



neural plasticity

LEARNING AND MEMORY

The process of learning is the acquisition of knowledge and ability; memory is the retention and storage of knowledge and ability. Memory is stored in the central nervous system by the creation of memory *engrams*, also called *memory patterns*, which are, in effect, recordings of what we have learned. Memory storage is usually divided into short-term memory, which lasts for only a few moments; and long-term memory, which can last indefinitely. Whenever any type of long-term memory occurs, whether it is of cognitive intellectual knowledge, a kinesthetic motor skill, emotional feelings, or even pain sensitivity, the concept of neural plasticity is involved. Neural plasticity is the term that describes the brain's ability to be formed or molded; the term *plastic* comes from the Greek word *plastikos*, which relates to molding.

Hence, memory is a recording within the nervous system of our experiences. If the experience is purely intellectual, we form a cognitive memory; if the experience

is a physical posture or movement pattern, we form a motor skill memory; if the experience is emotional, we form an emotional memory; and if the experience involves processing sensory pain signals, we can create a memory of pain sensitization. Most memory patterns are a combination of cognitive, motor, sensory, and emotion. In each case, the memory pattern is encoded by the activation/firing of neuronal pathways in a specific sequence.

CREATING MEMORY PATTERNS

The creation of a memory pattern occurs by encoding the activation/firing of specific pathways of neurons in a specific timed sequence. A simple memory pattern might involve only a few neuronal pathways. A more involved pattern might involve many, many neuronal pathways, with a precise interplay of timing.

For example, the motor skill memory pattern to play a simple song on the piano would involve learning to successively flex the metacarpophalangeal and proxi-

review of nervous system function:

The nervous system is composed of neurons and neuroglial cells (also known simply as glial cells). Neurons are linked together by synaptic connections, and are named for their positions relative to the synapse located between them: the pre-synaptic neuron is located before the synapse; the post-synaptic neuron is located after it (the post-synaptic neuron would then be a pre-synaptic neuron relative to the next synapse along the pathway of neurons). At a synaptic connection, the regions of the membranes where neurotransmitters are released by the pre-synaptic neuron and picked up by the post-synaptic neuron are called active zones. Glial cells are oligodendrocytes, astrocytes, microglial, and ependymal cells in the central nervous system, and Schwann cells in the peripheral nervous system. Neurons comprise 15% of the cells of the brain; glial cells comprise the other 85%.

When a neuron is sufficiently stimulated to reach action potential, an electrical impulse occurs within the neuron. This impulse travels in one direction, from the dendrites/cell body end of the (pre-synaptic) neuron to the ends of the terminal branches of the neuronal axon located at the synapse with the next (post-synaptic) neuron. Because the electrical impulse cannot cross the synaptic connection, the pre-synaptic neuron releases chemical neurotransmitter molecules that cross the synapse to the post-synaptic neuron. These neurotransmitters can have a facilitory or inhibitory effect; in other words, they can facilitate or inhibit the creation of an action potential and therefore nerve impulse in the post-synaptic neuron. Because many (thousands of) pre-synaptic neurons converge on a post-synaptic neuron, whether the post-synaptic neuron is sufficiently facilitated/stimulated to action potential is dependent upon the summation of all facilitory and inhibitory pre-synaptic neuron's neurotransmitters. If the post-synaptic neuron is sufficiently stimulated, a nerve impulse will be initiated that can then travel to the axonal end of that neuron and synapse with the next post-synaptic neuron. In this manner, impulses travel throughout the neuronal network. In effect, the presence or absence of impulses translates into binary-code information, just as a computer carries 1s and 0s.

This understanding of nervous system function is called the *neuron doctrine* because it holds that neurons are principally important for nervous system functioning. Although current research does not contradict our knowledge of neuronal functioning, it is beginning to show us that neurons are not the only important actors on the stage when it comes to impulse transmission. We are finding out that glial cells are far more important than previously thought. Glial cells were once thought to provide support functions and be little more than putty that held the neurons together; in fact, the term *glia* literally means *glue*. They are now becoming understood to be integral to the functional ability of neurons to carry their electrical impulses and transmit their chemical synaptic messages.

mal interphalangeal joints of the fingers in a certain sequence, with a specific timing. If it is a simple song such as *Mary Had a Little Lamb*, the sequence of fingers would be 3-2-1-2-3-3-3, 2-2-2, 3-5-5, 3-2-1-2-3-3-3, 2-2-3-2-1 (3, middle finger; 2, index finger; 1, thumb; and each comma represents a pause). At the same time, the nervous system would have to simultaneously isometrically contract extensor muscles of the wrist joint and flexor muscles of the elbow joint so that the hand and forearm would be positioned such that the fingers can strike the keys, as well as core muscles to hold the trunk and neck in position, while seated to play. If expression is added to the song, then cognitive and/or emotive (limbic system) pathways would be involved, as well as possible other upper extremity joint motions to allow the pianist to strike the keys harder or softer as desired. A memory pattern for this song would involve all these neuronal pathways to engage musculature spatially throughout the body, as well as temporally in sequence and timing to hit the proper order of notes to play the song. And this is a simple song. Imagine if the piece being played is a Beethoven Sonata!

A similar process occurs with a more complicated motor skill, such as hitting a forehand stroke in tennis. Neuronal pathways that encode for hip, knee, and ankle joint motions to place the feet in the right position; elbow, shoulder, shoulder girdle, and spinal joint motions to bring the racquet back; and then swinging the racquet forward with a concerted coordination of all the upper extremity; and spinal, and lower extremity joints for balance and to rotate the body to swing through the ball; all the time tracking the ball with the eyes, cognitively remem-

bering the usual court position of the opponent to determine in which direction to hit the ball, and experiencing the psychological/emotional feelings that are involved in competition.

LONG-TERM MEMORY AND NEURAL PLASTICITY

Therefore, every experience we encounter in our lives results in the formation of an encoded neuronal memory pattern. When first created, this memory pattern is unstable and located in short-term memory. As such, it can usually be accessed for only a few moments. If we want to place a memory into long-term memory, allowing for a more automatic recollection of the memory, we need to stabilize/consolidate it. The key is repetition. The consolidation of a memory pattern results from the repetitive firing of the neurons within the pathways of the memory pattern. With repetition come the functional and structural changes in the neuronal pathways that are the hallmark of neuronal plasticity. Shorter-term changes are functional; longer-term changes are structural.

NEURONAL PLASTICITY

With early repetition, as a synapse is repetitively fired, the first neural change is functional strengthening of the synapses. This occurs for two reasons. One is that the conductance of potassium (K⁺) ions within the pre-synaptic neuron is changed; this causes the action potential to lengthen in time, resulting in more neurotransmitter being released. The second functional change is that the transport of the neurotransmitter

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pain sensitization

Facilitation of pain pathways is termed *central sensitization*, or simply *sensitization*. This concept is of extreme importance in the world of manual and movement therapies. If a client has experienced chronic pain, then even if the physical cause of the pain is removed, the facilitation of the pain pathways can create a sensitization of pain in this pathway so that the degree of their pain will be out of proportion to the degree of the physical damage. In these cases, neural plasticity has created a learned pattern of pain that may last for months, years, or indefinitely. The function of sensitization is debated, but it is likely that it acts to heighten the client's awareness of pain stimuli in a vulnerable region of the body. Given that pain alerts us to physical damage that is occurring or is likely to occur, increased pain sensitization could be viewed as an effective and vigilant warning system that might prevent further damage. The reality is that the pain is overly vigilant and to the client experiencing sensitization, the chronic pain is not appreciated. Interestingly, the reverse of sensitization is also possible. Suppression of pain, termed *habituation*, can also occur. This results in a lessened degree of pain relative to physical damage that is present.

emotional plasticity

Pathways for emotions and psychology have also been shown to be plastic. Indeed, the entire field of talk-therapy could be viewed as a means of becoming aware of unhealthy memory patterns and learning how to change them. The limbic system of the brain is a group of brain structures that are generally considered to be important for emotions. Neuronal emotional plasticity is one reason why a client might have a difficult time letting go of negative feelings. Given the interplay between the motor and limbic systems, emotional plasticity memory patterns also explain why body armor occurs and why clients

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