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Hold your nerve: acting out chemical synaptic transmission

Synapse infosheet

Neurons are connected via synapses, where signals in the form of neurotransmitters are released. But how does this work?

Our nervous system consists of approximately 100 billion neurons and has an extremely high processing power based on the connection of neurons between each other. These neuronal connections are responsible for your ability to perceive your surroundings: with their help, you can feel, hear, see, and smell what's around you and send commands to your muscles. They are also in charge of your ability to recognize where you are and remember if you've been there before. Neuronal interactions define who we are as people.

The cell body of a neuron contains the nucleus and cytoplasm. The axon extends from the cell body and often gives rise to many smaller branches before ending at nerve terminals. Dendrites extend from the neuron cell body and receive messages from other neurons. Synapses are the contact points where one neuron communicates with another (figure 1).

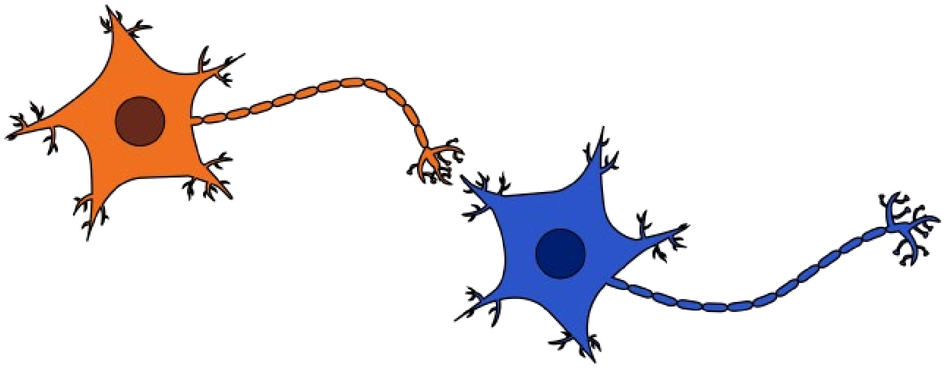

Figure 1: Parts of a neuron
Image: Dana Scarinci Zabaleta/Wikimedia, CC0 1.0

One cell talks, the other one listens

The incoming signals to a neuron (via the dendrites) are integrated, and the electrical impulse is transmitted along the axon. At the end of the axon, the structure splits and forms numerous synapses, where the information is conveyed to the next neuron (figure 1). At the synapse, the electrical impulse of the action potential is converted into a chemical signal. The number of formed synapses between neurons can vary from 1 to over 100 000 per neuron. The signal is transported in one direction only. One cell talks, while the other one listens.

Synapses – elemental units of neuronal communication

The basic elements of one synapse are as follows (figure 2A):

- the nerve end of the sender neuron (presynaptic membrane)
- the synaptic cleft, which divides the sender and the receiver cells
- the membrane of the receiver neuron (postsynaptic membrane)

The presynaptic nerve terminals contain signal molecules called neurotransmitters stored in synaptic membrane vesicles. Each presynaptic nerve terminal contains, on average, more than 100 synaptic vesicles. This number can increase up to 100 000 vesicles in presynaptic synapses that control our muscles.

Neurotransmitters play a fundamental role in neural communication, influencing everything from involuntary movements to learning and mood.

If an electrical signal in the form of an action potential reaches the presynaptic membrane of the synapse (figure 2B, step 1), Ca^{2+} channels open and Ca^{2+} enters the presynaptic synapse (figure 2B, step 2). This triggers fusion machinery that induces the movement of synaptic membrane vesicles to the presynaptic membrane. At the presynaptic membrane, the vesicles merge with the membrane and the neurotransmitter is released into the synaptic cleft (figure 2C, step 3). The molecules diffuse into the extracellular fluid of the synaptic cleft and some of them bind to receptors. This binding leads to an opening of the receptor and to an influx of ions into the postsynaptic site of the synapse (figure 2C, step 4). Neurotransmitters are specific for receptors. They fit together like a lock and key.

The regulation of the neurotransmitter concentration in the synaptic cleft is crucial. A disturbance of this key mechanism can cause serious mental illnesses, such as depression. In the synaptic cleft, neurotransmitters are destroyed by enzymes. The other process to reduce the concentration of neurotransmitters in the synaptic cleft is called neurotransmitter reuptake (figure 2C, step 5). The reuptake transporter in the presynaptic membrane removes the neurotransmitter from the synaptic cleft and stores it in a new membrane vesicle to be reused again.

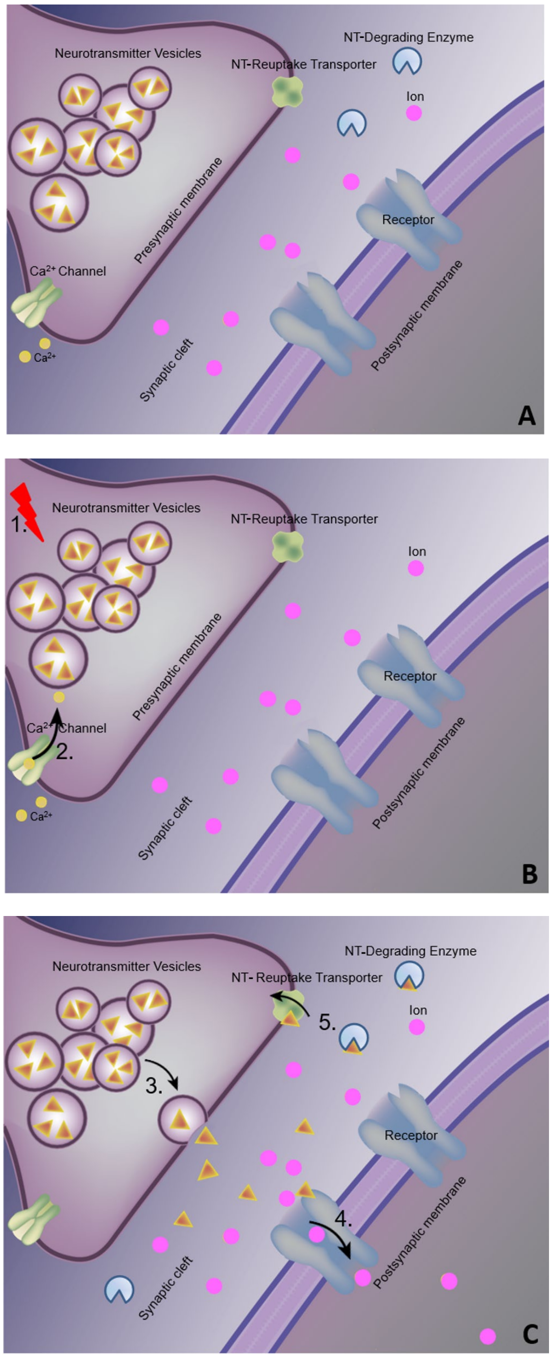

Figure 2: Mechanisms of synaptic transmission. A) Important structures and protagonists. B) An action potential triggers neurotransmitter release from the presynaptic site into the synaptic cleft. C) Neurotransmitter binds to receptors on the postsynaptic site and induces a change in concentration of ions in the postsynaptic neuron.
Image courtesy of the authors

Synapses can be excitatory or inhibitory, as a function of their effect on the postsynaptic neuron. In an excitatory synapse, an increase in the concentration of neurotransmitter makes it more likely that the postsynaptic neurone will produce an action potential. In an inhibitory synapse, an increase in the concentration of neurotransmitter makes it less likely that an action potential will occur.