vertebrates.

The nervous system is made up of neurons, specialized cells that can receive and transmit chemical or electrical signals, and glia, cells that provide support functions for the neurons. There is great diversity in the types of neurons and glia that are present in different parts of the nervous system.

Neurons and Glial Cells

The nervous system of the common laboratory fly, *Drosophila melanogaster*, contains around 100,000 neurons, the same number as a lobster. This number compares to 75 million in the mouse and 300 million in the octopus. A human brain contains around 86 billion neurons. Despite these very different numbers, the nervous systems of these animals control many of the same behaviors—from basic reflexes to more complicated behaviors like finding food and courting mates. The ability of neurons to communicate with each other as well as with other types of cells underlies all of these behaviors.

Most neurons share the same cellular components. But neurons are also highly specialized—different types of neurons have different sizes and shapes that relate to their functional roles.

Like other cells, each neuron has a cell body (or soma) that contains a nucleus, smooth and rough endoplasmic reticulum, Golgi apparatus, mitochondria, and other cellular components. Neurons also contain unique structures for receiving and sending the electrical signals that make communication between neurons possible (Figure 3.1.1). Dendrites are tree-like structures that extend away from the cell body to receive messages from other neurons at specialized junctions called synapses. Although some neurons do not have any dendrites, most have one or many dendrites.

The bilayer lipid membrane that surrounds a neuron is impermeable to ions. To enter or exit the neuron, ions must pass through ion channels that span the membrane. Some ion channels need to be activated to open and allow ions to pass into or out of the cell. These ion channels are sensitive to the environment and can change their shape accordingly. Ion channels that change their structure in response to voltage changes are called voltage-gated ion channels. The difference in total charge between the inside and outside of the cell is called the membrane potential.

A neuron at rest is negatively charged: the inside of a cell is approximately 70 millivolts more negative than the outside (–70 mV).

This voltage is called the resting membrane potential; it is caused by differences in the concentrations of ions inside and outside the cell and the selective permeability created by ion channels. Sodium-potassium pumps in the membrane produce the different ion concentrations inside and outside of the cell by bringing in two K^+ions and removing three Na^+ ions. The actions of this pump are costly: one molecule of ATP is used up for each turn. Up to 50 percent of a neuron's ATP is used in maintaining its membrane resting potential. Potassium ions (K^+), which are higher inside the cell, move fairly freely out of the neuron through potassium channels; this loss of positive charge produces a net negative charge inside the cell. Sodium ions (Na^+), which are low inside, have a driving force to enter but move less freely. Their channels are voltage dependent and will open when a slight change in the membrane potential triggers them.

A neuron can receive input from other neurons and, if this input is strong enough, send the signal to downstream neurons. Transmission of a signal between neurons is generally carried by a chemical, called a neurotransmitter, which diffuses from the axon of one neuron to the dendrite of a second neuron. Neurotransmitters bind to receptors on the postsynaptic membrane, producing effects that may increase or decrease the likelihood of an action potential. Whether the postsynaptic neuron generates an action potential depends on the combined effects of the signals it receives. Once a signal is received by the dendrite, it then travels passively to the cell body. A large enough signal from neurotransmitters will reach the axon. If it is strong enough (that is, if the threshold of excitation, a depolarization to around –60mV is reached), then depolarization creates a positive feedback loop: as more Na^+ ions enter the cell, the axon becomes further depolarized, opening even more sodium channels at further distances from the cell body. This will cause voltage dependent Na^+ channels further down the axon to open and more positive ions to enter the cell. In the axon, this "signal" will become a self-propagating brief reversal of the resting membrane potential called an action potential.

An action potential is an all-or-nothing event; it either happens or it does not. The threshold of excitation must be reached for the neuron to "fire" an action potential. As sodium ions rush into the cell, depolarization actually reverses the charge across the membrane form -70mv to +30mV. This change in the membrane potential causes voltage-gated K^+ channels to open, and K^+ begins to leave the cell, repolarizing it. At the same time, Na^+ channels inactivate so no more Na^+ enters the cell. K^+ ions continue to leave the cell and the membrane potential returns to the resting potential. At the resting potential, the K^+ channels close and Na^+channels reset. The depolarization of the membrane proceeds in a wave down the length of the axon. It travels in only one direction because the sodium channels have been inactivated and unavailable until the membrane potential is near the resting potential again; at this point they are reset to closed and can be opened again.

An axon is a tube-like structure that propagates the signal from the cell body to specialized endings called axon terminals. These terminals in turn then synapse with other neurons, muscle, or target organs. When the action potential reaches the axon terminal, this causes the release of neurotransmitter onto the dendrite of another neuron. Neurotransmitters released at axon terminals allow signals to be communicated to these other cells, and the process begins again. Neurons usually have one or two axons, but some neurons do not contain any axons.

Some axons are covered with a special structure called a myelin sheath, which acts as an insulator to keep the electrical signal from dissipating as it travels down the axon. This insulation is important, as the axon from a human motor neuron can be as long as a meter (3.2 ft)—from the base of the spine to the toes. The myelin sheath is produced by glial cells. Along the axon there are periodic gaps in the myelin sheath. These gaps are called nodes of Ranvier and are sites where the signal is "recharged" as it travels along the axon.

It is important to note that a single neuron does not act alone—neuronal communication depends on the connections that neurons make with one another (as well as with other cells, like muscle cells). Dendrites from a single neuron may receive synaptic contact from many other neurons. For example, dendrites from a Purkinje cell in the cerebellum are thought to receive contact from as many as 200,000 other neurons.

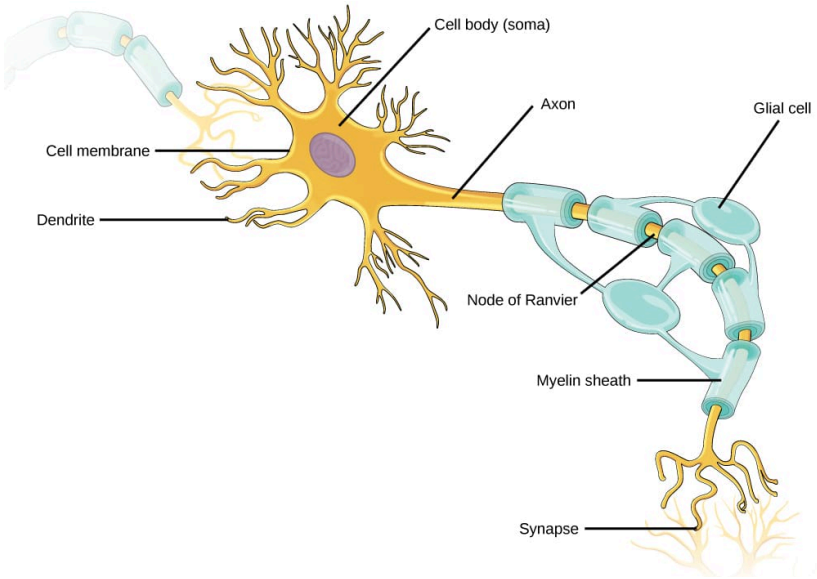


Figure 3.1.1: Neurons contain organelles common to other cells, such as a nucleus and mitochondria. They also have more specialized structures, including dendrites and axons.

BIOLOGY IN ACTION: Neurogenesis

At one time, scientists believed that people were born with all the neurons they would ever have. Research performed during the last few decades indicates that neurogenesis, the birth of new neurons, continues into adulthood. Neurogenesis was first discovered in songbirds that produce new neurons while learning songs. FResearch in some mammals has shown that new neurons develop in the hippocampus, a brain structure involved in learning and memory, during adulthood. Although many of these neurons do not survive, researchers have found that an increase in the number of surviving new neurons in the hippocampus is associated with better performance on learning tasks in rats. The extent of adult hippocampal neurogenesis in humans remains an area of ongoing research. Interestingly, both exercise and some antidepressant medications also promote neurogenesis in the hippocampus. Stress has the opposite effect. While neurogenesis is quite limited compared to regeneration in other tissues, research in this area may lead to new treatments for disorders such as Alzheimer's, stroke, and epilepsy.

How do scientists identify new neurons? A researcher can inject a compound called bromodeoxyuridine (BrdU) into the brain of an animal. While all cells will be exposed to BrdU, BrdU will only be incorporated into the DNA of newly generated cells that are in S phase. A technique called immunohistochemistry can be used to attach a fluorescent label to the incorporated BrdU, and a researcher can use fluorescent microscopy to visualize the presence of BrdU, and thus new neurons, in brain tissue (Figure 3.1.2).

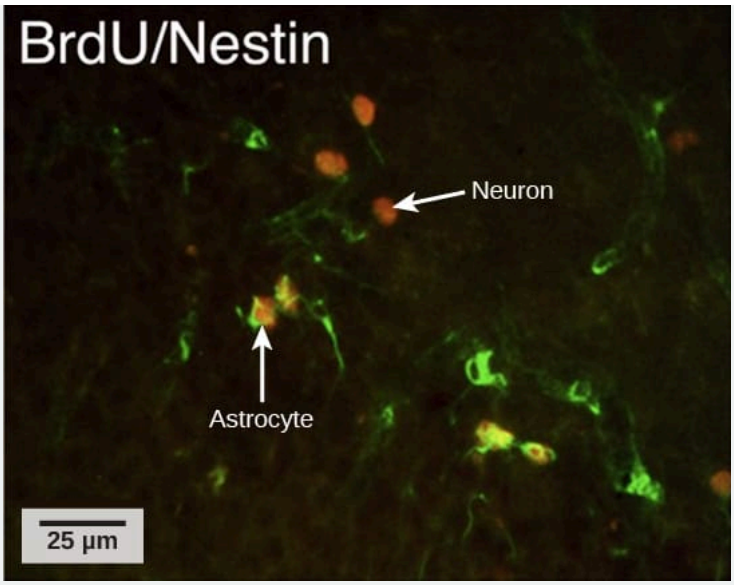


Figure 3.1.2: This image shows new neurons in a rat hippocampus. New neurons tagged with BrdU glow red in this micrograph. (credit: modification of work by Dr. Maryam Faiz, University of Barcelona)

CONCEPT IN ACTION

Visit this link interactive lab to see more information about neurogenesis, including an interactive laboratory simulation and a video that explains how BrdU labels new cells.

Glial cells play essential supporting roles in the nervous system and are approximately as numerous as neurons in the human brain, although their relative proportions vary across different brain regions. Neurons would be unable to function without the vital roles that are fulfilled by these glial cells. Glia guide developing neurons to their destinations, buffer ions and chemicals that would otherwise harm neurons, and provide myelin sheaths around axons. When glia do not function properly, the result can be disastrous—most brain tumors are caused by mutations in glia.

How Neurons Communicate

All functions performed by the nervous system—from a simple motor reflex to more advanced functions like making a memory or a decision—require neurons to communicate with one another. Neurons communicate between the axon of one neuron and the dendrites, and sometimes the cell body, of another neuron across the gap between them, known as the synaptic cleft. When an action potential reaches the end of an axon it stimulates the release of neurotransmitter molecules into the synaptic cleft between the synaptic knob of the axon and the post-synaptic membrane of the dendrite or soma of the next cell. The neurotransmitter is released through exocytosis of vesicles containing the neurotransmitter molecules. The neurotransmitter diffuses across the synaptic cleft and binds to receptors in the post-synaptic membrane. These receptor molecules are chemically regulated ion channels and will open, allowing sodium to enter the cell. If sufficient neurotransmitter has been released an action potential may be initiated in the next cell, but this is not guaranteed. If insufficient neurotransmitter is released the nerve signal will die at this point. There are a number of different neurotransmitters that are specific to neuron types that have specific functions.

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3.2: Action Potentials and Neural Communication Lab

Action Potentials and Neural Communication

Neurons communicate through electrical and chemical signals. An action potential is a rapid change in electrical potential across a neuron's membrane that propagates along its axon, allowing information to travel through the nervous system.

In this lab, you will use the PhET Neuron simulation (an online neuron simulator) to investigate how action potentials occur. You will observe the movement of sodium (Na^+) and potassium (K^+) ions, changes in membrane potential, and the opening and closing of membrane channels. You will also examine how these processes contribute to neural communication.

Materials Needed

- Computer, tablet, or other compatible device with internet access
- PhET Neuron simulation embedded on this page

Procedure

1. Locate the PhET Neuron simulation below.
2. Familiarize yourself with the simulation. The image represents a cross-section of an axon, allowing you to observe what happens at a small portion of the neuron's membrane as an action potential passes through.
3. Locate the "Stimulate Neuron" button and the options under "Show." Check all the boxes to display the available information.
4. Click "Stimulate Neuron" and observe what happens. Pay attention to the movement of ions, changes in membrane potential, and the opening and closing of membrane channels.
5. Experiment with the simulation controls. Practice pausing, adjusting the speed, zooming in and out, and reviewing the membrane potential graph.
6. Run the simulation multiple times as needed to complete the observations and questions below. Slowing down or pausing the simulation may help you identify changes that happen very quickly.

PhET Interactive Simulations, University of Colorado Boulder. (n.d.). Neuron [Interactive simulation]. https://phet.colorado.edu/en/simulations/neuronLinks to an external site.

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Lab Report

1. **Before stimulating the neuron, observe the axon membrane at rest.**
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2. **Observe the movement of sodium and potassium ions through the leak channels while the neuron is at rest.**
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3. **Click "Stimulate Neuron" and observe the graph showing how the membrane potential changes over time. Draw a copy of this graph, including labels and units for both axes. On your drawing, label the five stages of the action potential and upload an image of your drawing:**
    1. **Resting membrane potential**
    2. **Depolarization**
    3. **Peak of the action potential**
    4. **Repolarization**
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4. **Use the simulation to complete the following table. Record approximate membrane potentials and describe the behavior of the ion channels during each phase.**

Phase	Approximate membrane potential or range (mV)	Sodium channel activity	Potassium channel act
Resting potential			
Depolarization			
Peak of action potential			
Repolarization			

Hyperpolarization			

5. **Observe the sodium and potassium ions as the action potential occurs.**
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7. **Observe the "Stimulate Neuron" button during and immediately after an action potential. At certain points, the button becomes unavailable.**
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12. **Why is it important for neurons to maintain different concentrations of sodium and potassium ions inside and outside their membranes? Predict what might happen to neural communication if these concentration gradients could no longer be maintained.**

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4: NEUROANATOMY AND THE CRANIAL NERVES

4.1: Brain Anatomy and Organization
4.2: The 12 Cranial Nerves
4.3: Human Neuroanatomy and Cranial Nerves Lab
4.4: Sheep Brain Dissection and Comparative Neuroanatomy Lab

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4.1: Brain Anatomy and Organization

Skills to Develop

- Identify the spinal cord, cerebral lobes, and other brain areas on a diagram of the brain
- Describe the basic functions of the spinal cord, cerebral lobes, and other brain areas

The central nervous system (CNS) is made up of the brain, a part of which is shown in Figure 4.1.1 and spinal cord and is covered with three layers of protective coverings called meninges (from the Greek word for membrane). The outermost layer is the dura mater (Latin for "hard mother"). As the Latin suggests, the primary function for this thick layer is to protect the brain and spinal cord. The dura mater also contains vein-like structures that carry blood from the brain back to the heart. The middle layer is the web-like arachnoid mater. The last layer is the pia mater (Latin for "soft mother"), which directly contacts and covers the brain and spinal cord like plastic wrap. The space between the arachnoid and pia maters is filled with cerebrospinal fluid (CSF). CSF is produced by a tissue called choroid plexus in fluid-filled compartments in the CNS called ventricles. The brain floats in CSF, which acts as a cushion and shock absorber and makes the brain neutrally buoyant. CSF also functions to circulate chemical substances throughout the brain and into the spinal cord.

The entire brain contains only about 8.5 tablespoons of CSF, but CSF is constantly produced in the ventricles. This creates a problem when a ventricle is blocked—the CSF builds up and creates swelling and the brain is pushed against the skull. This swelling condition is called hydrocephalus ("water head") and can cause seizures, cognitive problems, and even death if a shunt is not inserted to remove the fluid and pressure.

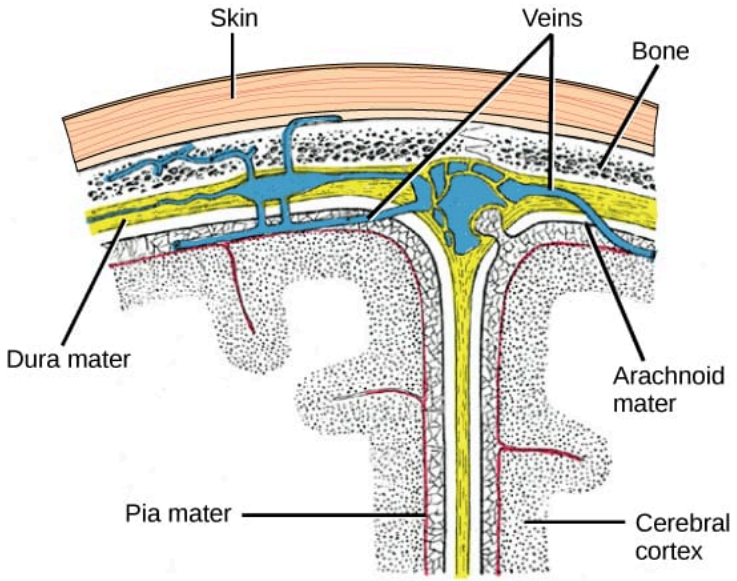


Figure 4.1.1: The cerebral cortex is covered by three layers of meninges: the dura, arachnoid, and pia maters. (credit: modification of work by Gray's Anatomy)

Brain

The brain is the part of the central nervous system that is contained in the cranial cavity of the skull. It includes the cerebral cortex, limbic system, basal ganglia, thalamus, hypothalamus, and cerebellum. There are three different ways that a brain can be sectioned in order to view internal structures: a sagittal section cuts the brain left to right, as shown in Figure 4.1.2**b**, a coronal section cuts the brain front to back, as shown in Figure 4.1.2**a**, and a horizontal section cuts the brain top to bottom.

Cerebral Cortex

The outermost part of the brain is a thick piece of nervous system tissue called the cerebral cortex, which is folded into hills called gyri (singular: gyrus) and valleys called sulci (singular: sulcus). The cortex is made up of two hemispheres—right and left—which are separated by a large sulcus. A thick fiber bundle called the corpus callosum (Latin: “tough body”) connects the two hemispheres and allows information to be passed from one side to the other. Although there are some brain functions that are localized more to one hemisphere than the other, the functions of the two hemispheres are largely redundant. In fact, sometimes (very rarely) an entire hemisphere is removed to treat severe epilepsy. While patients do suffer some deficits following the surgery, they can have surprisingly few problems, especially when the surgery is performed on children who have very immature nervous systems.

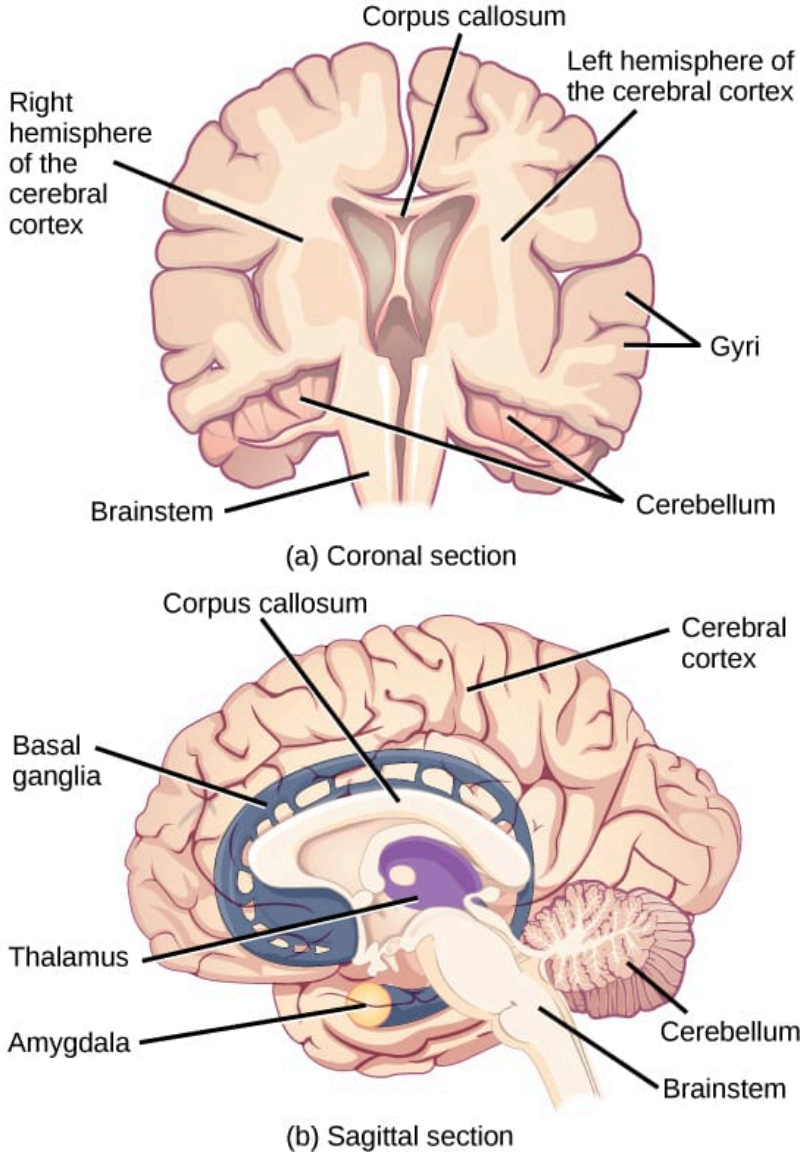


Figure 4.1.2: These illustrations show the (a) coronal and (b) sagittal sections of the human brain.

In other surgeries to treat severe epilepsy, the corpus callosum is cut instead of removing an entire hemisphere. This causes a condition called split-brain, which gives insights into unique functions of the two hemispheres. For example, when an object is presented to patients’ left visual field, they may be unable to verbally name the object (and may claim to not have seen an object at all). This is because the visual input from the left visual field crosses and enters the right hemisphere and cannot then signal to the speech center, which generally is found in the left side of the brain. Remarkably, if a split-brain patient is asked to pick up a specific object out of a group of objects with the left hand, the patient will be able to do so but will still be unable to vocally identify it.

Each cortical hemisphere contains regions called lobes that are involved in different functions. Scientists use various techniques to determine what brain areas are involved in different functions: they examine patients who have had injuries or diseases that affect specific areas and see how those areas are related to functional deficits. They also conduct animal studies where they stimulate brain areas and see if there are any behavioral changes. They use a technique called transmagnetic stimulation (TMS) to temporarily deactivate specific parts of the cortex using strong magnets placed outside the head; and they use functional magnetic resonance imaging (fMRI) to look at changes in oxygenated blood flow in particular brain regions that correlate with specific behavioral tasks. These techniques, and others, have given great insight into the functions of different brain regions but have also showed that any given brain area can be involved in more than one behavior or process, and any given behavior or process generally involves neurons in multiple brain areas. That being said, each hemisphere of the mammalian cerebral cortex can be broken down into four functionally and spatially defined lobes: frontal, parietal, temporal, and occipital. Figure 4.1.3 illustrates these four lobes of the human cerebral cortex.

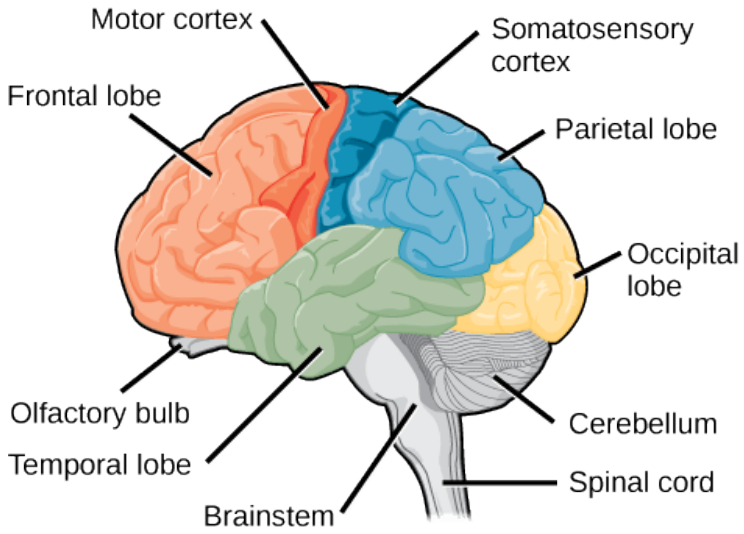


Figure 4.1.3: The human cerebral cortex includes the frontal, parietal, temporal, and occipital lobes.

The frontal lobe is located at the front of the brain, over the eyes. This lobe contains the olfactory bulb, which processes smells. The frontal lobe also contains the motor cortex, which is important for planning and implementing movement. Areas within the motor cortex map to different muscle groups, and there is some organization to this map, as shown in Figure 4.1.4. For example, the neurons that control movement of the fingers are next to the neurons that control movement of the hand. Neurons in the frontal lobe also control cognitive functions like maintaining attention, speech, and decision-making. Studies of humans who have damaged their frontal lobes show that parts of this area are involved in personality, socialization, and assessing risk.

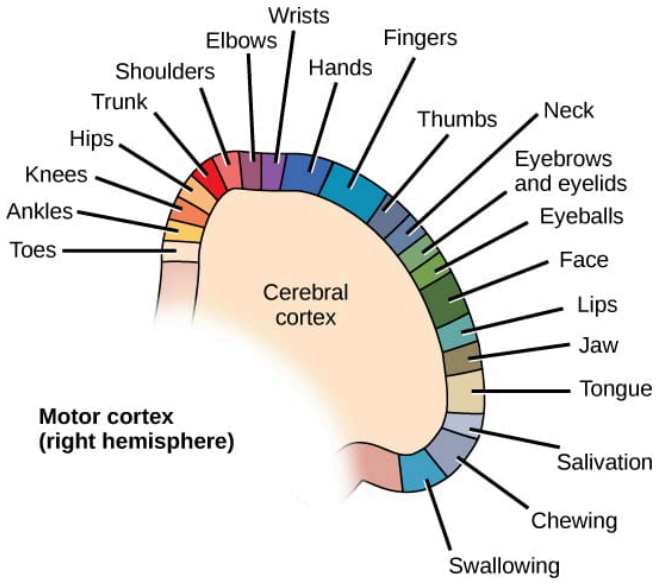


Figure 4.1.4: Different parts of the motor cortex control different muscle groups. Muscle groups that are neighbors in the body are generally controlled by neighboring regions of the motor cortex as well. For example, the neurons that control finger movement are near the neurons that control hand movement.

The parietal lobe is located at the top of the brain. Neurons in the parietal lobe are involved in speech and also reading. Two of the parietal lobe's main functions are processing somatosensation—touch sensations like pressure, pain, heat, cold—and processing proprioception—the sense of how parts of the body are oriented in space. The parietal lobe contains a somatosensory map of the body similar to the motor cortex.

The occipital lobe is located at the back of the brain. It is primarily involved in vision—seeing, recognizing, and identifying the visual world.

The temporal lobe is located at the base of the brain by your ears and is primarily involved in processing and interpreting sounds. It also contains the hippocampus (Greek for "seahorse")—a structure that processes memory formation. The hippocampus is illustrated in Figure 4.1.6. The role of the hippocampus in memory was partially determined by studying one famous epileptic patient, HM, who had both sides of his hippocampus removed in an attempt to cure his epilepsy. His seizures went away, but he could no longer form new memories (although he could remember some facts from before his surgery and could learn new motor tasks).

Evolution Connection: Cerebral Cortex

Compared to other vertebrates, mammals have exceptionally large brains for their body size. An entire alligator's brain, for example, would fill about one and a half teaspoons. This increase in brain to body size ratio is especially pronounced in apes, whales, and dolphins. While this increase in overall brain size doubtlessly played a role in the evolution of complex behaviors unique to mammals, it does not tell the whole story. Scientists have found a relationship between the relatively high surface area of the cortex and the intelligence and complex social behaviors exhibited by some mammals. This increased surface area is due, in part, to increased folding of the cortical sheet (more sulci and gyri). For example, a rat cortex is very smooth with very few sulci and gyri. Cat and sheep cortices have more sulci and gyri. Chimps, humans, and dolphins have even more.

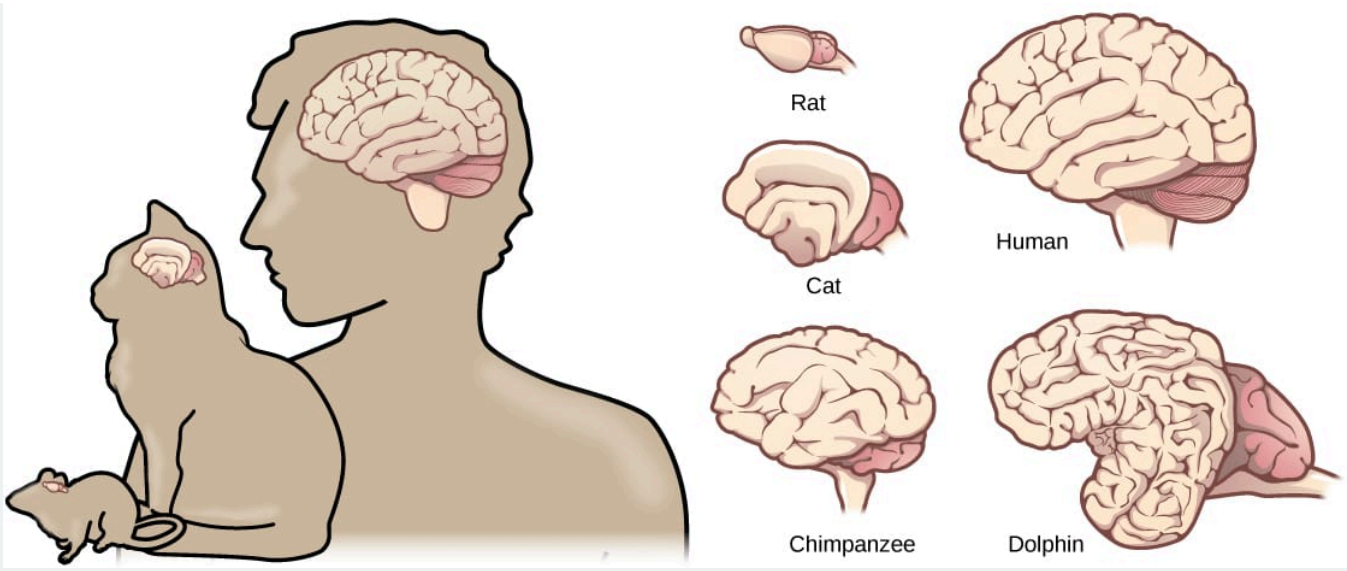


Figure 4.1.5: Mammals have larger brain-to-body ratios than other vertebrates. Within mammals, increased cortical folding and surface area is correlated with complex behavior.

Basal Ganglia

Interconnected brain areas called the basal ganglia (or basal nuclei) play important roles in movement control and posture. Damage to the basal ganglia, as in Parkinson's disease, leads to motor impairments like a shuffling gait when walking. The basal ganglia also regulate motivation. For example, when a wasp sting led to bilateral basal ganglia damage in a 25-year-old businessman, he began to spend all his days in bed and showed no interest in anything or anybody. But when he was externally stimulated—as when someone asked to play a card game with him—he was able to function normally. Interestingly, he and other similar patients do not report feeling bored or frustrated by their state.

Thalamus

The thalamus (Greek for "inner chamber"), illustrated in Figure 4.1.6, acts as a gateway to and from the cortex. It receives sensory and motor inputs from the body and also receives feedback from the cortex. This feedback mechanism can modulate conscious awareness of sensory and motor inputs depending on the attention and arousal state of the animal. The thalamus helps regulate consciousness, arousal, and sleep states. A rare genetic disorder called fatal familial insomnia causes the degeneration of thalamic neurons and glia. This disorder prevents affected patients from being able to sleep, among other symptoms, and is eventually fatal.

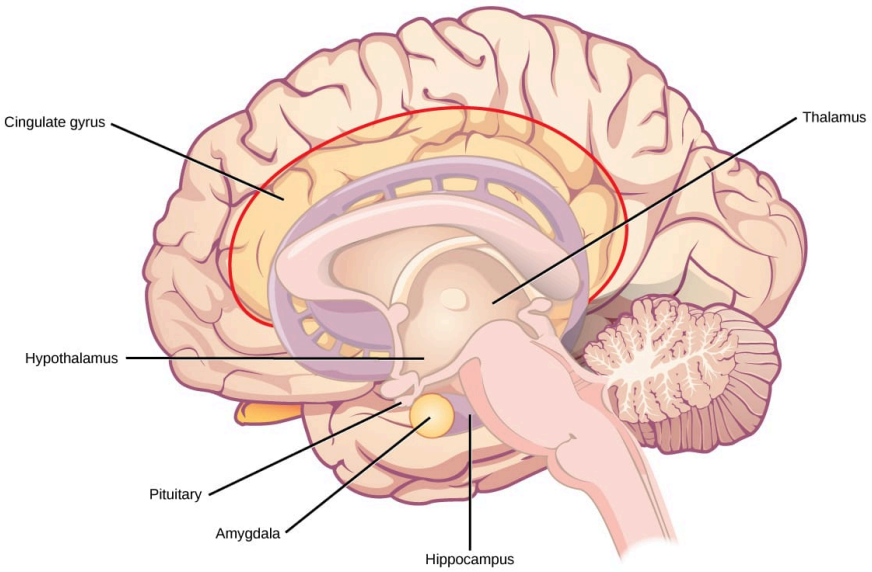


Figure 4.1.6: The limbic system regulates emotion and other behaviors. It includes parts of the cerebral cortex located near the center of the brain, including the cingulate gyrus and the hippocampus as well as the thalamus, hypothalamus and amygdala.

Hypothalamus

Below the thalamus is the hypothalamus, shown in Figure 4.1.6. The hypothalamus controls the endocrine system by sending signals to the pituitary gland, a pea-sized endocrine gland that releases several different hormones that affect other glands as well as other cells. This relationship means that the hypothalamus regulates important behaviors that are controlled by these hormones. The hypothalamus is the body's thermostat—it makes sure key functions like food and water intake, energy expenditure, and body temperature are kept at appropriate levels. Neurons within the hypothalamus also regulate circadian rhythms, sometimes called sleep cycles.

Limbic System

The limbic system is a connected set of structures that regulates emotion, as well as behaviors related to fear and motivation. It plays a role in memory formation and includes parts of the thalamus and hypothalamus as well as the hippocampus. One important structure within the limbic system is a temporal lobe structure called the amygdala (Greek for "almond"), illustrated in Figure 4.1.6. The two amygdala are important both for the sensation of fear and for recognizing fearful faces. The cingulate gyrus helps regulate emotions and pain.

Cerebellum

The cerebellum (Latin for "little brain"), shown in Figure 4.1.3, sits at the base of the brain on top of the brainstem. The cerebellum controls balance and aids in coordinating movement and learning new motor tasks.

Brainstem

The brainstem, illustrated in Figure 4.1.3, connects the rest of the brain with the spinal cord. It consists of the midbrain, medulla oblongata, and the pons. Motor and sensory neurons extend through the brainstem allowing for the relay of signals between the brain and spinal cord. Ascending neural pathways cross in this section of the brain allowing the left hemisphere of the cerebrum to control the right side of the body and vice versa. The brainstem coordinates motor control signals sent from the brain to the body. The brainstem controls several important functions of the body including alertness, arousal, breathing, blood pressure, digestion, heart rate, swallowing, walking, and sensory and motor information integration.

Spinal Cord

Connecting to the brainstem and extending down the body through the spinal column is the spinal cord, shown in Figure 4.1.3.

The spinal cord is a thick bundle of nerve tissue that carries information about the body to the brain and from the brain to the body. The spinal cord is contained within the bones of the vertebrate column but is able to communicate signals to and from the body through its connections with spinal nerves (part of the peripheral nervous system). A cross-section of the spinal cord looks like a white oval containing a gray butterfly-shape, as illustrated in Figure 4.1.7. Myelinated axons make up the "white matter" and neuron and glial cell bodies make up the "gray matter." Gray matter is also composed of interneurons, which connect two neurons each located in different parts of the body. Axons and cell bodies in the dorsal (facing the back of the animal) spinal cord convey mostly sensory information from the body to the brain. Axons and cell bodies in the ventral (facing the front of the animal) spinal cord primarily transmit signals controlling movement from the brain to the body.

The spinal cord also controls motor reflexes. These reflexes are quick, unconscious movements—like automatically removing a hand from a hot object. Reflexes are so fast because they involve local synaptic connections. For example, the knee reflex that a doctor tests during a routine physical is controlled by a single synapse between a sensory neuron and a motor neuron. While a reflex may only require the involvement of one or two synapses, synapses with interneurons in the spinal column transmit information to the brain to convey what happened (the knee jerked, or the hand was hot).

In the United States, there around 10,000 spinal cord injuries each year. Because the spinal cord is the information superhighway connecting the brain with the body, damage to the spinal cord can lead to paralysis. The extent of the paralysis depends on the location of the injury along the spinal cord and whether the spinal cord was completely severed. For example, if the spinal cord is damaged at the level of the neck, it can cause paralysis from the neck down, whereas damage to the spinal column further down may limit paralysis to the legs. Spinal cord injuries are notoriously difficult to treat because spinal nerves do not regenerate, although ongoing research suggests that stem cell transplants may be able to act as a bridge to reconnect severed nerves. Researchers are also looking at ways to prevent the inflammation that worsens nerve damage after injury. One such treatment is to pump the body with cold saline to induce hypothermia. This cooling can prevent swelling and other processes that are thought to worsen spinal cord injuries.

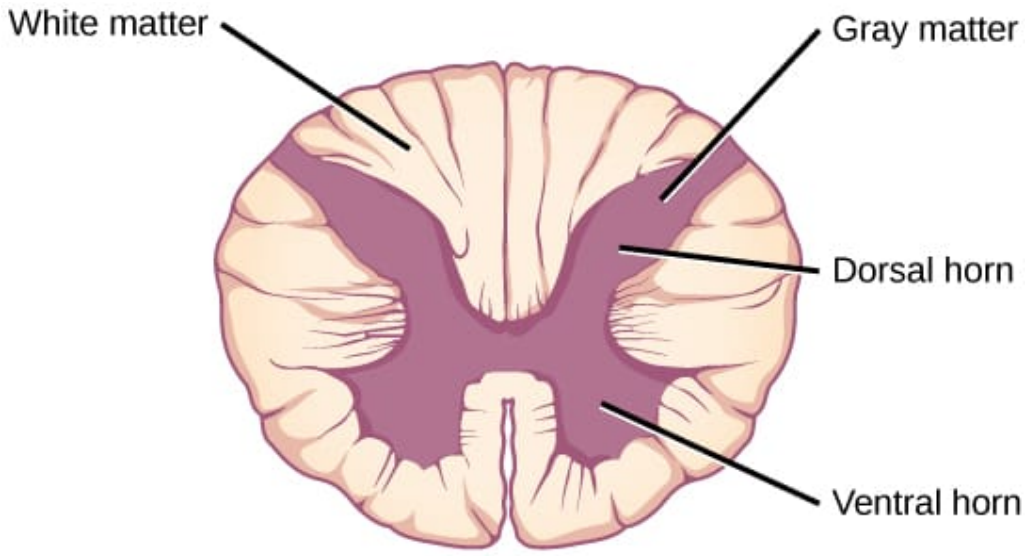


Figure 4.1.7: A cross-section of the spinal cord shows gray matter (containing cell bodies and interneurons) and white matter (containing axons).

Summary

The vertebrate central nervous system contains the brain and the spinal cord, which are covered and protected by three meninges. The brain contains structurally and functionally defined regions. In mammals, these include the cortex (which can be broken down into four primary functional lobes: frontal, temporal, occipital, and parietal), basal ganglia, thalamus, hypothalamus, limbic system, cerebellum, and brainstem—although structures in some of these designations overlap. While functions may be primarily localized to one structure in the brain, most complex functions, like language and sleep, involve neurons in multiple brain regions. The spinal cord is the information superhighway that connects the brain with the rest of the body through its connections with peripheral nerves. It transmits sensory and motor input and also controls motor reflexes.

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4.2: The 12 Cranial Nerves

Cranial Nerves

The nerves attached to the brain are the cranial nerves, which are primarily responsible for the sensory and motor functions of the head and neck (with the exception of one that targets organs in the thoracic and abdominal cavities as part of the parasympathetic nervous system). There are twelve cranial nerves, which are designated CNI through CNXII for "Cranial Nerve," using Roman numerals for 1 through 12, based on the anatomical location on the inferior view of the brain, from anterior to posterior (Figure 4.2.3). They can be classified as sensory nerves, motor nerves, or a combination of both, meaning that the axons in these nerves originate out of sensory ganglia external to the cranium or motor nuclei within the brainstem. Sensory axons enter the brain to synapse in a nucleus. Motor axons connect to skeletal muscles of the head or neck. Three of the nerves are solely composed of sensory fibers; five are strictly motor; and the remaining four are mixed nerves.

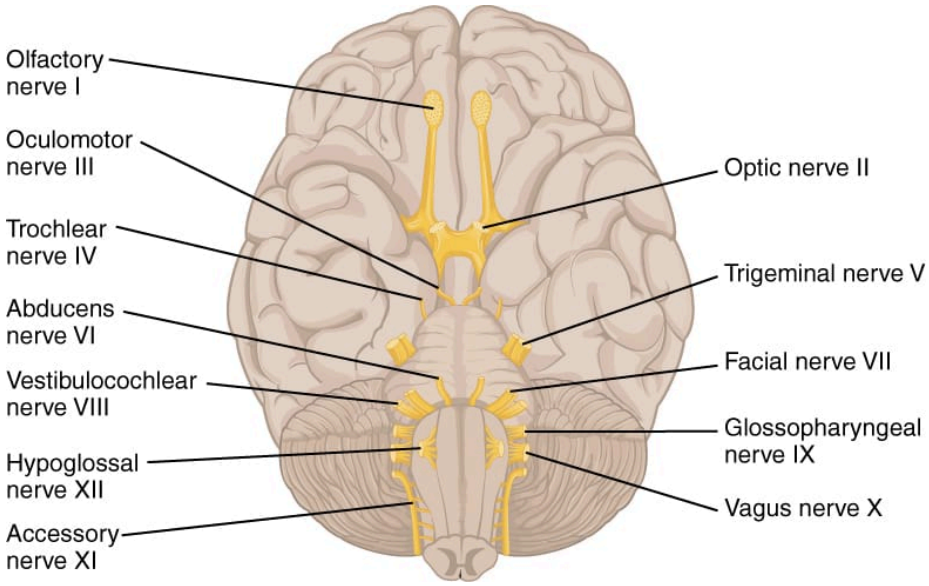


Figure 4.2.3: The anatomical arrangement of the roots of the cranial nerves observed from an inferior view of the brain. Cranial nerves are numbered with Roman numbers from 1 to 12 based on their exit from the brain, from anterior to posterior. (CC BY 3.0; via Cranial Nerves).
Alternate text description of the Figure 4.2.3.

Learning the cranial nerves is a tradition in anatomy courses, and students have always used mnemonic devices to remember the nerve names. A traditional mnemonic is the rhyming couplet, "Oh Oh Oh To Touch And Feel Very Good Velvet Ah Heaven," in which the initial letter of each word corresponds to the initial letter in the name of each nerve. The names of the nerves have changed over the years to reflect current usage and more accurate naming. An exercise to help learn this sort of information is to generate a mnemonic using words that have personal significance. The names of the cranial nerves are listed in Table 4.2.1 along with a brief description of their function, their source (sensory ganglion or motor nucleus), and their target (sensory nucleus or skeletal muscle). The **olfactory nerve** and **optic nerve** are responsible for the sense of smell and vision, respectively. The **oculomotor nerve** is responsible for eye movements by controlling four of the extraocular muscles. It is also responsible for lifting the upper eyelid when the eyes point up, and for pupillary constriction. The **trochlear nerve** and the **abducens nerve** are both responsible for eye movement, but do so by controlling different extraocular muscles. The **trigeminal nerve** is responsible for cutaneous sensations of the face and controlling the muscles of mastication. The **facial nerve** is responsible for the muscles involved in facial expressions, as well as part of the sense of taste and the production of saliva. The **vestibulocochlear nerve** is responsible for the senses of hearing and balance. The **glossopharyngeal nerve** is responsible for controlling muscles in the oral cavity and upper throat, as well as part of the sense of taste and the production of saliva. The **vagus nerve** is responsible for contributing to homeostatic control of the organs of the thoracic and upper abdominal cavities. The **accessory nerve** is responsible for controlling the muscles of the neck, along with cervical spinal nerves. The **hypoglossal nerve** is responsible for controlling the muscles of the lower throat and tongue.

Four of these cranial nerves make up the cranial component of the autonomic nervous system responsible for pupillary

constriction (oculomotor nerve), salivation and lacrimation (facial and glossopharyngeal nerves), and the regulation of the organs of the thoracic and upper abdominal cavities (vagus nerve).

Three of the cranial nerves also contain autonomic fibers, and a fourth is almost purely a component of the autonomic system. The oculomotor, facial, and glossopharyngeal nerves contain fibers that contact autonomic ganglia. The oculomotor fibers initiate pupillary constriction, whereas the facial and glossopharyngeal fibers both initiate salivation. The vagus nerve primarily targets autonomic ganglia in the thoracic and upper abdominal cavities.

Another important aspect of the cranial nerves that lends itself to a mnemonic is the functional role each nerve plays. The nerves fall into one of three basic groups. They are sensory, motor, or both (see Table 4.2.1). The sentence, "Some Say Marry Money But My Brother Says Brains Beauty Matter More," corresponds to the basic function of each nerve. The first, second, and eighth nerves are purely sensory: the olfactory (CNI), optic (CNII), and vestibulocochlear (CNVIII) nerves. The three eye-movement nerves are all motor: the oculomotor (CNIII), trochlear (CNIV), and abducens (CNVI). The accessory (CNXI) and hypoglossal (CNXII) nerves are also strictly motor. The remainder of the nerves contain both sensory and motor fibers. They are the trigeminal (CNV), facial (CNVII), glossopharyngeal (CNIX), and vagus (CNX) nerves. The nerves that convey both are often related to each other. The trigeminal and facial nerves both concern the face; one concerns the sensations and the other concerns the muscle movements. The facial and glossopharyngeal nerves are both responsible for conveying gustatory, or taste, sensations as well as controlling salivary glands. The vagus nerve is involved in visceral responses to taste, namely the gag reflex. This is not an exhaustive list of what these combination nerves do, but there is a thread of relation between them.

Table 4.2.1: Cranial Nerves

Mnemonic	Number	Name	Function (S/M/B)	Central connection (nuclei)	Peripheral connection (ganglion or muscle)
Oh	I	Olfactory	Smell (S)	Olfactory bulb	Olfactory epithelium
Oh	II	Optic	Vision (S)	Hypothalamus/thalamus/midbrain	Retina (retinal ganglion cells)
Oh	III	Oculomotor	Eye movements (M)	Oculomotor nucleus	Extraocular muscles (other 4), levator palpebrae superioris, ciliary ganglion (autonomic)
To	IV	Trochlear	Eye movements (M)	Trochlear nucleus	Superior oblique muscle
Touch	V	Trigeminal	Sensory/motor – face (B)	Trigeminal nuclei in the midbrain, pons, and medulla	Trigeminal
And	VI	Abducens	Eye movements (M)	Abducens nucleus	Lateral rectus muscle
Feel	VII	Facial	Motor – face, Taste (B)	Facial nucleus, solitary nucleus, superior salivatory nucleus	Facial muscles, Geniculate ganglion, Pterygopalatine ganglion (autonomic)
Very	VIII	Vestibulocochlear	Hearing/balance (S)	Cochlear nucleus, Vestibular nucleus/cerebellum	Spiral ganglion (hearing), Vestibular ganglion (balance)
Good	IX	Glossopharyngeal	Motor – throat Taste (B)	Solitary nucleus, inferior salivatory nucleus, nucleus ambiguus	Pharyngeal muscles, Geniculate ganglion, Otic ganglion (autonomic)
Velvet	X	Vagus	Motor/sensory – viscera (autonomic) (B)	Medulla	Terminal ganglia serving thoracic and upper abdominal organs (heart and small intestines)
Ah	XI	Accessory	Motor – head and neck (M)	Spinal accessory nucleus	Neck muscles
Heaven	XII	Hypoglossal	Motor – lower throat (M)	Hypoglossal nucleus	Muscles of the larynx and lower pharynx

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4.3: Human Neuroanatomy and Cranial Nerves Lab

This lab is divided into two weeks. Week 1 focuses on human neuroanatomy using MIT's Introduction to Neuroanatomy series. Week 2 focuses on sheep brain dissection and comparative neuroanatomy using the University of Guelph's virtual dissection resource.

Students will complete a separate lab report for each week.

WEEK 1: Human Neuroanatomy and Cranial Nerves Lab

Lab Objectives

By completing this lab, students will be able to:

1. Identify major structures of the human brain and describe their functions.
2. Apply anatomical terminology to describe brain structures and their locations.
3. Distinguish between gray matter and white matter.
4. Identify the 12 cranial nerves and explain their primary functions.
5. Explain how damage to selected brain structures can affect behavior.

Materials

- Paper and drawing materials or digital drawing software
- MIT Introduction to Neuroanatomy Series:

YouTube Video

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Procedure

Part 1: Anatomical Orientation and Brain Structures

1. Watch Part 1 of the MIT Introduction to Neuroanatomy series.
2. Identify the frontal, parietal, temporal, and occipital lobes. Review the primary functions associated with each lobe.
3. Familiarize yourself with the three anatomical planes: sagittal, coronal, and horizontal (axial).
4. Review the anatomical directional terms introduced in the video, including dorsal, ventral, medial, lateral, rostral, caudal, anterior, posterior, ipsilateral, and contralateral.
5. Watch Part 2 of the series.
6. Examine the differences between gray matter and white matter. Identify the cerebral cortex, gyri, sulci, and corpus callosum.
7. Pay attention to the discussion of hemispheric specialization, including Broca's area, Wernicke's area, and split-brain patients.

Part 2: Cranial Nerves and Sensory-Motor Functions

1. Watch Part 3 of the MIT series.
2. Identify the olfactory bulbs, optic nerves, optic chiasm, brainstem, and cerebellum.
3. Review the 12 cranial nerves introduced in the video. For each nerve, identify its number, name, and primary function.
4. Determine whether each cranial nerve is sensory, motor, or mixed.
5. Pay particular attention to the nerves involved in vision, eye movement, facial sensation, facial expression, hearing, and balance.
6. Review the relationship between the cerebellum and motor coordination, including the effects of cerebellar damage.

Part 3: Internal Brain Structures and Behavior

1. Watch Part 4 of the MIT series.
2. Identify the hippocampus, amygdala, basal ganglia, and thalamus.
3. Review the role of the hippocampus in memory formation, including the case of Patient H.M.

4. Examine how the amygdala contributes to emotional processing and how the basal ganglia contribute to movement and habit formation.
5. Review the role of the thalamus in sensory processing.

Lab Report Questions – Week 1

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4.4: Sheep Brain Dissection and Comparative Neuroanatomy Lab

WEEK 2: Sheep Brain Dissection and Comparative Neuroanatomy Lab

Lab Objectives

By completing this lab, students will be able to:

1. Identify major external and internal structures of the sheep brain.
2. Apply anatomical terminology to describe the orientation and location of brain structures.
3. Locate visible cranial nerves and other structures involved in sensory processing.
4. Compare the anatomical organization of sheep and human brains.
5. Explain how anatomical similarities and differences relate to nervous system function.

Materials

- University of Guelph Sheep Brain Dissection: https://www.uoguelph.ca/psychology/node/1485
- Paper and drawing materials or digital drawing software

Procedure

Part 1: External Anatomy of the Sheep Brain

1. Open the University of Guelph Sheep Brain Dissection resource.
2. Begin by examining the external anatomy of the sheep brain. Observe its overall shape and orientation.
3. Examine the dorsal surface. Identify the cerebral hemispheres, longitudinal fissure, gyri, sulci, and cerebellum.
4. Examine the ventral surface. Locate the olfactory bulbs, optic chiasm, pons, and medulla oblongata.
5. Examine the cranial nerves visible on the ventral surface of the sheep brain. Identify as many as possible using the dissection resource. Not all 12 cranial nerves will be visible.
6. Create an original drawing of the ventral surface of the sheep brain. Label the olfactory bulbs, optic chiasm, pons, medulla oblongata, and any additional cranial nerves you can identify.

Part 2: Internal Anatomy of the Sheep Brain

1. Navigate to the midsagittal dissection of the sheep brain.
2. Identify the corpus callosum, thalamus, hypothalamus, cerebellum, midbrain, pons, and medulla oblongata.
3. Examine the internal structure of the cerebellum. Identify the arbor vitae and observe how white matter is distributed within the cerebellum.
4. Locate the ventricles visible in the midsagittal section. Consider how these spaces are positioned relative to surrounding brain structures.
5. Identify any additional structures visible in the dissection, such as the fornix, pineal gland, and superior and inferior colliculi.
6. Create an original drawing of the midsagittal sheep brain. Label at least eight anatomical structures.

Part 3: Comparative Neuroanatomy

1. Using your observations from the sheep brain dissection and your knowledge of human neuroanatomy from Week 1, compare the organization of the two brains.
2. Consider the relative size and position of the cerebrum, cerebellum, brainstem, and olfactory bulbs.
3. Examine the differences in cortical folding between sheep and humans.

4. Consider how differences in sensory abilities, movement, and behavior may relate to the anatomical differences you observe.

Lab Report Questions – Week 2

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6. **Submit your two original, labeled drawings. Your drawings should accurately represent the relative positions of the structures. Artistic ability will not be graded. You may draw by hand and upload photographs or create digital drawings.**

    - **Ventral view of the sheep brain, identifying the olfactory bulbs, optic chiasm, pons, medulla oblongata, and any additional visible cranial nerves.**

    - **Midsagittal view of the sheep brain, labeling at least eight anatomical structures.**

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5: SENSORY PROCESSING AND REACTION TIME

5.1: Physiology of Hearing and Vision
5.2: Hearing Thresholds and Hearing Loss
5.3: Investigating Cognitive Processing Using Reaction Time
5.4: Reaction Time and Cognitive Processing Lab

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5.1: Physiology of Hearing and Vision

Audition (Hearing)

Hearing, or **audition**, is the transduction of sound waves into a neural signal that is made possible by the structures of the ear (Figure 5.1.1). The large, fleshy structure on the lateral aspect of the head is known as the **auricle**. Some sources will also refer to this structure as the pinna, though that term is more appropriate for a structure that can be moved, such as the external ear of a cat. The C-shaped curves of the auricle direct sound waves toward the **auditory canal**, also called **ear canal**. The canal enters the skull through the external auditory meatus of the temporal bone. At the end of the auditory canal is the **tympanic membrane**, or ear drum, which vibrates after it is struck by sound waves. The auricle, ear canal, and tympanic membrane are often referred to as the **external ear**. The **middle ear** consists of a space spanned by three small bones called the **ossicles**. The three ossicles are the **malleus**, **incus**, and **stapes**, which are Latin names that roughly translate to hammer, anvil, and stirrup. The malleus is attached to the tympanic membrane and articulates with the incus. The incus, in turn, articulates with the stapes. The stapes is then attached to the **inner ear**, where the sound waves will be transduced into a neural signal. The middle ear is connected to the pharynx through the **Eustachian (or auditory) tube**, which helps equilibrate air pressure across the tympanic membrane. The tube is normally closed but will pop open when the muscles of the pharynx contract during swallowing or yawning. This helps to equalize the pressure on both sides of the ear drum with change in altitude, such as driving up the mountain or in a plane.

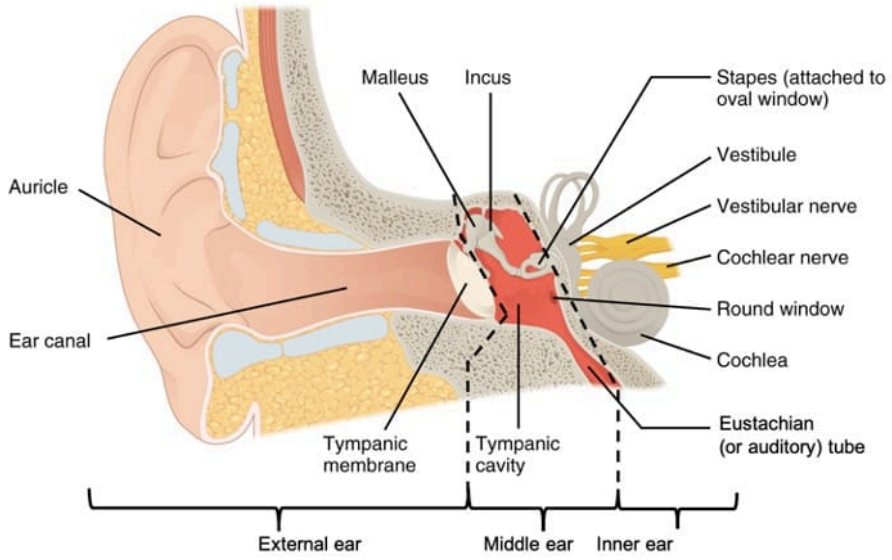


Figure 5.1.1: The external ear contains the auricle, ear canal, and tympanic membrane. The middle ear contains the ossicles and is connected to the pharynx by the Eustachian (or auditory) tube. The inner ear contains the cochlea and vestibule, which are responsible for audition and equilibrium, respectively. (CC BY 4.0 via Hearing, Balance and Vision). Alternative text description of the Figure 5.1.1.

Sound is transduced into neural signals within the cochlear region of the inner ear, which contains the sensory neurons of the **spiral ganglia**. These ganglia are located within the spiral-shaped cochlea of the inner ear. The cochlea is attached to the stapes through the **oval window**. The oval window is located at the beginning of a fluid-filled tube within the cochlea called the **scala vestibuli**. The scala vestibuli extends from the oval window, traveling above the **cochlear duct**, which is the central cavity of the cochlea that contains the sound-transducing neurons. At the uppermost tip of the cochlea, the scala vestibuli curves over the top of the cochlear duct. The fluid-filled tube, now called the **scala tympani**, returns to the base of the cochlea, this time traveling under the cochlear duct. The scala tympani ends at the **round window**, which is covered by a membrane that contains the fluid within the scala.

A cross-sectional view of the cochlea shows that the scala vestibuli and scala tympani run along both sides of the cochlear duct (Figure 5.1.2 and Figure 5.1.3). The cochlear duct contains several **organs of Corti**, which transduce the wave motion of the two scala into neural signals. The organs of Corti lie on top of the **basilar membrane**, which is the side of the cochlear duct located between the organs of Corti and the scala tympani. Another membrane called the **vestibular membrane** separates the cochlear duct from the scala vestibuli.

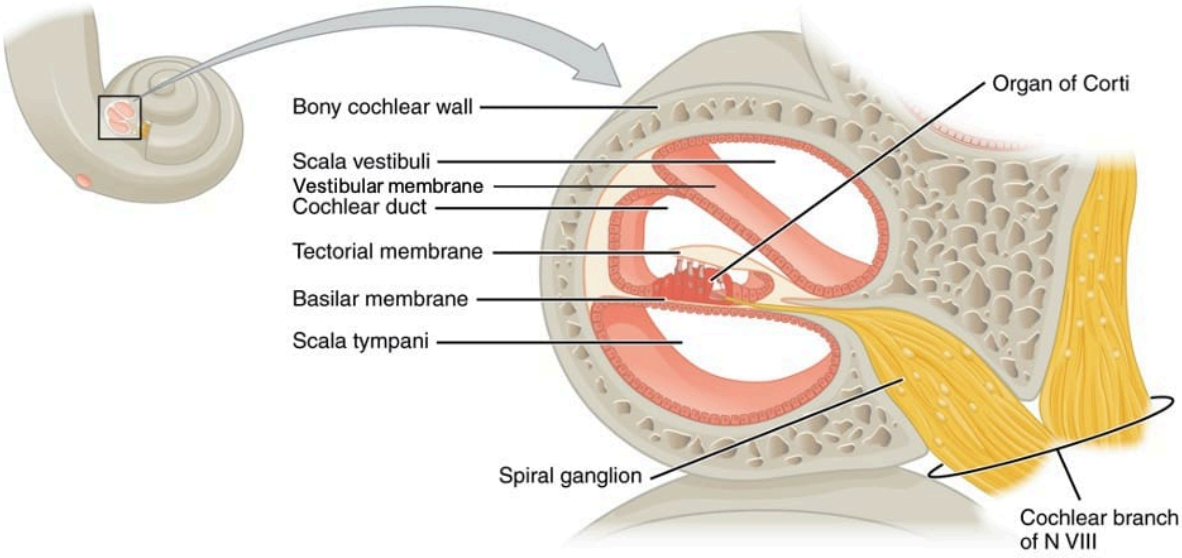


Figure 5.1.2: The membranous labyrinth separates the cochlea in three major regions. The scala vestibuli and scala tympani lie on either side of the cochlear duct. The roof of the cochlear duct is formed by the vestibular memrbane while the base of it is formed by the basilar membrane. Within the cochlear duct, the organ of Corti sits atop the basilar membrane and its cells extend towards the tectorial membrane. (CC BY 4.0 via Hearing, Balance and Vision). Alternative text description of the Figure 5.1.2.

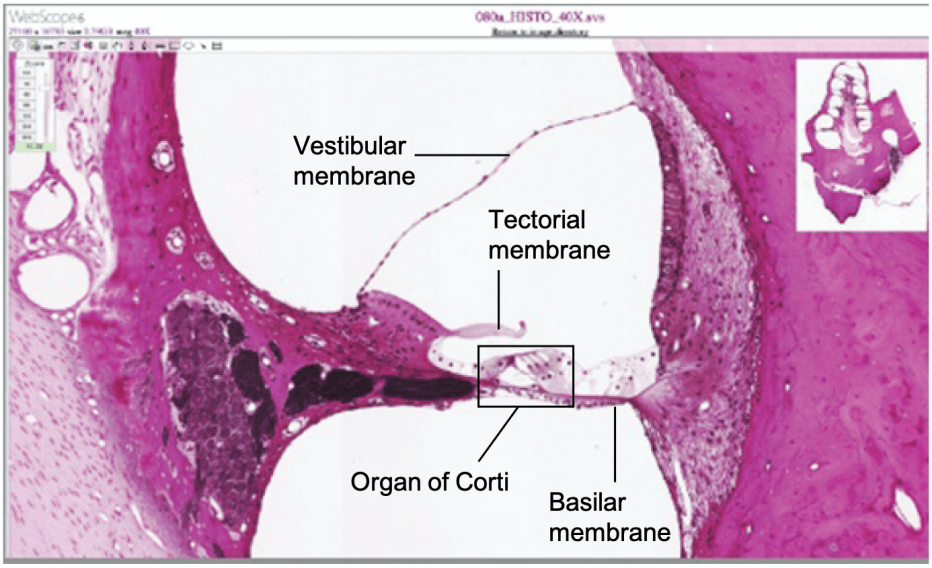


Figure 5.1.3: The organ of Corti sits on the basilar membrane and extends towards the tectorial membrane. The vestibular membrane forms the roof of the cochlear duct. LM × 412. (CC BY 4.0 via Hearing, Balance and Vision). Alternative text description of the Figure 5.1.3.

The organs of Corti contain **hair cells**, which are named for the hair-like **stereocilia** extending from the cell's apical surfaces (Figure 5.1.4). The stereocilia are an array of microvilli-like structures arranged from tallest to shortest. Protein fibers tether adjacent hairs together within each array, such that the array will bend in response to movements of the basilar membrane. The stereocilia extend up from the hair cells to the overlying **tectorial membrane**, which is attached medially to the organ of Corti.

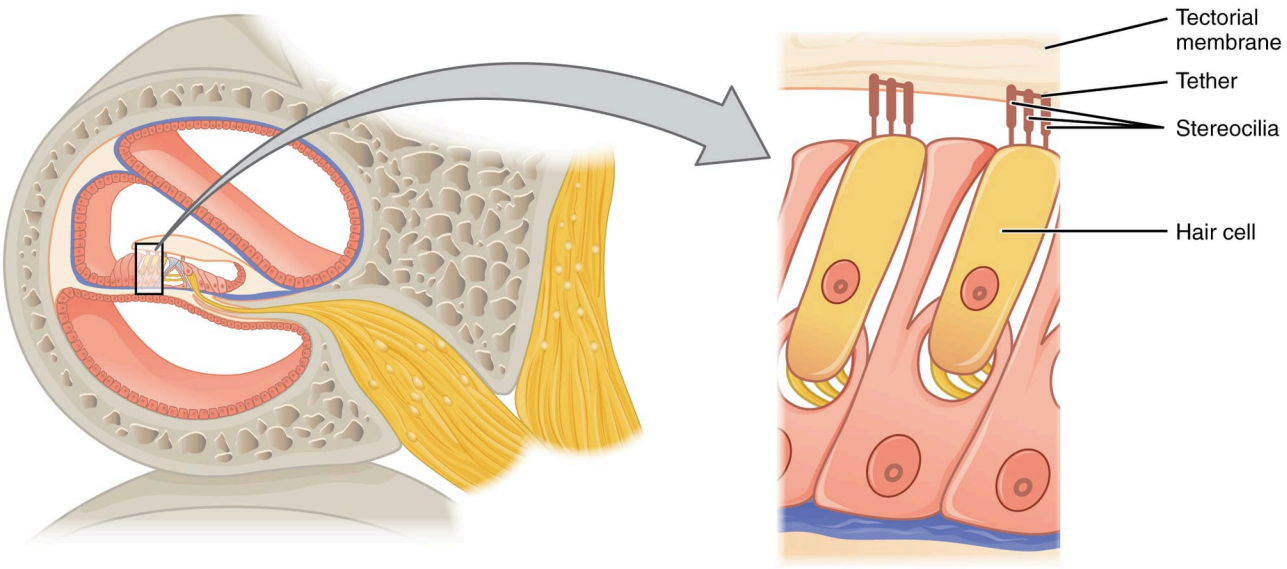


Figure 5.1.4: The hair cell is a mechanoreceptor with an array of stereocilia emerging from its apical surface. The stereocilia extend towards the tectorial membrane. The stereocilia are tethered together by proteins and bend in response to movements of the basilar membrane. (CC BY 4.0 via Hearing, Balance and Vision). Alternative text description of the Figure 5.1.4.

The transmission and transduction of sound require the participation of the majority of the structures of the ear. Each sound wave has a specific frequency, which depends on its pitch, and amplitude, which depends on its loudness. Sound waves are funneled into the ear canal by the auricle and reach the tympanic membrane (Figure 5.1.5). The vibration of the tympanic membrane is amplified across the ossicles. As vibrations of the ossicles travel through the oval window, the fluid of the scala vestibuli and scala tympani moves in a wave-like motion. The frequency of the fluid waves match the frequencies of the sound waves. The membrane covering the round window will bulge out or pucker in with the movement of the fluid within the scala tympani. As the fluid waves move through the scala vestibuli and scala tympani, the basilar membrane moves at a specific spot of the cochlea, depending on the frequency of the waves. Higher frequency waves move the region of the basilar membrane that is close to the base of the cochlea. Lower frequency waves move the region of the basilar membrane that is near the tip of the cochlea. When the fluid waves from the scala move the basilar membrane, the tectorial membrane slides across the stereocilia. This bends the stereocilia either toward or away from the tallest member of each array of stereocilia. When the stereocilia bend toward the tallest member of their array, tension in the protein tethers opens ion channels in the hair cell membrane. This will electrically change the hair cell membrane, triggering nerve impulses that travel down the afferent nerve fibers attached to the hair cells. When the stereocilia bend toward the shortest member of their array, the tension on the tethers slackens and the ion channels close. The relative movement of different arrays of stereocilia along the length of the basilar membrane allows the brain to perceive frequency, or pitch. The greater force of louder sounds causes an increase in the range of movement of the stereocilia of the hair cells, determining the loudness of a sound. The hair cells then transmit neural signals through the release of neurotransmitters to the **cochlear nerve** which travels within the **vestibulocochlear nerve (CN VIII)**. The nerve carries the auditory information into the brain, through the **thalamus**, and into the **primary auditory cortex** of the temporal lobe.

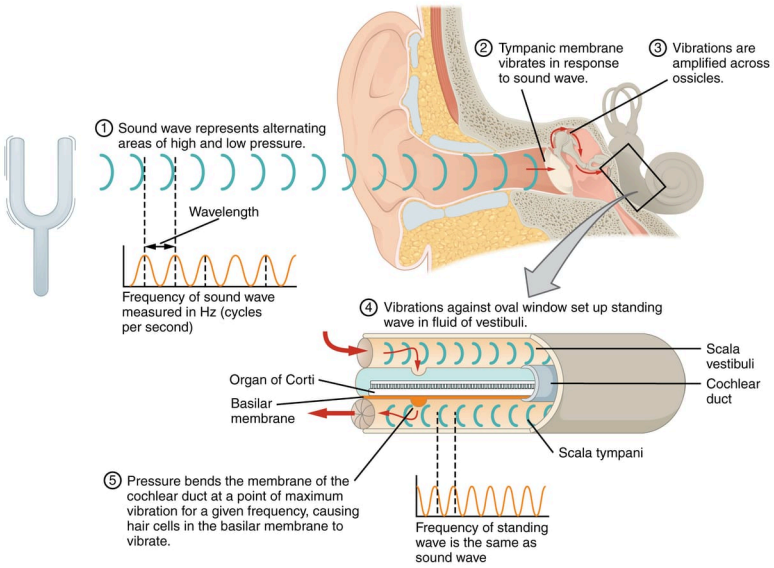


Figure 5.1.5: The transmission is represented in five steps. 1) Sound wave represents alternating areas of high and low pressure, whose frequency can be measured in Hz (cycles per second). 2) Tympanic membrane vibrates in response to sound wave. 3) Vibrations are amplified across the ossicles, in order malleus, incus, and stapes. 4) Vibrations against oval window set up standing wave in fluid of the scala vestibuli and scala tympani. The frequency of the standing wave is the same as the initial sound wave. 5) Pressure bends the membrane of the cochlear duct at a point of maximum vibration for a give frequency, causing hair cells of the Organ of Corti in the basilar membrane to vibrate. The complexity of the pressure waves is determined by the changes in amplitude and frequency of the sound waves entering the ear. (CC BY 4.0 via Hearing, Balance and Vision). Alternative text description of the Figure 5.1.5.

Vision

Vision is the special sense of sight that is based on the transduction of light stimuli received through the eyes. The eyes are located within either orbit in the skull. Supportive structures protect the eye, prevent objects from entering the eye, keep its surface lubricated and moist and provide superficial covering.

The eye itself is a hollow sphere composed of three layers of tissue. The outermost layer is the **fibrous tunic**, which includes the white sclera posteriorly and clear cornea anteriorly. The sclera accounts for five sixths of the surface of the eye, most of which is not visible, though humans are unique compared with many other species in having so much of the “white of the eye” visible (Figure 5.1.11). The transparent cornea covers the anterior tip of the eye and allows light to enter the eye. The middle layer of the eye is the **vascular tunic**, which is mostly composed of the choroid, ciliary body, and iris. The **choroid** is a layer of highly vascularized connective tissue that provides a blood supply to the eyeball. The choroid is posterior to the **ciliary body**, a muscular structure that is attached to the **lens** by **suspensory ligaments**. These two structures pull the lens, allowing it to focus light on the back of the eye. Overlaying the ciliary body, and visible in the anterior eye, is the **iris**—the colored part of the eye. The innermost layer of the eye is the **neural tunic**, or **retina**, which contains the nervous tissue responsible for photo reception. The retina consists of two layers: a pigmented layer and a neural layer. The **pigmented layer** is a layer of pigmented cells that absorb light after it passes through the retina and provides vital metabolic support for the photoreceptors of the retina. The **neural layer** consists of photoreceptors and blood vessels that supply the neural layer.

The eye is also divided into two cavities: the **anterior cavity** and the **posterior cavity**. The anterior cavity is the space between the cornea and lens, including the iris and ciliary body. It can be further divided into **anterior and posterior chambers** by the iris. These chambers are filled with a watery fluid called the **aqueous humor**. The posterior cavity is the space behind the lens that extends to the posterior side of the interior eyeball, where the retina is located. The posterior cavity is filled with a more viscous fluid called the **vitreous humor**. Aqueous humor is continually produced at the **ciliary processes** of the ciliary body. The aqueous humor passes through the pupil into the anterior chamber and drains into the **scleral venous sinus** at the edge of the cornea.

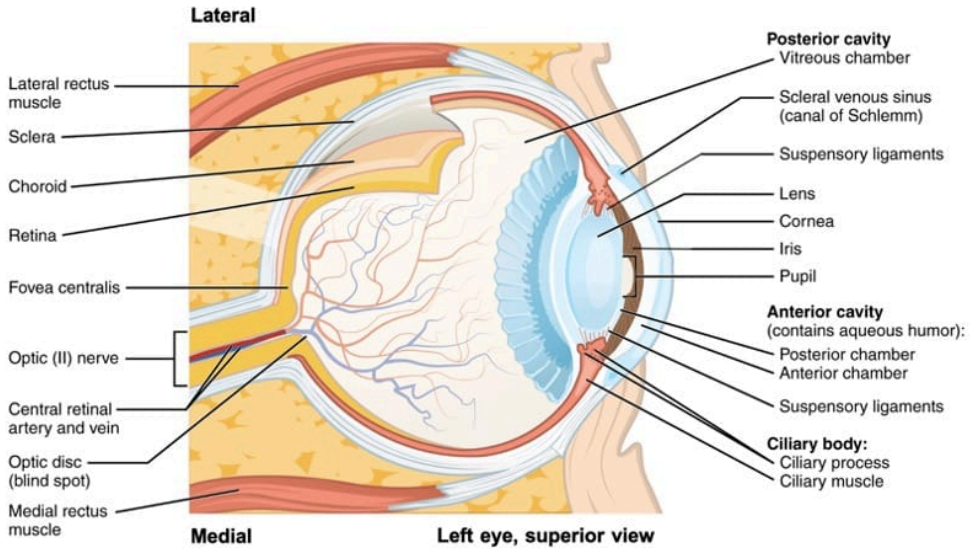


Figure 5.1.11: A superior view of the left eye shows the tissues and chambers composing the eye. The sphere of the eye can be divided into anterior and posterior cavities. The anterior cavity is the space between the cornea and the lens. It contains aqueous humor and is divided in anterior and posterior chambers by the iris, which forms the pupil. The posterior cavity is the space posterior to the lens and is filled with vitreous humor. The wall of the eye is composed of three layers: the fibrous tunic, vascular tunic, and neural tunic. The fibrous tunic is composed of the sclera and cornea. The vascular tunic is composed of the choroid, ciliary body and iris. The neural tunic is composed of the pigmented and neural layers. (CC BY 4.0 via Hearing, Balance and Vision). Alternative text description of the Figure 5.1.11.

The large interior space behind the lens is the **posterior cavity (vitreous chamber)**, which contains vitreous humor. At the front of the eye, the transparent **cornea** covers the eye and allows light to enter. Light then passes through the **pupil**, the opening in the center of the **iris**, before reaching the **lens**. The lens is suspended by **suspensory ligaments** attached to the **ciliary body**, which contains the **ciliary muscle** and **ciliary processes** that help control lens shape during focusing. The **anterior cavity**, which contains aqueous humor, is divided into the **anterior chamber** and **posterior chamber**. The diagram also labels the **scleral venous sinus (canal of Schlemm)**, which drains aqueous humor from the eye. Surrounding the eyeball are the **medial rectus** and **lateral rectus muscles**, which control horizontal eye movements. The image demonstrates the spatial relationships among the eye's optical, vascular, neural, and supporting structures.

The retina is composed of several layers and contains specialized cells for the initial processing of visual stimuli. The photoreceptors change their membrane electrical properties when stimulated by light energy. Light falling on the retina causes chemical changes to pigment molecules in the photoreceptors. There are two types of photoreceptors called rods and cones. **Cones** in human eyes are specialized in perceiving three different primary colors: red, green, and blue. **Rods** are sensitive to vision in low light conditions, for example in a darkened room. The change in electrical properties of these photoreceptors alters the amount of neurotransmitter that the photoreceptor cells release onto **bipolar cells** (see Figure 5.1.13). It is the bipolar cell in the retina that connects a photoreceptor to a **retinal ganglion cell (RGC)**. There, **amacrine cells** and **horizontal cells** additionally contribute to retinal processing before an action potential is produced by the RGC. The axons of RGCs, which lie at the innermost layer of the retina, collect at the **optic disc** and leave the eye as the **optic nerve**. Because these axons pass through the retina, there are no photoreceptors at the very back of the eye, where the optic nerve begins. This creates a "blind spot" in the retina, and a corresponding blind spot in our visual field. The visual information of the optic nerve will be transmitted through the **thalamus** and sent to the **primary visual cortex** of the occipital lobe.

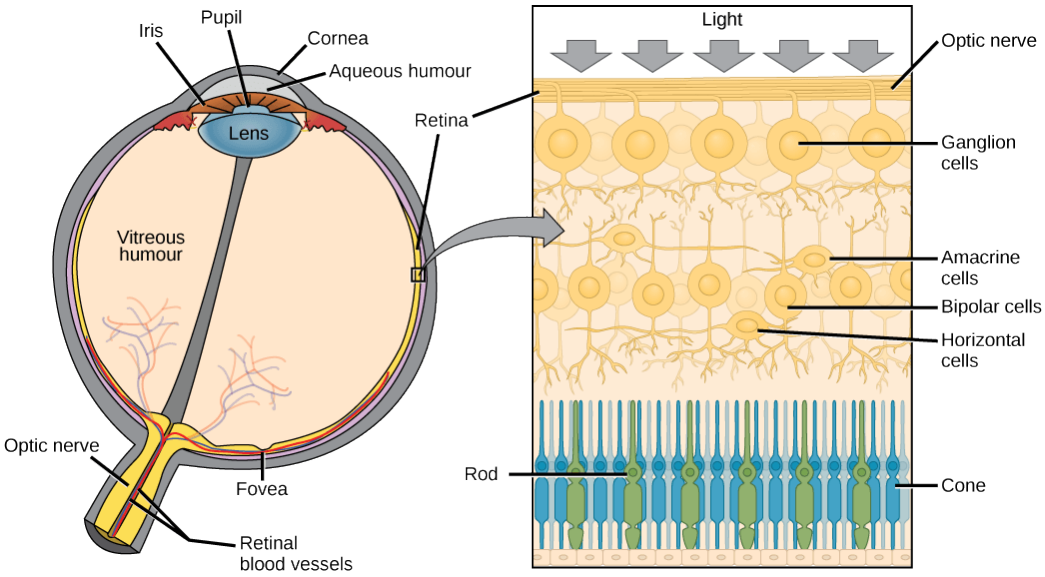


Figure 5.1.13: The retina is composed of several layers of cells that perceive changes in light and color. First, the light goes through the axons of ganglion cells that collect at the optic disc and leave the eye as the optic nerve. Ganglion cells synapse with bipolar cells. Amacrine and horizontal cells are scattered along the layer of bipolar cells. Bipolar cells synapse with the photoreceptors, composed of rods and cones. (CC BY 4.0 via Hearing, Balance and Vision). Alternative text description of the Figure 5.1.13.

Note that the photoreceptors in the retina (rods and cones) are located behind the axons, RGCs, bipolar cells, and retinal blood vessels. A significant amount of light is absorbed by these structures before the light reaches the photoreceptor cells. However, at the exact center of the retina is a small region known as the **macula lutea** at which center there is a depression called the **fovea** (Figure 5.1.14). In these regions, the retina lacks the supporting cells and blood vessels, and only contains cones. Therefore, **visual acuity**, or the sharpness of vision, is greatest at the fovea. As one moves in either direction from this central point of the retina, visual acuity drops significantly. In addition, each photoreceptor cell of the fovea is connected to a single RGC. Therefore, this RGC does not have to integrate inputs from multiple photoreceptors, which reduces the accuracy of visual transduction. Toward the edges of the retina, several photoreceptors converge on RGCs (through the bipolar cells) up to a ratio of 50 to 1. The difference in visual acuity between the fovea and peripheral retina is easily evidenced by looking directly at a word in the middle of this paragraph. The visual stimulus in the middle of the field of view falls on the fovea and is in the sharpest focus. Without moving your eyes off that word, notice that words at the beginning or end of the paragraph are not in focus. The images in your peripheral vision are focused by the peripheral retina, and have vague, blurry edges and words that are not as clearly identified. As a result, a large part of the neural function of the eyes is concerned with moving the eyes and head so that important visual stimuli are centered on the fovea.

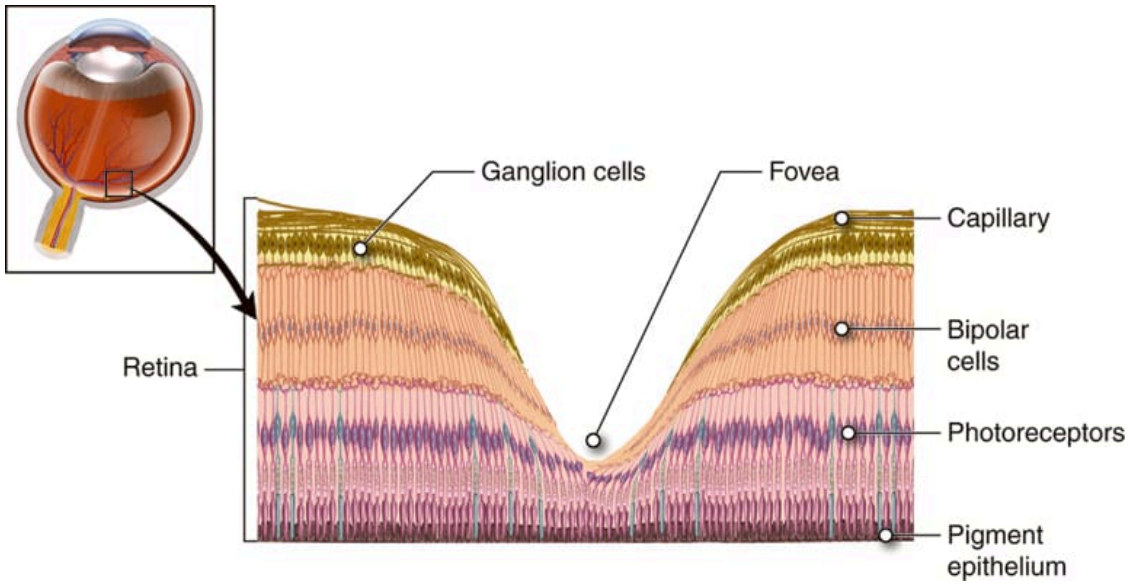


Figure 5.1.14: At the exact center of the retina is a region called the macula lutea where there is a depression called fovea. At the fovea there are no blood vessels, ganglion cells or bipolar cells to interrupt light reaching the receptor cells and only cones are present. Because more light passes to the receptor cells at the fovea, it is in this region that visual acuity is the greatest. (CC BY 4.0 via Hearing, Balance and Vision). Alternative text description of the Figure 5.1.14.

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5.2: Hearing Thresholds and Hearing Loss

Coding Sound: Pitch, Loudness, and Duration

The basilar membrane does not have the same mechanical properties along its entire length. Near the base of the cochlea, it is relatively narrow and stiff, so **high-frequency sounds** produce their greatest displacement there. Toward the **apex**, the membrane becomes wider and more flexible, allowing **lower-frequency sounds** to travel farther before reaching their region of greatest displacement. This orderly spatial representation of frequency is called **tonotopy**. Because different locations along the basilar membrane activate different populations of cochlear afferent neurons, the location of greatest activity provides an important place code for pitch.

Place coding is especially important across much of the audible frequency range, but timing also contributes. At lower frequencies, auditory neurons can synchronize aspects of their firing with repeating features of the sound wave, providing additional temporal information about frequency. Complex sounds such as speech, music, or a crowded room contain many frequencies at once, so multiple regions of the basilar membrane can be active simultaneously. The cochlea therefore begins separating a complex sound into its frequency components before that information reaches the CNS.

Loudness is the perception associated with sound intensity. As sound intensity increases, basilar membrane displacement becomes greater, the activity of responsive auditory nerve fibers changes, and a broader population of fibers can be recruited. Duration is represented by patterns of neural activity over time, including information about when a sound begins, how long it continues, and when it ends. These are hearing-specific applications of the intensity, duration, and population-coding mechanisms introduced earlier in the chapter (see Chapter 10, Section 10.1).

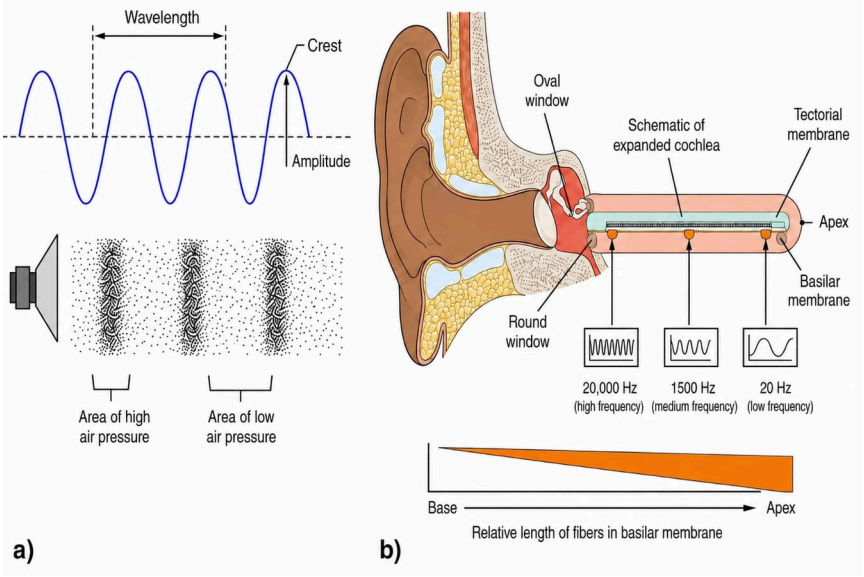


Figure 10.23 Sound Coding (a) Sound waves travel through air as alternating compressions and rarefactions, with wavelength and amplitude describing key physical properties. ("Properties of Sound waves" by Wiki commons, Public domain). (b) The basilar membrane is tonotopically organized, with high-frequency sounds producing maximal displacement near the base of the cochlea and low-frequency sounds near the apex. (OpenStax, 2022, licensed under CC BY 4.0, shared source content).

Real-World Connection: Your Listening Dose Adds Up

Earbuds and headphones are not inherently harmful. What matters is the combination of sound level and exposure time. As sound level rises, the amount of time that can be spent listening without accumulating a large sound dose falls rapidly. As a useful reference, an average exposure of about 80 decibels (dB) corresponds to roughly 40 hours per week, while 90 dB reduces that time to about 4 hours. At 100 dB, the comparable exposure falls to only about 20 minutes per week.

A phone's volume percentage does not tell you exactly how many decibels are reaching your ear. Actual sound level depends on the device, headphones or earbuds, recording, fit, and listening environment. Many newer phones can estimate headphone sound exposure directly. When that information is unavailable, keeping the volume below about 60% of maximum is a practical starting point. Well-fitted or noise-cancelling headphones can also help in places such as airplanes, buses, gyms, or busy campuses because they reduce the need to turn up the volume simply to compete with background noise.

Have you ever left a concert, club, sporting event, or loud workout with ringing ears or with everything sounding slightly muffled? That is a sign that the auditory system has been stressed, not simply that the ears need time to "adjust." Repeated or sufficiently intense sound exposure can permanently damage cochlear sensory structures, and mature human cochlear hair cells do not effectively regenerate after they are lost. Protecting your hearing now can therefore influence how well you hear decades from now.

Clinical Connection: Conductive and Sensorineural Hearing Loss

Hearing loss can arise at very different points in the auditory process. **Conductive hearing loss** occurs when sound transmission through the outer or middle ear is impaired. Impacted cerumen, fluid associated with a middle ear infection, damage to the tympanic membrane, or reduced movement of the ossicles can all decrease the amount of sound energy reaching the cochlea. The primary problem is therefore mechanical conduction rather than hair cell transduction.

Sensorineural hearing loss results from dysfunction or damage involving cochlear hair cells, their synapses, or auditory neurons. Aging, prolonged or intense sound exposure, inherited conditions, and some ototoxic medications can contribute. High-frequency hearing is often affected early in common forms of cochlear injury because structures toward the base of the cochlea, where higher frequencies produce their greatest displacement, are particularly vulnerable to several forms of damage.

For some people with severe sensorineural hearing loss, a cochlear implant can partly bypass damaged hair cell transduction. An external processor converts sound into coded electrical signals delivered to an electrode array within the cochlea. Different electrodes stimulate auditory nerve fibers associated with different locations along the cochlear tonotopic map. A cochlear implant therefore does not restore the normal mechanical operation of the cochlea. Instead, it substitutes patterned electrical stimulation for part of the missing receptor process.

Hearing Diversity

The categories of conductive and sensorineural hearing loss are useful clinically, but they do not capture the full range of human hearing. Auditory sensitivity varies among individuals because cochlear and neural function are influenced by genetics, age, lifetime sound exposure, medications, health, and other physiological factors. High-frequency sensitivity commonly decreases with age in a process called presbycusis, but both the timing and degree of this change vary considerably. Two people of the same age can therefore have quite different hearing histories and auditory abilities.

A basic **pure-tone hearing test** also captures only part of auditory function. Some people who can detect tones at expected thresholds still find it difficult to follow a conversation in a crowded restaurant, classroom, or social gathering. Changes at synapses between inner hair cells and auditory neurons are being investigated as one possible contributor to these hearing-in-noise difficulties, sometimes discussed under the broader term **hidden hearing loss.** The relationship in humans is complex, however, and difficulty hearing in noise should not automatically be attributed to cochlear synaptic damage. Central auditory processing, attention, and other neural mechanisms can also influence performance.

Experience adds another layer because the CNS becomes increasingly effective at extracting information from sounds it encounters repeatedly. Musical training, language experience, and other long-term listening experiences can influence sensitivity

to particular pitch, timing, or speech cues. Hearing diversity also includes people who are Deaf or hard of hearing. Some use hearing aids, cochlear implants, bone conduction devices, sign languages, visual information, or combinations of these approaches. For many people, Deaf identity also reflects language, culture, and community. Human hearing therefore varies not only in what the cochlea detects, but also in how sensory information is processed, experienced, and used for communication.

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5.3: Investigating Cognitive Processing Using Reaction Time

Reaction time is the amount of time between the presentation of a stimulus and a person's response. Psychologists use reaction-time experiments to investigate how the nervous system detects information, processes stimuli, makes decisions, and produces behavioral responses. By measuring how quickly individuals respond under different conditions, researchers can better understand the relationship between cognitive processing and behavior.

Mental Chronometry

The study of reaction time on cognitive tasks is a common psychological paradigm in trying to infer the duration, sequence and content of cognition. As seen in Figure 1.5, reaction time (or RT) is measured as the time between the onset of a stimuli and the response by the participant. The mean and the variance of reaction times are considered useful indices on processing speed. The most common form of reaction time experiments are button presses. However, eye movements and voice onset (in repetition and reading tasks) can also be employed.

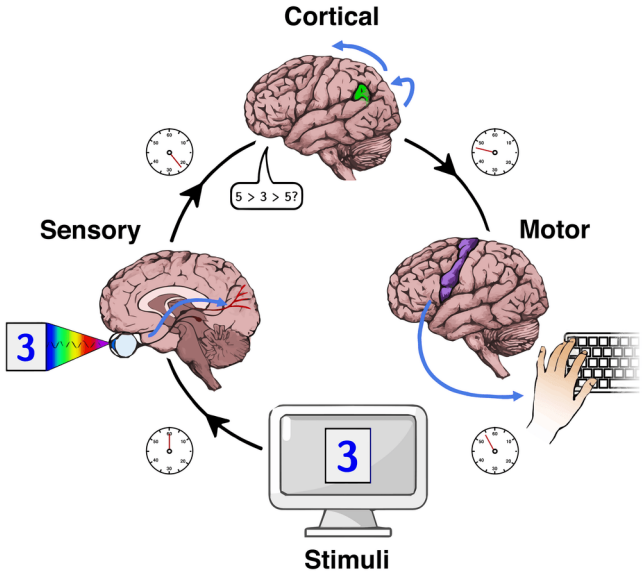


Figure 1.5 Reaction Time Experiment [Image description]

Simple and Choice Reaction Time

Reaction-time experiments can vary in how much information a person must process before responding. Two common approaches are simple reaction-time tasks and choice reaction-time tasks.

In a simple reaction-time task, participants respond to a stimulus using a predetermined response. For example, a participant might press the spacebar whenever a shape appears on a computer screen. Because the response is already known, the participant primarily needs to detect the stimulus and initiate the appropriate movement.

In a choice reaction-time task, participants must select a response based on the stimulus presented. For example, a participant might press one key when a stimulus appears on the left side of a screen and a different key when it appears on the right. This requires the participant to identify the stimulus, select the correct response, and execute the movement.

Choice reaction times are generally longer than simple reaction times because selecting among multiple responses introduces additional processing demands. Comparing these conditions allows researchers to investigate how decision-making influences behavioral responses.

Neural Processing and Reaction Time

Reaction time reflects several processes occurring within the nervous system. When a visual stimulus appears, photoreceptors in the retina detect light and convert it into neural signals. This information travels through the visual pathways to the brain, where the stimulus is processed.

The brain then determines the appropriate response and sends motor commands through descending neural pathways. Motor neurons activate the muscles needed to perform the response, such as pressing a key on a keyboard.

Although these processes occur rapidly, each contributes to the total time between stimulus presentation and the behavioral response.

Reaction-time tasks measure voluntary responses rather than simple spinal reflexes. Unlike a spinal reflex, which can be coordinated through circuits in the spinal cord without requiring conscious decision-making, these tasks involve processing visual information and initiating a deliberate response.

Reaction times can also be influenced by attention, practice, fatigue, and distractions. Consequently, reaction time is not a direct measurement of the speed of an individual neuron. Instead, it reflects the combined time required for sensory processing, cognitive processing, and motor activity.

Image descriptions

Figure 1.5 Reaction Time Experiment

A diagram showing the process of testing someone's reaction time to seeing a number on a computer screen and pressing the number on their keyboard:

1. Stimuli: The number 3 appears on the computer screen. The timer starts.
2. Sensory: The eyes see the number 3.
3. Cortical: The stimuli is processed by the brain.
4. Motor: The brain tells the hand to press the number 3 on the keyboard.

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5.4: Reaction Time and Cognitive Processing Lab

In this lab, you will compare simple reaction time and four-choice reaction time using visual stimuli. Both tasks require you to detect a stimulus and produce a motor response, but the choice reaction-time task also requires you to select the appropriate response. By comparing your results, you will investigate how additional cognitive processing influences response speed.

Learning Objectives

By completing this lab, students will be able to:

1. Distinguish between simple reaction time and choice reaction time.
2. Measure and compare reaction times under different response conditions.
3. Explain how sensory processing, decision-making, and motor responses contribute to reaction time.
4. Interpret experimental results and identify factors that may influence reaction-time measurements.

Materials Needed

- Computer with a keyboard and internet access
- Calculator
- Paper or a digital document for recording results

Part 1: Measuring Reaction Time

In this lab, you will use the Deary-Liewald Reaction Time Task, an experiment available through PsyToolkit. The task measures how quickly you respond to visual stimuli under two different conditions.

In the simple reaction-time condition, you respond when a stimulus appears. In the choice reaction-time condition, you must identify where a stimulus appears and select the corresponding response.

Procedure

1. Open the Deary-Liewald Reaction Time Task on PsyToolkit.
2. Read the description of the experiment and locate the option to run the demonstration.
3. Complete the simple reaction-time task, following the instructions provided by PsyToolkit.
4. Record your reaction-time results in the data table below.
5. Complete the four-choice reaction-time task, following the instructions provided by PsyToolkit.
6. Record your reaction-time results and any accuracy information provided.
7. Review your results before closing the experiment.

Data Table

Measurement	Simple Reaction Time	Choice Reaction Time
Mean reaction time (ms)		
Number of incorrect responses (if reported)		

Part 2: Data Analysis and Interpretation

Reaction time represents the interval between the presentation of a stimulus and the participant's response. Although both conditions involve detecting a visual stimulus and producing a motor response, the choice reaction-time condition introduces an additional requirement: selecting the appropriate response.

Data Analysis

1. Calculate the difference between your mean choice reaction time and your mean simple reaction time.

   Difference = Choice reaction time – Simple reaction time

2. Record your calculated difference in milliseconds.
3. Determine which condition produced the faster average response.
4. Examine any accuracy information reported by the experiment. Consider whether you responded correctly throughout the task or made errors.

Lab Report

1. **Compare your results from the simple and choice reaction-time conditions. Which condition produced a faster response, and how large was the difference?**

2. **Explain why reaction time might increase when a person must select between several possible responses rather than respond to a single stimulus.**

3. **Describe the general sequence of events in the nervous system between seeing a stimulus on the screen and pressing a key on the keyboard. Include sensory processing, the central nervous system, and motor output.**

4. **Are the responses measured in this experiment examples of spinal reflexes or voluntary responses? Explain your reasoning.**

5. **Identify two factors that could have influenced your reaction times during the experiment. Explain how each factor might affect your results.**

6. **If you completed the experiment a second time, would you expect your reaction times to remain exactly the same?**

Explain how practice, attention, or fatigue could influence your performance.

7. **What do the differences between simple and choice reaction times suggest about the relationship between cognitive processing and behavioral responses?**

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6: ATTENTION AND COGNITIVE INTERFERENCE

6.1: Attention and Cognitive Processing
6.2: Stroop Effect and Selective Attention Lab

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6.1: Attention and Cognitive Processing

Introduction to the History of Research on Attention

The study of attention is a major part of contemporary cognitive psychology and cognitive neuroscience. Attention plays a critical role in essentially all aspects of perception, cognition, and action, influencing the choices we make. The study of attention has been of interest to the field of psychology since its earliest days. However, many ideas about attention can be traced to philosophers in the 18th and 19th centuries, preceding the foundation of the field of psychology. The topic of attention was originally discussed by philosophers. Among the issues considered were the role of attention on conscious awareness and thought, and whether attention was directed voluntarily or involuntarily toward objects or events. The characterization of attention provided by each philosopher reflected that individual's larger metaphysical views of the nature of things and how we come to know the world.

John Ridley Stroop and The Stroop Effect

For over half a century, the Stroop effect has been one of the most well known standard demonstrations in undergraduate psychology courses and laboratories. In this cognitive task, participants asked to name the color of the ink in which an incompatible color word is printed (e.g., to say “red” aloud in response to the stimulus word GREEN printed in red ink) take longer than when asked to name the color in a control condition (e.g., to say "red" to the stimulus XXXXX printed in red ink). This effect, now known as the Stroop effect, was first reported in the classic article “Studies of Interference in Serial Verbal Reactions” published in the Journal of Experimental Psychology in 1935. Since then, this phenomena has become one of the most well known in the history of psychology.

Stroop’s article has become one of the most cited articles in the history of experimental psychology. It has more than 700 studies seeking to explain some nuance of the Stroop effect along with thousands of others directly or indirectly influenced by this article (MacLeod, 1992). However, at the time of its publication, it had relatively little impact because it was published at the height of Behaviourism in America (MacLeod, 1991). For the next thirty years after its publication, almost no experimental investigations of the Stroop effect occurred. For instance, between 1935 and 1964, only 16 articles are cited that directly examined the Stroop effect. In 1960s, with the advent of information processing as the dominant perspective in cognitive psychology, Stroop's work was rediscovered. Since then, the annual number of studies rose quickly, until by 1969 the number of articles settled in at just over 20 annually, where it appears to have remained (MacLeod, 1992).

Donald Broadbent and Dichotic Listening

Donald E. Broadbent has been praised for his outstanding contributions to the field of psychology since the 1950s, most notably in the area of attention. In fact, despite the undeniable role that attention plays in almost all psychological processes, research in this area was neglected by psychologists for the first half of the twentieth century (Massaro, 1996). During that time, behaviourists ignored the role of attention in human behaviour. Behaviourism was characterized by a stimulus-response approach, emphasizing the association between a stimulus and a response, but without identifying the cognitive operations that lead to that response (Reed, 2000). Subsequently, in the mid-1950s, a growing number of psychologists became interested in the information-processing approach as opposed to the stimulus response approach. It was Broadbent’s elaboration of the idea of the human organism as an information-processing system that lead to a systematic study of attention, and more generally, to the interrelation of scientific theory and practical application in the study of psychology.

Dichotic Listening Experiments

In 1952, Broadbent published his first report in a series of experiments that involved a dichotic listening paradigm. In that report, he was concerned with a person’s ability to answer one of two messages that were delivered at the same time, but one of which was irrelevant.

The participants were required to answer a series of Yes-No questions about a visual display over a radio-telephone. For example, the participant would be asked “S-1 from G.D.O. Is there a heart on Position 1?” Over,” to which the participant should answer

"G.D.O. from S-1. Yes, over." Participants in groups I, II, III, and IV heard two successive series of messages, in which two voices (G.D.O and Turret) spoke simultaneously during some of the messages. Only one of the voices was addressing S-1, and the other addressed S-2, S-3, S-4, S-5, or S-6. Participants were assigned to the following five groups:

- Group I: instructed to answer the message for S-1 and ignore the other on both runs
- Group II: instructed on one run to only answer the message from G.D.O. andon the second run was provided with a visual cue before the pairs of messages began for the name of the voice to be answered
- Group III: were given the same directions as Group I on one run, and on the other run had the experimenter indicate the correct voice verbally after the two messages had reached the "over" stage
- Group IV: had the correct voice indicated in all cases, but in one run it was before the messages began (like in Group II) and in the other run it was after the messages had finished (like in Group III)
- Group V: under the same conditions as Group I, heard the same recordings as Groups I, II, III and IV, but then also heard a two new recordings. One recording had a voice that addressed S-1 and a voice that addressed T-2, T-3, T-4, T-5, orT6 (thus the simultaneous messages were more distinct than for the other groups). The other recording had this same differentiation of messages, but also had both voices repeat the call-sign portion of the message (i.e., "S-1 from G.D.O., S-1 from G.D.O.)

For groups I and II, it is important to note that the overall proportion of failures to answer the correct message correctly was 52%. Results from Groups III and IV indicated that delaying knowledge of the correct voice until the message is completed makes that knowledge almost useless. More specifically, Broadbent (1952) stated:

> "The present case is an instance of selection in perception (attention). Since the visual cue to the correct voice is useless when it arrives towards the ends of the message, it is clear that process of discarding part of the information contained in the mixed voices has already taken place...It seems possible that one of the two voices is selected for response without reference to its correctness, and that the other is ignored...If one of the two voices is selected (attended to) in the resulting mixture there is no guarantee that it will be the correct one, and both call signs cannot be perceived at once any more than both messages can be received and stored till a visual cue indicates the one to be answered". (p. 55)

In 1954, Broadbent used the same procedure as discussed above with slight modifications. In that case, he found information that indicated the positive impact that spatial separation of the messages has on paying attention to and understanding the correct message. The dichotic listening paradigm has been utilized in numerous other publications, both by Broadbent and by other psychologists working in the field of cognition. For example, Cherry (1953) investigated how we can recognize what one person is saying when others are speaking at the same time, which be described as the "cocktail party problem" (p. 976). In his experiment, subjects listened to simultaneous messages and were instructed to repeat one of the messages word by word or phrase by phrase.

Information-Processing and the Filter Model of Attention

Cognitive psychology is often called human information processing, which reflects the approach taken by many cognitive psychologists in studying cognition. The stage approach, with the acquisition, storage, retrieval, and use of information in a number of separate stages, was influenced by the computer metaphor and the way people enter, store, and retrieve data from a computer (Reed, 2000). The stages in an information-processing model are:

- Sensory Store: brief storage for information in its original sensory form
- Filter: part of attention in which some perceptual information is blocked out and not recognized, while other information is attended to and recognized
- Pattern Recognition: stage in which a stimulus is recognized
- Selection: stage that determines what information a person will try to remember
- Short-Term Memory: memory with limited capacity, that lasts for about 20-30 seconds without attending to its content
- Long-Term Memory: memory that has no capacity limit and lasts from minutes to a lifetime

Using an information-processing approach, Broadbent collected data on attention (Reed, 2000). He used a dichotic listening paradigm (see above section), asking participants to listen simultaneously to messages played in each ear, and based on the difficulty that participants had in listening to the simultaneous messages, proposed that a listener can attend to only one message at a time (Broadbent, 1952; Broadbent, 1954). More specifically, he asked enlisted men in England's Royal Army to listen to three pairs of digits. One digit from each pair was presented to one ear at the same time that the other digit from the pair was presented to the other ear. The subjects were asked to recall the digits in whatever order they chose, and almost all of the correct reports involved recalling all of the digits presented to one ear, followed by all the digits presented to the other ear. A second group of participants were asked to recall the digits in the order they were presented (i.e., as pairs). Performance was worse than when

they were able to recall all digits from one ear and then the other.

To account for these findings, Broadbent hypothesized that the mechanism of attention was controlled by two components: a selective device or filter located early in the nervous system, and a temporary buffer store that precedes the filter (Broadbent, 1958). He proposed that the filter was tuned to one channel or the other, in an all-or-nothing manner. Broadbent's filter model, described in his book Perception and Communication (1958), was one of the first information-processing models to be examined by psychologists.

Shortly after, it was discovered that if the unattended message became highly meaningful (for example, hearing one's name as in Cherry's Cocktail Party Effect, as mentioned above), then attention would switch automatically to the new message. This result led to the paradox that the content of the message is understood before it is selected, indicating that Broadbent needed to revise his theory (Craik & Baddeley, 1995). Broadbent did not shy away from this task. In fact, he saw all scientific theories as temporary statements, a method of integrating current evidence in a coherent manner. According to Craik and Baddeley, (1995), although Broadbent always presented his current theories firmly and persuasively, he never took the position of obstinately defending an outmoded theory. When he published his second book on the topic, Decision and Stress (1971), he used his filter model as the starting point, to which he applied modifications and added concepts "to accommodate new findings that the model itself had stimulated" (Massaro, 1996, pp. 141). Despite its inconsistencies with emerging findings, the filter model remains the first and most influential information-processing model of human cognition.

Anne Treisman and Feature Integration Theory

Anne Treisman is one of the most influential cognitive psychologists in the world today. For over four decades, she has been using innovative research methods to define fundamental issues in the area of attention and perception. Best known for her Feature Integration Theory (1980, 1986), Treisman's hypotheses about the mechanisms involved in information processing have formed a starting point for many theorists in this area of research.

In 1980, Treisman and Gelade published a seminal paper proposing her enormously influential Feature Integration Theory (FIT). Treisman's research demonstrated that during the early stages of object perception, early vision encodes features such as color, form, and orientation as separate entities (in "feature maps") (Treisman, 1986). Focused attention to these features recombines the separate features resulting in correct object perception. In the absence of focused attention, these features can bind randomly to form illusory conjunctions (Treisman & Schmidt, 1982; Treisman, 1986). Feature integration theory has had an overarching impact both within and outside the area of psychology.

Feature Integration Theory Experiments

According to Treisman's Feature Integration Theory perception of objects is divided into two stages:

1. **Pre-Attentive Stage**: The first stage in perception is so named because it happens automatically, without effort or attention by the perceiver. In this stage, an object is analyzed into its features (i.e., color, texture, shapes etc.). Treisman suggests that the reason we are unaware of the breakdown of an object into its elementary features is that this analysis occurs early in the perceptual processes, before we have become conscious of the object. Evidence: Treisman created a display of four objects flanked by two black numbers. This display was flashed on a screen for one-fifth of a second and followed by a random dot masking field in order to eliminate residual perception of the stimuli. Participants were asked to report the numbers first, followed by what they saw at each of the four locations where the shapes had been. In 18 percent of trials, participants reported seeing objects that consisted of a combination of features from two different stimuli (i.e., color and shape). The combinations of features from different stimuli are called **illusory conjunctions** (Treisman and Schmidt, 1982). The experiment also showed that these illusory conjunctions could occur even if the stimuli differ greatly in shape and size. According to Treisman, illusory conjunctions occur because early in the perceptual process, features may exist independently of one another, and can therefore be incorrectly combined in laboratory settings when briefly flashed stimuli are followed by a masking field (Treisman, 1986).
2. **Focused Attention Stage**: During this second stage of perception features are recombined to form whole objects. Evidence: Treisman repeated the illusory conjunction experiment, but this time, participants were instructed to ignore the flanking numbers, and to focus their attention on the four target objects. Results demonstrated that this focused attention eliminated illusory conjunctions, so that all shapes were paired with their correct colours (Treisman and Schmidt, 1982). The experiment demonstrates the role of attention in the correct perception of objects.

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6.2: Stroop Effect and Selective Attention Lab

Stroop Effect and Selective Attention Lab

Introduction

Attention allows us to focus on relevant information while filtering out competing stimuli. However, some cognitive processes occur so automatically that they can interfere with tasks requiring deliberate attention. The Stroop effect demonstrates this interference by examining how the automatic process of reading can disrupt our ability to identify the color of a word.

Automatic processing refers to cognitive activities that occur quickly and with relatively little conscious effort. For proficient readers, recognizing familiar words is largely automatic. Controlled processing, in contrast, requires deliberate attention and cognitive effort. When a word's meaning conflicts with its ink color, individuals must selectively attend to the ink color while inhibiting the tendency to respond to the word's meaning.

This conflict creates cognitive interference, which can increase reaction time and sometimes lead to errors. The Stroop effect provides researchers with a way to investigate selective attention, inhibitory control, and how competing information influences behavioral responses.

In this lab, you will complete a computerized Stroop experiment, measure your reaction times under different conditions, and investigate whether repeated exposure to the task influences your performance.

Learning Objectives

By the end of this lab, you should be able to:

1. Explain how selective attention and automatic processing contribute to the Stroop effect.
2. Distinguish between congruent and incongruent stimuli.
3. Measure and compare reaction times across experimental conditions.
4. Calculate and interpret the magnitude of Stroop interference.
5. Evaluate how repeated testing may influence cognitive performance.

Materials Needed

- Computer with a keyboard and internet access
- PsyToolkit Stroop Experiment: https://www.psytoolkit.org/experiment-library/stroop.html
- Calculator

Part 1: Measuring the Stroop Effect

In this experiment, you will identify the ink color of words displayed on your screen. Some words will appear in matching ink colors (congruent trials), while others will appear in conflicting ink colors (incongruent trials).

Your task is to respond to the ink color, not the meaning of the word.

Procedure

1. Open the PsyToolkit Stroop Experiment using the link provided above.
2. Read the instructions on the website carefully before beginning.
3. Locate the option to run the demonstration and begin the experiment.
4. Follow the on-screen instructions to identify the ink color of each stimulus using the designated keyboard keys.
5. Respond as quickly and accurately as possible. Try to avoid distractions during the experiment.

6. When the experiment ends, review your results. Record the average reaction time for congruent trials, the average reaction time for incongruent trials, and the reported Stroop effect in Table 1.
7. Take a short break of approximately one minute.
8. Complete the experiment a second time, following the same instructions.
9. Record your results from the second attempt in Table 1.

Table 1. Stroop Experiment Results

Measurement	Attempt 1	Attempt 2
Mean reaction time — Congruent (ms)		
Mean reaction time — Incongruent (ms)		
Reported Stroop effect (ms)		

Part 2: Analyzing Your Results

The Stroop effect is calculated by subtracting the average reaction time for congruent trials from the average reaction time for incongruent trials.

Stroop Effect = Mean Incongruent Reaction Time – Mean Congruent Reaction Time

A positive value indicates that responses were slower during incongruent trials, consistent with the expected Stroop interference effect. A negative value indicates that responses were faster during incongruent trials.

Procedure

1. Using your results from Attempt 1, calculate the Stroop effect by subtracting the mean congruent reaction time from the mean incongruent reaction time.
2. Repeat this calculation using your results from Attempt 2.
3. Compare your calculated values with the Stroop effects reported by PsyToolkit.
4. Calculate the difference in Stroop interference between your two attempts.

Change in Stroop Effect = Attempt 2 Stroop Effect – Attempt 1 Stroop Effect

5. Record your calculations in Table 2.

Table 2. Stroop Interference Calculations

Measurement	Result (ms)
Calculated Stroop effect — Attempt 1	
Calculated Stroop effect — Attempt 2	
Change in Stroop effect between attempts	

Lab Report

Answer the following questions using your experimental results and the concepts discussed in the background reading.

1. **Compare your mean reaction times for congruent and incongruent trials during Attempt 1. Which condition produced slower responses? Was this consistent with the expected Stroop effect?**

2. **Explain why incongruent stimuli typically produce longer reaction times than congruent stimuli. In your explanation, discuss automatic processing, selective attention, and cognitive interference.**

3. **Describe the role of the nervous system in completing this task. Explain how visual information is processed and how the brain selects and produces an appropriate motor response.**

4. **Compare the Stroop effects from your first and second attempts. Did the amount of interference increase or decrease? What might explain this difference?**

5. **How might attention, fatigue, distractions, or familiarity with the task influence reaction times? Identify at least two factors and explain their potential effects.**

6. **How does the Stroop effect demonstrate the relationship between cognitive processing and observable behavior? Explain what reaction-time measurements can tell researchers about processes that cannot be directly observed.**

7. **Consider the experimental design. Identify the independent variable and dependent variable in the Stroop experiment. Explain how comparing congruent and incongruent trials allows researchers to investigate cognitive interference.**

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7: SPATIAL ATTENTION AND ATTENTIONAL CUEING

7.1: Spatial Attention and Attentional Cueing
7.2: Spatial Attention and Posner Cueing Task Lab

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7.1: Spatial Attention and Attentional Cueing

In this section, we focus on the established where aspect of parietal function. Even within the domain of spatial processing, there are many cognitive functions that can be performed using parietal spatial representations, but we focus here on their role in focusing attention to spatial locations.

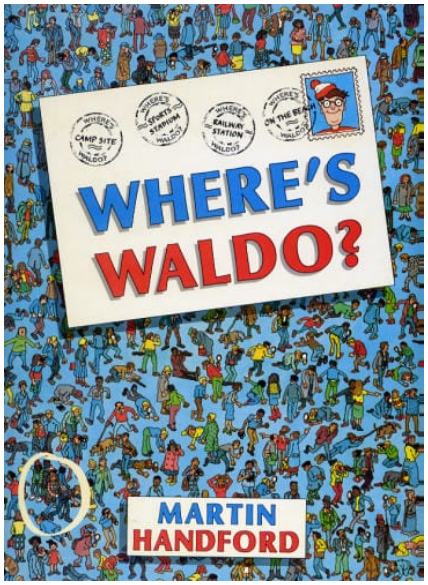


Figure 6.16: Where's Waldo visual search example.

One crucial function of spatial attention is to enable object recognition to function in visual scenes that have multiple different objects present. For example, consider one of those "where's Waldo" puzzles (Figure 6.16) that is packed with rich visual detail. Is it possible to perceive such a scene all in one take? No. You have to scan over the image using a "spotlight" of visual attention to focus on small areas of the image, which can then be processed effectively by the object recognition pathway. The ability to direct this spotlight of attention depends on spatial representations in the dorsal pathway, which then interact with lower levels of the object recognition pathway (V1, V2, V4) to constrain the inputs to reflect only those visual features that come from within this spotlight of attention.

Hemispatial Neglect

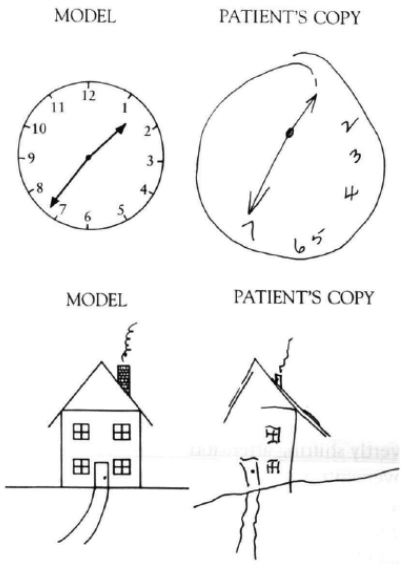


Figure 6.17: Drawings of given target objects by patients with hemispatial neglect, showing profound neglect of the left side of the drawings.



Figure 6.18: Progression of self portraits by an artist with hemispatial neglect, showing gradual remediation of the neglect over time.

Some of the most striking evidence that the parietal cortex is important for spatial attention comes from patients with hemispatial neglect, who tend to ignore or neglect one side of space (Figure 6.17, Figure 6.18, Figure 6.19). This condition typically arises from a stroke or other form of brain injury affecting the right parietal cortex, which then gives rise to a neglect of the left half of space (due to the crossing over of visual information shown in the biology section). Interestingly, the neglect applies to multiple different spatial reference frames, as shown in Figure 6.19, where lines on the left side of the image tend to be neglected, and also each individual line is bisected more toward the right, indicating a neglect of the left portion of each line.

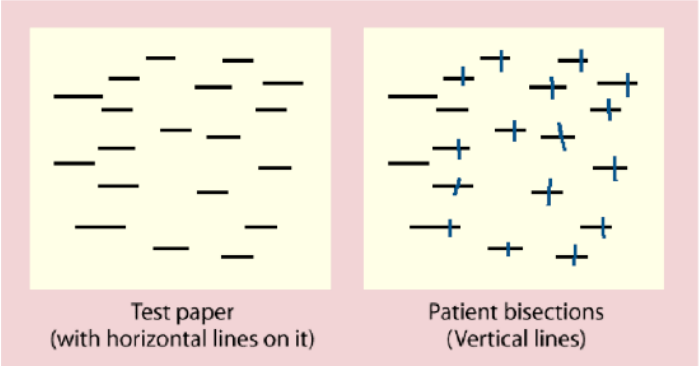


Figure 6.19: Results of a line bisection task for a person with hemispatial neglect. Notice that neglect appears to operate at two different spatial scales here: for the entire set of lines, and within each individual line.

The Posner Spatial Cueing Task

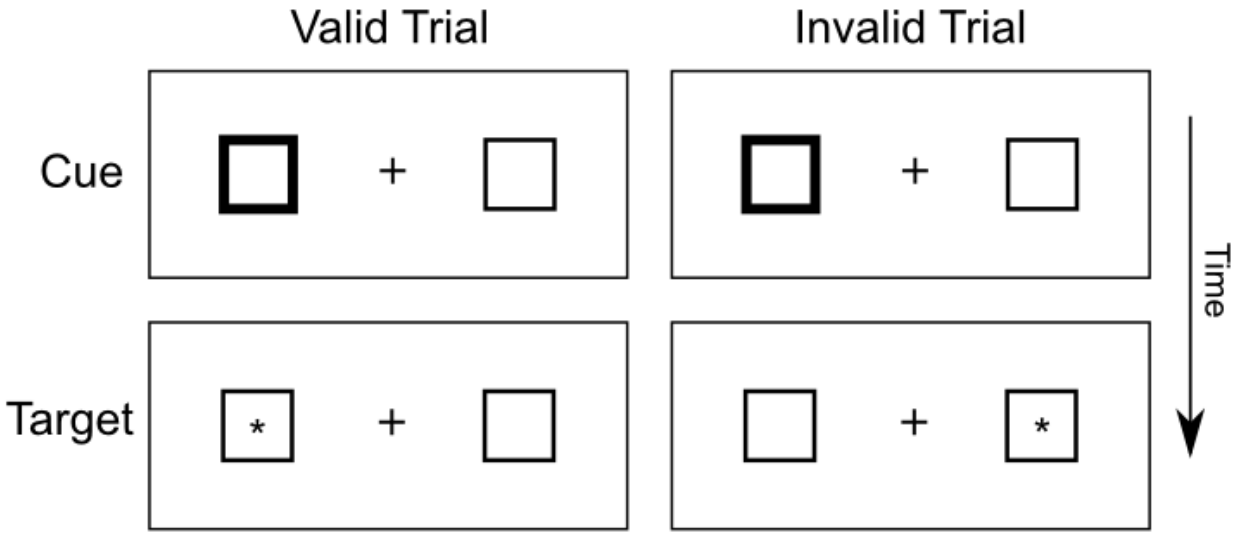


Figure 6.20: The Posner spatial cueing task, widely used to explore spatial attention effects. The participant is shown a display with two boxes and a central fixation cross -- on some trials, one of the boxes is *cued* (e.g., the lines get transiently thicker), and then a target appears in one of the boxes (or not at all on catch trials). The participant just presses a key when they first detect the target. Reaction time is quicker for valid cues vs. invalid ones, suggesting that spatial attention was drawn to that side of space. Patients with hemispatial neglect exhibit slowing for targets that appear in the neglected side of space, particularly when invalidly cued.

One of the most widely used tasks to study the spotlight of spatial attention is the Posner spatial cueing task, developed by Michael Posner (Figure 6.20). One side of visual space is cued, and the effects of this cue on subsequent target detection are measured. If the cue and target show up in the same side of space (*valid* cue condition), then reaction times are faster compared to when they show up on different sides of space (*invalid* cue condition) (Figure 6.21). This difference in reaction time (RT) suggests that spatial attention is drawn to the cued side of space, and thus facilitates target detection. The invalid case is actually worse than a neutral condition with no cue at all, indicating that the process of reallocating spatial attention to the correct side of space takes some amount of time. Interestingly, this task is typically run with the time interval between cue and target sufficiently brief as to prevent eye movements to the cue -- thus, these attentional effects are described as *covert* attention.

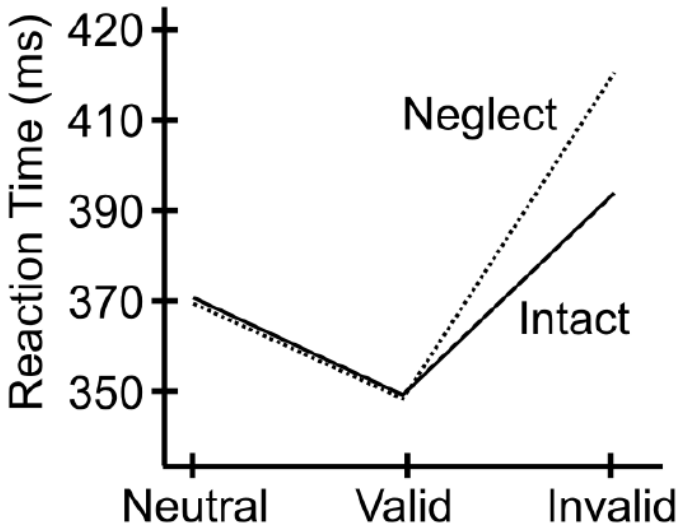


Figure 6.21: Typical data from the Posner spatial cueing task, showing a speedup for valid trials, and a slowdown for invalid trials, compared to a neutral trial with no cueing. The data for patients with hemispatial neglect is also shown, with their overall slower reaction times normalized to that of the intact case.

As shown in Figure 6.21, patients with hemispatial neglect show a disproportionate increase in reaction times for the invalid cue case, specifically when the cue is presented to the good visual field (typically the right), while the target appears in the left. Posner took this data to suggest that these patients have difficulty disengaging attention, according to his box-and-arrow model of the spatial cueing task (Figure 6.22).

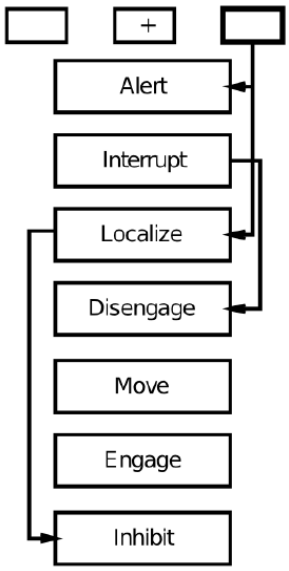


Figure 6.22: Posner's box-and-arrow model of the spatial cueing task. He suggests that spatial neglect deficits are attributable to damage to the disengage mechanism. However, this fails to account for the effects of bilateral parietal damage, for example.

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7.2: Spatial Attention and Posner Cueing Task Lab

Spatial Attention and the Posner Cueing Task Lab

Introduction

Spatial attention allows us to selectively focus on information appearing in different locations within our visual field. Although we often associate attention with directing our eyes toward something, we can also shift our attention without moving our eyes. This is called covert attention.

The Posner cueing task investigates how directing attention toward a particular location influences reaction time. In this experiment, a visual cue appears shortly before a target. When the cue and target appear in the same location, the cue is considered valid. When they appear in different locations, the cue is considered invalid.

Valid cues generally produce faster reaction times because attention has already been directed toward the target's location. Invalid cues may produce slower reaction times because attention must be redirected to another location.

In this lab, you will complete a computerized Posner cueing experiment, analyze your reaction times using Excel or Google Sheets, and create a graph to visualize how spatial attention influences your responses.

Learning Objectives

By the end of this lab, you should be able to:

1. Explain the role of spatial attention in visual processing.
2. Distinguish between valid and invalid attentional cues.
3. Calculate and compare mean reaction times across experimental conditions.
4. Create and interpret a graph displaying experimental results.
5. Explain how the parietal cortex contributes to spatial attention and how damage to this region can affect attention.

Materials Needed

- Computer with a keyboard and internet access
- PsyToolkit Posner Cueing Experiment: https://www.psytoolkit.org/experiment-library/cueing.html
- Microsoft Excel or Google Sheets

Part 1: The Posner Cueing Experiment

In this experiment, you will respond to visual targets appearing on either side of your screen.

Each trial may begin with an X appearing in one of two boxes. Shortly afterward, a green circle containing the word GO will appear. Your task is to respond to the location of the GO signal, not the X.

- Press A when the GO signal appears in the left box.
- Press L when the GO signal appears in the right box.

The experiment includes 100 trials. In approximately 75% of trials, the cue and target appear in the same location (valid cues). In approximately 25% of trials, they appear in different locations (invalid cues).

Procedure

1. Open the PsyToolkit Posner Cueing Experiment using the link provided above.

2. Read the instructions on the website carefully.
3. Select the option to run the demonstration.
4. Position yourself comfortably in front of your computer. Keep your eyes directed toward the center of the screen throughout the experiment.
5. Complete all 100 trials, responding as quickly and accurately as possible.
6. When the experiment ends, select the option to display your response times.
7. Copy the experimental data displayed on the screen.
8. Open a new spreadsheet in Microsoft Excel or Google Sheets.
9. Paste your experimental data into the spreadsheet. Save the spreadsheet so you can use it for the next part of the lab.

Part 2: Analyzing Reaction Times

Your experimental data contain information about the location of each cue and target, whether the cue was valid or invalid, your reaction time, and whether your response was correct.

The PsyToolkit data contain six columns:

Column	Measurement
A	Cue position
B	Target position
C	Cue validity (cued or uncued)
D	Cue validity as a number (1 = valid, 0 = invalid)
E	Reaction time (milliseconds)
F	Response status (1 = correct, 2 = incorrect, 3 = timeout)

If your data appear in a single column after pasting, separate them into six columns using Excel's Text to Columns feature or Google Sheets' Split text to columns feature. The values are separated by spaces or other whitespace.

Procedure

1. Check that each trial occupies one row and that the six measurements appear in separate columns.
2. If necessary, insert a new row above your data and add the column headings listed in the table above.
3. Locate Column D, which identifies valid and invalid trials, and Column E, which contains reaction times.
4. Locate Column F, which identifies whether each response was correct. Only correct responses should be included when calculating mean reaction times.
5. Use Column D to identify valid (1) and invalid (0) trials. Use Column F to identify correct responses (1). Only include correct responses when calculating your averages.
6. Filter your spreadsheet to display only valid trials with correct responses. Select the corresponding reaction times in Column E. In Excel, look at the status bar at the bottom of the window to find the average of the selected cells. In Google Sheets, select the cells, click the calculation menu at the bottom right of the window, and choose Average. Record this value in Table 1.
7. Repeat this process for invalid trials with correct responses. Record the average reaction time in Table 1.
8. Calculate the cueing effect using the following formula:

Cueing Effect = Mean Invalid Reaction Time – Mean Valid Reaction Time

9. Record your calculated cueing effect in Table 1.

Table 1. Posner Cueing Experiment Results

Measurement	Result (ms)
Mean reaction time — Valid cues	

Mean reaction time — Invalid cues	
Cueing effect	

A positive cueing effect indicates that responses were slower during invalid trials, consistent with the expected effect of spatial attention. A negative value indicates that responses were faster during invalid trials.

Part 3: Graphing Your Results

Graphs allow researchers to visualize patterns in experimental data. In this activity, you will create a bar graph comparing your mean reaction times for valid and invalid cues.

Procedure

1. In Excel or Google Sheets, create a two-column summary table containing the cue conditions and their corresponding mean reaction times.
2. Highlight the summary table, including the column headings.
3. Select Insert, then Chart (Google Sheets) or Insert, then Column or Bar Chart (Excel).
4. Select a vertical column chart displaying one bar for each experimental condition.
5. Give your graph the title "Mean Reaction Time by Cue Validity."
6. Label the horizontal axis "Cue Validity" and the vertical axis "Mean Reaction Time (ms)."
7. Check that your graph contains two bars representing the mean reaction times for valid and invalid cues.
8. Copy your completed graph into your lab report or save it as an image.

Lab Report

Answer the following questions using your experimental results and the concepts discussed in the background reading.

1. **Compare your mean reaction times for valid and invalid cues. Which condition produced faster responses? Were your results consistent with the expected Posner cueing effect?**

2. **Explain why valid cues generally produce faster reaction times than invalid cues. In your explanation, discuss how spatial attention influences the processing of visual information.**

3. **What is covert attention? Explain how the Posner cueing task allows researchers to investigate shifts in attention without requiring participants to move their eyes.**

4. **Describe the role of the parietal cortex in spatial attention. How does this region contribute to directing attention toward different locations in the visual field?**

5. **Hemispatial neglect can occur following damage to the parietal cortex. Explain how this condition affects spatial attention and predict how someone with left-sided hemispatial neglect might perform on the Posner cueing task.**

6. **Insert and examine the graph you created. What does the difference between the two bars indicate about the relationship between cue validity and reaction time? Explain how the graph helps communicate your experimental findings.**

7. **Identify the independent and dependent variables in the Posner cueing experiment. Explain how comparing reaction times across cue conditions allows researchers to investigate spatial attention.**

8. **Identify two factors that could influence reaction times during this experiment, such as distractions, fatigue, or familiarity with the task. Explain how these factors might affect the interpretation of your results.**

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8: WORKING MEMORY AND EXECUTIVE FUNCTIONING

8.1: Executive Functions and the Prefrontal Cortex
8.2: Working Memory and the N-Back Task

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8.1: Executive Functions and the Prefrontal Cortex

In this section, we'll consider the suite of cognitive processes that allow us to plan out and successfully engage in behaviors that help us to reach our goals, to maintain or shift focus on important tasks as the need arises, and to keep us from acting impulsively or inappropriately. Collectively, these refer to executive function, and we'll review the different pieces that make up this complex aspect of higher cognition, as well as the brain systems that underlie those processes.

Components of executive function (and their associated tests)

Executive function is a fairly dense and complicated topic, but it involves a host of processes such as setting goals and making concrete plans to achieve those goals ('What do I need to do to get an "A" on my lab writeup?"), being able to switch back and forth between competing tasks ("How am I going to juggle my psychology paper due next Monday and my Art History test next Tuesday?"), and monitoring yourself to know whether things are going well or not ("I made a lot of mistakes on that quiz—what can I do differently next time?"). It also involves our ability to suppress the urge to do things that either won't help you succeed or that would be inappropriate ("Don't look at another student's test."). Each of these represents a distinct aspect of our ability to coordinate information to make decisions and achieve goals, and while they overlap with some of the processes that we've already covered (such as top-down attentional control), they represent a different aspect of higher-level cognition.

We often cycle between multiple activities in our day-to-day lives (e.g., checking text messages while trying to read your textbook), and our ability to make those shifts is known as task switching (Monsell, 2003). Shifting back and forth between activities is effortful, and, critically, it levies a toll on our performance. That is, any time you switch between tasks, your performance will suffer in terms of speed, accuracy, or both. Switching between tasks makes you slower on each, compared to staying focused on just one or the other. This is known as a switch cost and it has been demonstrated in numerous experiments dating back to the early 20th century (Jersild, 1927). Rogers and Monsell (1995) developed a standard paradigm for examining these effects.

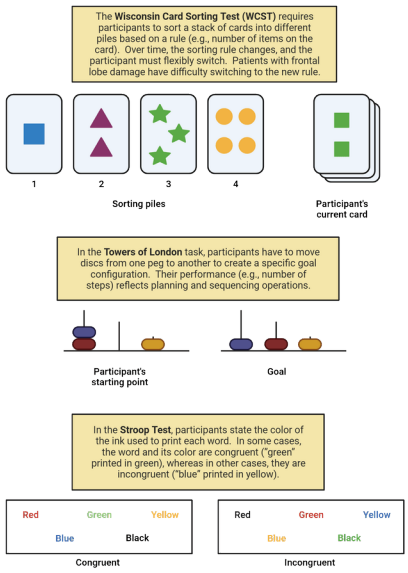


Figure 19.17 Tasks relying on frontal cortical function

A separate core component of executive function is our ability to break down complicated tasks into separate pieces, and then to arrange those pieces in a logical order to achieve our goals. This could involve simple tasks like brushing your teeth or more complicated, long-term activities like planning a wedding. In either case, we need to think about sequencing the behaviors in a way that will yield success. One method for studying these planning and sequencing processes is through a task developed by Shallice (1982) called the Tower of London (ToL) game (Figure 19.17). In this task, participants rearrange discs on a row of pegs. Their goal is to recreate a pattern that the experimenter shows them, and the rule is that they can only move one disc at a time. Researchers can vary the difficulty of the problem on each trial, and by examining the number (and kind) of moves that a person makes, as well as their speed, they can assess various components of planning and sequencing behavior.

A third critical aspect of executive function relates to inhibitory control, which generally refers to our ability to suppress thoughts or behaviors. We might need to suppress a response because it's inappropriate in the current context (yelling at the referee for your child's soccer match), or because it's a change from our normal, well-rehearsed routine (turning the opposite way on your commute home to run an unscheduled errand). In either case, we have to exercise mental effort in order to avoid the wrong choices. A number of tasks are used to study inhibitory control, with perhaps the most famous one being the Stroop task (Stroop, 1935; Figure 19.17). This task requires participants to look at a set of words on a paper or on a computer screen and selectively attend to, and report, the color of each word. They are told not to read the words out loud, but reading is a relatively automatic process, and so it requires a great deal of inhibitory control to say the color of the ink, rather than the word itself—especially when the words conflict with the ink color (e.g., the word "red" printed in blue). These tasks not only have value in experimental research, but are also important tools in many clinical settings. For instance, the Stroop tasks is commonly used to track and monitor the progression of neurodegenerative diseases such as Alzheimer's disease (Hutchison et al., 2010).

We'll briefly touch on two other aspects of executive function, which are the ability to *update* and *monitor* information that's relevant to your current task or your long-term goals. These processes are actually implemented in distinct ways, such as working memory, which allows us to not only *retain* important bits of information in a temporary buffer, but also to *manipulate* those bits as a task requires. We also monitor and update our own actions and assess how effective they are in allowing us to accomplish our goals. This is described as self-monitoring and it can operate on different time scales, from immediate ("did I just call you the wrong name?") to long-term ("am I saving enough to buy a car next year?)". One way to study short-term self-monitoring experimentally is to use a Flanker Task (Eriksen & Eriksen, 1974), in which a participant has to discriminate a central letter ("X" vs "S") that's surrounded by flanking letters that should be ignored. Sometimes the flanking letters are the same as the central letter (congruent) and sometimes they are the opposite letter (incongruent). People are slower and tend to make mistakes on incongruent trials, and by observing how their behavior changes after they recognize their mistake (error monitoring), you can study these self-reflection and updating processes. For instance, people typically respond more slowly but more accurately after an error, suggesting that they are updating their criteria for making a response.

Mapping executive function to the brain

Executive functions are carried out by a wide range of brain systems, most notably the prefrontal cortex (PFC; Figure 19.18).

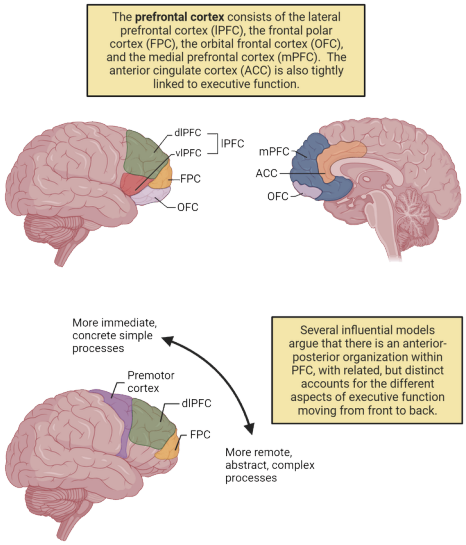


Figure 19.18 Brain regions associated with executive function

Anatomically, the prefrontal cortex can be broken down into several regions including the lateral prefrontal cortex (just anterior to the motor and premotor regions), the orbital frontal cortex and frontal pole (just in front of and below to the lateral prefrontal cortex), and the medial prefrontal cortex (located on the interior wall of each hemisphere). When researchers refer to the medial prefrontal cortex in the context of executive function, they also commonly include the anterior cingulate cortex, which lies just posterior to medial PFC and superior to the corpus callosum. The lateral prefrontal cortex is also commonly divided further into dorsolateral prefrontal cortex (dlPFC) and ventrolateral prefrontal cortex (vlPFC).

Activity in each of these brain regions has been linked to the different executive functions discussed above using functional brain

imaging (Methods: fMRI/MRI) and electrophysiological (Methods: EEG/ERP) techniques. For instance, fMRI studies show that that the WCST engages the dlPFC (Monchi et al., 2001) and vlPFC (Lie et al., 2006; for a review, see Nyhus & Barceló, 2009) and structural MRI evidence suggests that PFC volume correlates with performance in the task (Yuan & Raz, 2014). Other fMRI studies, using related task-switching paradigms, find activity in regions such as the ACC (Ravizza & Carter, 2008) and premotor cortex (Slagter et al., 2006). Planning and sequencing tasks such as the ToL reliably engage the dlPFC (van den Heuvel et al., 2003) and ACC (Lazeron et al., 2000), and non-invasive brain stimulation to the left dlPFC improves performance on the ToL task (Kaller et al., 2013). Tasks that involve inhibitory processing are associated with activity throughout the prefrontal cortex (for two recent reviews, see Banich, 2019; Hung et al., 2018). Finally, the ACC and mPFC have been closely linked to self- and error-monitoring tasks through electrophysiological markers such as the error-related negativity (Falkenstein et al., 1991; Gehring et al., 2018), which is a negative ERP component that occurs within the first ~100ms after a participant makes a mistake in a variety of tasks (e.g., the Flanker task) and is thought to be generated by the ACC (Dehaene et al., 1994). Functional MRI studies provide converging evidence for a critical role of the ACC in error-monitoring (e.g., Iannaccone et al., 2015).

It is important to note that while the bulk of the research discussed thus far focuses on human and non-human primates, there is in fact a wealth of research suggesting a link between executive function and prefrontal cortex in other species. Using analogs of many of the paradigms describe above, researchers have established a critical role of the rodent prefrontal cortex in executive functions such as task and set switching (e.g., Bortz et al., 2023; Ragozzino, 2007), spatial and olfactory working memory (e.g., Wang et al., 2023), the Flanker task (e.g., Fisher et al., 2020), and error monitoring (e.g., Olguin et al., 2023).

Although there is clear consensus that the prefrontal cortices are critical for many of the above-mentioned aspects of executive function, there is considerable debate about how to best characterize the division of labor within PFC. There isn't a single agreed-upon mapping between different executive functions and different brain regions (to paraphrase an old expression, if you ask 5 neuroscientists how executive functions are organized in the PFC, you'll get 6 opinions!). Nevertheless, two relatively popular models of PFC organization (Badre & D'Esposito, 2009; Koechnlin & Summerfield, 2007; for a recent review, see Badre & Nee, 2018) propose related hierarchical organizations going from anterior to posterior PFC, albeit with slightly different properties in each case (Figure 19.18). In both models, the basic premise is that more anterior regions of the PFC are tightly linked to temporally remote, abstract, and higher-level aspects of executive function and control, whereas more posterior regions are more tightly linked to immediate, concrete, and sensory-driven aspects of executive function and control. To be sure, this glosses over some major differences between the two, but it provides a first glance at one potential way to break down this large network of prefrontal regions into smaller units. Other organizational schemes suggest, for example, hemispheric differences related to things such as task-switching vs. monitoring (Ambrosini et al., 2019), or for different types of working memory content (D'Esposito et al., 1998). However, several recent reviews (Friedman & Robbins, 2021; Menon & D'Esposito, 2021) suggest that it might be better to conceive of cognitive control and executive function as emerging from a set of overlapping networks that all involve the PFC, rather than focusing on the specific roles of individual regions.

Effects of brain damage on executive function

Proper executive functions rely on the integrity of the prefrontal cortex (for a review, see Alvarez & Emory, 2006). For instance, patients with frontal lobe lesions are often impaired on the WCST (Milner, 1963; Goldstein et al., 2004) and will continue to apply an old sorting rule, even when it has changed (a phenomenon known as perseveration), and even when they know that it has changed. Monkeys with prefrontal lesions (Dias et al., 1996) are also impaired in an analog of the WCST, suggesting that the role of the frontal cortex in executive function is not specific to humans. Similar findings occur in rats (Birrell & Brown, 2000; McGaughy et al., 2008) and further suggest that norepinephrine plays a critical role in this process. This fits well with the fact that a number of common treatments for executive dysfunction such as ADHD (e.g., Adderall) involve blocking the reuptake of norepinephrine (recall 19.5 How Do Clinical Disorders Affect Attentional Function?).

Task switching paradigms reveal deficits after frontal lobe damage (e.g., Kumada & Humphreys, 2006; Rogers et al., 1998), as do tasks that involve planning and sequencing behaviors. Performance on the ToL game is impaired after damage to prefrontal regions (for a review, see Nitschke et al., 2017). Patients will sometimes perseverate on previous moves or attempt to break the rule of only moving one disc at a time. Moreover, they do not engage in strategic planning or sequencing, but rather often attempt to solve the task using "trial and error" approaches. Petrides & Milner (1982) showed a similar phenomenon using a self-ordered pointing task (SOPT), which requires patients to look at a set of objects on a computer screen and point to one that they choose. Then, on each subsequent trial, the researchers rearrange the objects and the patient has to point to a new object that they haven't already selected. This task relies on several aspects of executive function including working memory and sequencing since the patient needs to remember the objects that they have already selected even though they appear at new locations on the screen each trial, and, critically, damage to the frontal lobes impairs performance.

Damage to the prefrontal cortex and anterior cingulate cortex will also impact inhibitory control processes. For instance, Perret

(1974) argued that left frontal lesions selectively impair performance on the Stroop test, although not all researchers agree with this claim (e.g., Stuss et al., 2001). Impairments on other related inhibitory control tasks have been linked to right frontal lobe damage (Aron et al., 2003) and lateral prefrontal and orbitofrontal lesions in monkeys selectively impair non-affective (i.e., non-emotional) and affective (i.e., emotional) inhibitory control processes, respectively (Dias et al., 1997).

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8.2: Working Memory and the N-Back Task

Working Memory and the N-Back Task

Background

Working memory is the ability to temporarily maintain and manipulate information while performing a task. Unlike long-term memory, which allows us to store information for later retrieval, working memory helps us keep information accessible and update it as new information becomes available. Working memory is essential for activities such as following instructions, solving problems, reading, and making decisions.

Working memory depends on a network of brain regions, including the prefrontal cortex and parietal cortex. The dorsolateral prefrontal cortex is particularly important for maintaining task goals and regulating the information used during cognitive tasks. These regions work together to support executive functions such as attention, monitoring, and updating information.

One method researchers use to investigate working memory is the N-back task. During this task, participants view a sequence of stimuli, such as letters, and determine whether the current stimulus matches one presented a specified number of trials earlier. In a 2-back task, participants must determine whether the current letter matches the letter presented two trials previously. For example, in the sequence A, B, A, the third letter is a match because it is identical to the letter presented two positions earlier.

The N-back task requires participants to continuously monitor incoming information, maintain recently presented stimuli, and update the contents of working memory. Researchers measure performance using accuracy, reaction time, and different types of errors. These behavioral measures provide information about cognitive performance, although they do not directly measure brain activity.

In this lab, you will complete a computerized 2-back task and analyze your performance across three blocks of trials. You will investigate whether your accuracy and response speed change with repeated task exposure and consider how working memory and executive functioning contribute to your performance.

Learning Objectives

By the end of this lab, you should be able to:

1. Explain how the N-back task measures working memory and executive functioning.
2. Identify the neural systems involved in working-memory maintenance and updating.
3. Calculate accuracy, reaction time, and error rates using experimental data.
4. Create graphs illustrating changes in cognitive performance across repeated trials.
5. Evaluate the effects of practice, fatigue, and response strategies on experimental performance.

Materials

- Computer with an internet connection and keyboard
- PsyToolkit N-back experiment: https://www.psytoolkit.org/experiment-library/experiment_nback2.html
- Microsoft Excel, Google Sheets, or another spreadsheet program

Procedure

Part 1: Complete the N-Back Experiment

1. Open the PsyToolkit N-back experiment using the link provided above.
2. Read the instructions carefully before beginning. You will complete a 2-back task in which letters appear sequentially on the screen. Your goal is to identify when the current letter matches the letter presented two trials earlier.

3. When you identify a matching letter, press the response key indicated by PsyToolkit. Do not press the key when the current letter does not match the letter presented two trials earlier.
4. Complete the experiment in a quiet environment with minimal distractions. Keep your attention on the task and respond as quickly and accurately as possible.
5. PsyToolkit will automatically present three blocks of 25 trials, for a total of 75 trials. Complete all three blocks. Do not restart the experiment between blocks.
6. At the end of the experiment, locate the option to copy your experimental data to the clipboard. Copy the complete dataset.
7. Open Excel or Google Sheets and paste the data into a blank worksheet. The dataset should contain 75 rows and 12 columns. Each row represents one experimental trial.
8. Save your spreadsheet. You will use these data to calculate performance measures and create graphs.

Part 2: Understanding Your Experimental Data

The PsyToolkit dataset contains the following variables:

Column	Variable	Description
1	Block number	Identifies Block 1, 2, or 3
2	Trial number	Identifies the trial within each block
3	Trial type	1 = matching stimulus; 0 = non-matching stimulus
4	Score	1 = correct; 0 = incorrect
5	Match	1 = correctly identified match
6	Miss	1 = missed matching stimulus
7	False alarm	1 = incorrectly responded to non-matching stimulus
8	Reaction time	Response time in milliseconds
9	Memory	Internal variable used by PsyToolkit
10	Current letter	Numerical representation of the current stimulus
11	N-back 1	Letter presented one trial earlier
12	N-back 2	Letter presented two trials earlier

The most important columns for this lab are block number, trial type, score, match, miss, false alarm, and reaction time.

PsyToolkit records a reaction time of 3000 milliseconds when no response is made before the response deadline. This is a timeout value rather than a measured response time. Do not include these timeout values when calculating average reaction time.

Part 3: Calculate Accuracy and Error Rates

You will calculate the following measures separately for each of the three blocks.

1. Count the number of correct trials in each block using Column 4. A score of 1 indicates a correct response.
2. Calculate the percentage of correct trials using the following formula:

   Accuracy (%) = (Number of correct trials ÷ 25) × 100

3. Count the number of matching trials in each block using Column 3. A value of 1 indicates a matching trial.
4. Count the number of correctly identified matches using Column 5.
5. Calculate the hit rate using the following formula:

   Hit rate (%) = (Correctly identified matches ÷ Total matching trials) × 100

6. Count the number of non-matching trials in each block using Column 3. A value of 0 indicates a non-matching trial.
7. Count the number of false alarms using Column 7.

8. Calculate the false-alarm rate using the following formula:

   False-alarm rate (%) = (False alarms ÷ Total non-matching trials) × 100

9. Record your results in the table in your lab report.

Part 4: Calculate Reaction Time

Reaction time measures how quickly a participant responds after a stimulus appears. In this experiment, reaction time is recorded in milliseconds (ms).

1. Locate Column 8 of your dataset.
2. For each block, identify trials with recorded reaction times below 3000 ms.
3. Calculate the mean reaction time for each block using only trials with a recorded response. Exclude values of 3000 ms because they represent trials in which no response was made.

   Mean reaction time = Sum of valid reaction times ÷ Number of valid reaction times

4. Record the number of valid reaction times and the mean reaction time for each block in the table in your lab report.

If a block contains no valid reaction times, record N/A rather than calculating a mean.

Part 5: Graph Your Results

You will create two line graphs to examine how your performance changed across the three blocks of the N-back experiment. Line graphs are useful for displaying changes across sequential measurements.

Graph 1: Accuracy Across Blocks

1. Create a small table in Excel or Google Sheets with two columns labeled "Block" and "Accuracy (%)."
2. Enter Blocks 1, 2, and 3 in the first column.
3. Enter the accuracy percentage you calculated for each block in the second column.
4. Highlight the entire table, including the column headings.
5. Follow the instructions below for your spreadsheet program.

If using Google Sheets:

- Click Insert → Chart.
- In the Chart editor, under Setup, change Chart type to Line chart.
- Make sure the horizontal (X) axis displays the block numbers and the vertical (Y) axis displays accuracy.
- Under Customize → Chart & axis titles, enter the chart title "Accuracy Across N-Back Blocks."
- In the same section, select Horizontal axis title and enter "Block Number."
- Select Vertical axis title and enter "Accuracy (%)."

If using Microsoft Excel:

- Click Insert → Insert Line or Area Chart → Line with Markers.
- Make sure the horizontal (X) axis displays the block numbers and the vertical (Y) axis displays accuracy.
- Click the chart title and change it to "Accuracy Across N-Back Blocks."
- Select the chart, click Chart Design → Add Chart Element → Axis Titles → Primary Horizontal. Enter "Block Number."
- Repeat for Primary Vertical and enter "Accuracy (%)."

Graph 2: Mean Reaction Time Across Blocks

1. Create a second table with two columns labeled "Block" and "Mean Reaction Time (ms)."
2. Enter Blocks 1, 2, and 3 in the first column.

3. Enter the mean reaction time you calculated for each block in the second column.
4. Highlight the entire table, including the column headings.
5. Follow the same instructions above to create a second line graph.

For this graph, use the following labels:

- Chart title: "Mean Reaction Time Across N-Back Blocks"
- Horizontal (X) axis: "Block Number"
- Vertical (Y) axis: "Mean Reaction Time (ms)"

If you are using Google Sheets, select Line chart. If you are using Excel, select Line with Markers.

If a block has no valid reaction times, leave its mean reaction time cell blank. Do not enter zero, because zero milliseconds would incorrectly indicate an instantaneous response.

Check Your Graphs

Before continuing, make sure that:

1. You have created two separate line graphs.
2. Each graph displays the results for Blocks 1, 2, and 3.
3. Both graphs have descriptive titles.
4. Both axes are labeled correctly, including the units of measurement.
5. Your graphs accurately represent the values in your data tables.

Part 6: Compare Performance Across Blocks

Use your calculated values to examine whether performance changed during the experiment.

1. Calculate the change in accuracy between Block 1 and Block 3.

   Change in accuracy = Block 3 accuracy – Block 1 accuracy

   Report the result in percentage points.

2. Calculate the change in mean reaction time between Block 1 and Block 3.

   Change in reaction time = Block 3 mean reaction time – Block 1 mean reaction time

   Report the result in milliseconds. A negative value indicates faster responses in Block 3.

3. Examine your hit rates and false-alarm rates across blocks. Determine whether your ability to identify matching stimuli changed and whether you made more or fewer incorrect responses to non-matching stimuli.

Lab Questions

Answer the following questions using your experimental data and the concepts discussed in the background reading. Include all requested calculations, tables, and graphs with your answers.

1. **Explain how the 2-back task requires both the maintenance and continuous updating of information in working memory. Why is this task more demanding than simply remembering a list of letters?**

2. **Identify the independent variable or repeated-measures factor and the dependent variables examined in this investigation. Explain how each variable was measured.**

3. **Complete the table below using your experimental data. Include your calculations for accuracy, hit rate, and false-alarm rate for each block. Show your work for each calculation.**

Measure	Block 1	Block 2	Block 3
Correct trials			
Accuracy (%)			
Matching trials			
Correctly identified matches			
Hit rate (%)			
Non-matching trials			
False alarms			
False-alarm rate (%)			

4. **Complete the table below using your experimental data. Calculate the mean reaction time for each block, excluding timeout values of 3000 ms. Show your calculations. If a block contains no valid reaction times, enter N/A.**

Measure	Block 1	Block 2	Block 3
Number of valid reaction times			
Mean reaction time (ms)			

5. **Create and insert a line graph titled "Accuracy Across N-Back Blocks" using your accuracy percentages from Question 3. Include all three blocks, label both axes, and include the appropriate units. Describe how your accuracy changed across the experiment, using specific values from your graph.**

6. **Create and insert a line graph titled "Mean Reaction Time Across N-Back Blocks" using your mean reaction times from Question 4. Include all three blocks, label both axes, and include the appropriate units. Describe how your reaction time changed across the experiment, using specific values from your graph.**

7. **Calculate the change in accuracy and mean reaction time between Block 1 and Block 3. Show both calculations, including units. Based on these results, did your performance improve, decline, or remain relatively consistent? Explain your interpretation using both measures.**

8. **Compare your accuracy and reaction-time graphs. Is there evidence of a speed–accuracy tradeoff? Explain your interpretation using specific results from both graphs. If your results do not show a clear relationship, explain that as well.**

9. **Why can overall accuracy be misleading when evaluating N-back performance? Explain how hit rate and false-alarm rate provide additional information. Using the values in your table from Question 3, describe what these measures suggest about your response strategy and ability to detect matching stimuli.**

10. **Explain how the prefrontal cortex and parietal cortex contribute to working-memory performance. How might these neural systems support successful performance on the 2-back task?**

11. **Identify at least two factors, such as practice, fatigue, or changes in attention, that could have influenced your performance across the three blocks. Explain how each factor might affect accuracy or reaction time and why your results cannot establish which factor caused any observed changes.**

12. **The N-back task measures behavioral performance rather than recording neural activity directly. Explain what your results can tell us about working-memory performance and what conclusions cannot be drawn about activity in specific brain regions.**

Source and Attribution

N-back experiment developed and hosted by PsyToolkit.

Stoet, G. (2010). PsyToolkit: A software package for programming psychological experiments using Linux. *Behavior Research Methods, 42*, 1096–1104.

Stoet, G. (2017). PsyToolkit: A novel web-based method for running online questionnaires and reaction-time experiments. *Teaching of Psychology, 44*(1), 24–31.

https://www.psytoolkit.org/experiment-library/nback2.html

Lab instructions and analysis activities developed for PSYC 3L: Biopsychology Laboratory.

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9: EMOTION AND PHYSIOLOGICAL AROUSAL

9.1: Emotion and Physiological Responses
9.2: Galvanic Skin Response and Emotional Arousal Lab

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9.1: Emotion and Physiological Responses

Are there categories of basic emotions for all humans? The potential for contextual stimuli from the environment to signal opportunities for social engagement, rewards, safety or signs of danger are appraised by cognitive processes in the brain. The interpretations evolving from this process coordinate a range of appropriate behavioral reactions that fall into the class of either approach towards, or avoidance from, stimuli in the immediate environment. In essence, the collection of brain systems that contribute to the appraisal process allow organisms to learn what will work in a given context. Brain systems also encode in memory the environment-body-brain interactions and use these memories to guide behavior in a more automatic and seamless fashion when similar events arise in the future. As we have learned, the selection of either form of engagement with the environment (approach or withdrawal) is determined by both the level of physiological arousal elicited by the experience and the emotional labels assigned to the represent the subjective feelings created inwardly from that transient event. This framework of understanding leads to another important topic in the field of emotion research, *are there categories of basic emotions that are present across all human species*?

Answers to this question were not initially addressed through direct investigations. They evolved from studies questioning whether the same appraisal processes that generate subjective affective experiences (i.e. conscious awareness of a state of feeling) are also capable of interpreting the nature of emotions inferred in facial expressions that accompany different emotional states of others. For example, when we are enthralled in an emotionally-laden circumstance, a cascade of involuntary unconscious changes occur such as split second changes in body functions in the autonomic nervous system, the volume, pitch and rate of our speaking, as well as the generation of different expressions on our face. Expressions involving smiles, frowns, clinched eyebrows and other forms of facial utterances are overt expressions of the internal emotions humans and animals may experience. This observation implies that feelings and emotions can be inferred through body language and more specifically, facial expressions.

Paul Ekman.

Paul Ekman and Wallace Friesen (Ekman & Friesen, 1975) were the first researchers to provide empirical support that humans possess a core set of six or more fundamental emotions. Their initial research examined whether research participants could identify the emotion a person was experiencing in a series of photographs by paying attention to different cues among the facial expressions, similar to those shown in Figure 13.6:

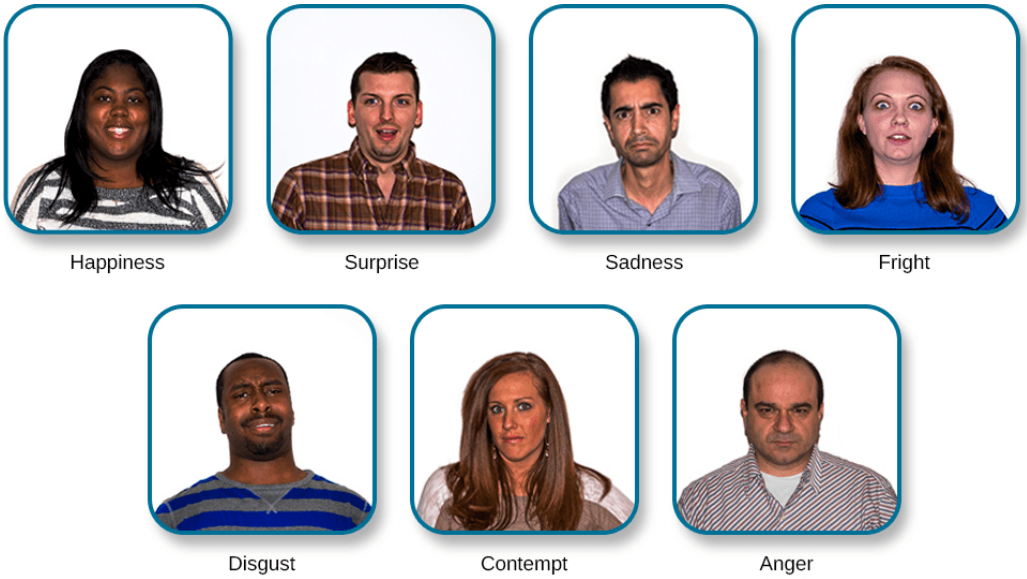


Figure 13.6 Facial expression of basic emotions The initial research by Paul Ekman determined if participants from several cultures could identify the emotion a person is experiencing from a series of photographs similar to those shown here. Image credit: Image courtesy of David Matsumoto and Humintell, LLC www.humintell.com

Ekman's research participants revealed a great deal of accuracy and uniformity in discerning the emotions of *anger, disgust, fear, happiness, sadness or surprise* from the facial expressions portrayed in photographs. His group solidified these findings

by repeating the experiment with participants living in different cultures such as Argentina, Brazil, Chile, and Japan. The spoken language of these cultures differs drastically, yet participants showed a remarkable degree of overlap in identifying the six basic emotions across cultures.

The experimental procedures to generate these findings were also applied to three separate groups of non-English speaking natives in New Guinea who were completely unfamiliar with Western Culture. Ekman's team considered it vital to include these essential experimental groups to verify that the ability to perceive emotions from facial expressions shown across cultural boundaries was not the result of exposure to Western cultural influences such as television, magazines, newspaper or theatrical movies. Ekman found that three separate native groups could also identify the six basic emotions from the expressions of models in photographs, although with less accuracy than the combined Western and non-Western participants.

Taken together, Paul Ekman's group was instrumental in revealing that all humans are endowed with an innate capacity to identify a basic set of internal core emotions through the combination of stimuli that comprise different facial expressions. From these and similar empirical studies, Ekman and Cordaro (2011) provided operational definitions to categorize the following six basic emotions.

Anger: the response to interference with our pursuit of a goal we care about. Anger is also triggered by someone attempting to harm us or someone we care about either physically or psychologically. In addition to removing the obstacle or stopping the harm, anger often involves the wish to hurt the target.

Fear: the response to the threat of harm, physical or psychological. Fear activates impulses to freeze or flee. Often fear triggers anger.

Surprise: the response to a sudden unexpected event. It is the briefest emotion.

Sadness: the response to the loss of an object or person to which you are very attached. The prototypical experience is the death of a loved child, parent, or spouse. In sadness, there is resignation, but it can turn into anguish in which there is agitation and protest over the loss and then return to sadness again.

Disgust: repulsion by the sight, smell, or taste of something; disgust may also be provoked by people whose actions are revolting or by ideas that are offensive.

Happiness: feelings that are enjoyed or sought by the person. There are a number of quite different enjoyable emotions, each triggered by a different event, involving a different signal and likely behavior. The evidence is not as strong for all of these as it is for the emotions listed above.

The concept that there are a core set of basic emotions has been corroborated by research using extensions of the procedures developed by Ekman's group. It is essential to note here that other psychological theories of emotion include more than 6 basic emotions, as we will see in the section on Robert Plutchik. Despite this disagreement about the number of core emotions, other research studies have identified specific changes in the body that accompany the 6 basic emotion categories identified by Ekman and colleagues.

The diagrams depicted in Figure 13.7; represent what is known as body maps and they reveal how the induction of each basic emotion is reflected by elevations (i.e. red to yellow shading) or reductions (i.e. black to blue shading) in a diverse number of bodily regions (Nummenmaa, Glerean, Hari, & Hietanen, 2014).

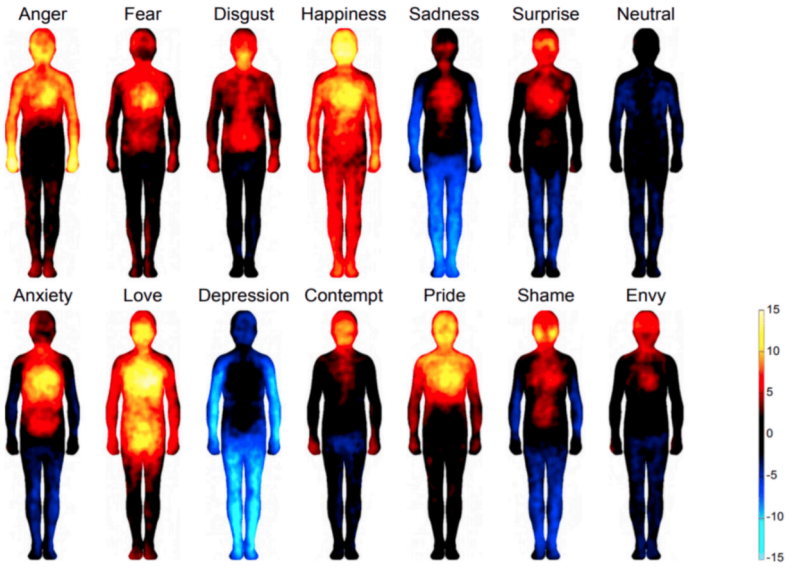


Figure 13.7 Body maps associated with each basic emotion The Body Maps reveal how experiencing each basic emotion elicit elevations (i.e. red to yellow shading) or reductions (i.e. black to blue shading) in bodily activity. Image credit: Mummenmaa et al., 2014. "Bodily maps of emotions." Proceedings of the National Academy of Sciences 111 (2) 646-651; DOI: 10.1073/pnas.1321664111.

For example, states of Anger correspond to increased blood flow to the hands and arms presumably to prepare organisms to defend themselves or fight in the face of threatening environmental stimuli (Levenson, Ekman, & Friesen, 1990). In contrast, states of Fear direct blood flow away from the hands and arms and distribute increased circulation to the legs and feet to prepare organisms to escape and flee from external signals of danger (Ekman, 2003). External stimuli that lead to Disgust (also see row 3 of Figure 13.2) trigger intense muscle activation in the face. Depending on the intensity or modality of the stimuli, this emotion may also induce a gag reflex and restrict further airflow to the nose to reduce the repugnant nature of external olfactory stimuli (Koerner & Antony, 2010). The positive emotion of Happiness increases circulation throughout the body as a consequence of elevated output of oxytocin and serotonin (Uvnaes-Moberg, 1998), whereas states of Sadness are reported to reduce circulation to external limbs used to interact with the environment and direct blood flow to internal visceral organs. The final emotion of Surprise affects facial expression by raising the eyebrows and increasing respiratory functioning in the lungs to prepare organisms to generate sudden approach or avoidance responses to rapidly presented stimuli (Ekman & Friesen, 1975).

Findings from neuroimaging studies with functional magnetic resonance imaging (fMRI) capture the collection of brain neural systems that are engaged in response to experiencing each of the core basic emotions (Saarimäki et al., 2016) (see Methods: fMRI). To provide this snapshot, the brains of human participants were scanned with fMRI while they viewed 10 second affective movie clips that were selected from a database, with scenes representing 5 emotion categories. A second experiment assessed brain related changes in response to emotional imagery. Imagery was manipulated by presenting words to study subjects that commonly evoke affective feelings associated with anger, disgust, fear, happiness, sadness or surprise. It is important to note that all participants were given 36 emotion words (i.e. 6 per words per emotion category) one-week prior to be scanned in the fMRI. The 7-day interval was imposed to allow participants to devise a personal method of eliciting emotions to each word category by either, a) imagining a previous event associated with the words, b) relating the words to a movie scene, or c) producing a body state that corresponds to emotions associated with the word categories. The data in the top left of Figure 13.8 shows that the experimental procedures were successful in generating a specific emotion. Participants were between 90-95% accurate in subjectively identifying the specific emotion category researcher's intended to induce through presentation of the short movie clips.

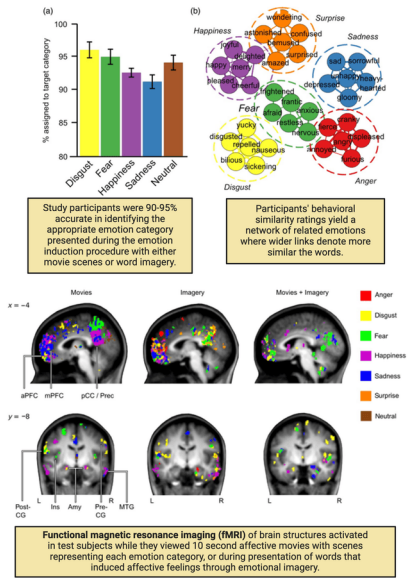


Figure 13.8 Neural systems engaged during the experience of basic emotions Image credit: Images from: Saarimäki H, Gotsopoulos A, Jääskeläinen IP, Lampinen J, Vuilleumier P, Hari R, Sams M, Nummenmaa L. Discrete Neural Signatures of Basic Emotions. Cereb Cortex. 2016 Jun;26(6):2563-2573. Reused with author permission

Data in the top right of Figure 13.8 represents a cluster analysis to show that the pre-selected emotion words specifically induced feelings associated with a specific emotion. The separation of presented words into clearly defined categories provides evidence that select words evoked affective reactions in discrete emotion categories, as opposed to across more than one emotion category.

The findings from fMRI scans are shown in the bottom of Figure 13.8 (brain diagram). The separate emotion categories are represented by the different colors displayed on the right of the figure. The location of brain regions that actively responded to emotions induced by movies or imagery are displayed in brain images on the left of the figure (see abbreviations below). One striking finding that is easily identified in the brain diagrams is that specific emotion categories are not represented in a single brain structure, but rather across brain regions. Take for instance the color purple, that represents Happiness. When this emotion was elicited by movies, imagery or both procedures, there are clear functional changes in the medial and anterior prefrontal cortex (mPFC, aPFC), posterior cingulate cortex (pCC), amygdala and medial temporal gyrus. The remaining fMRI results did not reveal a one-to-one correspondence between changes in any specific brain region with a given emotion category. Rather, some brain structures, such as the insula (Ins), displayed increased activity to stimuli generating the emotions of fear and disgust. There were also notable increases in the amygdala (Amy) by words or movie scenes that induced the emotions of happiness, fear and disgust.

We will discuss the brain systems mediating emotion much more in 13.3 What Is the Contribution of Brain Structures in Emotional States?. For now, we can learn from this experiment that, although we may subjectively discern one given emotion from another, the lack of selective activation of specific brain regions per emotion category reflects that the process of generating emotions from internal states involves several brain systems. This involvement of multiple regions to generate single emotions is quite reasonable given that any given emotion is a collection of processes that result from binding together the context the emotion occurs in, evaluating the constellation of bodily changes created by an event, the value of stimuli that elicits the emotion and the role of memory in retrieving affective states associated with previous encounters with similar events. These findings illustrate how distinct categories of emotion translate into characteristic patterns of neural activity or neural signatures across a network of brain structures, rather than within any specific brain structure. The neural signatures were induced in subjects by a wide spectrum of emotion-eliciting training conditions and the changes produced in the specific distribution of brain networks were consistent across individual participants. These findings raise the question of whether our current imaging tools are sophisticated enough to predict the subjective emotion an individual is experiencing from using solely brain activity.

Robert Plutchik

Ekman's group was instrumental in identifying a basic category of emotions generated by environmental stimuli across all cultures. However, you may judge this discovery as being somewhat limited when considering the range of emotions you experience personally at any single point in time is both complex and multifaceted. This type of concern was raised by Robert Plutchik who opposed this abbreviated category of emotions. He proposed that the vast range of subjective feelings humans

experience may be better explained by considering that basic emotions do not occur in isolation, but may combine to capture the richness and intensity of personal experiences generated by external events. For example, one may immediately experience the emotion of happiness when notified in an email of a job promotion that also comes with a major increase in salary. It is not a far stretch to say that the emotion of happiness garnered by reading this document may also be combined with some fear and apprehension of the greater responsibilities, expectations and demands on time that accompany this new promotion. In a similar vein, consider the range of emotions generated when you are the subject of a surprise birthday party. The unpredicted festive event may be filled with cherished individuals that bring you great joy, happiness and comfort. When all are combined, the joy, happiness and comfort elicited by the surprise party may also be met with extreme anger when considering that the organizers of this event are well aware of your previously stated disdain of surprises. Sports fans are quite familiar with the subjective feeling of disgust over an unfair call by a referee during the final seconds of a match with your rival team. However, when your team is victorious, joy, happiness and excitement join the feelings of disgust that were generated only seconds ago by the referee's error.

The inability for current theories to account for the consequences inherent in each type of scenario described above motivated Robert Plutchik (1960; 1984) to propose that the rich constellation of emotions experienced in humans are a byproduct of eight basic emotions (e.g. *joy, trust, fear, surprise, sadness, disgust, anger and anticipation*) that are depicted in the table and color wheel in the second circle from the center of Figure 13.9.

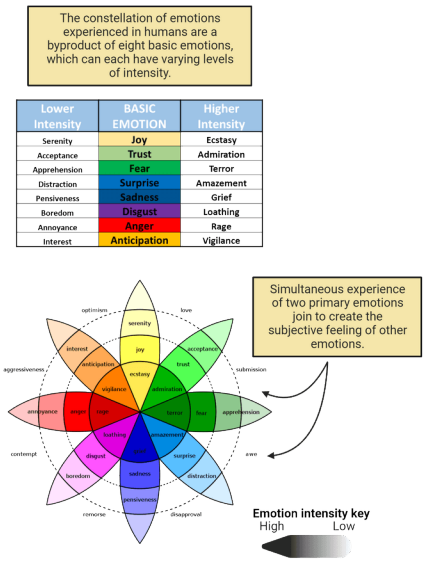


Figure 13.9 Wheel of emotions Image credit: Color wheel from public domain: https://commons.wikimedia.org/wiki/F...chik-wheel.svg

There are low and high degrees of intensity of Plutchik's eight basic emotions that are represented by the lighter and darker hues of colors on the wheel, respectively. Plutchik envisioned basic emotions as building blocks with more complex emotions being blends of the basic ones shown in the second circle. For example, the Covid-19 related mask mandates on airplanes garnered different emotions depending on how serious one may view the long-term health consequences of this virus. An individual may initially experience the lower intensity emotion of *annoyance* by viewing someone in the waiting area without a mask. However, the more intense emotions of *anger* may erupt once you hear the mask-less passenger sneezing upon entering the plane and the higher intensity emotion of *rage* may result when you realize the "mask-less, sneezer" seat is next to yours on a 6-hour flight.

According to Plutchik, the extensive number of subjective emotions produced during any encounter arise from some unique clustering of the emotions included in this spectrum. The separate emotions shown without colors in the outer sphere of the wheel demonstrate how the simultaneous experience of two primary emotions join to create the subjective feeling of other emotions. For example, life experiences that foster both *anticipation* and *joy* will combine to produce *optimism*, or a positive view on future events, whereas events that generate *disgust* and *anger* lead to the experience of *contempt*. The three-dimensional form of the Wheel of Emotions is a separate way to demonstrate that as the color of the emotion moves from the exterior to the center, the intensity of the emotion experienced, intensifies within an individual. Using the airline flight example above, anger that is manifested at its lowest level of intensity is annoyance, yet when combined with anger will lead to the full expression of rage. Plutchik's Wheel of Emotions can also explain how polar opposite emotions may evolve within the same experience. Take for example the emotions you may experience while attending a funeral for a cherished loved one who battled cancer for the past three years. Although it is clear one will experience extreme grief and sadness (depicted as blue in the wheel) at this lost, these subjective emotions may be accompanied by both a sense of serenity and joy (depicted as light yellow in the wheel) by knowing that the loved one is now free from constant pain, a loss of independence and daily suffering.

How emotions are studied in neuroscience: methods and techniques

Ekman and Cordaro (2011) provided a list of forms of emotional expression that are common across the human species. This list suggests that there are representative overt and internal changes that accompany the experiential or subjective feeling of a given emotion. The four overt responses include changes in verbalizations (i.e. tone, speed, and pitch), facial expressions, body posture and physical responses (i.e. affiliative or positive bonding reactions or aggressive and opposing actions) toward individuals or objects that elicited the emotion. The two internal or unobservable responses include physiological changes in the body and neural changes in activity across critical brain structures. The sheer range of internal and external changes that represent the onset of a given emotion produces a challenge for those studying the underpinnings of emotions. Fortunately, there are several technical tools to address these challenges. In a general sense, there are 2 core components of any emotion experiment. The first includes procedures for eliciting a selected emotion and the second includes the use of technology to capture and quantify how the experimentally elicited emotion impacts any of the overt or internal changes. The following section provides an overview of the tools available to researchers to combine these approaches in understanding brain-behavior relationships.

Emotion Induction, a traditional method of eliciting emotions involves presentation of words, pictures, sounds or movie clips that are already verified to induce a certain emotion. There are several databases containing thousands of pictures that have been evaluated by large, heterogeneous groups of men and women to ensure the pictures elicit emotions in a given category. One commonly used database is known as the International Affective Picture System (IAPS) that was developed by Peter Lang and Margaret Bradley at the University of Florida. Pictures developed for the IAPS have been verified across a large number of research studies and each photo is assigned a rating number so that potential users are informed on how well a picture in the database is rated for emotional arousal and valence in terms of positive or negative impact. There are a number of other emotional picture datasets including the Open Affective Standardized Image Set (OASIS) Emotional Picture Set (EmoPicS) and Geneva affective picture database (GAPED) just to name a few. Movie clips, sounds, words and other emotion-eliciting stimuli are also extracted from commercial databases or other emotion research labs that have validated that these stimuli elicit a targeted emotion with a high degree of accuracy.

Assessing Emotional Reactions. The impact of stimuli used to induce emotions are measured by a number of tools and devices that can reveal changes in either the subjective experience of feelings or fluctuations in the body or brain. The *subjective experience of emotions* is traditionally assessed by providing study participants with a SELF-REPORT survey that contains questions to identify the subject's personal reflection of the emotion experienced, its intensity and duration. A commonly used measure of *physiological change*s that correspond to emotional arousal involves the use of a Polygraph Test. As shown in Figure 13.10, the polygraph contains several sensors that measure the magnitude of an emotional stimulus on several bodily changes.

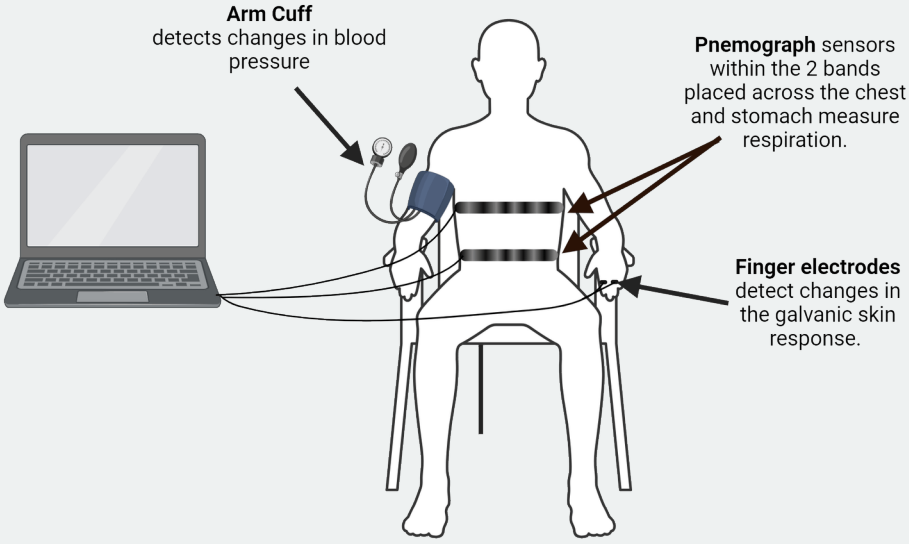


Figure 13.10 Methods of identifying changes in physiological arousal after the induction of emotions Image credit: Photo by Sherkiya Wedgeworth - federalsoup.com/articles/201...pplicants.aspx, CC BY-SA 4.0, commons.wikimedia.org/w/inde...urid=110940529

This device detects the Galvanic Skin Response (GSR), a measure of electrodermal fluctuations in skin (i.e. sweat) that occurs when arousal-induced stimuli increase activity in the sympathetic nervous system. Although GSR is a reliable indicator of physiological changes, this type of measurement is poor at identifying the source of the arousal. For example, increased GSR responses may occur rapidly after presenting research participants with a vivid picture of a snake. However, the GSR cannot reveal whether the picture-related arousal is due to elevations in heart rate, blood pressure, respiration, dilation of the pupils, or the secretion of stress hormones such as epinephrine or cortisol. These changes reflect intense activation of the sympathetic division of the autonomic nervous system and are reflected by electrodes shown in Figure 13.10. When multiple electrodes are used with the polygraph, researchers are able to develop a profile or "physiological fingerprint" that corresponds to the induction for emotions triggered by stimuli that produce sadness, anger, fear, happiness, disgust, etc.

The gold standard used in the search to unravel which brain areas are absolutely essential for generating the basic emotions is functional Magnetic Resonance Imaging (see Methods: fMRI). fMRI is an imaging technique that is capable of capturing the structure and location of individual brain structures that respond to emotional encounters. fMRI scans of participant's brains are recorded before, during and following the induction of emotions. In brief, the brain scans document how these time-locked events activate or suppress neural activity across different brain regions by tracking changes in blood flow across several brain regions that may be critical for processing and generating emotional responses. fMRI is a valuable tool for understanding if individual categories of emotion are mediated by changes in specific brain regions, or alternatively, revealing the constellation of brain structures that are responsible for this process. Functional imaging is also necessary for identifying how the separate stages of emotion perception, emotion evaluation and emotion regulation are effectively carried out by changes across different brain regions.

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9.2: Galvanic Skin Response and Emotional Arousal Lab

Instructor Note: This lab uses the WESAD dataset. Instructors should select and prepare a spreadsheet-compatible subset (CSV or Excel) containing participant IDs, experimental conditions (1 = neutral, 2 = stress, 3 = amusement), and electrodermal activity (EDA) measurements. The number of participants and observations is at the instructor's discretion. Because the original data require preprocessing, students should receive a prepared dataset. Consider retaining the selected participant data for use in subsequent labs. Review the dataset's reuse terms before distributing adapted data.

Galvanic Skin Response and Emotional Arousal Lab

Introduction

Have you ever noticed your palms becoming sweaty before an exam, during an important conversation, or while watching a suspenseful movie? These physical reactions are examples of how our nervous system responds to emotionally significant situations.

The autonomic nervous system regulates involuntary physiological processes, including heart rate, respiration, and sweating. During emotional arousal, the sympathetic division of the autonomic nervous system can activate sweat glands, producing small changes in the electrical conductance of the skin. These changes are measured using electrodermal activity (EDA), which is closely related to what is commonly called the galvanic skin response (GSR).

Researchers use EDA to investigate physiological arousal because sweat gland activity can change in response to stress, excitement, anticipation, and other emotionally significant experiences. However, EDA cannot identify which specific emotion a person is experiencing. For example, both fear and excitement may produce increased physiological arousal.

In this lab, you will analyze physiological data collected during a published research study. Rather than collecting your own measurements, you will work with an archival dataset to investigate how electrodermal activity varies across different experimental conditions.

Learning Objectives

By the end of this lab, you should be able to:

1. Explain how the sympathetic nervous system influences electrodermal activity.
2. Describe the purpose of archival research datasets and codebooks.
3. Identify and interpret variables in a physiological dataset.
4. Calculate and compare mean electrodermal activity across experimental conditions.
5. Create and interpret a graph displaying physiological measurements.
6. Explain the limitations of using physiological arousal to identify emotional experiences.

Materials Needed

- Computer with internet access
- Microsoft Excel or Google Sheets
- Dataset provided by your instructor (adapted from the WESAD (Wearable Stress and Affect Detection) Dataset: https://archive.ics.uci.edu/dataset/465/wesad+wearable+stress+and+affect+detection)

Part 1: Understanding Archival Research Data

What Is Archival Data?

In psychological research, scientists frequently collect information from participants to investigate relationships between

behavior, physiological processes, and psychological experiences. These data may include questionnaire responses, reaction times, physiological recordings, or measurements of brain activity.

After a study has been completed, researchers may make their data available for other scientists to examine. These previously collected data are called archival data.

Archival datasets allow researchers to investigate new questions without collecting an entirely new set of measurements. For example, a researcher might collect physiological data to develop a system for detecting stress, while another researcher could use the same data to investigate how the autonomic nervous system responds to different experimental conditions.

Working with archival data is an important part of scientific research. However, before analyzing any dataset, researchers must understand how the data were collected, what the variables represent, and how the measurements should be interpreted.

Introducing the WESAD Dataset

For this lab, you will use data from the Wearable Stress and Affect Detection (WESAD) study.

The WESAD dataset contains physiological measurements collected from 15 participants using wearable sensors. The researchers recorded physiological activity while participants experienced different experimental conditions.

Three conditions are particularly relevant to this lab:

1. Neutral condition: Participants completed a baseline period intended to represent a relatively neutral physiological state.
2. Stress condition: Participants completed activities designed to produce psychological stress.
3. Amusement condition: Participants experienced activities intended to produce amusement.

The researchers collected several physiological measurements, including electrodermal activity, heart activity, respiration, and skin temperature.

For this lab, we will focus specifically on electrodermal activity (EDA).

The original dataset is available through the UCI Machine Learning Repository:

https://archive.ics.uci.edu/dataset/465/wesad+wearable+stress+and+affect+detection

What Is a Codebook?

When researchers share data, they often provide a codebook. A codebook is a reference document that explains what the variables in a dataset represent, how they were measured, and what different values or codes mean.

For example, a dataset might identify experimental conditions using numbers rather than written descriptions. Without a codebook, someone examining the data might not know what those numbers represent.

The following table describes the variables you will use in this lab.

Table 1. WESAD Dataset Codebook

Variable	Description	Values or Units
Participant ID	Identifies the participant whose physiological measurements were recorded	Unique participant identifier
Experimental Condition	Identifies the experimental condition during which the measurement was collected	Neutral, Stress, or Amusement
EDA	Electrodermal activity, a measurement of the electrical conductance of the skin	Microsiemens (µS)

Time (if included)	Identifies when a physiological measurement was recorded	Time unit specified in the dataset

In the original WESAD dataset, experimental conditions are coded numerically. The relevant condition codes are 1 = neutral, 2 = stress, and 3 = amusement. Your instructor may provide these as numbers or written labels.

Procedure

1. Open the WESAD dataset webpage using the link provided above.
2. Read the dataset description to learn about the original research study and the physiological measurements collected.
3. Open the spreadsheet provided by your instructor in Microsoft Excel or Google Sheets.
4. Examine the column headings and compare them with the codebook in Table 1.
5. Identify which column contains the participant identifiers, which identifies the experimental conditions, and which contains EDA measurements.
6. Examine several rows of the dataset. Notice how each row represents a recorded observation and how the values differ across observations.

Part 2: Analyzing Electrodermal Activity

Electrodermal activity is measured in microsiemens (µS), a unit describing electrical conductance. Higher EDA values generally indicate greater skin conductance, which can reflect increased sweat gland activity associated with sympathetic nervous system activation.

In this part of the lab, you will compare EDA measurements across the neutral, stress, and amusement conditions.

Procedure

1. Open your dataset in Microsoft Excel or Google Sheets.
2. Locate the columns identifying experimental condition and EDA.
3. Examine the EDA measurements for each experimental condition.
4. Use the spreadsheet's filter feature to display only observations from the neutral condition.
5. Highlight the EDA values for the neutral condition.
6. In Microsoft Excel, locate the Average value in the status bar at the bottom of the window. In Google Sheets, use the calculation menu at the bottom right of the window and select Average.
7. Record the mean EDA for the neutral condition in Table 2.
8. Repeat this process for the stress condition.
9. Repeat this process for the amusement condition.
10. Record all three mean values in Table 2.

Table 2. Mean Electrodermal Activity by Experimental Condition

Experimental Condition	Mean EDA (µS)
Neutral	
Stress	
Amusement	

Examine your results. Consider whether EDA measurements appear to increase or decrease across the different experimental conditions.

Remember that EDA is a measure of physiological activity, not a direct measure of emotional experience. Differences in EDA may reflect changes in sympathetic nervous system activity, but they do not necessarily indicate that every participant experienced the same emotional response.

Part 3: Graphing Electrodermal Activity

Graphs help researchers visualize patterns in their data and communicate their findings.

In this activity, you will create a bar graph comparing mean EDA across the three experimental conditions.

Procedure

1. In Excel or Google Sheets, create a two-column summary table containing the three experimental conditions and their corresponding mean EDA values from Table 2.
2. Highlight the summary table, including the column headings.
3. Select Insert, then Chart (Google Sheets) or Insert, then Column or Bar Chart (Excel).
4. Select a vertical column chart displaying one bar for each experimental condition.
5. Give your graph the title "Mean Electrodermal Activity by Experimental Condition."
6. Label the horizontal axis "Experimental Condition" and the vertical axis "Mean EDA (µS)."
7. Check that your graph contains three bars representing the neutral, stress, and amusement conditions.
8. Copy your completed graph into your lab report or save it as an image.

Lab Report

Answer the following questions using your experimental results and the concepts discussed in the background reading.

1. **What is an archival dataset, and why might researchers choose to analyze previously collected data rather than collect new data? Explain one advantage of using archival research data.**

2. **Identify the independent and dependent variables in this investigation. Explain how these variables allow researchers to examine the relationship between experimental conditions and physiological arousal.**

3. **Compare the mean EDA values across the neutral, stress, and amusement conditions. Which condition produced the highest mean EDA? Which produced the lowest? Describe any differences you observed.**

4. **Explain how the sympathetic nervous system influences electrodermal activity. Why might EDA increase when someone experiences a stressful or emotionally significant event?**

5. **Insert and examine the graph you created. What does the graph reveal about differences in physiological arousal across the experimental conditions? Explain how the graph helps communicate your findings.**

6. **Imagine that the stress and amusement conditions produced similar mean EDA values. Would this mean that participants experienced the same emotion during both conditions? Explain why or why not, considering what EDA measures and its limitations.**

7. **Physiological responses can differ considerably between individuals. Identify two factors that might influence a person's electrodermal activity, even when experiencing the same experimental condition.**

8. **Researchers often use multiple physiological measurements, such as heart rate, respiration, and EDA, when studying emotional responses. Why might measuring several physiological processes provide a more complete understanding of emotional arousal than measuring EDA alone?**

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10: SKIN TEMPERATURE & AUTONOMIC REGULATION

10.1: Autonomic Regulation of Skin Temperature
10.2: Skin Temperature & Physiological Responses to Stress Lab

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10.1: Autonomic Regulation of Skin Temperature

Learning Objectives

By the end of this section, you will be able to:

- Describe the different functions of the skin and the structures that enable them
- Explain how the skin helps maintain body temperature

The skin and accessory structures perform a variety of essential functions, such as protecting the body from invasion by microorganisms, chemicals, and other environmental factors; preventing dehydration; acting as a sensory organ; modulating body temperature and electrolyte balance; and synthesizing vitamin D. The underlying hypodermis has important roles in storing fats, forming a “cushion” over underlying structures, and providing insulation from cold temperatures.

Protection

The skin protects the rest of the body from the basic elements of nature such as wind, water, and UV sunlight. It acts as a protective barrier against water loss, due to the presence of layers of keratin and glycolipids in the stratum corneum. It also is the first line of defense against abrasive activity due to contact with grit, microbes, or harmful chemicals. Sweat excreted from sweat glands deters microbes from over-colonizing the skin surface by generating dermicidin, which has antibiotic properties.

Everyday Connection

Tattoos and Piercings

The word “armor” evokes several images. You might think of a Roman centurion or a medieval knight in a suit of armor. The skin, in its own way, functions as a form of armor—body armor. It provides a barrier between your vital, life-sustaining organs and the influence of outside elements that could potentially damage them.

For any form of armor, a breach in the protective barrier poses a danger. The skin can be breached when a child skins a knee or an adult has blood drawn—one is accidental and the other medically necessary. However, you also breach this barrier when you choose to “accessorize” your skin with a tattoo or body piercing. Because the needles involved in producing body art and piercings must penetrate the skin, there are dangers associated with the practice. These include allergic reactions; skin infections; blood-borne diseases, such as tetanus, hepatitis C, and hepatitis D; and the growth of scar tissue. Despite the risk, the practice of piercing the skin for decorative purposes has become increasingly popular. According to the American Academy of Dermatology, 24 percent of people from ages 18 to 50 have a tattoo.

Interactive Link

Tattooing has a long history, dating back thousands of years ago. The dyes used in tattooing typically derive from metals. A person with tattoos should be cautious when having a magnetic resonance imaging (MRI) scan because an MRI machine uses powerful magnets to create images of the soft tissues of the body, which could react with the metals contained in the tattoo dyes. Watch this video to learn more about tattooing.

Sensory Function

The fact that you can feel an ant crawling on your skin, allowing you to flick it off before it bites, is because the skin, and especially the hairs projecting from hair follicles in the skin, can sense changes in the environment. The hair root plexus surrounding the base of the hair follicle senses a disturbance, and then transmits the information to the central nervous system (brain and spinal cord), which can then respond by activating the skeletal muscles of your eyes to see the ant and the skeletal muscles of the body

to act against the ant.

The skin acts as a sense organ because the epidermis, dermis, and the hypodermis contain specialized sensory nerve structures that detect touch, surface temperature, and pain. These receptors are more concentrated on the tips of the fingers, which are most sensitive to touch, especially the Meissner corpuscle (tactile corpuscle) (Figure 10.1.1), which responds to light touch, and the Pacinian corpuscle (lamellated corpuscle), which responds to vibration. Merkel cells, seen scattered in the stratum basale, are also touch receptors. In addition to these specialized receptors, there are sensory nerves connected to each hair follicle, pain and temperature receptors scattered throughout the skin, and motor nerves innervate the arrector pili muscles and glands. This rich innervation helps us sense our environment and react accordingly.

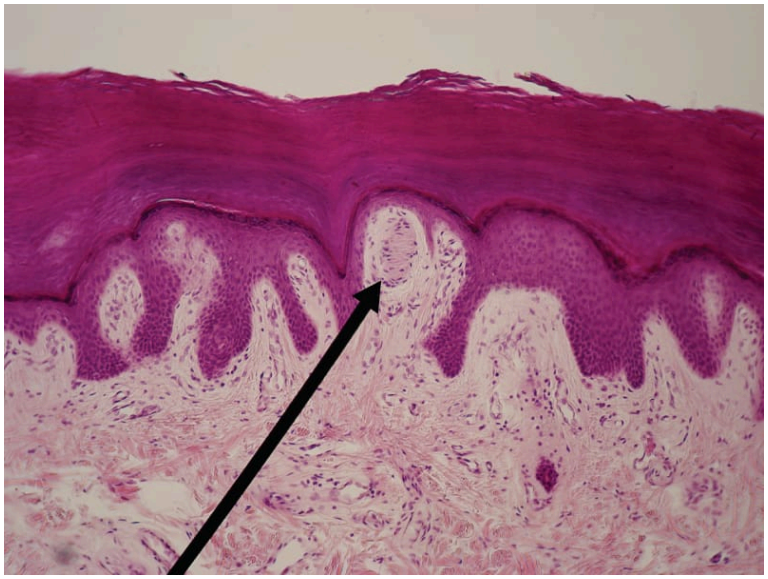


Figure 10.1.1: Light Micrograph of a Meissner Corpuscle In this micrograph of a skin cross-section, you can see a Meissner corpuscle (arrow), a type of touch receptor located in a dermal papilla adjacent to the basement membrane and stratum basale of the overlying epidermis. LM × 100. (credit: "Wbensmith"/Wikimedia Commons)

Thermoregulation

The integumentary system helps regulate body temperature through its tight association with the sympathetic nervous system, the division of the nervous system involved in our fight-or-flight responses. The sympathetic nervous system is continuously monitoring body temperature and initiating appropriate motor responses. Recall that sweat glands, accessory structures to the skin, secrete water, salt, and other substances to cool the body when it becomes warm. Even when the body does not appear to be noticeably sweating, approximately 500 mL of sweat (insensible perspiration) are secreted a day. If the body becomes excessively warm due to high temperatures, vigorous activity (10.1.2**ac**), or a combination of the two, sweat glands will be stimulated by the sympathetic nervous system to produce large amounts of sweat, as much as 0.7 to 1.5 L per hour for an active person. When the sweat evaporates from the skin surface, the body is cooled as body heat is dissipated.

In addition to sweating, arterioles in the dermis dilate so that excess heat carried by the blood can dissipate through the skin and into the surrounding environment (Figure 10.1.2**b**). This accounts for the skin redness that many people experience when exercising.

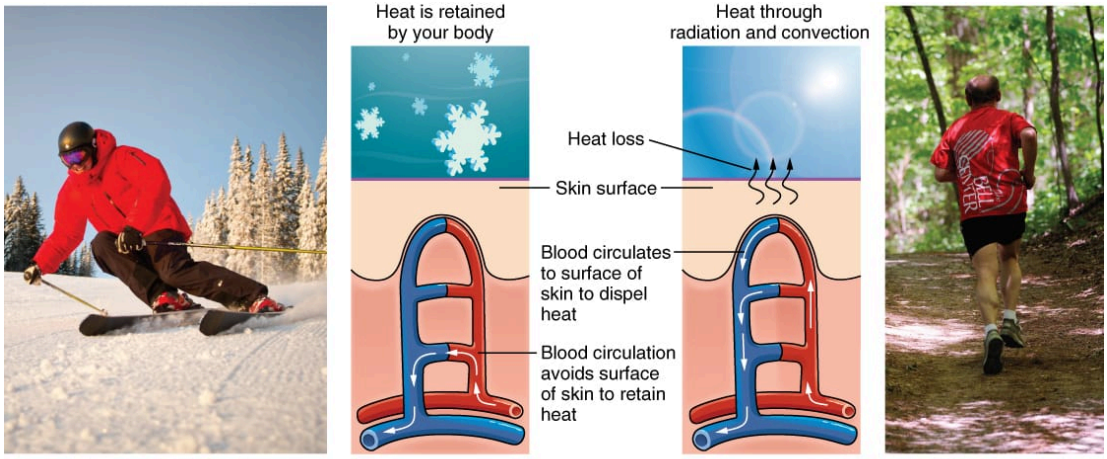


Figure 10.1.2: Thermoregulation During strenuous physical activities, such as skiing (a) or running (c), the dermal blood vessels dilate and sweat secretion increases (b). These mechanisms prevent the body from overheating. In contrast, the dermal blood vessels constrict to minimize heat loss in response to low temperatures (b). (credit a: "Trysil"/flickr; credit c: Ralph Daily)

When body temperatures drop, the arterioles constrict to minimize heat loss, particularly in the ends of the digits and tip of the nose. This reduced circulation can result in the skin taking on a whitish hue. Although the temperature of the skin drops as a result, passive heat loss is prevented, and internal organs and structures remain warm. If the temperature of the skin drops too much (such as environmental temperatures below freezing), the conservation of body core heat can result in the skin actually freezing, a condition called frostbite.

Aging and the...

Integumentary System

All systems in the body accumulate subtle and some not-so-subtle changes as a person ages. Among these changes are reductions in cell division, metabolic activity, blood circulation, hormonal levels, and muscle strength (Figure 10.1.3). In the skin, these changes are reflected in decreased mitosis in the stratum basale, leading to a thinner epidermis. The dermis, which is responsible for the elasticity and resilience of the skin, exhibits a reduced ability to regenerate, which leads to slower wound healing. The hypodermis, with its fat stores, loses structure due to the reduction and redistribution of fat, which in turn contributes to the thinning and sagging of skin.



Figure 10.1.3: Aging Generally, skin, especially on the face and hands, starts to display the first noticeable signs of aging, as it loses its elasticity over time. (credit: Janet Ramsden)

The accessory structures also have lowered activity, generating thinner hair and nails, and reduced amounts of sebum and sweat. A reduced sweating ability can cause some elderly to be intolerant to extreme heat. Other cells in the skin, such as melanocytes and dendritic cells, also become less active, leading to a paler skin tone and lowered immunity. Wrinkling of the skin occurs due to breakdown of its structure, which results from decreased collagen and elastin production in the dermis, weakening of muscles lying under the skin, and the inability of the skin to retain adequate moisture.

Many anti-aging products can be found in stores today. In general, these products try to rehydrate the skin and thereby fill out the wrinkles, and some stimulate skin growth using hormones and growth factors. Additionally, invasive techniques include collagen injections to plump the tissue and injections of BOTOX® (the name brand of the botulinum neurotoxin) that paralyze the muscles that crease the skin and cause wrinkling.

Vitamin D Synthesis

The epidermal layer of human skin synthesizes vitamin D when exposed to UV radiation. In the presence of sunlight, a form of vitamin D_3 called cholecalciferol is synthesized from a derivative of the steroid cholesterol in the skin. The liver converts cholecalciferol to calcidiol, which is then converted to calcitriol (the active chemical form of the vitamin) in the kidneys. Vitamin D is essential for normal absorption of calcium and phosphorous, which are required for healthy bones. The absence of sun exposure can lead to a lack of vitamin D in the body, leading to a condition called rickets, a painful condition in children where the bones are misshapen due to a lack of calcium, causing bowleggedness. Elderly individuals who suffer from vitamin D deficiency can develop a condition called osteomalacia, a softening of the bones. In present day society, vitamin D is added as a supplement to many foods, including milk and orange juice, compensating for the need for sun exposure.

In addition to its essential role in bone health, vitamin D is essential for general immunity against bacterial, viral, and fungal infections. Recent studies are also finding a link between insufficient vitamin D and cancer.

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10.2: Skin Temperature & Physiological Responses to Stress Lab

Instructor Note: This lab uses the WESAD dataset. Instructors should prepare a manageable CSV or Excel file containing participant IDs, experimental conditions (1 = neutral, 2 = stress), time, and skin temperature (TEMP, °C). Include temperature measurements across time for both conditions. The number of participants and observations is at the instructor's discretion. Because the original recordings require preprocessing, students should receive a prepared spreadsheet rather than the raw files. This dataset is also used in other labs, so instructors may wish to retain the same participant data for consistency. Review the dataset's reuse terms before distributing adapted data.

Skin Temperature & Physiological Responses to Stress Lab

Introduction

Have you ever noticed that your hands become cold when you're nervous or stressed? Although we often associate stress with increased body temperature, psychological stress can actually cause the temperature of our fingers and other extremities to decrease.

The autonomic nervous system regulates many involuntary physiological processes, including heart rate, sweating, and blood flow. During stressful situations, the sympathetic division of the autonomic nervous system prepares the body to respond to perceived challenges or threats. One way it accomplishes this is by regulating the diameter of blood vessels.

Vasoconstriction occurs when blood vessels narrow, reducing blood flow to a particular region. During psychological stress, sympathetic nervous system activation can cause blood vessels near the surface of the skin to constrict. This reduces blood flow to peripheral areas, such as the fingers, and may cause skin temperature to decrease.

Vasodilation occurs when blood vessels widen, allowing more blood to circulate through an area. When peripheral blood vessels dilate, increased blood flow can raise skin temperature and facilitate heat loss.

These mechanisms are important for thermoregulation, but they also demonstrate how psychological experiences can influence physiological processes. Researchers can investigate these responses by recording skin temperature during different experimental conditions.

In this lab, you will analyze skin temperature measurements collected during a research study. You will examine how temperature changes over time during neutral and stressful conditions and investigate how these patterns relate to autonomic nervous system activity.

Learning Objectives

By the end of this lab, you should be able to:

1. Explain how the autonomic nervous system regulates peripheral skin temperature.
2. Distinguish between vasoconstriction and vasodilation.
3. Identify and interpret skin temperature measurements in an archival research dataset.
4. Examine changes in physiological measurements over time.
5. Create and interpret a line graph displaying skin temperature recordings.
6. Explain how psychological stress and other factors may influence peripheral skin temperature.

Materials Needed

- Computer with internet access
- Microsoft Excel or Google Sheets
- Dataset provided by your instructor (adapted from the WESAD dataset: https://archive.ics.uci.edu/dataset/465/

wesad+wearable+stress+and+affect+detection)

Part 1: Understanding the Dataset

The Wearable Stress and Affect Detection (WESAD) dataset is an archival research dataset containing physiological measurements collected from participants using wearable sensors during different experimental conditions.

Researchers collected several types of physiological measurements, including electrodermal activity (EDA), heart activity, respiration, and skin temperature. These measurements reflect different physiological processes regulated by the autonomic nervous system.

In this lab, you will investigate skin temperature.

The WESAD researchers recorded peripheral skin temperature using wearable sensors. These measurements allow us to examine how temperature changes during different experimental conditions, including a neutral baseline period and activities designed to produce psychological stress.

This experiment will examine how physiological responses change over time.

Understanding Time-Series Data

A time series is a collection of measurements recorded at different points in time.

For example, researchers might record someone's skin temperature repeatedly over several minutes. Rather than producing a single temperature value, the recording provides a sequence of measurements showing how temperature changes throughout the observation period.

Time-series data are particularly useful in biopsychology because many physiological processes are dynamic. Heart rate, respiration, electrodermal activity, and skin temperature can fluctuate as the nervous system responds to internal and external conditions.

By examining these measurements over time, researchers can identify patterns that might not be apparent when looking only at averages.

Table 1. WESAD Dataset Codebook

Variable	Description	Values or Units
Participant ID	Identifies the participant whose physiological measurements were recorded	Unique participant identifier
Experimental Condition	Identifies the experimental condition during which the measurement was collected	Neutral (1) or Stress (2)
Time	Identifies when each physiological measurement was recorded	Seconds or another time unit specified by the instructor
TEMP	Peripheral skin temperature recorded by a wearable sensor	Degrees Celsius (°C)

Procedure

1. Open the spreadsheet provided by your instructor in Microsoft Excel or Google Sheets.
2. Examine the column headings and compare them with the codebook in Table 1.
3. Identify the columns containing participant ID, experimental condition, time, and skin temperature.
4. Locate the temperature measurements recorded during the neutral and stress conditions.
5. Examine several consecutive measurements. Notice how the temperature values change as time progresses.
6. Identify the time interval between consecutive measurements. Consider how frequently the wearable sensor recorded skin temperature.

Part 2: Examining Skin Temperature Changes

Skin temperature is influenced by several physiological processes, including blood flow through vessels near the surface of the skin.

When peripheral blood vessels constrict, reduced blood flow may cause skin temperature to decrease. When these vessels dilate, increased blood flow may cause skin temperature to rise.

However, skin temperature does not always respond immediately to changes in autonomic activity. Temperature changes may occur gradually, and the direction and magnitude of the response can vary between individuals.

In this part of the lab, you will examine skin temperature measurements from the neutral and stress conditions to investigate whether temperature increased, decreased, or remained relatively stable over time.

Procedure

1. Open your dataset in Microsoft Excel or Google Sheets.
2. Locate the skin temperature measurements recorded during the neutral condition.
3. Identify the first and last temperature measurements for this condition.
4. Record these values in Table 2.
5. Calculate the change in temperature by subtracting the initial temperature from the final temperature.

   Temperature Change = Final Temperature – Initial Temperature

6. Record the temperature change in Table 2.
7. Repeat Steps 2–6 for the stress condition.
8. Examine your results. A positive temperature change indicates that skin temperature increased during the recording, while a negative change indicates that it decreased.

If your instructor provided data from multiple participants, repeat these calculations for each participant.

Table 2. Changes in Skin Temperature

Experimental Condition	Initial Temperature (°C)	Final Temperature (°C)	Temperature Change (°C)
Neutral			
Stress			

Part 3: Graphing Skin Temperature Over Time

Line graphs are particularly useful for time-series data because they allow researchers to visualize changes in a measurement across consecutive time points.

In this lab, you will create a line graph to examine how skin temperature changes over time.

Procedure

1. In Excel or Google Sheets, locate the time and skin temperature measurements for the neutral and stress conditions.
2. Organize the measurements so that time is displayed in one column and the corresponding skin temperature values are displayed in adjacent columns.
3. If necessary, create a separate summary table containing the time and temperature measurements for each condition. Align the recordings using elapsed time from the beginning of each condition, rather than their original recording timestamps.
4. Highlight the time and temperature data you want to graph.
5. Select Insert, then Chart (Google Sheets) or Insert, then Scatter Chart (Excel).
6. Choose a chart that displays the measurements as connected points, creating a line for each experimental condition.
7. Give your graph the title "Skin Temperature Changes During Neutral and Stress Conditions."

8. Label the horizontal axis "Time (seconds)" and the vertical axis "Skin Temperature (°C)."
9. Make sure the graph contains two clearly identified lines: one representing the neutral condition and one representing the stress condition.
10. Examine the graph for patterns, including increases, decreases, or periods of relatively stable temperature.
11. Copy your completed graph into your lab report or save it as an image.

Lab Report

Answer the following questions using your experimental results and the concepts discussed in the background reading.

1. **Insert your completed Table 2 showing the initial temperature, final temperature, and temperature change for the neutral and stress conditions.**

2. **Compare the temperature changes observed during the neutral and stress conditions. Did skin temperature increase, decrease, or remain relatively stable during each condition? Describe any differences you observed.**

3. **Explain the difference between vasoconstriction and vasodilation. How does each process influence blood flow through the skin and contribute to changes in peripheral skin temperature?**

4. **Insert the line graph you created showing skin temperature over time during the neutral and stress conditions. Describe the patterns shown in your graph. Were temperature changes gradual, sudden, or relatively stable?**

5. **Explain how activation of the sympathetic nervous system during psychological stress can influence peripheral blood flow and skin temperature. Were your experimental results consistent with this physiological mechanism? Explain your answer.**

6. **Why might examining skin temperature over time provide more information about physiological responses than calculating a single average temperature for each condition?**

7. **Skin temperature is influenced by factors other than psychological stress. Identify two additional factors that could affect peripheral skin temperature and explain how they might influence the interpretation of your results.**

8. **Researchers often use multiple physiological measurements, such as heart rate, respiration, and electrodermal activity (EDA), when studying emotional responses. Explain how EDA and skin temperature reflect different physiological processes regulated by the autonomic nervous system. Why might researchers benefit from measuring both when studying stress?**

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11: FACIAL EXPRESSIONS AND ELECTROMYOGRAPHY

11.1: Facial Expressions and Emotion
11.2: Facial Electromyography and Emotional Mimicry Lab

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11.1: Facial Expressions and Emotion

Learning Objectives

- Explain the biological experience of emotion.
- Summarize the psychological theories of emotion.
- Give examples of the ways that emotion is communicated.

The most fundamental emotions, known as the basic emotions, are those of *anger, disgust, fear, happiness, sadness, and surprise*. The basic emotions have a long history in human evolution, and they have developed in large part to help us make rapid judgments about stimuli and to quickly guide appropriate behavior (LeDoux, 2000). The basic emotions are determined in large part by one of the oldest parts of our brain, the limbic system, including the amygdala, the hypothalamus, and the thalamus. Because they are primarily evolutionarily determined, the basic emotions are experienced and displayed in much the same way across cultures (Ekman, 1992; Elfenbein & Ambady, 2002, 2003; Fridland, Ekman, & Oster, 1987), and people are quite accurate at judging the facial expressions of people from different cultures.

Not all of our emotions come from the old parts of our brain; we also interpret our experiences to create a more complex array of emotional experiences. For instance, the amygdala may sense fear when it senses that the body is falling, but that fear may be interpreted completely differently (perhaps even as "excitement") when we are falling on a roller-coaster ride than when we are falling from the sky in an airplane that has lost power. The *cognitive interpretations that accompany emotions*—known as cognitive appraisal—allow us to experience a much larger and more complex set of *secondary emotions*, as shown in Figure 11.1.2. Although they are in large part cognitive, our experiences of the secondary emotions are determined in part by arousal (on the vertical axis of Figure 11.1.2) and in part by their *valence*—that is, whether they are pleasant or unpleasant feelings (on the horizontal axis of Figure 11.1.2)

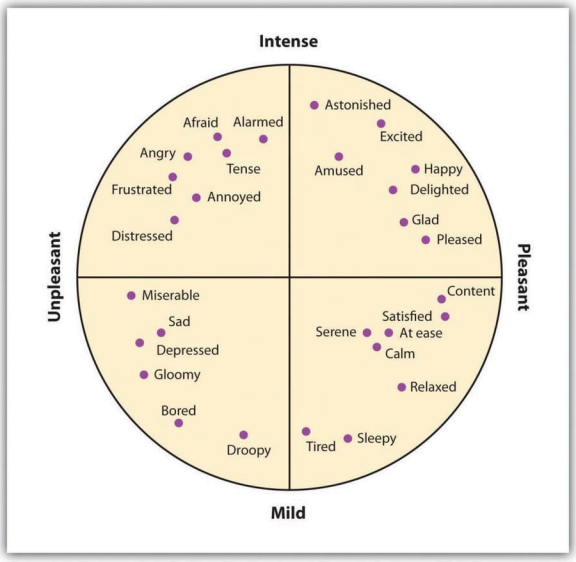


Figure 11.1.2: The Secondary Emotions. The secondary emotions are those that have a major cognitive component. They are determined by both their level of arousal (low to high) and their valence (pleasant to unpleasant). Adapted from Russell, J. A. (1980). A circumplex model of affect. *Journal of Personality and Social Psychology, 39*, 1161–1178.

When you succeed in reaching an important goal, you might spend some time enjoying your secondary emotions, perhaps the experience of joy, satisfaction, and contentment. But when your close friend wins a prize that you thought you had deserved, you might also experience a variety of secondary emotions (in this case, the negative ones)—for instance, feeling angry, sad, resentful, and ashamed. You might mull over the event for weeks or even months, experiencing these negative emotions each time you think about it (Martin & Tesser, 2006).

The distinction between the primary and the secondary emotions is paralleled by two brain pathways: a fast pathway and a slow

pathway (Damasio, 2000; LeDoux, 2000; Ochsner, Bunge, Gross, & Gabrielli, 2002). The thalamus acts as the major gatekeeper in this process (Figure 11.1.3). Our response to the basic emotion of fear, for instance, is primarily determined by the fast pathway through the limbic system. When a car pulls out in front of us on the highway, the thalamus activates and sends an immediate message to the amygdala. We quickly move our foot to the brake pedal. Secondary emotions are more determined by the slow pathway through the frontal lobes in the cortex. When we stew in jealousy over the loss of a partner to a rival or recollect on our win in the big tennis match, the process is more complex. Information moves from the thalamus to the frontal lobes for cognitive analysis and integration, and then from there to the amygdala. We experience the arousal of emotion, but it is accompanied by a more complex cognitive appraisal, producing more refined emotions and behavioral responses.

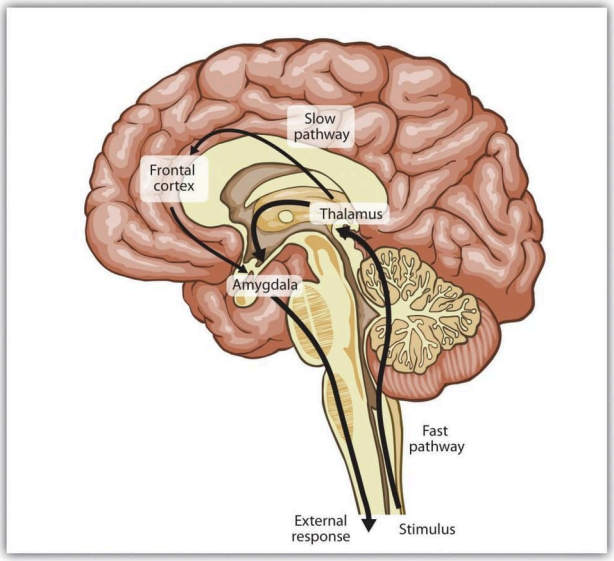


Figure 11.1.3: Slow and Fast Emotional Pathways. There are two emotional pathways in the brain (one slow and one fast), both of which are controlled by the thalamus.

Although emotions might seem to you to be more frivolous or less important in comparison to our more rational cognitive processes, both emotions and cognitions can help us make effective decisions. In some cases we take action after rationally processing the costs and benefits of different choices, but in other cases we rely on our emotions. Emotions become particularly important in guiding decisions when the alternatives between many complex and conflicting alternatives present us with a high degree of uncertainty and ambiguity, making a complete cognitive analysis difficult. In these cases we often rely on our emotions to make decisions, and these decisions may in many cases be more accurate than those produced by cognitive processing (Damasio, 1994; Dijksterhuis, Bos, Nordgren, & van Baaren, 2006; Nordgren & Dijksterhuis, 2009; Wilson & Schooler, 1991).

Communicating Emotion

In addition to experiencing emotions internally, we also express our emotions to others, and we learn about the emotions of others by observing them. This communication process has evolved over time, and is highly adaptive. One way that we perceive the emotions of others is through their nonverbal communication, that is, *communication that does not involve words* (Ambady & Weisbuch, 2010; Anderson, 2007). Nonverbal communication includes our tone of voice, gait, posture, touch, and facial expressions, and we can often accurately detect the emotions that other people are experiencing through these channels. Table 11.1.1 shows some of the important nonverbal behaviors that we use to express emotion and some other information (particularly liking or disliking, and dominance or submission).

Table 11.1.1: Some Common Nonverbal Communicators

Nonverbal cue	Description	Examples
Proxemics	Rules about the appropriate use of personal space	Standing nearer to someone can expressing liking or dominance.
Body appearance	Expressions based on alterations to our body	Body building, breast augmentation, weight loss, piercings, and tattoos are often used to appear more attractive to others.

Nonverbal cue	Description	Examples
Body positioning and movement	Expressions based on how our body appears	A more “open” body position can denote liking; a faster walking speed can communicate dominance.
Gestures	Behaviors and signs made with our hands or faces	The peace sign communicates liking; the “finger” communicates disrespect.
Facial expressions	The variety of emotions that we express, or attempt to hide, through our face	Smiling or frowning and staring or avoiding looking at the other can express liking or disliking, as well as dominance or submission.
Paralanguage	Clues to identity or emotions contained in our voices	Pronunciation, accents, and dialect can be used to communicate identity and liking.

Just as there is no “universal” spoken language, there is no universal nonverbal language. For instance, in the United States and many Western cultures we express disrespect by showing the middle finger (the “finger” or the “bird”). But in Britain, Ireland, Australia and New Zealand, the “V” sign (made with back of the hand facing the recipient) serves a similar purpose. In countries where Spanish, Portuguese, or French are spoken, a gesture in which a fist is raised and the arm is slapped on the bicep is equivalent to the finger, and in Russia, Indonesia, Turkey, and China a sign in which the hand and fingers are curled and the thumb is thrust between the middle and index fingers is used for the same purpose.

The most important communicator of emotion is the face. The face contains 43 different muscles that allow it to make more than 10,000 unique configurations and to express a wide variety of emotions. For example, happiness is expressed by smiles, which are created by two of the major muscles surrounding the mouth and the eyes, and anger is created by lowered brows and firmly pressed lips.

In addition to helping us express our emotions, the face also helps us feel emotion. The facial feedback hypothesis proposes that *the movement of our facial muscles can trigger corresponding emotions*. Fritz Strack and his colleagues (1988) asked their research participants to hold a pen in their teeth (mimicking the facial action of a smile) or between their lips (similar to a frown), and then had them rate the funniness of a cartoon. They found that the cartoons were rated as more amusing when the pen was held in the “smiling” position—the subjective experience of emotion was intensified by the action of the facial muscles.

These results, and others like them, show that our behaviors, including our facial expressions, are influenced by, but also influence our affect. We may smile because we are happy, but we are also happy because we are smiling. And we may stand up straight because we are proud, but we are proud because we are standing up straight (Stepper & Strack, 1993).Stepper, S., & Strack, F. (1993). Proprioceptive determinants of emotional and nonemotional feelings. *Journal of Personality and Social Psychology, 64*(2), 211–220.

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11.2: Facial Electromyography and Emotional Mimicry Lab

Instructor Note: This lab uses the University of York's Incidental Retrieval of Prior Emotion Mimicry dataset (CC BY 4.0). Instructors should prepare a manageable CSV or Excel file focusing on zygomaticus major and corrugator supercilii activity during happy and angry facial expressions. The number of participants and measurements is at the instructor's discretion. The original dataset contains processed measurements relative to baseline, not raw EMG recordings. Students should receive a prepared spreadsheet rather than the original research files.

Facial Electromyography and Emotional Mimicry Lab

Introduction

Have you ever found yourself smiling when someone else smiles at you? Or noticed that your facial expression changes when you see someone who appears upset or angry?

Facial expressions are an important form of nonverbal communication. They allow us to communicate emotional states and provide information about the emotions of others. However, facial expressions involve more than visible movements of the face. They are produced through the coordinated activation of muscles controlled by the nervous system.

When the nervous system sends signals to skeletal muscles, electrical activity occurs as muscle fibers become activated. Researchers can measure this electrical activity using electromyography (EMG).

Facial electromyography (fEMG) is a technique that measures electrical activity produced by facial muscles. Small electrodes placed on the surface of the skin detect changes in muscle activity, allowing researchers to examine facial responses that may be too subtle to observe visually.

Two muscles commonly investigated in emotion research are:

- Zygomaticus major: A facial muscle involved in pulling the corners of the mouth upward during smiling. Increased activity in this muscle is commonly associated with positive facial expressions.
- Corrugator supercilii: A facial muscle involved in drawing the eyebrows together during frowning. Increased activity in this muscle is commonly associated with negative facial expressions.

Researchers use fEMG to investigate emotional mimicry, which occurs when observing another person's emotional expression produces corresponding activity in the observer's facial muscles.

For example, seeing someone smile may activate the observer's zygomaticus major muscle, while seeing someone frown may activate the corrugator supercilii muscle. These responses can occur even when the observer does not produce an obvious facial expression.

Emotional mimicry is relevant to understanding how the nervous system processes social and emotional information. It also illustrates the relationship between emotion perception, motor activity, and nonverbal communication.

In this lab, you will analyze facial muscle activity collected during a research experiment. You will investigate how the zygomaticus major and corrugator supercilii muscles respond when people observe happy and angry facial expressions.

Learning Objectives

By the end of this lab, you should be able to:

1. Explain how facial electromyography measures electrical activity produced by facial muscles.
2. Identify the zygomaticus major and corrugator supercilii muscles and describe their roles in facial expressions.
3. Explain the concept of emotional mimicry.
4. Identify and interpret facial muscle activity measurements in an archival research dataset.

5. Compare facial muscle responses during the observation of happy and angry expressions.
6. Create and interpret a graph displaying facial muscle activity across experimental conditions.
7. Explain how fEMG contributes to our understanding of emotion and nonverbal communication.

Materials Needed

- Computer with internet access
- Microsoft Excel or Google Sheets
- Dataset provided by your instructor, adapted from the University of York's Incidental Retrieval of Prior Emotion Mimicry dataset

Part 1: Understanding Facial EMG Research Data

The dataset used in this lab comes from a research study investigating how people respond to emotional facial expressions.

During the experiment, participants viewed faces displaying happy and angry expressions while researchers recorded electrical activity from their facial muscles.

Researchers measured activity in the zygomaticus major and corrugator supercilii muscles using facial electromyography.

The original study included additional procedures investigating whether previously observed emotional expressions influenced later responses. For this lab, you will focus on the initial phase, during which participants viewed emotional facial expressions.

Understanding the Measurements

The dataset contains processed measurements of facial muscle activity.

Rather than showing the original electrical signals recorded by the electrodes, the values represent changes in average muscle activity relative to a baseline measurement.

A baseline is a reference measurement collected before or during a comparison period. Researchers use baseline measurements to evaluate whether physiological activity increases or decreases in response to a stimulus.

When examining the dataset:

- A positive value indicates that muscle activity increased relative to baseline.
- A negative value indicates that muscle activity decreased relative to baseline.
- A value near zero indicates relatively little change from baseline.

A negative value does not mean that the muscle produced negative electrical activity. It simply indicates that the measured activity was lower than the baseline level.

Table 1. Facial EMG Dataset Codebook

Variable	Description	Values
Participant ID	Identifies the participant whose facial muscle activity was recorded	Unique participant identifier
Facial Expression	Emotional expression viewed by the participant	Happy or Angry
Muscle	Facial muscle being measured	Zygomaticus major or Corrugator supercilii
Muscle Activity	Change in mean facial muscle activity relative to baseline	Positive, negative, or zero
Attention Task (if included)	Indicates what participants were instructed to attend to	1 = Facial identity; 2 = Emotion

The original dataset uses variable names that combine the experimental phase, muscle, facial expression, and measurement repetition.

For example:

- Mimicry_ZygoHappy_1: Zygomaticus major activity during the first happy-expression measurement.
- Mimicry_CorrHappy_1: Corrugator supercilii activity during the first happy-expression measurement.
- Mimicry_ZygoAngry_1: Zygomaticus major activity during the first angry-expression measurement.
- Mimicry_CorrAngry_1: Corrugator supercilii activity during the first angry-expression measurement.

The second measurement for each combination is identified by the number 2.

Your instructor may have simplified these variable names or combined repeated measurements.

Procedure

1. Open the spreadsheet provided by your instructor in Microsoft Excel or Google Sheets.
2. Examine the column headings and compare them with the codebook in Table 1.
3. Identify the participant ID column and the measurements corresponding to each facial muscle.
4. Locate the measurements recorded while participants viewed happy facial expressions.
5. Locate the measurements recorded while participants viewed angry facial expressions.
6. Examine several values in the dataset. Identify examples of positive and negative changes in muscle activity.
7. Consider what these values indicate about facial muscle activation relative to baseline.

Part 2: Analyzing Facial Muscle Activity

Researchers can investigate emotional mimicry by comparing the activity of different facial muscles while participants observe emotional expressions.

If emotional mimicry occurs, we might expect to observe greater zygomaticus major activity when participants view happy expressions and greater corrugator supercilii activity when they view angry expressions.

However, physiological responses vary between individuals. Not every participant will demonstrate the same pattern, and changes in muscle activity do not necessarily indicate that a person consciously experienced the corresponding emotion.

In this part of the lab, you will calculate average changes in facial muscle activity for each muscle-expression combination.

Procedure

1. Open your dataset in Microsoft Excel or Google Sheets.
2. Locate the column containing zygomaticus major measurements during happy expressions.
3. Highlight the numerical values in this column.
4. Find the Average displayed in Excel's status bar or the calculation menu in the bottom-right corner of Google Sheets. Record the average in Table 2.
5. Repeat this process for zygomaticus major activity during angry expressions.
6. Locate the corrugator supercilii measurements during happy expressions and calculate their average.
7. Repeat the process for corrugator supercilii activity during angry expressions.
8. Record all four averages in Table 2.
9. Compare the averages for each muscle. Consider whether the observed pattern is consistent with the concept of emotional mimicry.

If your instructor provided data from more than one attention-task group, follow their directions regarding which participants to include in your analysis.

Table 2. Average Change in Facial Muscle Activity

Facial Muscle	Happy Expressions	Angry Expressions
Zygomaticus major		
Corrugator supercilii		

All values represent average changes in muscle activity relative to baseline, in the measurement units provided by your instructor.

Part 3: Graphing Facial Muscle Activity

Graphs allow researchers to compare physiological responses across experimental conditions and identify patterns that may be difficult to recognize by examining individual measurements.

In this part of the lab, you will create a grouped bar graph comparing the average activity of the two facial muscles during happy and angry facial expressions.

A grouped bar graph allows multiple measurements to be compared across the same experimental conditions.

Procedure

1. Open your completed Table 2 in Microsoft Excel or Google Sheets.
2. Organize the data so that the facial muscles are listed in the first column and the average activity measurements for happy and angry expressions appear in the next two columns.
3. Highlight the table, including the column headings.
4. Select Insert, then Chart.
5. Choose a grouped or clustered column chart that displays separate bars for the happy and angry conditions.
6. Give your graph the title "Facial Muscle Activity During Happy and Angry Expressions."
7. Label the horizontal axis "Facial Muscle" and the vertical axis "Mean Change in Muscle Activity Relative to Baseline."
8. Make sure the graph includes a legend identifying the happy and angry expression conditions.
9. Check that the graph accurately represents positive and negative values, including a zero reference point.
10. Examine the graph and compare the patterns of activity for the two facial muscles.
11. Copy your completed graph into your lab report or save it as an image.

Lab Report

Answer the following questions using your experimental results and the concepts discussed in the background reading.

1. **Explain how facial electromyography measures muscle activity. What information can fEMG provide that might not be apparent from simply observing someone's facial expressions?**

2. **Identify the zygomaticus major and corrugator supercilii muscles. Describe the facial movement associated with each muscle and explain how these movements relate to emotional expressions.**

3. **Insert your completed Table 2 showing the average changes in muscle activity for the happy and angry expression conditions.**

4. **Compare the average zygomaticus major activity during happy and angry expressions. During which condition was activity greater? Was this consistent with what you would expect based on the muscle's role in smiling?**

5. **Compare the average corrugator supercilii activity during happy and angry expressions. During which condition was activity greater? Was this consistent with what you would expect based on the muscle's role in frowning?**

6. **Insert the grouped bar graph you created showing average facial muscle activity during happy and angry expressions. Describe the patterns shown in your graph. Were the responses of the two muscles similar or different?**

7. **Explain the concept of emotional mimicry. Based on your analysis, do the results support the idea that observing another person's emotional expression can activate corresponding facial muscles? Use specific examples from your data.**

8. **Some measurements in the dataset may have negative values. Explain what a negative change in muscle activity means and why it does not indicate that a muscle produced negative electrical activity.**

9. **Facial muscle activity does not always correspond directly to someone's subjective emotional experience. Explain why researchers should be cautious about using fEMG measurements alone to determine what emotion a person is feeling.**

10. **The facial feedback hypothesis proposes that facial muscle activity can influence emotional experience. How does this hypothesis differ from emotional mimicry? Explain how fEMG research might contribute to investigating the relationship between facial expressions and emotion.**

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12: EEG AND BRAIN STATES

12.1: EEG Recording and Brain Activity
12.2: Neural Synchronization and Brain Rhythms
12.3: EEG Lab

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12.1: EEG Recording and Brain Activity

Advances in technology have led to increasingly sophisticated brain recording techniques. Just as X-rays allow us to peer inside the body, neuroimaging techniques enable us to view the working brain (Raichle, 1994). Biopsychology employs various noninvasive methods to study human brain function, each with its own advantages and disadvantages. It's crucial to recognize that each technique offers a unique perspective on brain activity. Understanding these methods is essential, as our comprehension of the brain is closely tied to available technologies. As new techniques develop, we can anticipate an even deeper understanding of brain function (Biswas-Diener, 2023).

Electroencephalography (EEG) measures the electrical activity of the brain and has been used for a century (e.g., Berger, 1929). When large populations of neurons are active, they create a small electrical voltage that passes through the skull and scalp. Electrodes on the participant's head pick up the voltages, which are amplified and recorded. Researchers can record the voltages from brain activity as the participant performs a task.

The electrical signals generated in the brain become distorted as they travel through brain tissue, skin, and bone. As a result, researchers can only approximate the original source of these signals within the brain. This uncertainty is especially pronounced for signals originating deep within the brain (even with advanced tools such as structural brain scans, high-density electrode coverage from a cap with 256 electrodes, and sophisticated analysis algorithms for localization). Thus, EEG's ***spatial* resolution**—its ability to pinpoint *where* activity occurs in the brain—is relatively low. Conversely, EEG's ***temporal* resolution** is excellent and indicates *when* something happens in the brain with millisecond precision. EEG's superior temporal resolution makes it ideal for examining the brain's rapid response to a stimulus event, or the event-related potentials (ERP). In a typical ERP experiment, researchers might play a visual or auditory event like a word, and measure the corresponding voltage changes that unfold in the brain over the next few hundred milliseconds. The amplitude, timing, and topography (position) of the EEG signal capture the underlying neural/mental processes.

The high temporal resolution and continuous recording of EEG allows it to capture different frequency brain waves, such as theta waves (oscillating at 4-7 Hertz (Hz), i.e., cycles per second), alpha waves (at 8-13 Hz), and beta waves (at 14-30 Hz). Brain oscillations, reflecting the combined activity of millions of neurons, capture attentional and conscious states. These oscillations play a crucial role in information encoding and attention modulation in the brain (da Silva, 2013). In addition to research applications, EEG plays a crucial role in clinical diagnosis, particularly in identifying epilepsy, seizures, and sleep disorders.

Picture of an EEG recording cap.

Figure 6. Participant wearing an EEG cap that uses electrodes to pick up voltages on the scalp.

Example of the EEG spike waves.

Figure 7. An EEG readout of voltages at 16 electrode sites. Each row is one electrode; the voltage of each electrode is mapped on the vertical axis; and time is mapped on the horizontal axis with each vertical line marking 1 second. This particular EEG readout shows the characteristic 3 Hz spike and wave discharges in a child with epilepsy (notice the 3 peaks occurring every second).

Magnetoencephalography (MEG) is similar to EEG, but instead of electrical signals, MEG picks up the weak *magnetic* fields generated by the flow of electrical charge associated with neural activity. Because the magnetic fields generated by brain activity are so small, special rooms are needed that shield out magnetic fields in the environment so that the MEG sensors pick up magnetic fields from neural activity without environmental contamination. Similar to EEG, MEG also has excellent (millisecond) temporal resolution. The spatial resolution of MEG is far better than EEG because magnetic fields pass relatively unchanged through hard and soft tissue, so are not distorted by skull and scalp. Despite MEG's excellent spatial *and* temporal resolution, it is less widely used than EEG because its much more expensive and complex to operate.

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12.2: Neural Synchronization and Brain Rhythms

EEG

Electroencephalography (EEG) is used to measure brain rhythms through recording electrical activity at the scalp, making it a non-invasive and painless tool to detect brain activity. EEG detects the general activity of the cortex by measuring small (~10 uV) fluctuations in voltage. This technique does not measure electrical activity of a single neuron, but rather measures the electrical activity of a large population of neurons, on the order of thousands of cells, in order to generate a signal that is large enough to detect.

An EEG reading depicts differences in both **amplitude** and **frequency** over time. An increase in amplitude on an EEG indicates a higher degree of synchronous activity of cortical neurons, whereas the frequency of an EEG indicates how often neural synchrony occurs. EEG is used to measure patterns of brain activity during different behavioral states and is used in both research and in the diagnosis of various neurological conditions such as sleep disorders and **epilepsy**.

Figure 56.1. EEG recording setup. In an EEG, electrodes are placed on the head that can detect and record neuronal activity of the cortex.

How is synchronous activity generated?

Though EEG is used to measure brain rhythms, the function of these rhythms is unknown, but they have been correlated to different behavioral states such as wakefulness, sleep, attentiveness, and various pathologies. Brain rhythms generated through synchronous neuron activity can be created through two different mechanisms.

1. Cells within the thalamus have been demonstrated to have pacemaker properties that allow it to generate rhythmical cortical activity.
2. Collections of cells can also generate intrinsic rhythms through their collective activity.

EEG patterns during sleep

Each night when we go to sleep, our brains undergo a very stereotyped pattern of activity changes. At times, neurons in the cortex exhibit synchronized patterns of firing. And at other times, cortical activity looks very similar to an awake brain. We can divide sleep roughly into two different phases depending on one of the first physiological measures that sleep scientists studied: eye movement. A study published in 1953 used a device to detect eye movement while a person was asleep. Interestingly, they noticed that at some points in the night, usually first occurring around 90 minutes after falling asleep, the patient's eyes would dart rapidly and jerkily back and forth, a pattern of activity that the University of Chicago researchers called **rapid eye movement (REM)**. This first period of REM activity lasted for about 20 minutes, after which the eyes would stop moving again. This activity pattern repeated every hour or two for the rest of the night. They used eye movement to separate sleep into two phases: **REM sleep**, and **nonREM sleep (NREM sleep.)**

In addition to eye movement, they observed and measured other physiological behaviors. Respiration rate and heart rate both increased during the REM phase of sleep and dipped during NREM sleep. They also (rudely) woke up patients throughout the two phases of sleep and found that patients were more likely to recall dreams with visual imagery if their REM sleep was interrupted. Those woken during NREM sleep were less likely to recall dreams, hinting that dreaming is more likely to happen during REM sleep. While eye movement could differentiate between two phases of sleep, EEG could further subdivide NREM sleep. Using EEG, scientists discovered three distinct NREM phases based on neuron activity patterns: NREM1, NREM2, and NREM3 sleep.

Currently, readings collected via EEG are considered to be the gold standard for measuring the stages of sleep. But before we describe EEG traces while asleep, we should describe the EEG of a person who is awake. Usually, the awake EEG is dominated by high-frequency waves, that increases with attention and mental activity.

NREM1 is the earliest stage of sleep. It's also described as relaxed wakefulness, drowsiness, or light sleep. During NREM1, alpha wave activity decreases as theta waves become more prominent, and a person's muscles are still somewhat active. Their eyelids may open and close every so often, and they may still respond to questions. Basically, the deeper into NREM1 sleep a person

becomes, more waves with lower and lower frequencies start to emerge. NREM1 transitions into **NREM 2**, which mostly has theta waves.

Lastly, **NREM3** occurs, which is also called deep sleep. At this phase of the night, a person's physiological activity drops to its lowest point of the night: heart rate, respiration, blood pressure, and metabolism all reach minimum during NREM3. In this stage of sleep, many of the cortical neurons fire in synchronicity with one another, and the subsequent change in potentials cause large amplitude deflections in the EEG, called delta waves.

The EEG trace of a person in **REM sleep** is quite the opposite of what is seen in deep sleep. Instead of large amplitude events at a low frequency, the REM brain has a lot of low amplitude events at a high frequency. In fact, the brain in REM sleep has a pattern of activity that is more similar to a person who is awake than asleep! Because of this asynchronous firing activity, REM sleep is sometimes also called paradoxical sleep.

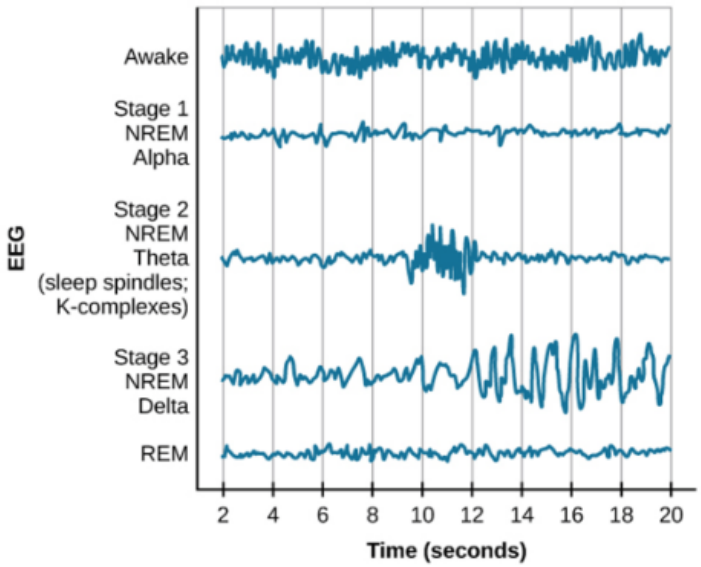


Figure 56.2. EEG activity during different stages of sleep. Brainwave activity changes drastically over the course of the different stages of sleep. REM sleep brain activity most closely resembles brain activity while awake.

Progression through the stages of sleep

To illustrate the stages of sleep that a person experiences each night, we can use a **hypnogram**. These charts to plot time on the x-axis, and stage of sleep on the y-axis. Awake is represented at the top, and deep sleep is at the bottom. For an average night's rest, neural activity will fluctuate through the four phases relatively predictably. When a person first falls asleep, they will move from NREM1 down through NREM2 then NREM3, before coming back out of deep sleep progressively back to NREM1. After NREM1, they may enter REM sleep before transitioning back through the stages to NREM3 again. This cycle of activity repeats roughly every one and a half hours. People spend a larger percentage of each cycle in deep sleep and very little time in REM sleep early in the night. On the other hand, in the last few cycles before waking up from a full night's rest, people spend a larger percentage of each cycle in REM sleep, and almost no time in deep sleep.

Image of a hypnogram showing the progression of sleep stages throughout the night. Details in caption and text.

Figure 56.3. Hypnogram showing progression of sleep stages through the night. After falling asleep, an individual progresses through NREM1, NREM2, and NREM3 before returning to lighter sleep and entering REM sleep. They then progressively return to REM sleep. As the night progresses, an individual spends less time in deep sleep and more time in REM sleep.

Why do we sleep?

All organisms that we know of experience some type of sleep. But we still haven't figured out exactly why animals sleep. Here, we will discuss three theories that have been proposed to explain sleep. None of these theories alone fully explains the complex phenomenon of sleep, and they are not mutually exclusive. The most likely reason we sleep is probably some combination of the following three theories.

Recuperation Theory

The recuperation theory of sleep is centered around the idea that being awake is stressful and exerts a physically demanding toll on the body. The body therefore needs a period of time when energy usage decreases and the body's natural repair systems can work without disruption. Sleep is how the body "wipes the slate clean" and resets. Evidence for the recuperation theory comes from experiments tailored around the idea of looking at what happens when a person doesn't get sufficient sleep.

As anyone who has ever pulled an all-nighter can attest, a single night of sleep deprivation often leads to significant psychological changes, including anxiety, irritability, and mood swings. Staying awake even longer than 24 hours can cause more severe changes in mind state, such as temporary psychosis, hallucinations, or delusions.

While the support for the recuperation theory is generally true for almost all people, there are about 1% of people who seemingly gain the restorative benefits of sleep, even with fewer than 6 hours of sleep each night. They may wake up at 4:30 in the morning feeling completely refreshed. And yet, despite getting so little sleep, these short sleepers have similar health outcomes with respect to body mass index and psychiatric measures such as depression and overall optimism. Something about the circadian rhythms of these short sleepers allows them to "maximize" their sleep efficiency. Many have very short sleep latencies, meaning they fall asleep within minutes after lying down – as quickly as someone with narcolepsy. They also spend a larger percentage of their night in deep sleep and REM sleep while minimizing NREM1 and NREM2.

Evolutionary Adaptation Theory

The evolutionary adaptation theory is the idea that animal sleep patterns are different across species for reasons that most efficiently benefit each animal. Over millions of years of evolution, individuals with the most ideal sleep patterns have an advantage, and their sleep habits will be selected for in the following generation. For example, consider humans. As an animal highly dependent on light and the visual system for navigation and accurate performance of tasks, the dark is a very dangerous time to be active. The risks of wandering off a cliff, running head-first into a tree while escaping a predator, or eating a wrong-colored poisonous berry would all be elevated in the dark. We benefit from behaviors that minimize those risks, such as inactivity until the sun rises. During this inactive period, sleeping decreases our metabolism and our body's need for energy.

Humans are just one animal that has an evolutionarily fine-tuned sleep pattern. If you look across the animal kingdom, you'll find all varieties of sleep behaviors that are best fitted to the needs of the individual species. In the wild, for example, dolphins are generally prey. They evolved with the ability to put one half of their brain to "sleep" at a time, allowing the "awake" half to keep an eye out for potential predators. Small prey animals, like squirrels, are faced with the threat of being attacked at night. For them, remaining very still, quiet, and hidden improves their survival. Tigers, the top alpha predators in any ecological niche, have almost no predators to hide from, allowing them the luxury of sleeping up to 20 hours a day.

This evolutionary adaptation theory argument has a major weakness, however. In almost all animals, sleep represents a period of time when an organism's ability to use their sensory organs to detect the hallmark signs of an approaching predator, like the flurry of feathers from a hungry owl or the soft padding of a wolf footsteps, decreases drastically. For an animal that can't hide very effectively, sleep represents a period of vulnerability, as they would be unable to sense incoming threats.

Brain Plasticity Theory

The brain plasticity theory suggests that the brain needs some period of time for critical changes to occur. During sleep, circuits in the brain undergo consolidation processes that are important for memory formation. For example, academic performance and examination grades worsen as a person's nightly sleep decreases. Both the REM and NREM3 phases of sleep are important for different types of memories, and studies suggest that **declarative memory**, pieces of information about facts, benefits more from slow-wave sleep while **procedural memory**, the learning of motor skills, is enhanced by REM sleep.

Although the exact mechanisms about how sleep improves memory are unknown, we theorize that brain activity during sleep helps move memories held in "temporary" areas into areas of stable, long-term storage. The evidence in support of this theory starts with looking at the brains of newborns. When you were first born, during those first few weeks of life, you slept close to nearly 70% of the day, almost 17 hours! At this point in your life, your brain starts to experience all sorts of new sensations: your eyes detect visible light for the first time, the skin feels the air blow past it, and the ears sense new frequencies and combinations of sound waves. As a result of these stimuli, scientists hypothesize that your brain undergoes as many learning events as rapidly as possible. This rapid learning helps you remember what you learned each day so you can respond to your environment as you grow up.

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12.3: EEG Lab

EEG Lab

Introduction

The human brain is constantly producing electrical activity as neurons communicate with one another. Although individual neurons generate electrical signals, researchers can also investigate the combined activity of large populations of neurons using electroencephalography (EEG).

EEG measures changes in electrical voltage detected by electrodes placed on the scalp. These recordings produce waveforms that reflect patterns of synchronized neural activity. Researchers examine characteristics such as amplitude, frequency, and rhythm to investigate how brain activity changes during different behavioral and cognitive states.

Amplitude refers to the height of a waveform and represents the magnitude of the recorded electrical signal. Frequency refers to the number of oscillations occurring each second and is measured in hertz (Hz). Together, these characteristics help researchers distinguish different patterns of brain activity.

EEG recordings can change substantially depending on whether a person is awake, relaxed, attentive, or asleep. For example, alpha activity is often prominent when a person is awake, relaxed, and has their eyes closed. When the eyes open, this rhythmic activity may decrease as the brain processes visual information.

Sleep is also associated with characteristic changes in EEG activity. During different stages of sleep, researchers can observe changes in waveform frequency, amplitude, and synchronization. Certain patterns, such as sleep spindles, K-complexes, and slow waves, are particularly useful for identifying sleep stages.

In this lab, you will examine EEG recordings from different states of consciousness using an online educational resource. Rather than collecting EEG data directly, you will practice identifying waveform characteristics and interpreting how patterns of neural activity change during wakefulness and sleep.

Learning Objectives

By the end of this lab, you should be able to:

1. Explain how EEG measures electrical activity generated by populations of neurons.
2. Distinguish between waveform amplitude and frequency.
3. Identify common EEG rhythms and describe their relationship to different brain states.
4. Explain how EEG activity changes when a person opens or closes their eyes.
5. Recognize characteristic EEG patterns associated with different stages of sleep.
6. Interpret EEG recordings using waveform characteristics and physiological concepts.

Materials Needed

- Computer with internet access
- Learning EEG: Normal Awake EEG
- Learning EEG: Normal Asleep EEG

Part 1: Examining EEG During Wakefulness

EEG recordings provide information about patterns of neural activity during wakefulness. However, these patterns are not identical across all waking states.

A person who is awake and relaxed may demonstrate different EEG activity than someone who is actively processing information

or responding to environmental stimuli.

One characteristic pattern is the posterior dominant rhythm, which commonly consists of alpha-frequency activity recorded over posterior regions of the scalp. This rhythm is often more prominent when a person is awake with their eyes closed.

When the eyes open, the posterior dominant rhythm typically decreases in amplitude or becomes less prominent. This change is sometimes called alpha blocking or alpha attenuation.

In this part of the lab, you will examine EEG recordings during wakefulness and investigate how brain activity changes in response to eye opening and closure.

Procedure

1. Open the Normal Awake EEG webpage from Learning EEG.
2. Read the introductory information explaining normal EEG activity during wakefulness.
3. Examine the EEG recordings illustrating the posterior dominant rhythm.
4. Locate the example demonstrating changes in EEG activity when the eyes are opened and closed.
5. Observe the waveform characteristics during the eyes-closed condition. Pay attention to the regularity, amplitude, and frequency of the rhythmic activity.
6. Compare these characteristics with the EEG activity recorded when the eyes are open.
7. Examine the other examples of normal waking EEG activity provided on the webpage.
8. Complete Questions 1–3 in the Lab Report.

Part 2: Examining EEG During Sleep

EEG is an important tool for investigating sleep because patterns of neural activity change as people transition between different stages of sleep.

Sleep is broadly divided into non-rapid eye movement (NREM) sleep and rapid eye movement (REM) sleep.

NREM sleep includes three stages:

- NREM1 (N1): The transition between wakefulness and sleep. Alpha activity decreases as slower theta activity becomes more prominent.
- NREM2 (N2): A stage characterized by distinctive EEG features, including sleep spindles and K-complexes.
- NREM3 (N3): Deep sleep characterized by prominent, high-amplitude, low-frequency slow-wave activity.

REM sleep is associated with relatively low-amplitude, mixed-frequency EEG activity that can resemble wakefulness.

These differences reflect changes in neural synchronization and brain activity throughout the sleep cycle.

Procedure

1. Open the Normal Asleep EEG webpage from Learning EEG.
2. Read the introductory information about EEG patterns during sleep.
3. Locate the examples of NREM1 (N1) sleep and examine the waveform characteristics. Compare the activity with the waking EEG recordings you observed previously.
4. Locate the examples of NREM2 (N2) sleep.
5. Examine the recordings demonstrating sleep spindles and K-complexes. Pay attention to the appearance of each pattern and how it differs from the surrounding EEG activity.
6. Locate the examples of NREM3 (N3) sleep and examine the slow-wave activity.
7. Compare the amplitude and frequency of these recordings with the examples from lighter stages of sleep.
8. Locate the examples of REM sleep and examine their waveform characteristics.
9. Compare REM activity with NREM3 activity. Consider why REM sleep is sometimes described as paradoxical sleep.
10. Complete Questions 4–7 in the Lab Report.

Part 3: Identifying EEG Patterns

Researchers and clinicians use recognizable EEG patterns to interpret changes in brain activity. However, identifying these patterns requires examining multiple characteristics rather than relying on a single feature.

For example, slow-wave activity is characterized by relatively low frequency and high amplitude, while sleep spindles appear as brief bursts of rhythmic activity.

The relationship between waveform characteristics and behavioral states is important because EEG reflects the synchronized electrical activity of populations of neurons.

In this part of the lab, you will practice identifying EEG patterns using the examples and identification exercises available on Learning EEG.

Procedure

1. Return to the Normal Asleep EEG webpage.
2. Locate the EEG identification questions or practice examples included on the webpage.
3. Examine each recording before revealing the correct answer.
4. Identify the waveform characteristics that helped you determine which sleep pattern or stage was represented.
5. Check your answer using the explanation provided on the website.
6. Complete the available identification exercises related to normal sleep EEG patterns.
7. Review any examples you identified incorrectly and examine the features that distinguish them from other EEG patterns.
8. Complete Questions 8–10 in the Lab Report.

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Lab Report

Answer the following questions using your observations from Learning EEG and the concepts discussed in the background reading.

1. **Explain the difference between amplitude and frequency in an EEG recording. What does each characteristic tell researchers about patterns of neural activity?**

2. **Describe the posterior dominant rhythm observed during relaxed wakefulness with the eyes closed. What happens to this rhythm when the eyes open, and why might visual stimulation influence EEG activity?**

3. **EEG records electrical activity from large populations of neurons rather than individual neurons. Explain why synchronized neural activity is important for producing measurable EEG signals.**

4. **Describe the changes in EEG activity that occur as a person transitions from wakefulness into NREM1 sleep. How do the frequency and rhythmic characteristics of the recordings change?**

5. **Identify two characteristic EEG patterns associated with NREM2 sleep. Describe the appearance of each pattern and explain how these features help researchers identify this stage of sleep.**

6. **Compare the EEG recordings associated with NREM2 and NREM3 sleep. How do the amplitude and frequency of the waveforms differ, and what do these differences suggest about neural synchronization?**

7. **Compare the EEG activity observed during REM sleep with the activity observed during NREM3 sleep. Why is REM sleep sometimes described as paradoxical sleep?**

8. **Using the identification exercises on Learning EEG, select one EEG pattern that you correctly identified. Name the pattern and explain which waveform characteristics helped you recognize it.**

9. **Select one EEG pattern that you initially identified incorrectly or found difficult to distinguish from another pattern. Explain what made the recording challenging and which characteristics helped you determine the correct identification. If you identified every pattern correctly, select two similar-looking patterns and explain how you distinguished them.**

10. **Imagine that a researcher records EEG activity from a participant who is initially awake and relaxed, then becomes drowsy and eventually enters deep sleep. Describe how the EEG recordings would be expected to change throughout this progression. Include specific examples of changes in frequency, amplitude, and characteristic waveforms.**

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13: BIOFEEDBACK AND PHYSIOLOGICAL SELF-REGULATION

13.1: Biofeedback and Psychological Self-Regulation
13.2: Biofeedback Lab

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13.1: Biofeedback and Psychological Self-Regulation

Introduction

Throughout this course, we have explored the relationship between psychological processes and physiological functioning. We have examined how the nervous system communicates, how the brain processes information, and how physiological measurements can provide insight into processes that are not directly observable. We have also considered how psychological experiences, including attention, emotion, and stress, influence the activity of the nervous system.

Biofeedback brings many of these concepts together by asking an interesting question: **Can we learn to regulate physiological processes that ordinarily occur outside of conscious awareness?**

Consider your heart rate. Although you can voluntarily increase your heart rate by exercising, you cannot ordinarily decide to lower it in the same way that you can decide to raise your arm. Similarly, you may recognize that you are experiencing muscle tension or stress, but you might not be aware of the specific physiological changes occurring in your body. Many physiological processes are regulated automatically, without requiring conscious attention.

Biofeedback provides a way to observe these processes as they occur. By measuring physiological activity and presenting that information to an individual, biofeedback makes normally inaccessible bodily processes more observable. With repeated practice, individuals may learn strategies that influence their physiological responses.

Frank and colleagues (2010), in their article *Biofeedback in Medicine: Who, When, Why and How?*, provide an overview of the principles underlying biofeedback, the physiological measurements used in training, the learning mechanisms involved, and its potential clinical applications. Their discussion illustrates how psychological learning processes can influence physiological regulation.

Importantly, biofeedback is not simply a method for measuring physiological activity. It is a process through which physiological measurements become information that individuals can use to modify their responses.

What Is Biofeedback?

Biofeedback is a technique that uses information about physiological activity to help individuals develop greater awareness and regulation of bodily processes.

In a typical biofeedback session, sensors measure a particular physiological response, such as muscle tension, heart rate, or skin conductance. Equipment converts the recorded activity into information that can be presented visually or through sound. The individual can then observe changes in the measurement while practicing strategies intended to influence that response.

For example, imagine that a student is wearing sensors that measure muscle activity in the shoulders. Although the student believes their muscles are relaxed, the recording indicates relatively high muscle activity. When the student deliberately releases tension, the recorded activity decreases.

The student now has information that was not previously available through conscious awareness alone. The recording provides evidence that the relaxation strategy produced a measurable physiological change.

This illustrates the central principle of biofeedback: **physiological information can serve as feedback that helps individuals recognize, practice, and refine self-regulation strategies.**

Frank et al. (2010) compare this process to using a mirror. A mirror allows us to observe aspects of our appearance and movement that we cannot otherwise see directly. Biofeedback serves a similar purpose for physiological processes by providing information about activity occurring inside the body.

The authors emphasize that biofeedback is an active learning process. The equipment provides information, but the individual must learn how to use that information. Simply observing a physiological recording does not guarantee that a person will develop greater control over the process being measured.

Physiological Measurements Used in Biofeedback

Biofeedback can involve several different physiological measurements. The measurement selected depends on the physiological process that the individual is attempting to regulate.

Frank et al. (2010) describe multiple forms of biofeedback, including measurements of muscle activity, brain activity, cardiovascular functioning, respiration, skin temperature, and skin conductance.

Electromyographic Biofeedback

Electromyography (EMG) measures electrical activity associated with muscle activation. Surface electromyography (sEMG) uses electrodes placed on the skin to record activity from underlying muscles.

EMG biofeedback can help individuals recognize muscle tension that they may not consciously notice. For example, someone experiencing persistent tension in their forehead, jaw, or shoulders may learn to identify when these muscles are activated and practice reducing that activity.

During training, the individual receives continuous information about muscle activity. As they experiment with relaxing particular muscles, changes in the recorded signal provide information about whether their efforts are producing the intended response.

Frank et al. (2010) identify EMG biofeedback as a commonly used approach, particularly in applications involving muscle tension and pain.

The important physiological concept is that muscle activity can be measured objectively. Biofeedback uses this measurement to help individuals connect their subjective experience of tension or relaxation with observable muscular activity.

Electroencephalographic Biofeedback

Electroencephalography (EEG) measures electrical activity associated with the coordinated activity of neuronal populations in the brain.

When EEG measurements are incorporated into biofeedback training, the process is often called **neurofeedback**.

Neurofeedback provides information about selected patterns of brain activity. The individual receives feedback associated with the recorded EEG signal and practices strategies intended to influence that activity.

Frank et al. (2010) discuss neurofeedback in connection with research and clinical applications involving attention-deficit/hyperactivity disorder (ADHD) and epilepsy.

It is important to distinguish between measuring brain activity and demonstrating that an intervention produces a clinical benefit. An EEG recording can show that particular patterns of electrical activity are occurring. However, determining whether neurofeedback improves symptoms requires additional research using appropriate comparison groups and outcome measures.

This distinction is relevant to the broader study of physiological psychology: **the ability to measure a physiological process does not automatically establish that changing that process will improve a particular condition.**

Heart Rate and Heart Rate Variability

Heart rate is the number of times the heart beats within a given period, typically expressed in beats per minute.

Heart rate is influenced by several physiological systems, including the sympathetic and parasympathetic divisions of the autonomic nervous system. Although heart rate is regulated automatically, it can also change in response to breathing, physical activity, emotional experiences, and other factors.

Biofeedback can provide individuals with continuous information about their heart rate while they practice strategies intended to influence cardiovascular activity.

A related measurement is **heart rate variability (HRV)**, which describes variation in the time intervals between successive heartbeats.

Although the heart may beat at an average rate of 70 beats per minute, the intervals between individual beats are not necessarily identical. This variation reflects the dynamic regulation of cardiovascular functioning.

Frank et al. (2010) identify both heart rate and HRV among the physiological measurements used in biofeedback training.

These measurements are particularly relevant when examining autonomic regulation. Rather than treating cardiovascular activity as a fixed response, biofeedback allows individuals to observe how it changes across different psychological and physiological conditions.

Respiratory Biofeedback

Respiratory biofeedback involves measuring breathing-related activity, such as respiratory rate.

Breathing is unusual because it is regulated automatically but can also be modified voluntarily. We do not ordinarily need to think about breathing, yet we can deliberately change its rate or pattern.

Respiratory biofeedback allows individuals to observe their breathing while practicing different breathing strategies.

Because respiration and cardiovascular activity are physiologically connected, changes in breathing may also be associated with changes in heart rate and other autonomic responses.

Frank et al. (2010) include respiration among the measurements used when biofeedback training focuses on physiological arousal and stress management.

Skin Temperature Biofeedback

Skin temperature is influenced partly by blood flow near the surface of the skin. Changes in peripheral circulation can affect the temperature measured at locations such as the fingertips.

Peripheral blood vessels are regulated by autonomic processes, including sympathetic influences on vascular tone.

During skin temperature biofeedback, individuals receive information about changes in skin temperature while practicing relaxation or other self-regulation strategies.

The measurement provides an indirect indicator of changes in peripheral physiological activity.

However, skin temperature is influenced by several factors, including environmental conditions. It should not be interpreted as a direct or exclusive measurement of psychological stress.

Skin Conductance Biofeedback

Skin conductance measures how readily electrical current passes across the skin.

Conductance changes partly because of activity in sweat glands, which are regulated by the sympathetic nervous system. Consequently, skin conductance is frequently used as an indicator of sympathetic arousal.

When an individual experiences a psychologically demanding situation, sympathetic activation may increase sweat gland activity and produce a measurable change in skin conductance.

Biofeedback makes these changes visible to the individual.

For example, a student might observe an increase in skin conductance while completing a difficult mental task, followed by a decrease during a recovery period.

Skin conductance is not a direct measure of a specific emotion. Increased conductance can occur during different experiences,

including anxiety, excitement, concentration, and other forms of arousal.

This is an important distinction when interpreting physiological recordings: a measurement may indicate that physiological activity has changed without revealing the exact psychological experience responsible for that change.

How Does Biofeedback Work?

One of the most important contributions of Frank et al. (2010) is their discussion of the learning mechanisms underlying biofeedback.

The authors describe two general approaches: operant conditioning and feedback learning, and psychophysiological psychotherapy.

Although these approaches differ in emphasis, both involve using physiological information to develop greater awareness and regulation of bodily responses.

Operant Conditioning and Feedback Learning

Operant conditioning is a form of learning in which the consequences of behavior influence the likelihood that the behavior will occur again.

In biofeedback, information about a physiological response can function as feedback that helps reinforce successful regulation.

Imagine that an individual is practicing reducing muscle tension. A computer displays a measurement of muscle activity. When the individual relaxes the targeted muscles, the displayed activity decreases.

The individual can use this information to identify which strategies produce the desired physiological response.

With repeated practice, successful strategies may become easier to recognize and reproduce.

The authors also emphasize **feedback learning**, in which individuals adjust their behavior based on information about the results of previous attempts.

Consider learning a physical skill, such as throwing a basketball. Each attempt provides information about the accuracy of the movement. If the ball consistently falls short, the individual may adjust their technique. Over time, feedback helps refine performance.

Biofeedback applies a similar learning principle to physiological activity.

Instead of observing where a basketball lands, an individual observes changes in muscle tension, heart rate, or another physiological measurement.

The goal is to learn which actions or strategies are associated with the desired physiological response.

An important feature of this approach is that the individual does not necessarily need a complete understanding of the biological mechanisms producing the change. Learning can occur through repeated attempts, feedback, and adjustment.

Psychophysiological Psychotherapy

The second model described by Frank et al. (2010) incorporates biofeedback into a broader psychological approach.

Rather than focusing exclusively on changing a physiological measurement, this approach examines how thoughts, emotions, behaviors, and stressful experiences may influence physiological functioning.

For example, an individual may experience increased muscle tension during periods of psychological stress. Biofeedback can demonstrate the physiological response, while psychological interventions help the individual identify situations and thought patterns associated with that response.

Training may involve relaxation, stress management, or other psychological strategies.

The purpose is not simply to lower a number displayed on a screen. It is to help individuals understand relationships between their psychological experiences and physiological responses, then develop strategies for managing those responses.

This approach reflects a central principle of physiological psychology: psychological and biological processes interact continuously.

Biofeedback as Training Rather Than Passive Treatment

Frank et al. (2010) emphasize that biofeedback should be understood as a form of training.

In many medical treatments, the patient receives an intervention without necessarily needing to learn a new skill. Biofeedback differs because the individual must actively participate in the learning process.

The authors compare biofeedback to acquiring a skill such as riding a bicycle. Instruction can help, but developing the skill requires practice.

A biofeedback practitioner may explain the measurements, demonstrate the equipment, and help identify useful strategies. However, the individual must practice recognizing and modifying physiological responses.

This also explains why biofeedback training may involve repeated sessions and practice outside the clinical setting.

The long-term objective is not necessarily for the individual to remain dependent on the equipment. Ideally, the person learns strategies that can be used even when physiological feedback is no longer available.

This is an important distinction between **physiological monitoring** and **physiological self-regulation**.

Monitoring tells us what the body is doing. Self-regulation involves learning to influence that activity.

Psychological Stress and Physiological Reactivity

One particularly interesting component of the article is its discussion of psychophysiological assessment.

During an assessment, individuals may complete activities designed to produce changes in physiological activity. Measurements are recorded before, during, and after these activities.

Frank et al. (2010) describe a sequence involving an initial relaxation period, a mentally demanding task, and a subsequent recovery period.

Examples of the mental tasks include the Stroop Color–Word Test and the Serial Sevens Test, which requires repeated mental subtraction.

These tasks can produce physiological changes associated with cognitive demand or stress.

By examining the recorded signals, the practitioner and individual can observe how physiological activity changes during the task and how it responds afterward.

This approach highlights three related concepts.

Baseline activity refers to physiological functioning during an initial reference period.

Physiological reactivity refers to the change in physiological activity associated with a stimulus or task.

Recovery refers to the process through which physiological activity changes after the task has ended, including whether and how quickly it returns toward baseline.

These measurements provide different kinds of information.

For example, two individuals might show similar increases in heart rate during a stressful task but differ in how quickly their heart rates return toward baseline afterward.

Alternatively, one individual might show relatively little cardiovascular change but a substantial increase in muscle tension.

These differences illustrate why physiological responses should not be treated as interchangeable. Different systems can respond differently to the same psychological experience.

The authors describe using these measurements to help individuals recognize the connection between stressful experiences and bodily responses.

Once individuals can observe their physiological reactivity, they can begin practicing strategies intended to influence those responses.

Who Might Benefit From Biofeedback?

Frank et al. (2010) describe several circumstances in which biofeedback may be considered as a clinical intervention.

Biofeedback may be used alongside conventional medical care, particularly when an individual experiences symptoms that may be influenced by physiological arousal or muscle activity.

The authors also discuss situations in which medication is ineffective, produces undesirable side effects, or cannot be used.

However, the suitability of biofeedback depends on the individual, the condition being addressed, and the physiological processes involved.

For example, EMG biofeedback intended to reduce muscle tension may be less useful if the targeted muscles do not demonstrate elevated activity.

This illustrates why selecting a physiological measurement should be guided by the specific problem being investigated.

Biofeedback is not one uniform intervention. Different applications involve different measurements, training strategies, and intended outcomes.

Evaluating the Effectiveness of Biofeedback

An especially useful part of the article concerns the evaluation of scientific evidence.

Frank et al. (2010) describe a five-level classification system developed to evaluate the effectiveness of biofeedback interventions.

The levels reflect differences in the amount and quality of research supporting particular applications.

Level	Classification	General meaning
1	Not empirically supported	Evidence is limited to anecdotal reports or case studies that have not undergone peer review.
2	Possibly efficacious	At least one adequately designed study provides evidence, but important methodological limitations remain, such as the absence of random assignment to a control condition.
3	Probably efficacious	Multiple studies provide supportive findings, although the evidence does not yet meet the stricter requirements of Level 4.
4	Efficacious	Controlled research demonstrates effectiveness using clearly defined methods, appropriate outcome measures, and replication in independent research settings.
5	Efficacious and specific	The intervention meets Level 4 requirements and demonstrates superiority to credible comparison treatments in independent studies.

The distinction between these levels is important because the existence of published research does not necessarily mean that an intervention has been established as effective.

A case study may demonstrate that an individual improved after receiving biofeedback, but it cannot establish whether biofeedback caused that improvement.

Similarly, improvement following treatment may reflect several factors, including natural changes in symptoms, expectations, other treatments, or characteristics of the individual.

Controlled research is necessary to determine whether the intervention itself produces benefits beyond those alternative explanations.

The authors summarize efficacy ratings from a 2008 review by Yucha and Montgomery. At that time, applications involving anxiety, adult headaches, hypertension, chronic pain, and several other conditions received Level 4 ratings. Biofeedback for female urinary incontinence received a Level 5 rating.

Other applications received lower ratings because the available research was less conclusive.

These classifications describe the evidence reviewed at that time, not necessarily the current scientific consensus. The article was published in 2010, and additional research has been conducted since then. Consequently, the ratings should be interpreted as a historical summary of the evidence rather than a definitive statement about present-day treatment effectiveness.

A lower evidence rating also does not automatically mean that an intervention is ineffective. It may indicate that the available studies were insufficient to establish effectiveness.

At the same time, promising findings should not be confused with strong evidence of clinical benefit.

This is an important lesson in research evaluation: scientific conclusions depend not only on whether results appear positive, but also on the quality, consistency, and reproducibility of the evidence.

Clinical Applications and Research Limitations

Frank et al. (2010) discuss biofeedback in relation to a variety of medical and psychological conditions.

The authors present biofeedback as a potentially useful approach for addressing physiological processes associated with symptoms, particularly when individuals can learn to recognize and modify relevant bodily responses.

However, different clinical applications should not be treated as equally well supported.

For example, demonstrating that individuals can learn to change an EEG pattern does not necessarily establish that neurofeedback effectively treats a particular neurological or psychological condition.

Likewise, demonstrating that a person can lower muscle tension does not automatically establish that the intervention will resolve every condition associated with pain.

A physiological change and a clinically meaningful improvement are related but distinct outcomes.

The effectiveness of an intervention should be evaluated in terms of the outcomes that matter for the condition being treated, such as symptom severity, daily functioning, or quality of life.

It is also important to recognize that biofeedback is not necessarily intended to replace conventional medical care. The authors describe its use both as an alternative in selected circumstances and as an additional intervention alongside other treatments.

The most appropriate application depends on the available evidence and the individual's clinical needs.

What Does Biofeedback Teach Us About the Nervous System?

Beyond its clinical applications, biofeedback provides an interesting demonstration of the relationship between psychological

learning and physiological functioning.

The autonomic nervous system regulates many processes without requiring conscious control. However, this does not mean that autonomic activity is completely independent of psychological influences.

Thoughts, emotions, attention, breathing, and behavior can all be associated with changes in physiological activity.

Biofeedback provides information that allows individuals to observe some of these relationships directly.

For example, an individual may notice that muscle activity increases during a difficult cognitive task or that cardiovascular activity changes while practicing a breathing strategy.

These observations can help individuals recognize patterns that might otherwise go unnoticed.

Repeated practice may then help them identify strategies that influence particular physiological responses.

However, **learning to influence a physiological measurement is not the same as acquiring complete voluntary control over the underlying biological system**.

Physiological activity remains subject to multiple regulatory mechanisms, and the amount of influence an individual can develop varies across processes and circumstances.

Biofeedback therefore illustrates both the potential and the limitations of learned physiological self-regulation.

Connecting Biofeedback to Physiological Psychology

Biofeedback is especially relevant to the topics explored throughout this course because it integrates physiological measurement, psychological processes, and learning.

Consider several connections:

Autonomic nervous system activity: Measurements such as heart rate, skin conductance, and peripheral temperature provide information about physiological processes influenced by autonomic regulation.

Neural activity: EEG-based neurofeedback uses recordings of brain activity to provide information about selected patterns of neural functioning.

Muscle activation: EMG biofeedback allows individuals to observe electrical activity associated with muscle contraction and relaxation.

Attention and cognitive demand: Psychophysiological assessments may use tasks such as the Stroop test to examine physiological changes associated with mental effort.

Learning: Operant conditioning and feedback learning help explain how individuals may acquire strategies for modifying physiological responses.

Emotion and stress: Biofeedback can illustrate how psychological experiences are associated with measurable changes in bodily functioning.

These connections demonstrate why biofeedback is more than a clinical technique. It also provides a practical example of the principles underlying physiological psychology.

Conclusion

Frank and colleagues (2010) present biofeedback as a technique through which individuals use information about their physiological activity to develop greater awareness and self-regulation.

The authors emphasize that biofeedback involves active learning rather than passive treatment. Physiological measurements

provide feedback, but the individual must practice identifying and modifying responses.

The article also demonstrates that biofeedback encompasses several distinct approaches. Different physiological measurements are used for different purposes, and the effectiveness of specific applications must be evaluated through scientific research.

Although the article provides a useful overview of biofeedback and its clinical applications, its publication date is important when interpreting claims about treatment effectiveness. The efficacy ratings summarized by the authors reflect evidence available before 2010 and should not be assumed to represent the current state of research.

The central contribution of this reading is its explanation of how physiological measurements can be incorporated into learning. By making bodily processes observable, biofeedback creates opportunities for individuals to recognize relationships between psychological experiences and physiological responses and to practice strategies that may influence those responses.

Ultimately, biofeedback illustrates an important principle of physiological psychology: **psychological processes and physiological functioning are interconnected, and learning can play a role in how individuals regulate their bodily responses.**

Reference

Frank, D. L., Khorshid, L., Kiffer, J. F., Moravec, C. S., & McKee, M. G. (2010). Biofeedback in medicine: Who, when, why and how? *Mental Health in Family Medicine, 7*(2), 85–91. https://pmc.ncbi.nlm.nih.gov/articles/PMC2939454/

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13.2: Biofeedback Lab

Biofeedback Lab

Introduction

Many physiological processes, including heart rate, breathing, and muscle tension, are regulated automatically by the nervous system. However, psychological activities such as relaxation, meditation, and controlled breathing can influence these processes.

Biofeedback involves using information about physiological activity to develop greater awareness and control of bodily responses. For example, a person might monitor their heart rate while practicing relaxation techniques and use that information to determine which strategies are associated with changes in their physiological activity.

In this lab, you will investigate the relationship between relaxation and cardiovascular activity by measuring your heart rate before and after completing a guided relaxation exercise. You will then use your measurements as feedback to guide a second attempt at relaxation.

Although this activity does not provide the continuous physiological feedback used in traditional biofeedback training, it demonstrates the principles of physiological self-monitoring, feedback learning, and self-regulation.

Learning Objectives

By the end of this lab, you should be able to:

1. Measure and record heart rate as an indicator of cardiovascular activity.
2. Explain how relaxation strategies may influence autonomic nervous system functioning.
3. Use physiological measurements as feedback when practicing self-regulation.
4. Compare heart rate measurements across different phases of a relaxation activity.
5. Explain the difference between physiological self-monitoring and continuous biofeedback.

Materials

- A computer or other device capable of playing audio or video
- Access to a guided meditation, breathing, or relaxation exercise
- A clock or timer that displays seconds
- Paper or a digital document for recording measurements
- Optional: A smartwatch, fitness tracker, blood pressure monitor, or other device capable of measuring heart rate

Choosing Your Relaxation Exercise

For this lab, you may select your own guided meditation, breathing exercise, or relaxation recording. You can search YouTube or another free online resource for an exercise that interests you.

Choose an exercise that:

- Lasts approximately 5–10 minutes.
- Focuses on relaxation, meditation, or gentle breathing.
- Can be completed while sitting comfortably.
- Does not require specialized equipment or physical activity.

Examples include guided mindfulness meditation, progressive muscle relaxation, and gentle paced breathing.

You may use the same recording for both relaxation sessions or select a different relaxation strategy for the second session.

Instructor Note: If you would prefer not to have students search for their own relaxation exercise, you can provide an appropriate recording for your students to use.

Measuring Your Heart Rate

You do not need specialized equipment to complete this lab. You can measure your heart rate manually by locating your pulse at your wrist and counting the number of beats for 60 seconds.

To measure your pulse manually:

1. Sit comfortably and rest your forearm on a stable surface.
2. Place your index and middle fingers on the inside of your opposite wrist, just below the base of your thumb.
3. Apply gentle pressure until you can feel your pulse. Do not use your thumb to measure your pulse.
4. Using a timer, count the number of beats you feel during 60 seconds.
5. Record this number as your heart rate in beats per minute (BPM).

If you have a smartwatch, Fitbit, WHOOP, Oura Ring, blood pressure monitor, or another device that measures heart rate, you may use it instead. These devices are entirely optional and are not required to complete the activity.

Use the same measurement method throughout the lab to keep your measurements as consistent as possible. If your device cannot provide an immediate heart rate reading, use manual pulse measurements instead.

Part 1: Baseline Heart Rate

Before beginning the relaxation exercise, you will establish a baseline measurement of your heart rate.

1. Find a quiet location where you can sit comfortably without interruptions.
2. Sit quietly for three minutes. Avoid talking, using your phone, or engaging in other activities during this period.
3. At the end of the three minutes, measure your heart rate using your chosen method.
4. Record your baseline heart rate in Table 1.

Part 2: Guided Relaxation

You will now complete your first relaxation session.

1. Open the guided relaxation recording you selected.
2. Record the title or description of the exercise, the source, and its approximate duration.
3. Sit comfortably and follow the instructions provided in the recording.
4. When the exercise ends, measure your heart rate as soon as reasonably possible.
5. Record your heart rate in Table 1.
6. Briefly record any observations about your experience, such as changes in your breathing, muscle tension, or perceived relaxation.

Do not worry if your heart rate does not decrease. Physiological responses vary, and the purpose of this lab is to observe and interpret your measurements rather than achieve a particular result.

Part 3: Feedback and Self-Regulation

Biofeedback involves using physiological information to guide attempts at changing bodily responses.

Review your baseline and post-relaxation heart rate measurements. Consider whether your first relaxation strategy was associated with a change in heart rate.

You will now complete a second relaxation session, using what you learned from your first attempt.

1. Compare your baseline heart rate with your heart rate after the first relaxation exercise.
2. Consider whether you would like to repeat the same strategy or try a different relaxation technique.

3. Record the strategy you plan to use for your second session and explain why you selected it.
4. Complete another 5–10-minute guided relaxation exercise. You may replay your original recording or select a different one.
5. When the exercise ends, measure your heart rate using the same method as before.
6. Record your final heart rate in Table 1.
7. Record any observations about how your second relaxation experience compared with the first.

Remember that heart rate is influenced by many factors. A change in heart rate does not necessarily mean that one relaxation strategy is more effective than another.

Part 4: Data Collection and Visualization

Table 1. Heart Rate Measurements

Measurement	Heart Rate (BPM)
Baseline (before relaxation)	
After first relaxation session	
After second relaxation session	

Using your measurements, create a bar graph showing your heart rate across the three measurement periods.

Your graph should include:

- A descriptive title.
- The three measurement periods on the horizontal axis.
- Heart rate in beats per minute (BPM) on the vertical axis.
- One bar representing each measurement.

Insert your graph here:

Lab Report

Answer the following questions using your measurements, observations, and the concepts discussed in the background reading.

1. **What relaxation exercise did you select for your first session? Describe the technique and explain why you chose it.**

2. **Compare your baseline heart rate with your heart rate after the first relaxation session. Did your heart rate increase, decrease, or remain approximately the same?**

3. **Explain how the sympathetic and parasympathetic divisions of the autonomic nervous system influence heart rate. How might these processes relate to relaxation?**

4. **What did you learn from your first heart rate measurement? Explain how you used this information to guide your second relaxation session.**

5. **Did you repeat your original relaxation strategy or try a different approach? Explain your decision and describe any differences you noticed between the two sessions.**

6. **Compare your heart rate measurements after the first and second relaxation sessions. What do these measurements suggest about your physiological responses? Were the results consistent with your expectations?**

7. **The background reading describes biofeedback as a learning process involving physiological measurements and feedback. Explain how this activity demonstrates feedback learning and identify one important difference between this activity and traditional continuous biofeedback.**

8. **Heart rate can be influenced by factors other than psychological relaxation. Identify two factors that might have affected your measurements and explain how they could influence your interpretation of the results.**

9. **Do your results demonstrate that you have learned to voluntarily control your heart rate? Explain why or why not.**

10. **Based on your experience, explain how biofeedback might help individuals develop greater awareness of the relationship between psychological experiences and physiological functioning.**

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14: DESIGNING A BIOPSYCHOLOGY EXPERIMENT

14.1: Fundamentals of Experimental Design
14.2: Design Your Own Biopsychology Experiment Lab

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14.1: Fundamentals of Experimental Design

Learning Objectives

By the end of this chapter, you should be able to:

- Identify a research question that can be investigated using physiological measurements.
- Distinguish between independent variables, dependent variables, and experimental conditions.
- Explain the importance of controlling extraneous variables when designing an experiment.
- Identify potential confounding variables and describe how they may influence experimental results.
- Design a simple experiment that uses physiological measurements to investigate a psychological process.

What Is an Experiment?

An **experiment** is a type of study designed specifically to answer the question of whether there is a causal relationship between two variables. In other words, whether changes in one variable (referred to as an **independent variable**) cause a change in another variable (referred to as a **dependent variable**). Experiments have two fundamental features. The first is that the researchers manipulate, or systematically vary, the level of the independent variable. The different levels of the independent variable are called **conditions** . For example, in Darley and Latané's experiment, the independent variable was the number of witnesses that participants believed to be present. The researchers manipulated this independent variable by telling participants that there were either one, two, or five other students involved in the discussion, thereby creating three conditions. For a new researcher, it is easy to confuse these terms by believing there are three independent variables in this situation: one, two, or five students involved in the discussion, but there is actually only one independent variable (number of witnesses) with three different levels or conditions (one, two or five students). The second fundamental feature of an experiment is that the researcher exerts **control** over, or minimizes the variability in, variables other than the independent and dependent variable. These other variables are called **extraneous variables** . Darley and Latané tested all their participants in the same room, exposed them to the same emergency situation, and so on. They also randomly assigned their participants to conditions so that the three groups would be similar to each other to begin with. Notice that although the words manipulation and control have similar meanings in everyday language, researchers make a clear distinction between them. They manipulate the independent variable by systematically changing its levels and control other variables by holding them constant.

Manipulation of the Independent Variable

Again, to **manipulate** an independent variable means to change its level systematically so that different groups of participants are exposed to different levels of that variable, or the same group of participants is exposed to different levels at different times. For example, to see whether expressive writing affects people's health, a researcher might instruct some participants to write about traumatic experiences and others to write about neutral experiences. The different levels of the independent variable are referred to as conditions , and researchers often give the conditions short descriptive names to make it easy to talk and write about them. In this case, the conditions might be called the "traumatic condition" and the "neutral condition."

Notice that the manipulation of an independent variable must involve the active intervention of the researcher. Comparing groups of people who differ on the independent variable before the study begins is not the same as manipulating that variable. For example, a researcher who compares the health of people who already keep a journal with the health of people who do not keep a journal has not manipulated this variable and therefore has not conducted an experiment. This distinction is important because groups that already differ in one way at the beginning of a study are likely to differ in other ways too. For example, people who choose to keep journals might also be more conscientious, more introverted, or less stressed than people who do not. Therefore, any observed difference between the two groups in terms of their health might have been caused by whether or not they keep a journal, or it might have been caused by any of the other differences between people who do and do not keep journals. Thus the active manipulation of the independent variable is crucial for eliminating potential alternative explanations for the results.

Of course, there are many situations in which the independent variable cannot be manipulated for practical or ethical reasons and therefore an experiment is not possible. For example, whether or not people have a significant early illness experience cannot be manipulated, making it impossible to conduct an experiment on the effect of early illness experiences on the development

of hypochondriasis. This caveat does not mean it is impossible to study the relationship between early illness experiences and hypochondriasis—only that it must be done using nonexperimental approaches.

Independent variables can be manipulated to create two conditions and experiments involving a single independent variable with two conditions are often referred to as a **single factor two-level design.** However, sometimes greater insights can be gained by adding more conditions to an experiment. When an experiment has one independent variable that is manipulated to produce more than two conditions it is referred to as a **single factor multi level design.** So rather than comparing a condition in which there was one witness to a condition in which there were five witnesses (which would represent a single-factor two-level design), Darley and Latané's experiment used a single factor multi-level design, by manipulating the independent variable to produce three conditions (a one witness, a two witnesses, and a five witnesses condition).

Control of Extraneous Variables

As we have seen previously in the chapter, an extraneous variable is anything that varies in the context of a study other than the independent and dependent variables. In an experiment on the effect of expressive writing on health, for example, extraneous variables would include participant variables (individual differences) such as their writing ability, their diet, and their gender. They would also include situational or task variables such as the time of day when participants write, whether they write by hand or on a computer, and the weather. Extraneous variables pose a problem because many of them are likely to have some effect on the dependent variable. For example, participants' health will be affected by many things other than whether or not they engage in expressive writing. This influencing factor can make it difficult to separate the effect of the independent variable from the effects of the extraneous variables, which is why it is important to control extraneous variables by holding them constant.

Extraneous Variables as "Noise"

Extraneous variables make it difficult to detect the effect of the independent variable in two ways. One is by adding variability or "noise" to the data. Imagine a simple experiment on the effect of mood (happy vs. sad) on the number of happy childhood events people are able to recall. Participants are put into a negative or positive mood (by showing them a happy or sad video clip) and then asked to recall as many happy childhood events as they can. The two leftmost columns of Table 14.1.1 show what the data might look like if there were no extraneous variables and the number of happy childhood events participants recalled was affected only by their moods. Every participant in the happy mood condition recalled exactly four happy childhood events, and every participant in the sad mood condition recalled exactly three. The effect of mood here is quite obvious. In reality, however, the data would probably look more like those in the two rightmost columns of Table 14.1.1. Even in the happy mood condition, some participants would recall fewer happy memories because they have fewer to draw on, use less effective recall strategies, or are less motivated. And even in the sad mood condition, some participants would recall more happy childhood memories because they have more happy memories to draw on, they use more effective recall strategies, or they are more motivated. Although the mean difference between the two groups is the same as in the idealized data, this difference is much less obvious in the context of the greater variability in the data. Thus one reason researchers try to control extraneous variables is so their data look more like the idealized data in Table 14.1.1, which makes the effect of the independent variable easier to detect (although real data never look quite *that* good).

Table 14.1.1: Hypothetical Noiseless Data and Realistic Noisy Data

Idealized "noiseless" data		Realistic "noisy" data	
Happy mood	**Sad mood**	**Happy mood**	**Sad mood**
4	3	3	1
4	3	6	3
4	3	2	4
4	3	4	0
4	3	5	5
4	3	2	7
4	3	3	2
4	3	1	5

Idealized “noiseless” data		Realistic “noisy” data	
4	3	6	1
4	3	8	2
$M = 4$	$M = 3$	$M = 4$	$M = 3$

One way to control extraneous variables is to hold them constant. This technique can mean holding situation or task variables constant by testing all participants in the same location, giving them identical instructions, treating them in the same way, and so on. It can also mean holding participant variables constant. For example, many studies of language limit participants to right-handed people, who generally have their language areas isolated in their left cerebral hemispheres[1]. Left-handed people are more likely to have their language areas isolated in their right cerebral hemispheres or distributed across both hemispheres, which can change the way they process language and thereby add noise to the data.

Extraneous Variables as Confounding Variables

The second way that extraneous variables can make it difficult to detect the effect of the independent variable is by becoming confounding variables. A **confounding variable** is an extraneous variable that differs on average *across* levels of the independent variable (i.e., it is an extraneous variable that varies systematically with the independent variable). For example, in almost all experiments, participants’ intelligence quotients (IQs) will be an extraneous variable. But as long as there are participants with lower and higher IQs in each condition so that the average IQ is roughly equal across the conditions, then this variation is probably acceptable (and may even be desirable). What would be bad, however, would be for participants in one condition to have substantially lower IQs on average and participants in another condition to have substantially higher IQs on average. In this case, IQ would be a confounding variable.

To confound means to confuse , and this effect is exactly why confounding variables are undesirable. Because they differ systematically across conditions—just like the independent variable—they provide an alternative explanation for any observed difference in the dependent variable. Figure 14.1.1 shows the results of a hypothetical study, in which participants in a positive mood condition scored higher on a memory task than participants in a negative mood condition. But if IQ is a confounding variable—with participants in the positive mood condition having higher IQs on average than participants in the negative mood condition—then it is unclear whether it was the positive moods or the higher IQs that caused participants in the first condition to score higher. One way to avoid confounding variables is by holding extraneous variables constant. For example, one could prevent IQ from becoming a confounding variable by limiting participants only to those with IQs of exactly 100. But this approach is not always desirable for reasons we have already discussed. A second and much more general approach—random assignment to conditions—will be discussed in detail shortly.

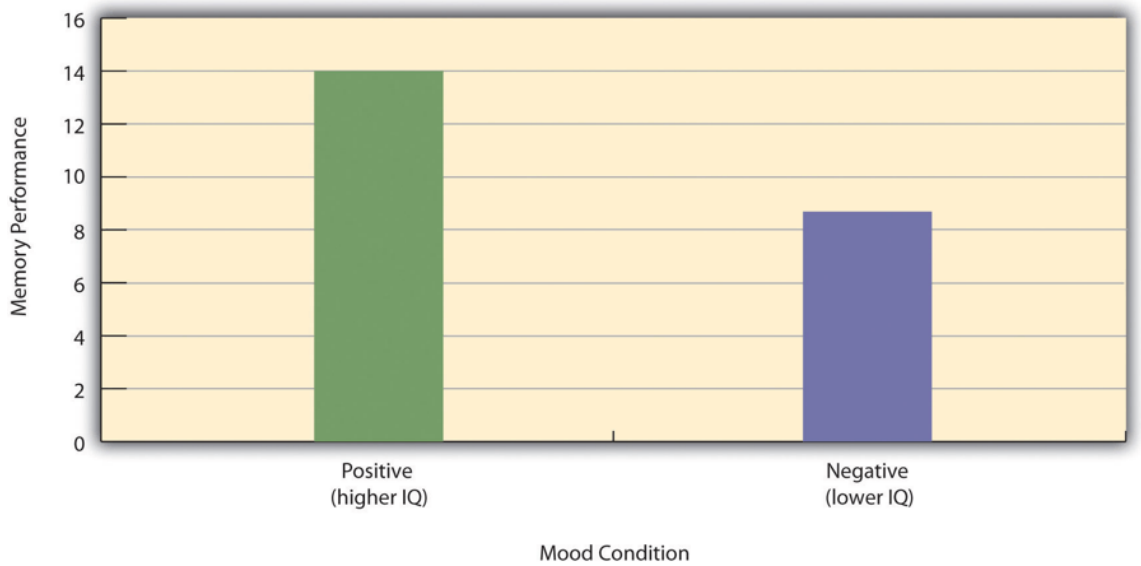


Figure 14.1.1: Hypothetical Results From a Study on the Effect of Mood on Memory. Because IQ also differs across conditions, it is a confounding variable.

Comparison Conditions in Physiological Psychology

When designing an experiment, researchers need a way to determine whether changes in a physiological response are associated with the independent variable. One approach is to compare measurements across two or more conditions.

For example, a researcher interested in the relationship between cognitive demand and heart rate might measure participants' heart rates while resting quietly and while completing a Stroop task. The resting condition provides a baseline for comparison, while the Stroop task introduces a cognitive challenge. By comparing heart rate across conditions, the researcher can investigate whether physiological activity changes in response to the task.

Comparison conditions do not necessarily require separate groups of participants. In some experiments, the same individuals complete multiple conditions, allowing researchers to compare each participant's physiological responses across different situations. However, researchers must also consider whether the order of conditions, fatigue, or other factors could influence the measurements.

The important consideration is that the experiment includes a meaningful comparison that helps address the research question.

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14.2: Design Your Own Biopsychology Experiment Lab

Design Your Own Biopsychology Experiment Lab

Introduction

Throughout this course, you have explored how researchers investigate relationships between psychological processes and physiological activity. You have examined techniques used to measure neural activity, sensory processing, muscle activity, autonomic nervous system responses, and other biological processes associated with behavior.

Now, you will apply what you have learned by designing your own biopsychology experiment.

In this lab, you will develop a research proposal investigating how a psychological or behavioral factor influences a measurable physiological response. You may investigate any reasonable biopsychological research question, provided your proposed experiment uses at least one measurement technique introduced in this course.

Your goal is to demonstrate that you understand how to design an experiment that could realistically be conducted using appropriate laboratory equipment and experimental procedures.

You are designing an experiment, not conducting one. You will not collect data, invent results, or create hypothetical datasets. Instead, you will explain what data you would collect, how you would collect them, and what you predict your experiment would reveal.

Learning Objectives

By the end of this lab, you should be able to:

1. Develop a testable research question investigating a relationship between psychological processes and physiological activity.
2. Identify and operationally define independent and dependent variables.
3. Develop a hypothesis predicting the relationship between experimental conditions and physiological responses.
4. Select appropriate physiological measurement techniques and explain their purpose.
5. Design experimental procedures that allow for meaningful comparisons between conditions.
6. Identify potential confounding variables and explain how they can be controlled.
7. Develop an appropriate data collection table for recording physiological measurements.
8. Explain the expected results and potential limitations of a proposed experiment.

Assignment Overview

You will design an original biopsychology experiment using at least one technique you have learned about in this course.

Your experiment must include:

- A clearly defined research question and hypothesis.
- At least one independent variable that you will manipulate.
- At least one measurable physiological dependent variable.
- Two or more experimental conditions that allow for comparison.
- An appropriate physiological measurement technique.
- A detailed procedure explaining how the experiment would be conducted.
- A blank data collection table designed specifically for your experiment.
- An explanation of your expected results and potential limitations.

You may assume that you have access to the laboratory equipment and technology introduced throughout this course. You do not need to own or have access to this equipment.

Your experiment should be scientifically reasonable, ethical, and feasible to conduct in a biopsychology laboratory.

Examples of Possible Research Questions

The following examples illustrate the types of questions you might investigate:

- Does listening to calming music reduce heart rate compared with sitting in silence?
- Does performing a Stroop task increase electrodermal activity compared with a neutral task?
- Does viewing happy versus angry facial expressions produce different patterns of facial muscle activity?
- Does anticipating a stressful task influence skin temperature?
- Does performing a cognitively demanding task influence EEG activity compared with resting quietly?

You are encouraged to develop your own research question based on your interests and the physiological techniques covered in this course.

Part 1: Background and Research Question

Begin by identifying a psychological or behavioral process that interests you.

Consider how this process might influence physiological activity and which measurement techniques could be used to investigate the relationship.

Write a brief background section (approximately 1–2 paragraphs) that addresses the following:

1. What psychological or behavioral phenomenon are you interested in investigating?
2. Why is this phenomenon relevant to biopsychology?
3. What do you already know about the relationship between this phenomenon and physiological activity based on concepts covered in this course?
4. Why would investigating this relationship be interesting or useful?

After completing your background section, write one clearly defined research question.

Your research question must identify a relationship that can be investigated experimentally using a physiological measurement.

Part 2: Hypothesis and Experimental Variables

Develop a hypothesis that predicts how your independent variable will influence your dependent variable.

Your hypothesis should make a specific, directional prediction whenever possible.

Then identify the following components of your experiment:

1. **Independent variable:** What factor will you manipulate?
2. **Experimental conditions:** What are the different levels or conditions of your independent variable? Describe at least two.
3. **Dependent variable:** What physiological response will you measure?
4. **Operational definitions:** How will you manipulate your independent variable, and how will you measure your dependent variable? Include the measurement units where appropriate.
5. **Hypothesis:** What differences do you predict between your experimental conditions, and why?

Your independent variable must be actively manipulated rather than simply comparing naturally occurring groups.

Part 3: Experimental Design

Describe how your experiment will be organized.

Address each of the following:

1. **Participants:** Who would participate in your experiment? Approximately how many participants would you recruit?
2. **Experimental design:** Would participants be assigned to separate experimental groups, or would the same participants complete multiple conditions? Explain your choice.
3. **Comparison conditions:** How will your experimental conditions allow you to investigate your research question? Will you include a baseline or control condition?
4. **Assignment and order:** How would you assign participants to conditions or determine the order in which conditions are completed?
5. **Experimental controls:** Identify at least three extraneous variables that could influence your measurements. Explain how you would control or minimize their effects.

Your design should allow you to make a meaningful comparison between experimental conditions while minimizing alternative explanations for your findings.

Part 4: Equipment and Physiological Measurements

Identify the equipment and technology required to conduct your experiment.

You must use at least one physiological measurement technique introduced in this course.

For each piece of equipment or technology, explain:

1. What equipment or technology would you use?
2. What physiological activity would it measure?
3. Why is this measurement appropriate for investigating your research question?
4. How would the equipment be used during your experiment?

You may include additional materials needed to present stimuli, administer tasks, or record participant responses.

Be specific about the measurements you intend to collect. For example, rather than stating that you would measure stress, explain which physiological response you would record and how that response relates to stress.

Part 5: Experimental Procedures

Write a detailed, step-by-step procedure explaining how your experiment would be conducted.

Your procedure should be specific enough that another researcher could follow your instructions and reproduce the experiment.

Include the following information:

1. How participants would be prepared for the experiment.
2. How the physiological recording equipment would be positioned or used.
3. How participants would complete each experimental condition.
4. What instructions participants would receive.
5. How long each condition or measurement period would last.
6. When physiological measurements would be recorded.
7. How you would maintain consistent testing conditions across participants.
8. How you would conclude the experiment.

You should also explain any procedures intended to minimize order effects, fatigue, or other potential confounding variables.

You do not need to provide detailed technical instructions for operating laboratory software, but you should demonstrate an understanding of how the selected physiological measurement technique would be used.

Part 6: Data Collection Table

Design a blank data collection table that could be used to record the measurements obtained during your experiment.

Your table should reflect your specific research question, independent variable, dependent variable, and experimental conditions.

Your table must:

- Include appropriate column headings.
- Identify the experimental conditions.
- Include space for participant identifiers or individual trials, as appropriate.
- Identify the physiological measurements being recorded.
- Include measurement units where applicable.
- Be organized so that the measurements can be compared across experimental conditions.

You may create your table using Microsoft Word, Excel, Google Sheets, or another appropriate program.

Do not enter any numerical data into your table. Your table should be completely blank except for column headings, condition labels, participant identifiers, or other organizational information.

You are demonstrating how you would organize and collect data, not generating results.

Insert your blank data collection table below.

[Insert your data collection table here.]

Part 7: Expected Results

Explain what you predict your experiment would reveal if your hypothesis were supported.

Address the following:

1. What pattern of physiological responses would you expect to observe across your experimental conditions?
2. Which condition would you expect to produce a higher, lower, or otherwise different physiological response?
3. Why would you expect this pattern based on your understanding of the relevant psychological and physiological processes?
4. How would the predicted pattern of results help answer your research question?

Your explanation should focus on the anticipated direction and nature of the relationship between your variables.

Do not invent numerical results, calculate statistics, create graphs, or fabricate participant responses. You are describing the pattern you expect to observe, not presenting findings from a completed experiment.

Part 8: Limitations and Final Evaluation

Even carefully designed experiments have limitations.

Evaluate your proposed experiment by answering the following questions:

1. What are two potential limitations of your experimental design?
2. Identify one potential confounding variable that might be difficult to control. How could it influence your findings?
3. What are the ethical considerations associated with your experiment? How would you protect participants?
4. If you had the opportunity to conduct this experiment, what challenges might you encounter?
5. How could your experimental design be improved to produce more reliable or interpretable results?

Final Submission

Submit your completed experimental proposal, including all eight sections and your blank data collection table.

Your proposal should be written in your own words and demonstrate your understanding of the biopsychological techniques and experimental design concepts introduced throughout this course.

Your experiment does not need to be complicated. A straightforward, well-designed experiment with clearly defined variables, appropriate physiological measurements, and meaningful comparison conditions is preferable to an overly ambitious experiment that would be difficult to conduct.

Important: This is an experimental design assignment only. You are not expected to conduct your study or collect actual data. Do not fabricate data, participant responses, statistical results, or graphs. Your work will be evaluated based on the scientific reasoning, feasibility, and methodological quality of your proposed experiment.

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