

Neurological Basis of Learning

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Learning Objectives

1. Describe how neurons communicate information.
2. Explain how learning may occur at the cellular level.
3. Describe how classical conditioning theory explains basic associative learning.
4. Define skill learning, and identify the optimal forms of practice and feedback for learning.
5. Define implicit learning, and describe what is learned in implicit learning.

Overview

Underlying all learning and the act of storing information for later retrieval are the biological structures that support those activities. The dramatic importance of the biological support for learning and memory can be seen in cases where the biological functioning stopped, or was curtailed, such as in the following famous case.

The Case of H.M.

Prior to the 1950s, it was commonly assumed that the memories we store are distributed across the brain and that no single area in the brain was responsible for memories. Henry G. Molaison, in 1953 at the age of twenty-seven, had an operation on his brain to attempt to relieve the blackouts and convulsions from seizures that he had been experiencing since about the age of nine. At this age, the seizures were incapacitating, and he was unable to perform his job as a mechanic. (The seizures might have begun due to a head injury stemming from a collision with a bicycle rider, but the ability to evaluate the brain for damage at that time was relatively poor by today's standards.) Mr. Molaison's neurosurgeon, having tried everything else, proposed an experimental surgery to remove two small slivers from his brain, both cuts primarily from the **hippocampus**, a part of the brain shaped like a small curved horn about level with the ears.

Mr. Molaison's personality remained intact, but he lost the ability to form new memories. Surprising researchers of the day, he retained all prior knowledge about his earlier life before the surgery, but he was unable to form any new memories. So each time he met with someone, read a story, or engaged in an activity, it was like the first time. Conscious learning stopped. He was able to store information for about twenty seconds, and then it was gone. The fact that a relatively small amount of brain damage had had such a major impact on his memory was surprising at the time.

This sparked an intense amount of research and study on both Mr. Molaison and other amnesiacs—people who suffered some form of permanent memory loss. Despite initial skepticism, by the 1970s, it was clear that amnesiacs had trouble retaining new memories (Roediger & Craik, 2014). “H.M.,” as he was known in the scientific literature to protect his privacy, was believed to be one of the most “pure” amnesiacs, and he participated in about five decades of research before his death in 2008. More clinical data has been gathered about him than any other man in history (Dittrich, n.d.). After his death, his brain was exhaustively scanned to get more information on how his memory characteristics related to his brain.

So, let's turn to what we know today about the underpinnings of how we learn, at a cellular level. How do the cells in our nervous system function, and how do they adapt to new circumstances in order to help us learn, or to make basic associations between events and ideas?

In this chapter, we will review the fundamentals of how cells in the nervous system communicate ("neurotransmission") before looking at some hypothesized ways our nervous system may adapt to support learning. Then, we'll examine three areas of research on simple, noncomplex forms of learning.

How Neurons Communicate: Neurotransmission

The basis of all learning is, at some point, represented by cellular activity within the central nervous system, the brain, and the spinal cord. The cells that appear to be primarily responsible for information flow throughout the central nervous system are called **neurons**. Let's review how they communicate with each other, so that we can conceptually understand how they are likely to adapt to changes in our environment.

Neurons are uniquely equipped for communication, relative to other cells in the body. Besides a cell body, mitochondria, and an outer membrane like other cells have, neurons have **dendrites** and at least one **axon** (see Fig. 3.1).

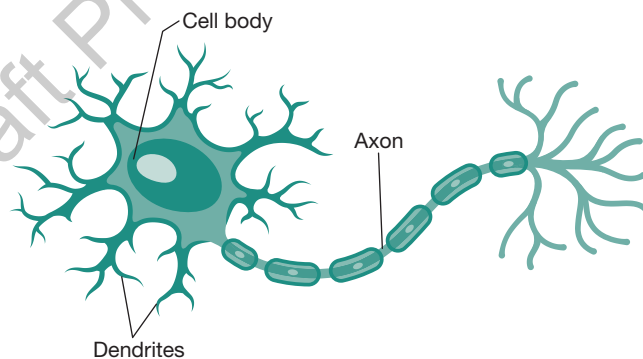
Like branches on a tree, any one neuron can have many dendrites. These dendrites play the role of accepting incoming information; they support the sites on the neuron where information can be received. These **receptor sites**, like landing pads, wait for molecules to land on them and chemically bind to them. Not every receptor site will accept every kind of transmitted molecule that they are exposed to. Usually they specialize in particular molecules, the way different keys fit into different locks.

In contrast, axons send information to other cells. When a neuron fires, a process that starts at the neuron's cell body, a chemical and electrical wave runs down the length of the axon. This wave, called an **action potential** or "neural impulse," moves down the axon at a set, fixed rate. This action potential is what readies the neuron to send information to other cells.

This process is entirely chemical and electrical. Neurons, when resting, are negatively charged at between -50 and -80 millivolts. This is because of the presence of negatively charged ions and/or molecules in the axon. A neuron fires when its overall polarity reaches to a specific threshold (the precise threshold required varies across neurons).

When a neuron fires, the "wave" of energy that rolls down the axon is the result of the negatively charged molecules being pushed out of gates along the axon and permitting positively charged molecules to be drawn into the axon. This process runs down the axon and, at the end, the action potential causes chemicals to be released.

FIGURE 3.1 Diagram of a basic neuron



Neurons generate their own chemicals to be used in the act of communicating with other cells. These chemicals, molecules called **neurotransmitters**, are made at the cell body. When a neuron fires, the action potential pushes collections of the neurotransmitters down the axon in synaptic vesicles, tiny sacks made of membrane. These vesicles ride the wave down the axon. At the end of the axon, these vesicles attach or **dock** to the ends of the axon, open, and release the neuron's neurotransmitters.

Neurons do not touch each other. They come microscopically close—within 30 nm—but they do not connect. When these neurotransmitters are released, they float into a gap or **synapse** between the neuron and other cells. Some, but not necessarily all, of these neurotransmitters will float across the gap and find **receptor sites** on the next neuron and bind to them, continuing the path of information. These receptor sites are supported by **dendritic spines**, like mushrooms or tiny branches, that extend from the shaft of the dendrite itself. Some will not find a receptor site that will accept them, and they may decay in the gap. Others may be reabsorbed by the original neuron in a process called **reuptake**.

What causes a neuron to change polarity enough to meet the firing threshold? Neurotransmitters are themselves molecules with positive or negative charges. As they cross the synapse from the first, **presynaptic**, neuron to bind with dendrites on the next, **postsynaptic**, neuron, they alter the polarity of that second neuron. Some neurotransmitters bring the neuron closer to the threshold; other neurotransmitters discourage the neuron from meeting the threshold. Neurotransmitters that make the postsynaptic neuron less polarized (closer to the “threshold” for firing) are called **excitatory**. Likewise, those neurotransmitters that decrease the polarity of the postsynaptic neuron, making it less likely to fire, are called **inhibitory**.

Any one neuron might be on the receiving end of numerous axons of different neurons and neurotransmitters with positive or negative charges. These charges may cancel each other out. The polarity of the cell body of a neuron then will bob until it reaches the firing threshold, which triggers the action potential that will distribute its neurotransmitters into the synapse, possibly to reach other cells. This overall process is remarkable for the kind of flexibility it provides to living organisms for learning and adapting to experiences.

Neurons produce a number of different chemicals we refer to as neurotransmitters; there are more than one hundred. About thirty are known to be important for psychological functioning, and nine have been the focus of most research. Neurons may focus primarily on sending or receiving one particular neurotransmitter or may handle several; the end result is that different neurons can become chemical “pathways” through the brain. It's tempting to think of the pathways as chains of neurons, sequentially processing information, but this is not the case. Clusters of neurons will specialize in particular neurotransmitters and route information to different parts of the brain in more of a web-like fashion than single, sequential neurons strung together.

Given this description of how neurotransmission works, how do neurons accommodate new experiences to support the act of learning?

How Neurons Adapt to Support Learning

Having an understanding of how neurotransmission works helps to explain the possible ways that “learning” happens at a physiological level. Research with rats in different

kinds of environments led to the realization that neurons adapt to the experiences of the organism (Rosenzweig, 1984). This adaptation can continue for the entire lifespan. Neurobiologists have found that the structure of neurons and their chemistry can change due to exposure to different environments, a phenomenon often referred to as **plasticity**. Plasticity can occur in one of several ways.

Chemical Changes Across Existing Synapses

First, there can be changes to the chemical aspect of the neurotransmission process, as opposed to changes to the structure of interacting neurons. Possibly, the presynaptic neuron will generate and release more of a neurotransmitter. Studying neurons up close to see whether this kind of change is possible has been challenging. The brain is a complex organ, and monitoring for learning of a new concept at a neural level as it occurs in someone's mind is extremely difficult.

One strategy for trying to learn and test learning at the neural level is to find a simpler organism that is easier to study than humans. Kandel (1976) focused on a large sea slug named *Aplysia californica* to reduce the complexity of the brain being studied to find out more about how neurons adapt when learning occurs. The *Aplysia* is about the size of a fist. From an anatomical perspective, it has a number of advantages for research. First, the sea slug has a relatively simple brain, making it easier to study. Second, its neurons are considered to be the largest in the animal kingdom, so they can be seen without high-powered imaging techniques. Also, it's possible to move the sea slug's brain, which normally resides in its gut, away from its body for study while leaving it neurally connected, allowing for easier observation (see Fig. 3.2).

From a behavioral perspective, the sea slug provides a particular advantage as well. It has a reflex that can be modified with experience. The sea slug defensively withdraws its gill when its **siphon**—a tube that ingests and expels water—is stimulated, called the **gill withdrawal reflex**. This choice for learning research turned out to be extremely

FIGURE 3.2 Photo of a sea slug



beneficial. Given a simpler life-form with reflexive behavior that can change depending on how it is stimulated, research on the neural level of learning was possible without advanced equipment.

The Aplysia is capable of some basic forms of learning that are nonassociative (Kandel, 1976). **Nonassociative learning**, originally proposed by Ivan Pavlov (1927/2015), includes the forms of learning in which only one stimulus is involved. Learning comes from the mere exposure to that specific stimulus. For instance, the sea slug's gill withdrawal reflex weakens if the siphon is touched repeatedly, a kind of simple learning called habituation. **Habituation** is the decrease of a behavioral response to a stimulus after repeated stimulation. With exposure, the response decreases with familiarity. Imagine cheerleaders at a game asking people in the stands to clap and cheer. With the initial encouragement, the fans will respond; but if the cheerleaders ask continuously for too long, eventually people tire and start to ignore the requests.

The Aplysia shows other kinds of learning phenomena. If there is a long delay between taps on the Aplysia's siphon, however, the original strength of the reflex returns, a learning phenomenon called spontaneous recovery. **Spontaneous recovery** is when a response reappears after a delay. Staggered stimulation can work best to initiate a strong response. This may be why cheerleaders time their requests to the crowd. Other animals and people learn these basic reflexive responses as well. Also, the sea slug can reflexively react strongly to a *weak* stimulus to its siphon if its tail has just received a strong shock. This stronger response is because of being overly ready due to an earlier stimulus is called **sensitization**. This is similar to hearing a door slam loudly and becoming "on edge," ready for it to happen again.

With further research, Kandel and his associates were able to locate where, neurologically, habituation was occurring in sea slugs. The change in the communication between the neurons that sensed the touch and the neurons that issued the command to withdraw the gill was happening in the synapse between these cells. The synaptic connection was being weakened; essentially, less excitatory information is sent from the presynaptic, sensory neuron to the postsynaptic, motor neuron (Kandel, 2001).

The term "habituation" is a general term for decreases in responding to a stimulus, and can be applied to a wide range of learning situations (see Thompson & Spencer, 1966, for an overview). The specific neurobiological term for the decrease in neural responding at a synapse is known as **long-term depression** (LTD). The opposite of LTD can happen as well. Repeatedly stimulating a neuron that triggers the stimulation of the next postsynaptic cell can also cause improved long-lasting efficiencies in the neurotransmission between two cells. This process, known as **long-term potentiation** (LTP), strengthens the neural connection. Such a relationship between neurons was predicted by Donald Hebb in 1949. He expected that when the axon of one neuron repeatedly stimulates the dendrites of another neuron, eventually those neurons were going to develop ways of becoming more efficient with their communication. The idea that "neurons that fire together, wire together" became known as **Hebbian learning** and led researchers to explore the possibility of "Hebb synapses." LTP appears to be one form of Hebbian learning.

In laboratory conditions, slices of areas of the brain known to be involved in memory can be "trained" using electrical stimulation to respond less frequently for about an hour (see, e.g., Bear, 2003). LTD and LTP have been most extensively studied in the tissue that makes up the hippocampus, the area of the brain that was part of

the surgery that Henry Molaison underwent (see, e.g., Davies, Lester, Reymann, & Collingridge, 1989).

To measure learning with infants, child psychologists use highly creative techniques to get a sense of what an infant is used to. Renée Baillargeon developed a novel approach for measuring what infants are capable of learning on the idea of habituation (1995). She measured how long infants look at stimuli, or **gaze time**. The assumption is that infants look away from stimuli they have habituated to and, thus, have learned; but they will continue to look at stimuli that are surprising or novel to them. Baillargeon assessed whether infants have a sense of intuitive physical reasoning by showing them physically possible scenes, such as a ball rolling behind a screen to be stopped by a block, and physically impossible scenes, such as a ball rolling behind a screen and somehow passing through the block that should have stopped it. Baillargeon found that infants stare longer at the physically impossible task, concluding that infants have the ability to reason about physics on an elementary level (see Fig. 3.3).

Kibbe and Leslie (2011) evaluated whether infants can remember the features of objects that have been hidden from view. They placed two objects on a platform in front of infants and hid them both behind screens. When the screen in front of one or the other was removed, infants saw either the correct object, the incorrect object, or nothing. Kibbe and Leslie found that the six-month-olds were not surprised to find the wrong object, but they were surprised if the object didn't return when the screen was lifted (see Fig. 3.4). Apparently six-month-olds can habituate to the idea of an object being present, but not necessarily to the visual features of that object.

The basic assumption of child psychologists' use of gaze time to evaluate learning is conceptually similar to neural patterns of habituation, as Kandel (2001) described. However, we cannot assume at this time that infant studies like those explained earlier are in fact producing the exact same neural adaptations as neuroscientists describe.

FIGURE 3.3 Physical situations that are impossible (a ball traveling through a wall) triggers a longer gaze time from infants

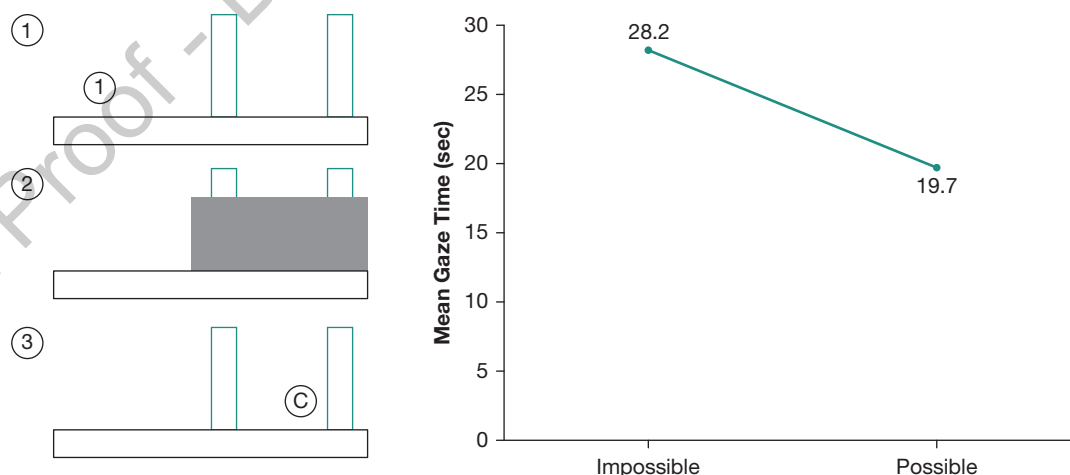
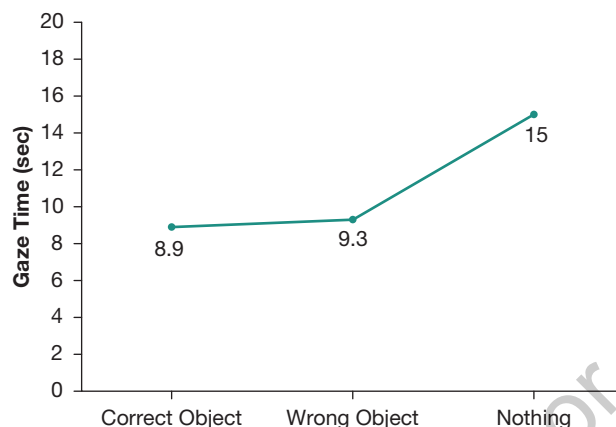


FIGURE 3.4 A longer average gaze time when an object is missing implies surprise



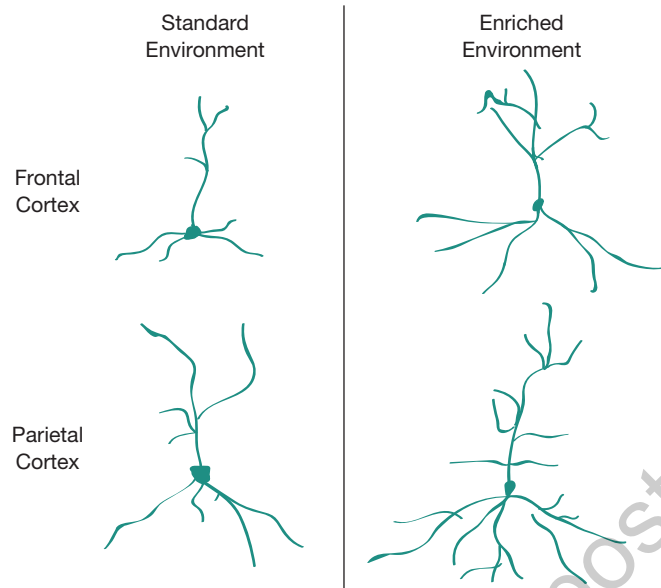
They may be, but the imaging techniques haven't yet been developed to allow this level of data collection.

Changes to the Dendrites

Another way that neurons could change in order to accommodate new experiences is with changes to the dendrites of the postsynaptic neuron. Possibly, the dendrites on the postsynaptic neuron will become more sensitive to a particular transmitter, either through more receptor sites or thicker dendrites, so that the electrical conduction is greater for the same amount of neurotransmitter.

The ability to track changes at the level of dendrites is a relatively recent development. To do this, neuroscientists will generally use simpler life-forms than humans, and they will alter the environments of the animals they use in order to spark the neurological adaptation for learning. With humans, we might be concerned with more specific issues such as when a child can grasp a certain concept, like “verbs” as opposed to “nouns,” but researchers use a different scale of learning when working with nonhuman animals.

Gelfo, De Bartolo, Giovine, Petrosini, and Leggio (2009) found evidence of several kinds of changes to the dendrites when learning occurs. Male Wistar rats were housed in different kinds of environments for three and a half months. Some of the rats were housed in environments that were considered to be “enriched”—meaning that they provided additional opportunities for the rats to learn—while some were not. This meant more social interaction, more room to explore, more objects to play with, and more physical activity (Gelfo et al., 2009). More than three months later, neuron samples from prefrontal and parietal cortices of the rats in the enriched and the standard, nonenriched environments were taken for study. Examining the samples for how many dendrites were present, their density, and their length, the researchers found that some of the dendrites were longer for the rats in the enriched conditions (see Fig. 3.5). Often they were greater in number. Sometimes they had more “nodes,” surface areas that receive neurotransmitters. The environment did appear to stimulate substantial change in the dendrites of rats in an enriched environment. However, these changes did not happen in

FIGURE 3.5 Neurons in enriched environments show more dendritic branching

every area of the cortex from which they had samples from, and one type of dendrite was often more affected by the enrichment than the other!

Although this is generally hypothetical at the moment, some neuroscientists have proposed that larger, mushroom-shaped receptor sites or spines on the shaft of dendrites tend to be resistant to change (Hayashi & Majewska, 2005; for an overview, see Bhatt, Zhang, & Gan, 2009). Those larger parts of dendrites might indicate where learning has become relatively fixed and permanent. Some change is still possible; changes at the synapse could still occur. Smaller, thinner receptor sites can be generated that are more flexible for forming weaker connections with other neurons. Possibly, the larger sites on a dendrite have become part of the pathways for well-learned memories, whereas the thinner tendrils are still being shaped by learning (Rudy, 2013).

Additional Neurons

Another way to learn is by the creation of new neurons entirely, called **neurogenesis**, creating new synapses along the way. This clearly happens just prior to birth and in the first year of life (Leuner & Gould, 2010), and it appears to continue for the duration of life for all mammals (Gould, 2007). At a young age, it could be primarily driven by physical maturation, but some adapting to the environment will be happening during this time as well. In human infants, the number of neurons and synapses tends to peak for the entire lifespan at the age of two! Often there are “extra” neurons making redundant synaptic connections with the same muscle tissue, for example. This rapid production of many synaptic connections, **synaptogenesis**, permits human infants to be as adaptable as possible to their new surroundings. As the infant develops the abilities to see, hear, and move better, the unnecessary neural connections in the central nervous system are discarded in a process called **pruning**.

Rats and other primates in enriched environments tend to have heavier brains because of more brain tissue, a sign of greater neural growth (Rosenzweig, 1984). However, the evidence is not clear on whether neurons are always necessarily the result of learning in adulthood (Leuner, Gould, & Shors, 2006). This is because of the correlational nature of the research at this time.

In sum, there are a variety of ways that neurological changes can occur to adapt to experience. These can involve changes at the synapses, the dendrites, or with wholly new neurons. The methods of adapting are constantly being researched and documented now, but knowing which method is used for any organism more complex than *Aplysia* is less clear. At this time, it is difficult to pinpoint which specific method is occurring, for example, when someone learns the name of a new coworker.

Having reviewed neurotransmission and how neurons are believed to adapt to environmental change, we are now ready to take a look at an area of learning theory that shares many conceptual similarities with that of the *Aplysia*. Classical conditioning involves associative learning between two events, instead of just one.

Classical Conditioning

Classical conditioning, also known as **Pavlovian conditioning**, is a model of how people and animals can make a simple association or connection between events, or an event and an emotional reaction, or an event and a memory (Pavlov, 1927/2015). It has been broadly tested for different settings and a wide variety of animals, as well as people of different ages. One of the remarkable aspects of this particular theory is how ubiquitous it is.

At its most basic, classical conditioning explains how we learn to use a cue as a signal for what is about to happen (see, e.g., Hollis, 1997; Mineka & Zinbarg, 2006; Rescorla, 1988). It has generally been thought to occur involuntarily (Skinner, 1938). Some researchers will refer to the process of classical conditioning as “signaling,” describing the way animals learn from their environments, and from each other, how to detect rivals and predators (Hollis, 1997). It’s an advantage for animals if they can quickly detect those cues that will let them know about important events for their survival. Of course, animals do not teach each other these cues though a formal education process like we humans do. It’s been an evolutionary advantage for all kinds of animal life-forms to develop a biological system that can support rapid learning of important environmental signals. These signals may involve territory marking, predator-prey interactions, courtship, and reproduction.

Most modern researchers today see classical conditioning as describing how ideas can become connected (e.g., Bouton, 1994; Jara, Vila, & Maldonado, 2006), but Pavlov’s original framework for his theory of learning was modeled after physiological reflexes. Ivan Petrovich Pavlov (1849–1936), a Russian scientist who won a Nobel Prize in 1904 for his work on digestion, was well-known for his systematic and careful approach to his work. He was highly organized and ran a laboratory that required new workers to replicate work that had already been done. So, besides introducing new students to the field, all prior work in the lab was verified for its results. (If the replication failed, another lab worker would be brought in to replicate the original.) In this manner, the amount and quality of the research he produced was impressive.

Pavlov’s primary interest was in how the digestive system worked. At the time, this area of physiology was considered difficult to study due to the nature of the digestive organs—they were too hard to observe through normal surgery. Pavlov developed new and cleaner methods for operating on animals (dogs) that allowed for observation of the

digestive tract by creating **fistulas**, openings, in parts of the dogs' digestive systems. To his credit, most of his animal subjects survived his surgeries because of his surgical skill and focus on extreme cleanliness when operating (apparently, he disliked the sight of blood).

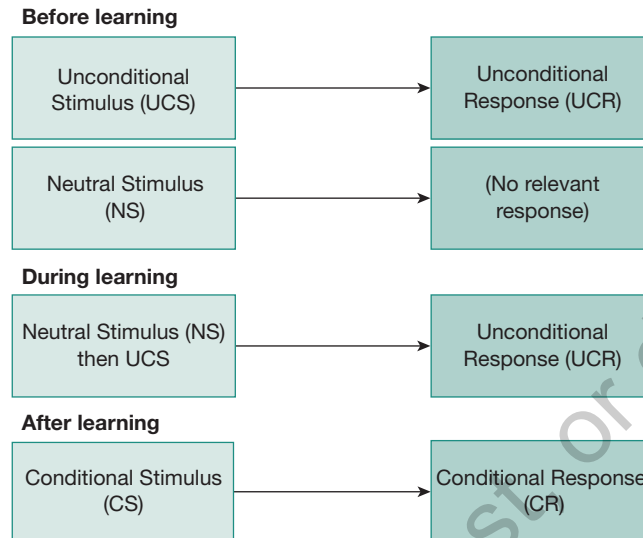
Naturally, Pavlov's research on the digestive system would mean accounting for the kinds of innate secretions that are made in the digestive system, including salivation. These secretions are reflexive and untrained. He found that a small amount of diluted acid on a dog's tongue produced a strong response of salivation. After a while he noticed that the dogs became used to the routine of having the splash on their tongues as he carried out his studies, and the dogs would salivate too early—before the acid had been placed on their tongues. This could happen when they saw a bowl that contained food because of their consistent feeding schedule, or when they heard the lab workers who were going to feed them. Initially this was seen as a problem for accurate recording of the properties of the digestive system. Given that the nature of the digestive system is to help break down food to absorb nutrients for survival, the “premature” salivation seemed to be mental in nature, and Pavlov called them “psychic secretions.”

As a physiologist foremost, describing this finding presented a problem. Pavlov had questioned whether psychology could be considered a true science, and this finding was clearly the result of the dog's mental activities. Pavlov resolved this by adopting the view that a concept of “reflexes” could be used to describe the functioning of the brain, such as connections between sensations and motor responses—a view another Russian physiologist had recently proposed (Sechenov, 1863, reprinted 1965). In this way, he reframed his findings of mental associations as a matter of learned reflexes, using terminology that sounded more like what a physiologist would use. This background should explain Pavlov's reasoning for his terminology that does not sound terribly like psychology.

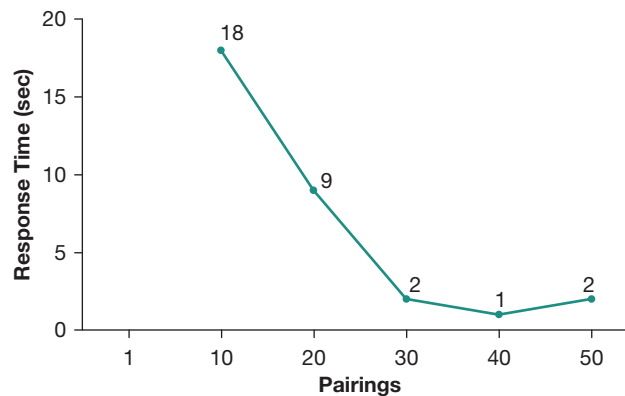
As Pavlov introduced in his 1904 Nobel Prize address, “A neutral stimulus can be associated or paired with an existing stimulus and response repeatedly, until the neutral stimulus becomes a learned cue for the response on its own.” This **conditional reflex** (sometimes the past tense is used, as in **conditioned reflex**) can act as a predictor or trigger to an existing reflex.

Before a conditional reflex can be learned, an innate reflex must already exist between two events, such as between the presentation of food on the tongue and the salivation response. Pavlov termed these the **unconditional stimulus** (UCS) and **unconditional response** (UCR). (Most introductory textbooks use the past tense of these terms, which stems from a mistranslation of Pavlov's original terms.) They are “unconditional” because together they make up an innate, physiological reflex and, as such, are not learned. No one had to actively teach the dog to salivate when presented with food.

Next, during learning, some new stimulus that previously had no direct association with the unconditional stimulus and response is introduced. This could be the sight of lab workers carrying a bowl of food, or the sound of their feet as they approach, or even the time of day. Essentially, this new stimulus is being paired repeatedly with the already-existing unconditional reflex as the lab worker then feeds the dog. After a while, the visual stimulus of the lab worker or any other relevant cue triggers the response of salivation, before the food has been placed on the tongue. After learning, what had been a neutral stimulus is now a **conditional stimulus** (CS) that can trigger the response, now called a **conditional response** (see Fig. 3.6).

FIGURE 3.6 Flowchart of the stages of learning in classical conditioning


To study conditional reflexes, Pavlov and his assistants began to experiment with different kinds of stimuli, how many pairings were necessary, when the learning or conditioning occurred, and how strong the salivary response was (see Fig. 3.7). Pavlov was well-suited for pursuing this line of work with his large staff and systematic approach. It is not clear whether he ever used a bell as the conditional stimulus, as many textbooks report, but he did appear to use whistles, metronomes, buzzers, and other auditory stimuli. Just to control the presence of sound around the dogs when running his experiments, he had a laboratory space built for the dogs with two feet of dirt in the walls for insulation (his “Tower of Silence”).

FIGURE 3.7 Response times decrease with more pairings


Classical conditioning has a dramatically broad number of applications, which is surprising given the rather restricted and unconventional line of research that inspired the theory. Yet classical conditioning captures the learning to associate an environmental cue to another situation or our own responses very well. One dramatic example comes from combat veterans who have returned home from serving overseas in the past decade. Some of them have found that the sounds of fireworks around holidays trigger memories and emotions from combat (“Veteran asks for courtesy with holiday fireworks,” 2014). In combat areas, there is exposure to bombs, small-arms fights, as well as rocket attacks. The physical and mental impact of explosions—even assuming no injury—is likely to be reflexively unconditional to many negative emotions, such as fear and anxiety. The accompanying sounds then are quickly conditioned as stimuli that accompany those explosions and become cued reminders of past trauma. Some of these veterans have begun encouraging their local community to set off fireworks with some consideration, since unexpected fireworks can trigger days of sleepless nights and an increase in post-traumatic stress disorder symptoms.

A less dramatic but common form of classical conditioning is involved in test anxiety. **Test anxiety** is used to describe situations where a test taker’s anxiety causes a drop in performance on the exam (Sarason, 1961). Most research on test anxiety supports the idea that it can cause test takers with normal skills to underperform and do worse than they are capable of. Research has looked at the role of the instructions for a test, and what the nature and source of the “anxiety” in test anxiety might be. Highly anxious test takers tend to perform worse on tasks that are complex and timed (Siegman, 1956), and when they are told that the test is an important one (Sarason, 1961). What appear to be happening are not only the symptoms of physiological arousal, but the negative thinking that comes from a fear of being evaluated (Paulman & Kennelly, 1984; Sarason, 1984).

However, one cause of test anxiety appears to be a history of poor test results. Highly anxious test takers have been found to have poor organizational skills when studying that then sets them up for difficulty (Naveh-Benjamin, McKeachie, & Lin, 1987). Over time, they develop a history of frustration and disappointment with testing. It’s possible that this anxiety leads to becoming a conditional response to test taking as well as to education in general.

To review, an organism learns to associate what had been a neutral stimulus with a preexisting stimulus and response during learning. Afterward, the now-conditional stimulus can trigger the response (or something similar to it) on its own.

Pavlov and later researchers spent a great amount of time and effort on examining the process of acquiring a conditional reflex. **Timing** of the presentation of the neutral stimulus during learning has been found to matter greatly. Let’s use the end of a class period as an example. Most teachers have one or more “tells” when they are nearing the end of the material they have for the class period and when they anticipate winding down. Perhaps it is looking at their watch quickly, or turning off the projector. It could be verbal, such as saying, “Do we have any questions?” While they may or may not realize it, students learn to read these cues after a while and start packing up before the end of class is announced. So, what makes for the most effective presentation timing for learning the conditional reflex? Presenting the neutral stimulus after the unconditional stimulus has appeared rarely turns the neutral stimulus into a conditional stimulus (Miller & Barnet, 1993). If the professor announces the end of class and then looks at her watch, students are not likely to make a connection. If the neutral stimulus is presented at exactly the same time as the unconditional stimulus, there can be a weak association with the unconditional response. So if the professor announces the end of class while glancing

at her watch, a weak conditional reflex might be learned. Perhaps during the term, she will look at her watch during lecture one day and some students in class will wonder, “Is it time to leave already?”

The strongest conditional reflex is built when the neutral stimulus occurs just before the unconditional stimulus. If a professor always looks at her watch and then a second or two later announces the end of the class, the neutral stimulus becomes a conditional “cue” that acts as a signal. That the unconditional stimulus and response are *contingent up* the neutral stimulus creates a learned association that is rapidly acquired and strong. Predictability is key (Rescorla, 1988). This is why cats so quickly develop a learned response to hearing a can opened in the kitchen, why people will start to wince if they see someone about to drag their nails along a chalkboard, and why they may salivate when they smell someone making microwavable popcorn.

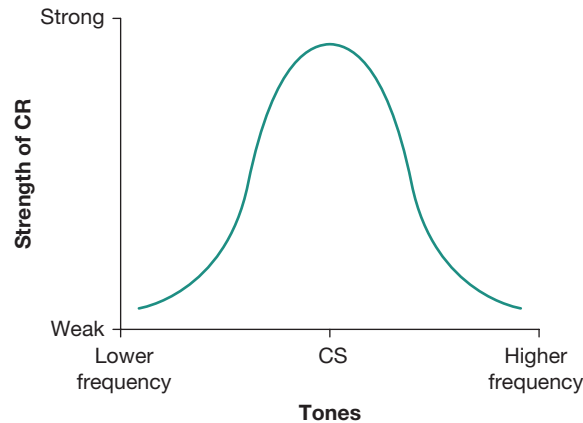
Can any stimulus become a conditional stimulus? Some stimuli appear to be more apparent, or salient, to the learning organism and will become associated more quickly (Forsyth & Eifert, 1998; Maltzman & Boyd, 1984). Our hypothetical professor who checks her watch at the end of the lecture is providing an action that probably can be fairly easily associated with the end of class, since her action alludes to “time,” and classes usually have a fixed end time. Another action, like adjusting a shirt collar, may not be learned as quickly. The relationship between her checking the watch and the end of class gives the impression of a cause-and-effect relationship to the students in her classes. Note this cause-and-effect relationship only has to be apparent to the students and might not be true in reality; it’s possible that the professor has some other unknown reason for glancing down at her watch, but it won’t matter to the students.

Is a learned, conditional reflex permanent? No, but then again, it can return quickly after being unlearned. The connection between the conditional stimulus and conditional response can end, particularly if the organism finds that the conditional stimulus no longer predicts the unconditional stimulus that provokes the response. For example, perhaps a professor usually ends an evening class about ten minutes early. After a while, the students become conditioned to the ten-minute early time as signaling the end of the class. But alas, at about midterm, he begins to lecture all the way through and sometimes goes overtime. The significance of the ten-minute early time fades.

And this is what has been found (Bouton, 1994; Pavlov, 1927/2015). The learned connection can weaken in a process called **extinction**. By repeatedly presenting the conditional stimulus without the unconditional stimulus, the response to later presentations of the conditional stimulus alone fades. The CS as a cue is no longer as predictive. Another example of this could be the tension one would feel driving past the scene of a car accident he or she had been in previously. A new accident doesn’t happen (hopefully) each time that section of road is driven on, and after a while, the scene becomes decoupled from having had the accident (UCS) that provokes an emotional response (CS) of fear and pain.

The idea that emotional responses to a situation or thought can be learned is powerful, since the emotional response should be able to be unlearned. Mental health professionals are typically most concerned with those emotional responses that are negative and can interfere with daily functioning and obligations such as anxiety and depression. Hence, one entire approach to psychotherapy has been based on the idea of extinction from classical conditioning theory. “Behavioral theories,” those that approach change in a client by asking him or her to alter their actions, often have a component that is based on the concept of extinction, called **exposure**. In exposure therapies, the client is

FIGURE 3.8 Responsiveness to a CS can generalize to other similar stimuli, but it will be weaker

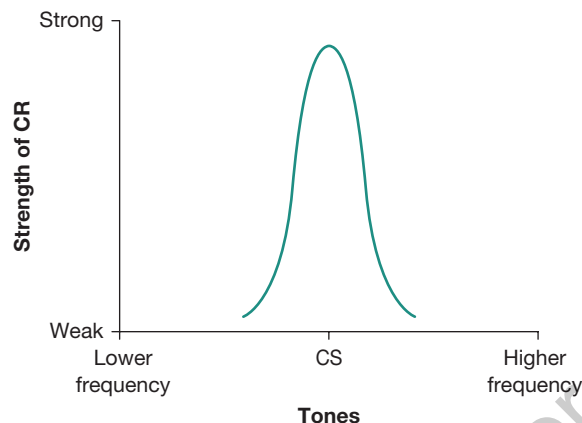


presented with stimuli that has been connected to a situation that provoked a negative emotional response, whether an assault, a traumatic car accident, or combat experience. The stimuli can be real or imagined. Then the client has to wait out the emotional response. Essentially the cue that has been predicting something traumatic becomes disassociated by repeating this kind of activity. The client finds that the thought of spiders or germs or the sound of fireworks no longer implies the actual traumatic event that was feared. This kind of approach has had success with treating phobias as well as obsessive-compulsive disorders, both of which have anxiety as a fundamental, emotional conditioned response (for an overview, see Mineka & Zinbarg, 2006). One challenge with this approach to therapy is that the process of extinction, as a learning mechanism, can take much longer than the original conditional reflex took to learn. The therapist and client have to commit to working on the extinction procedure.

But after extinction, the connection is not completely gone. Extinction itself can end very quickly if the UCS is reintroduced after extinction, or **spontaneous recovery**, just as can happen to *Aplysia*. When spontaneous recovery occurs, the initial strength of the conditional reflex is weaker than before, but it recovers at a much higher rate than the initial trials of learning.

Likewise, the extinction of a connection that had been spontaneously recovered is faster as well. Although the connection remains, it is weaker all around. So if the professor begins to end class ten minutes early again, relearning will happen much more quickly than before but the strength of the connection will not be as great. If the following week, as the professor goes overtime again, then extinction happens again all the more rapidly (see Fig. 3.8).

Pavlov found other properties of this kind of learning to make associations. Once a conditional stimulus had been learned, the organism will respond to other stimuli that are similar in nature but not exactly the same, a property called **generalization**. Pavlov's dogs would respond to a tone that was similar in pitch to the learned CS, but it could be a little higher or lower. Typically, however, the strength of the response (in salivation) would decrease the more dissimilar the CS was from the stimulus (see Fig. 3.9).

FIGURE 3.9 Discrimination for a specific stimulus can be learned as well

Hence it is quite likely that fireworks do not actually have the fully physical or auditory impact of a rocket, gunfire, or a land mine, but their sound may be similar enough to create a resurgence of emotional responses.

Pavlov also found he could teach the dogs to discriminate between two or more stimuli, a process called **differentiation**. He could teach them to salivate at one symbol but not another that was similar. The presentation of a tone at one pitch might be followed by food, but not a tone at another pitch. The dogs would then learn to respond only to the conditional stimulus and ignore (even fall asleep) when presented with the other. Using this technique, Pavlov found that dogs didn't distinguish between colors very well and concluded they were colorblind.

Computer user interface design impacts millions of consumers and office workers daily. When working with a device, a primary issue is properly identifying which keys perform which functions. This is additionally difficult when the same key may do more than one task or have an “off/on” state, as the SHIFT key does. The digital keyboard that is used on a popular model of cellular phone presents a shift key as “on” when the up arrow is dark and contrasts with a white background, matching other letter keys on the keyboard, so the keyboard will produce capital letters. When the shift key is shown as “off,” the up arrow is bright white. In both cases the letters on the keyboard are displayed in all caps. A website has been created to act as a reminder (<http://ismyshift-keyonornot.com>). This presents difficulties in distinguishing the proper role and wastes time; an earlier version of the keyboard had the shift key turn blue when enabled. While this example is mostly humorous, the implementation of confusing controls and signs can have life-or-death consequences in the medical, construction, and aerospace fields (Norman, 2013; Proctor & Van Zandt, 1994).

Besides associating a neutral stimulus to the unconditional stimulus to create a conditional reflex, classical conditioning can be extended to explain how another neutral stimulus, like a flash of light, can be associated with the original conditional stimulus (CS1). This new conditional stimulus (CS2) can then trigger the response too, in what is called **second-order conditioning** (or “higher-order conditioning”). The CS2 is presented with the CS1 and, after some trials, can generate the UCR even though the CS2 was never paired with the UCS. It's possible that higher-order conditioning underlies our ability to form “mental models” of situations and events by enabling us to perceive

causal connections between the events, even when they do not necessarily occur together (Jara et al., 2006).

Attitudes, or our evaluations of objects, ideas, or people, appear to develop from classical conditioning. Olson and Fazio (2001) demonstrated how a classical-conditioning paradigm can create an attitude toward a novel object without conscious awareness of the association by pairing different Pokemon with positive or negative words as part of a larger task for the participants. Without any awareness, the pairings altered the participants' pleasantness ratings of the Pokemon. Similarly, Baccus, Baldwin, and Packer (2004) used a classical conditioning paradigm to increase the self-esteem of computer users by showing them a smiling face while they completed a word task.

One particularly troubling consequence of second-order classical conditioning is the development and maintenance of negative social attitudes that are derived from exposure to media reporting of the news. Just the exposure to the people presented as criminals on the nightly news means conditioning viewers to associate characteristics of gender, race, religion, age, and geographic location with "criminality." These implicit attitudes are viewed as involuntary, uncontrollable, and often unconscious evaluations of groups of people (Gawronski & Bodenhausen, 2006). While much of the news after the attacks on September 11, 2001, attempted to remain neutral to the nationality and apparent religion of the plane hijackers, the repeated presentations of "Arab," "Muslim," and "terrorist" within news stories should have, according to Pavlovian conditioning, conditioned people to make connections between those terms and the bombings (see, e.g., Das, Bushman, Bezemer, Kerkhof, & Vermeulen, 2009). These associations might be unconsciously learned and do not rise to the level of media framing or bias by themselves, but they still could exert an influence if unchecked by more controlled, consciously aware thinking. It's completely possible for someone, without awareness, to espouse one set of values or political views while behaving contrarily. Relatedly, Galdi, Arcuri, and Gawronski (2008) found that most of the voters in their sample who stated that they were undecided about a political event (like an election) already had implicit attitudes that predicted their eventual explicit attitude.

Implicit attitudes may be formed from childhood experiences. Implicit attitudes toward obesity was predicted better by the participants' own childhood weight and the weight of their mothers, but explicit attitudes toward obesity were predicted best by the participants' current weight (Rudman, Phelan, & Heppen, 2007). If findings like these hold true for most implicit attitudes, then they may be resistant to change since they tend to be outside of voluntary control and current experiences.

Further Applications

Since classical conditioning theory describes such a fundamental form of learning, the applications of it extend well past the examples we have looked at so far. This section looks at the role of classical conditioning in three surprisingly connected areas: sleep habits, drug overdoses, and education.

Virtually everyone struggles with **insomnia** at some point in their lives. The inability to get to sleep and stay asleep affects our waking lives in several ways, including weaker concentration, irritability, and poorer memory formation. In the worst cases, it can create a mental fatigue that is symptomatically similar to drunkenness. These situations create a problem for driving, operating machinery, or simply sticking to a good routine of diet and exercise. In some cases, insomnia can result from prescribed medications, stress from school or work, or a sleep disorder such as sleep apnea. But for many, insomnia is tied to the poor sleep habits that people develop (Lacks & Morin, 1992).

The bedroom, particularly the bed itself, is a stimulus that can trigger associations with the activities that commonly take place there; and for some, these include studying, watching television, checking social media, playing video games, eating, or hanging with friends, in addition to sleep and sex. From a classical conditioning perspective, the “bed” does not form a strongly conditioned cue to the activity of sleep, since it’s associated with so many other activities. Part of maintaining good **sleep hygiene** is to use the bed primarily for sleep, so the body becomes conditioned to that activity in that space. When wanting to rest, getting into bed at night signals the proper activity, and the body relaxes (Smith & Haythornthwaite, 2004; Stepanski & Wyatt, 2003). If the sleeper wakes up too soon, sleep hygienists recommend quietly getting something to drink, mostly in the dark, and returning to bed.

While combating insomnia may involve training the body to do a desired activity in a particular spot, educators face a different problem: encouraging the activation of knowledge in places other than the classroom. *Transfer* involves being able to correctly identify real-world situations outside the classroom where some learned information or skill is applicable (Mayer & Wittrock, 1996), such as algebra or physics (Bassok, 1990). Unfortunately, most formal learning occurs in a staid classroom environment well removed from daily life, and (as you might have guessed) this means what is learned in that space can become conditioned to that environment. Hence, foreign language skills become easier to retrieve in Spanish class than at a Mexican restaurant. This means educators may find they need to schedule field trips to rehearse these skills outside the school building and encourage parents to practice learned skills at home (Bransford, Sherwood, Vye, & Rieser, 1986). Here the goal is to dilute the conditioned stimulus of the classroom. (In a later chapter, we will take a closer look at research on learning that is dependent on the context in which it was learned.)

While students may struggle with retrieving knowledge in contexts other than where they learned them, the role classical conditioning plays in uncontrolled, illicit drug use can be deadly. The public is more aware of drug use and the corresponding physiological impact on the body—terms like “tolerance” and “withdrawal” are now part of the common lexicon. To review, **tolerance** describes the effect of a drug losing its effectiveness with repeated use as the body’s immune system adapts to the foreign substance. **Withdrawal** describes the effect of the immune system continuing to counteract the foreign substance if a person stops taking it as often as before. The body’s attempt to adapt to the drug use now works against the individual, sometimes severely.

The counteractions of the body’s immune system appear to be somewhat conditioned to the environment. That is, when the individual repeatedly uses a drug at home, the immune system starts to trigger the counteractions whenever the person is at home; the home environment has become a conditioned stimulus for self-administration of the drug (Siegel, Baptista, Kim, McDonald, & Weise-Kelly, 2000). Most likely, the thoughts and awareness of the person spontaneously trigger the body to prepare for possible usage of the drug in the same way that someone who has been experiencing stress at work begins to tense up involuntarily around the office. Unfortunately, these counteractions will not engage when the person decides to get high with a friend at his or her home. The body hasn’t been conditioned to this new environment. So, the experienced drug user who now ingests the same amount of a drug that he or she has taken before finds the learned tolerance for the drug does not kick in and a “normal” amount of the drug creates a stronger reaction and can cause an overdose (Siegel, 1984; Siegel, Hinson, Krank, & McCully, 1982; Siegel & MacRae, 1984). This has become a commonly accepted explanation for why people tend to overdose in new environments rather than the usual ones.

Now let's turn to how skills are learned, particularly repetitive motor tasks. Like classical conditioning, the development of motor skills involves associating the correct movements with cues in the environment. Like classical conditioning, much of skill learning can be involuntary.

Skill Learning

Skills provide the ability to function in a wide range of contexts, including educational, recreational, and work settings. Starkes, Deakin, Allard, Hodges, and Hayes (1996) interviewed professional golfer Moe Norman who, by his 60s, had won over fifty tournaments and set over twenty-four course records. He is viewed now as one of the most accurate ball hitters ever in the sport (Neuman, 2014). When asked what made him such a good golfer, he would show “his left hand, the surface of which is so black and calloused that it looks like the tire of a race car” (p. 103). Extended practice is critical for extremely high levels of performance. At the age of 16, Moe Norman began hitting 800 balls a day to practice.

The study of how people acquire skills is often different from other areas of learning because the procedural skills themselves are of interest, not the language and knowledge needed to talk about them (Lee & Schmidt, 2008). How actions are made is the focus. **Motor skills** are those specific behaviors involved in the procedure necessary for tracing a line, shooting a basketball, using a tool, or dancing. The ability to move is a critical part of life—for feeding, survival, and reproduction. The issue is not usually which behavior to make so much as making the needed behavior when necessary. Some motor skills are seen as “closed-loop” skills, meaning that the execution of the behavior gives immediate feedback on what is next step for continuous motion, such as tracing a line. The environment for the activity is predictable and not likely to change: the task for the performer is to pick the correct action and to execute it. Table air hockey is an example—the nature of play is straightforward and contained. In contrast, “open-loop” skills may be necessary in more dynamic, complex environments where the precise action necessary may not be clear, such as a team sport like hockey or soccer.

There is evidence that learning a new motor skill appears to make structural changes to the brain, beyond just changes to the neurons themselves. Draganski and colleagues (2004) made brain scans of people both before and after spending three months learning to juggle, and found that structural changes to the temporal and parietal lobes had occurred. These areas are known for their relationship to movement, spatial thinking, and visual attention. These changes started to reverse themselves after three months of not juggling.

While we are generally aware of the activities that we do to improve ourselves, it appears the conscious memory of having done the activity for practice is not necessary for learning motor skills. We might be familiar with the general task but be unable to verbalize the rules behind the task or when we might have experienced the activity last. Amnesiacs such as Henry Molaison may do well with learning new motor skills, but they will not remember having practiced (Corkin, 1968; Milner, Corkin, & Teuber, 1968).

During the past one hundred years of research into motor skill learning, researchers develop tasks that their participants have not learned before, such as using Morse code, typing, or unusual drawing tasks such as tracing a mirror image (Snoddy, 1926, is an early example). As with any learning, motor skill learning will require gathering information about the procedure and what needs to be done, retaining that information over time, and successfully transferring those skills to similar or new environments.

Fitts (1964) proposed three stages for motor skill learning. First, the individual works to understand the requirements of the task and what is involved. This is primarily a cognitive stage, and the person is likely to need instructions to follow. Next, there is a motor stage, in which the typical movement patterns are gradually strengthened through repetition and with the help of sensory feedback. Usually the instructions are no longer necessary at this stage. Finally, the movements become automatic, and those behavior patterns are integrated into longer sequences that don't require much attention. It's possible at this point to engage in some secondary activity simultaneously while doing this primary one.

Another approach to the study of skill learning has been to observe experts in a range of fields, including physics, sports, music, and chess, and see how they acquire *expertise*. These researchers try to find skilled behaviors and decisions that can be recreated in laboratory conditions and tracked over time to see how those skills are developed. For many intense sports, performance may peak when the athlete is in his or her twenties (Ericsson, 1996). For more cognitive skills, such as physics and chess, peak age is highly variable and centers around the thirties. Long-term study of world-class experts in a domain has found that after starting practice, the experts-to-be transition to full-time at a critical point in their careers. At that point, they begin trying to set achievements for themselves, such as breaking records. The cost involved in the transition to full-time is often an issue for many (Ericsson, 1996).

Researchers have primarily investigated both the role of practice and the role that knowledge of the results (typically in the form of feedback) have on skill learning.

Role of Practice

The aspect of skill learning most commonly researched is, perhaps unsurprisingly, the role of **practice**. The default conception of practice is that more is better, and this is mostly true. The **power law of practice** describes the finding that simply repeating a task in practice trials tends to speed up performance, but the rate of improvement varies over time. The improvement in performance happens in a logarithmic (curved) function. There are great improvements to be made in the beginning of learning, but after a while, the improvements in performance become smaller despite many more trials.

Chase and Simon (1973), comparing length of time most internationally recognized performers had spent in training to reach that status, found it took about ten years for someone to reach that level of performance. This period of time seems to be a constant across many domains (Anders & Charness, 1994; Anders, Krampe, & Tesch-Römer, 1993; Charness, Krampe, & Mayr, 1996). This does not mean that participating in an activity for ten years will automatically make one an expert, so much as that dedicated focus for about a decade seems to be a commonly necessary prerequisite for national-grade expertise (see Fig. 3.10).

Ericsson, Krampe, and Tesche-Römer (1993) also claim that it is not a matter of simply repeating a task to reach a peak level of performance. Ericsson and his colleagues have proposed that to truly advance beyond one's peers, a specific kind of practice is needed—essentially, practice with the goal of removing errors. **Deliberate practice** involves working on a clear task of appropriate difficulty, with feedback and repetitions to correct mistakes. The purpose of deliberate practice is to become able to create an optimal performance reliably. Enjoyment of the activity itself is secondary.

Ericsson's focus on deliberate practice is not likely to be the entire story. Many people who engage in some activity wishing to excel at a national or international level drop

FIGURE 3.10

Hours of estimated practice by age for good violinists. The ranges show the variance in reported practice from low performing to expert and professional violinists



out at some point, due to many possible factors, including financial strain, lack of motivation, or a lack of innate talent (Sternberg, 1996). The combination of those factors may be simply impossible to study empirically over the lifetimes of randomly selected individuals who might attempt to excel at a task.

To what extent should a specific motor skill be studied in isolation from or in combination with other skills? In other words, does practicing switching from one skill to a related one create a **contextual interference** in learning those skills? Most complex activities, such as playing soccer, require mastery of a number of movements that are not reproduced one at a time in a predictable sequence—instead, the player is expected to have mastered a range of movements that can be produced as the situation demands.

Shea and Morgan (1979) reported on a classic test of this sort of situation. Participants had to complete either blocked schedules of movements—that is, one movement executed repeatedly—or schedules of random moves. In the blocked schedule, the participant would be able to execute a move, get feedback in the form of seeing the result, and repeat it. In the random schedule of moves, it would not be clear from one moment to the next which move would be next. Nothing would be repeated more than once. It's possible to imagine the blocked schedule as being similar to a soccer coach who asks the team to work on a particular skill, such as an outside-of-the-foot pass, repeatedly. The random block would be more like calling out random skills or scrimmage.

The blocked schedule produced faster learning in the participants in the Shea and Morgan study (1979). However, when participants returned ten days later and repeated the schedules from before, the participants who had experienced the random schedule showed greater improvement. Possibly, the interference of other skills may be worse for learning a new skill but has a benefit with retention. Learning an isolated task is a problem for incorporating into a context of numerous moves; learning in a context can help to retain the skill by providing more variety (Battig, 1979). So, blocked practice means that the movement prepares the individual only to repeat the movement—it cues itself—whereas random practice means having to learn to be ready for something else. This random practice might help for retaining and transferring skills since the wider

range of behaviors cues any one movement. An example of this might be a fifth grader who is struggling with timed multiplication tests. Initially it might be best to focus on just one set of multiplication factors, but eventually the range of possible combinations should become more flexible so the child is best prepared for whatever sequence of quiz prompts are presented in class.

The benefit of randomized practice might be because the varied movements present an opportunity for the learner to discern contrasts between the different movements; the entire experience might be more memorable (Lee & Schmidt, 2008). Wright and Shea (1991) found that with increasingly complex tasks, the learners became more dependent on the situation for contextual cues to improve performance. This could be a problem for, say, baseball players who begin to forget their skills in ball parks that are not where the team typically practices. Additionally, for each movement, there will be a space in time between when it is practiced and when it is called for again. This means that the learner has to recall and reconstruct the movement, practicing the retrieval of that movement in addition to the action itself (Lee & Magill, 1983).

Of course, these principles assume that a coach or teacher is picking the training schedule for the learner. What if the learner picks the schedule? Some evidence indicates that the schedules the learner picks out individually are what are best for him or her (Keetch & Lee, 2007). But in some cases, knowing the best overall schedule appears to be a challenge, particularly if the results are counterintuitive. Is it better to have long, infrequent practice sessions? Or short ones that are repeated frequently? Often, because of busy schedules and procrastination, we are left to put all of the effort into a task near a deadline. Working at the last minute for long hours often feels like we are shouldering the burden of effort simply because we can feel the strain. But is that the best way to learn a skill?

Role of Feedback

Another factor heavily researched in motor skill learning is the role of **feedback**, or being presented with **knowledge of results** of a performance. Outside of research environments, feedback often has a social element, and can come from a variety of other people beyond ourselves, including coaches and teachers (Glaser, 1996). For example, figure skaters are usually under a very high level of monitoring from a team of coaches (Starkes, Deakin, Allard, Hodges, & Hayes, 1996). Other people may structure the tasks to be performed so they gradually increase in difficulty and choose those tasks more likely to provide growth and feedback. Ideally the instructor can remove support over time as the learner masters the necessary skills and becomes more self-regulated and reliant on self-study (Charness, Krampe, & Mayr, 1996). For example, figure skaters are usually under a very high level of monitoring from a team of coaches (Starkes et al., 1996).

Is having knowledge of the results while learning helpful? Feedback has been found to be good for learning a motor skill, generally, but it can be overdone. If too much feedback was given, the learning process was disrupted (Salmoni, Schmidt, & Walter, 1984; Winstein & Schmidt, 1990). Feedback may primarily act as guidance, and it doesn't necessarily cause learning to occur.

If providing feedback helps with learning, when should it be given—while the learner is performing the task, or after? Wulf and Schmidt (1989) found providing feedback during the task itself was helpful when learning the task, but reducing the amount of feedback over all helped to improve memory for the skill. In one condition, participants who did not receive any feedback during the learning phase retained the

information longer than those who did. Possibly the presence of guiding feedback, while helpful to learn a skill, can become a crutch if the learner begins to expect it. Wulf and Schmidt suggest starting training with guiding feedback but reducing it over time.

Encouraging self-analysis appears to help retention as well. Swinnen, Schmidt, Nicholson, and Shapiro (1990) found the timing of feedback was best for retention when the participants were asked to describe how well they did after a trial performance, encouraging some open reflection, before providing any feedback. Providing instantaneous feedback after a performance didn't allow the participants to develop their own ability to detect the mistakes they were making.

Should feedback be given on every trial, or only occasionally? Providing feedback during every trial, such as a video display showing the best arm movement, helps when someone is learning a new skill but not once the skill has been mastered (Schmidt & Wulf, 1997). However, if the guidance is not available at all after learning, performance drops.

Ordinarily, not every performance of a task can be acknowledged by a coach or teacher. Given the need to reduce the frequency of feedback, how often should summary feedback of several trials be given? Researchers have experimented with feedback of performance over fewer trials as well as with longer sets of about fifteen. Yao, Fischman, and Wang (1994) found that summaries over mid-sized sets of trials of about five were best compared to 15-trial summaries. One advantage of not receiving feedback from an instructor on every trial is that the learner has an opportunity to mentally estimate his or her own performance, and receives less interference from others during this self-evaluation.

In our final section on simple learning, we'll take a look at research on the nature of unintentional or implicit learning. As noted above, Henry Molaison showed some signs of learning after all—but only for very specific simple tasks, and he never remembered any prior experiences with those tasks (Corkin, 1968). For example, he improved his ability to follow a dot on a spinning disc with both his preferred hand and his nonpreferred hand over several days.

Molaison's learning included improved performance on simple mazes (Milner, Corkin, & Teuber, 1968). Once, given a particularly challenging task he had done many times before, Molaison commented to one of the researchers that the task was "easier than I thought it would be" (Carey, 2008). He gradually became more familiar and comfortable with the scientists who were visiting him so frequently, despite not remembering having previously met them. So, some form of unintentional, non-conscious learning was happening over time after all (see Fig. 3.11). Let's take a look now at research on unintentional, implicit learning.

Implicit Learning

Implicit learning is the act of learning a task incidentally, without intent. It is not necessarily a conscious act, although we might become aware of implicitly learning something after the fact with improved performance. An early study on amnesiacs found evidence for this kind of unintentional learning. Warrington and Weiskrantz (1968, 1974) asked volunteers and amnesiac patients to study lists of common words for several minutes. When shown a list of words that included a mix of studied and unstudied words, however, the amnesiac patients were unable to recognize words that they had seen previously. Yet when asked to complete some word fragments with several possible answers—that is, when shown a part of a word such as "TAB__" and asked to finish the

FIGURE 3.11

On a two-handed tracking task, H.M. showed improvement similar to controls, while not remembering having attempted the task before

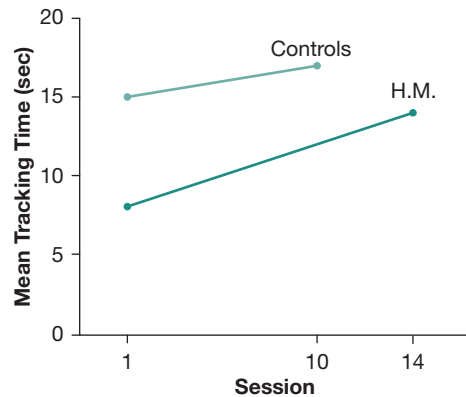
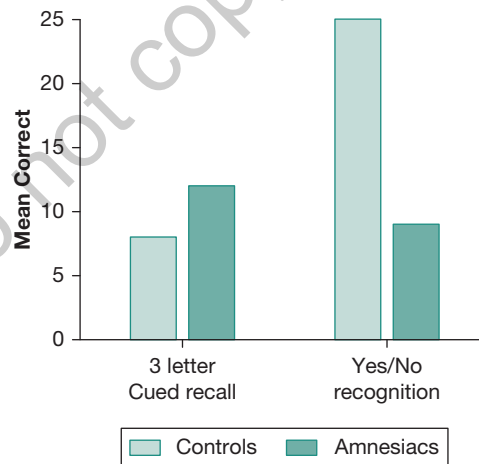


FIGURE 3.12

Amnesiacs showed the same level of recall studied words with a cue as controls, but an inability to consciously recognize words they had studied (adapted from Warrington & Weiskrantz, 1974)



word—the amnesiac patients finished the fragments using the words they had studied earlier, at the same rate as did the volunteers. This was despite not being aware that they had seen the words previously (see Fig. 3.12).

The philosopher Bergson asserted that the past survived “in two forms,” one more conscious and the other unconscious, like a habit (1911, reprinted 2004). The term “implicit learning” appears to have been first used in print by Reber in (1967). Graf and Schacter (1985) defined implicit learning as learning that is unconscious. In an implicit memory, there is no study period to reflect back to, and usually verbally stating what

was learned is not possible. Teenagers may find they can mimic and master how other young adults are dancing more quickly than they can explain the moves to a younger sibling, for example. Similarly, Lewicki, Czyzewska, and Hoffman (1987) point out that few people can explain what they find attractive about the faces of other people, yet we make decisions about what we like and don't like rapidly. Some theorists see implicit learning to be largely about learned associations between concepts, ideas, and patterns, whereas explicit learning gives us the ability to state a proposition (Gawronski & Bodenhausen, 2006). So, a child might taste a new, healthy vegetable in his or her dinner meal and have a quick, automatic emotional response that gives rise to the comment of disgust, "I don't like this!"

If the process of implicit learning can't be seen or talked about, how is implicit learning to be studied? The only way to show evidence for implicit learning is to track changes in behavior, such as a participant's improving on a task over time, rather than to recall studying the skill, using reaction time and other behavioral measures. The process of implicit learning is generally seen as quick, automatic, and unconscious. The process of explicit learning is consciously controlled and is more in line with analytical thinking and complex problem-solving skills that fall under the construct of "intelligence," or abstract problem solving (Stanovich & West, 2000). As others have argued (e.g., Baddeley, 1999 p. 86), the distinction between implicit and explicit memory is not firm. The group of processes that psychologists consider to be "implicit" are defined primarily by the lack of conscious learning. They are not necessarily the opposite of "explicit" learning, as much as conscious control isn't present in those forms of learning, so the field has labeled them as "implicit."

Some characteristics of implicit learning and the resulting memories are agreed on. First, we have trouble verbalizing that which we have learned implicitly. Second, the implicit memory that results is usually not flexible, and it can't be consciously reconsidered. The process generally relies on superficial processing, such as the recognition of patterns, and generally involves simple associations. Third, the biological mechanisms underlying implicit learning play a more singular role than do those in intentional learning.

To help see the difference in research, Lewicki, Czyzewska, and Hoffman (1987) provided a classic example of a study using an implicit learning task. In the first of two reported experiments, participants looked for a target character, a single digit, in one of the four quadrants on a screen. When they found it, they were to push a button that identified the quadrant where they had found the digit. Their performance was timed to see how quickly they could find the digit. For each trial, they did this visual search of the screen seven times: the first six were relatively easy since there were no other characters to distract the participants onscreen. In the last search, other digits were present onscreen as distractors. These trials were repeated over a twelve-hour period, which meant each participant completed 4,608 trials and pushed a button more than 30,000 times. (They did get breaks.) As is common with studies where small differences of reaction time are being examined and a lot of data are collected in a within-subjects design, this study used very few subjects—one male and two females.

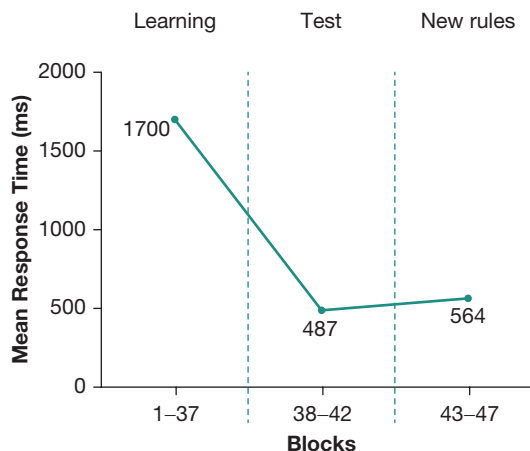
Here's how implicit learning was examined in this study. Unbeknownst to the participants, there was a pattern to the placement of the digit. On the first, third, fourth, and sixth search of each trial, there was a rule to the order of where the digit would appear; and this would predict exactly where the digit would appear in the last, seventh search. During the other searches, the placement was randomly picked by the computer, as distractor trials. There were twenty-four²⁴ different sequences

that the computer would select from when presenting the trials to the participants. Lewicki, Czyzewska, and Hoffman were essentially testing whether participants could unknowingly pick up on a complex pattern to quicken their reaction time on the final search that included distracting digits. Interviews conducted after the study found the participants to be completely unaware of the presence of any pattern. (A pilot study with the same materials had found other participants were unable to find a pattern when told about the pattern in advance, with the promise of an extra \$100 if they found it.)

All three participants improved their reaction time dramatically during the twelve hours by more than a second on average. They had implicitly learned to pick up on the sequences that gave away the location of the target character in the last search of each trial. Just to make a more compelling test, in the final hours of the study, the researchers changed the rules for locating the digit, so the patterns that the participants were exposed to would no longer help. As expected, this slowed the participants' rate of response. Now, they had prior knowledge that momentarily worked against them (see Fig. 3.13). Somehow they had picked up the rules implicitly. As the researchers point out, not only did the participants learn some complex patterns without awareness, but they employed them without awareness. Both the implicit acquisition of the knowledge as well as its use appeared to be outside their control.

Implicit learning appears to be important in aspects of life outside of the laboratory. One example is the role of implicit learning in how infants learn. Unlike what adults experience, babies in the first six months of life do not have decades of knowledge or verbal skills built up during the experience of daily living. Life is mostly a matter of sensing patterns and trends in the environment and making basic connections between them; what a baby learns is likely to be heavily implicit in nature. Despite our lack of conscious awareness of this form of learning, it appears to have a fairly strong impact on what we retain, can impact how we behave later, and may be a core part of what it means to be an organism that can adapt successfully to its surroundings (Lieberman, 2000).

FIGURE 3.13 Participants appeared to learn the sequence rules implicitly, and were disrupted when the rules suddenly changed



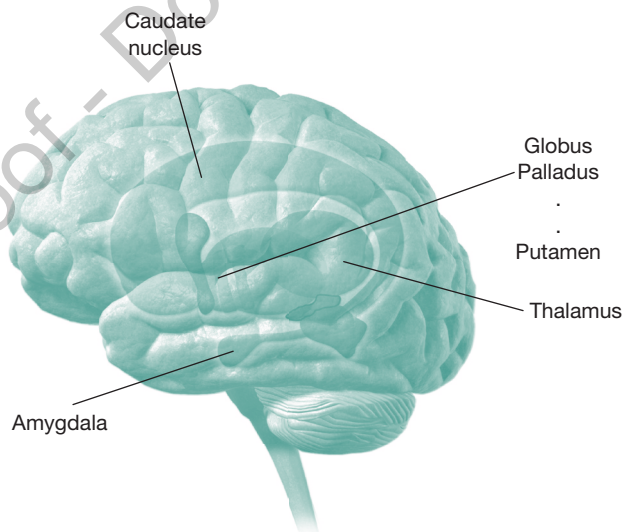
What Is Learned in Implicit Learning

Other researchers have tried to establish what is retained from implicit learning. Most see implicit learning as primarily a matter of learning simple patterns, with more conscious attention required for complex patterns. There are three theories surrounding what is learned during implicit learning. First, implicit learning may involve learning basic **rules** behind the structures of sentences and meaning. An early study on implicit learning found that participants could learn the artificial grammar of a fictitious language of letters (Reber, 1967). In contrast to a group of participants who had to work with randomly arranged letters, the participants who received the letters that followed a rule-based system made fewer errors, even though the rules were never explicitly taught.

Second, implicit learning may involve simply learning to pool the **averages of an overall sample of items**. As we engage in an activity repeatedly, we implicitly learn the general nature of the activity and its characteristics. Third, implicit learning may involve becoming familiar with the **statistical patterns and regularities** over time, for example, how often certain characteristics of the situation tend to appear; which cues present themselves first, or what characteristics often present themselves in combination with other characteristics. These learned patterns become units or chunks of information. At the moment, all three of these options are still considered viable theories.

Reviewing a broad amount of research, Lieberman (2000) concluded that areas of the brain inside the basal ganglia were responsible for implicit learning (see Fig. 3.14). Parkinson's and Huntington's diseases are known typically to affect the basal ganglia, and patients of either disease have an inability to learn implicitly (Lieberman, 2010; Lieberman, Chang, Chiao, Bookheimer, & Knowlton, 2004). This connection was later verified using neuroimaging studies (e.g., Lieberman et al., 2004; Poldrack et al., 2001).

FIGURE 3.14 The basal ganglia is nested deep inside the brain



CHAPTER SUMMARY

This chapter examined the biological basis of learning and described three research areas that involve basic forms of learning. First, the process of neurotransmission or how neurons communicate in the central nervous system was reviewed in order to provide the conceptual basis of how neurons may adapt to changes in our environment. Of most importance are the ideas that neurons communicate by releasing chemicals (“neurotransmitters”) between them, and neurons have “dendrites” that accept incoming neurotransmitters. So, on a physiological level, neurons support learning in one of three ways: through changes in the amount of neurotransmitters that are released between them, by modifying existing dendrites, or by new neuron growth.

The sea slug, *Aplysia*, demonstrates some of the more basic aspects of nonassociative learning, or learning in which only one stimulus is involved. The sea slug can habituate to a stimulus, meaning that it will respond less after repeated exposure to the stimulus of having its gill poked. If the gill hasn't been poked in a while, it can respond at full strength again, a phenomenon known as spontaneous recovery. Additionally, if it's given a strong touch, then it becomes sensitized and will essentially overreact when given a weak touch.

Classical conditioning describes the process that results in our ability to take cues from the environment as to what is about to occur. Research on classical conditioning finds that having the novel stimulus

precede the original, an unconditional stimulus and response works best for establishing that connection. Like nonassociative learning, classically conditioned associations can be habituated and spontaneously recover as well. Associations can be generalized to other similar stimuli as well.

Skill learning involves executing a series of actions on demand. Practice makes perfect, but initial progress usually is much better than later progress. Expertise in a skilled area appears to require years of practice that is aimed at eliminating mistakes. It is slower to practice an interrelated set of skills, but the learner performs better later on than when he or she has studied each skill only in isolation. Knowledge of the results of one's performance seems to matter greatly to the learning process. Guidance is helpful initially, but it needs to be tapered off; and cumulative feedback often works better than feedback on each performance.

The final form of learning discussed in this chapter was implicit learning, or learning without conscious awareness. Amnesiacs have been found to be able to make incremental performance improvements with tasks such as mazes over time, despite having no awareness of having attempted them before. What we learn implicitly seems to be relatively shallow and is hard to verbalize or reorganize. It's likely that what are learned implicitly are averages and patterns of the general nature of some stimulus.

REVIEW QUESTIONS

1. Describe the steps involved in neurotransmission. Hypothetically, what is “learning” at the neural level?
2. What is a conditional reflex you realize now that you have formed? What would be the conditional stimulus? Has the conditional reflex generalized? How would extinction work, if you wanted to weaken the reflex?
3. As a coach hired to turn around a struggling high school soccer team, what kinds of steps would you take to instill your players with the best retention of their skills? How often should the team practice? What kind of feedback should they receive?
4. Are we aware of all of the learning we acquire? How do we know that we are not learning?

KEY TERMS

Action potential 000	Gill withdrawal reflex 000	Pruning 000
Averages of an overall sample of items 000	Habituation 000	Receptor sites 000
Axon 000	Hebbian learning 000	Reuptake 000
Classical conditioning 000	Hippocampus 000	Rules 000
Conditional reflex 000	Implicit learning 000	Second-order conditioning 000
Conditional response 000	Inhibitory 000	Sensitization 000
Conditional stimulus 000	Insomnia 000	Siphon 000
Contextual interference 000	Knowledge of results 000	Sleep hygiene 000
Deliberate practice 000	Long-term depression 000	Spontaneous recovery 000
Dendrites 000	Long-term potentiation 000	Statistical patterns and regularities 000
Dendritic spines 000	Motor skills 000	Synapse 000
Differentiation 000	Neurogenesis 000	Synaptogenesis 000
Dock 000	Neurons 000	Test anxiety 000
Excitatory 000	Neurotransmitters 000	Timing 000
Exposure 000	Nonassociative learning 000	Tolerance 000
Extinction 000	Pavlovian conditioning 000	Unconditional response 000
Feedback 000	Plasticity 000	Unconditional stimulus 000
Fistulas 000	Postsynaptic 000	Withdrawal 000
Gaze time 000	Power law of practice 000	
Generalization 000	Practice 000	
	Presynaptic 000	

FURTHER RESOURCES

- Video on sea slugs for memory research by NOVAscienceNOW: “A Memorable Snail” | PBS—YouTube
- Kandel talks about his research with Aplysia: Memories Are Made of This—YouTube
- An interactive site on synapses: synapses.clm.utexas.edu
- “Apollo” Robbins, stage pickpocket
 - New Yorker profile: A Pickpocket’s Tale
 - also his own website: www.ist stealstuff.com
- A photo collection of Pavlov’s dogs: http://dubnaulab.cshl.edu/data/JD_dogs.html

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