NEUROBIOLOGY OF LEARNING

"EXCUSE ME, WHAT DID YOU JUST SAY?"

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The goal of this column series is to explore the neurological processes that occur during learning. Even though our knowledge of "the molecular signals that translate activity into structural and functional changes in connections" (McAllister, 1999) is incomplete, research pushes back the horizons of our understanding daily. We hope that this series will expand your knowledge and, more importantly, raise critical questions in the minds of both you and your students. The best possible long-term outcome would be to excite students to seek careers in neuroscience and to help all of us appreciate the intricacies of the neurobiology of learning.

Over the course of the next school year, we will explore learning by moving through layers of neural organization, including

- Intracellular signaling pathways and processes such as protein synthesis
- Synaptic stability, dendritic spines, long-term potentiation, and long-term depression
- Glial cells, neurons, neurotransmitters, and synapses
- Neural networks and structural and functional neuroplasticity

While recognizing that the definition of learning itself could be the focus of many discussions, we will use a relatively simple definition: "Learning is the acquisition of knowledge or skills through experience, study, or by being taught" (Oxford Dictionaries, http://oxforddictionaries.com/us/definition/american_english/learning).

In this first column, we address the functions of glial cells, neurons, neurotransmitters, and synapses as they are related to memory formation. The hallmark of learning is the creation of memory. We know that the temporal lobe is a brain area critical for the formation of long-term memories, and we owe this understanding to Henry Molaison (HM), who, in 1957, at the age of 27, had surgery on his medial temporal lobes that included removal of both hippocampi to prevent epileptic seizures. The surgery controlled HM's epilepsy but left him with a global amnesia. So, what happened to HM's memory? Removing his hippocampi erased his ability to create any new memories; the effects of HM's surgery were so devastating that this surgery (bilateral removal of the hippocampi) has never been done again (Ogden, 2012).

Memory is essentially a cellular process, summarized by Carla Schatz as "neurons that fire together, wire together" (Piochon et al., 2012). The central nervous system contains two types of cells – glia and neurons. Glia surround, support, nourish, and insulate neurons that do the work of communication with other neurons and the rest of the body. Neurons communicate both electrically and chemically. Like other cells, they have a nucleus and cell body as well as specialized processes known as *dendrites* and *axons*. Dendrites receive input from other neurons. A neuron has many dendrites, but only one axon, though that one axon branches, allowing communication with multiple cells. Neurons do not touch one another but are separated by a microscopic space called the *synapse*.

Neurons have ion channels and ion pumps on both the dendrites and cell body that open and close, allowing a flow of ions into or out of the cell membrane. At the axon hillock (the beginning of the axon just outside the soma), these tiny electrical differentials are summated. If a critical threshold is reached, an action potential fires down the axon. At the end of the axon, the electrical charge is changed to a chemical neurotransmitter

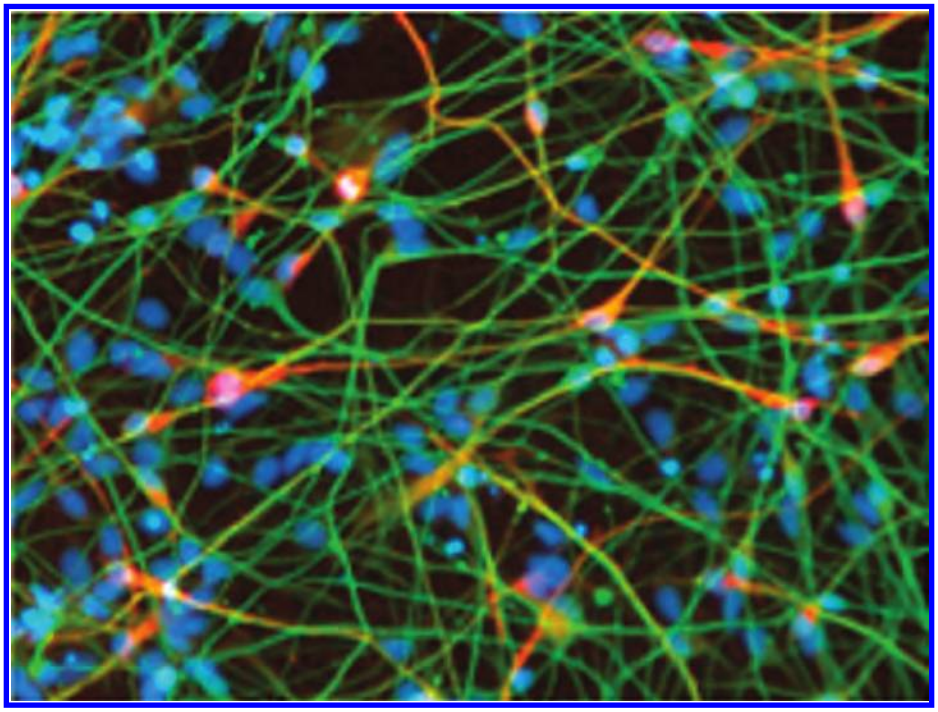

Figure 1. Neurons connecting to and communicating with other neurons.

The American Biology Teacher, Vol. 75, No. 6, pages 424–425. ISSN 0002-7685, electronic ISSN 1938-4211.
DOI: 10.1525/abt.2013.75.6.13

that diffuses across the synapse to receptors on the dendrites of neighboring neurons. The neurotransmitters fit into their specialized receptors on the dendrites like a lock-and-key mechanism and cause changes in the postsynaptic cells' membranes (http://www.brainfacts.org/brain-basics/neuroanatomy/). These changes are a critical step in creating memories – or forgetting! Neurotranmitters fall into two basic categories – either excitatory (increasing the likelihood of postsynaptic cells firing an action potential down their axons) or inhibitory, which decreases the chances of subsequent action potentials (Lovinger, 2010). We will take a look at these neurotransmitters and their actions on memory in subsequent articles.

Although most illustrations show just one neuron communicating with another neuron, it's important to remember that one neuron can, and almost always does, communicate to thousands of other neurons (Figure 1). Thus, one neuron can influence the firing of many other neurons. This process of neuron transmission is repeated over and over in infancy and childhood to mold synapses and neural networks that are the basis for perception, memory, learning and cognition (McAllister, 2007).

Persistence of these neural networks results in memories (Caroni et al., 2012). Conversely, if these networks are not reinforced by repetition they will be weakened and memory will not occur; we forget. Both memory and forgetting are important components of learning (Storm et al., 2008).

Connections between neurons can change over time and can be influenced by things like drugs, stress, nutrition, and lack of sleep. Before we look at environmental conditions that influence learning, we will take time in our next column to focus on synaptic stability and plasticity, long-term depression and potentiation, and how these processes shape neuronal networks and memory. Join us and challenge your neurons to incorporate these new concepts into your memory!

Acknowledgments

The grant "How Do I Learn" (R25DA033002) is funded by the NIH Blueprint for Neuroscience Research and administered by the National Institute on Drug Abuse (NIDA), part of the National Institutes of Health. The content is solely the responsibility of the authors and does not necessarily represent the official views of NIDA.

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