Sensorimotor Nervous System

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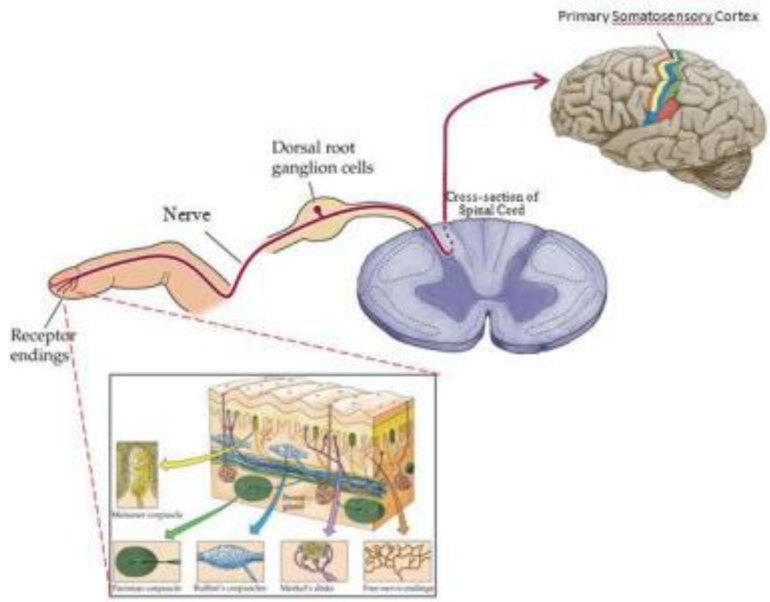
Lesson Objectives:

- Explore how the brain allows touch perception and body movements by conducting electrophysiological recording and micro-stimulation experiments in the *Blaberus discoidalis* cockroach leg.
- Understand the principle that the brain uses electrical signals to communicate:
  1) electrical signals containing information about touch are sent from sensors in our skin to the brain for interpretation
  2) the brain sends movement commands in the form of electrical signals to our muscles to allow body movement

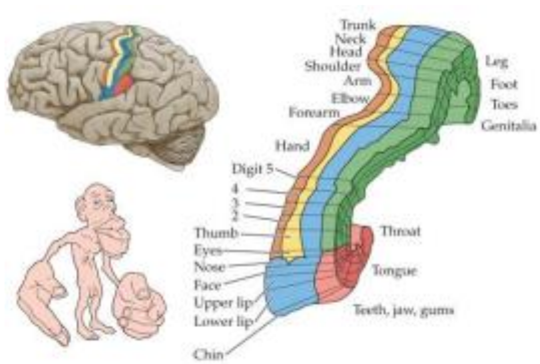
What you need to know:

Every day of our lives, we take in sensory information from our surroundings and make appropriate movements in response to the sensory information. For example, when someone taps your shoulder from behind, you react to this tactile information and turn around to see who tapped you on your shoulder. This seemingly simple behavior of perceiving sensory stimuli and moving in response to it is mediated by the ***sensorimotor nervous system*** of your body.



The sensorimotor nervous system consists of regions within your brain and in the periphery that are specialized for sensing particular types of stimuli (i.e. 5 senses: touch, sight, sound, taste, smell) and for making body movements. The interaction and communication between these regions makes it possible for us to make appropriate body movements in response to information coming from the external world.

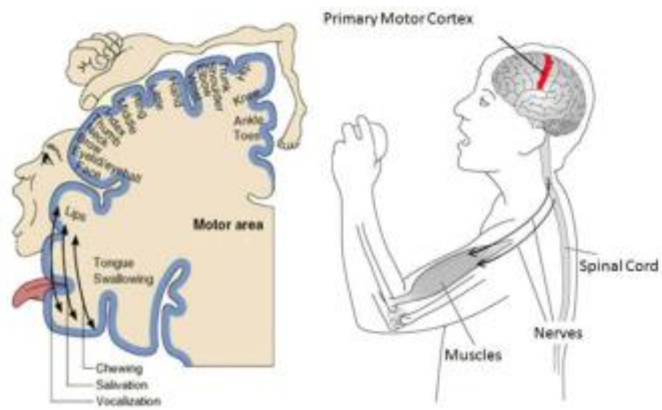
In the above example, when someone taps your shoulder from behind, specialized sensors located in your skin called ***sensory neurons*** initially detect touch, texture, and pressure information (there are many types of sensory neurons that detect touch: messiners, merkels, pacinian, ruffinis). These sensory neurons convert this touch (aka, *somatosensory*) information into electrical nerve signals, called ***action potentials***, which are then sent to the brain via the nerves and the spinal cord. The action potentials arrive to an area of the brain called the **primary somatosensory cortex** where neurons in the area interpret these signals and forms the perception that someone tapped you on your shoulder.



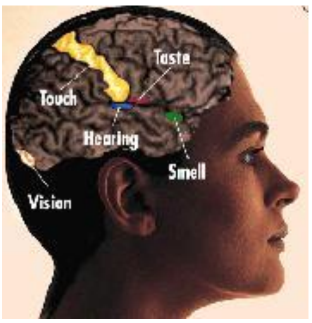
The primary somatosensory cortex is divided into subsections and organized by body part: nerve signals coming from a particular area of the body, such as the fingers, end up in a distinct area of the primary somatosensory cortex whereas, nerve signals originating from other areas of the body such as the face, end up in another location within the primary somatosensory cortex. In addition, body parts which are more sensitive (i.e. face and fingertips) have larger portions of the primary somatosensory cortex allocated to it whereas areas that are less sensitive (i.e. the trunk) have smaller portions allocated to it.

Once the sensation of being tapped on the shoulder is perceived by the primary somatosensory cortex, neurons within the area interact with neurons in other parts of the brain to decide what to do, such as moving in response to the shoulder tap. In this situation, neurons in the primary somatosensory cortex send action potentials to an area called the ***primary motor cortex*** which is specialized for making body movements. The primary motor cortex is located adjacent to the primary somatosensory cortex and is also organized by body part: subregions within the primary motor cortex are responsible for making movements of a specific body part and body parts that are finely controlled have larger portions of the primary motor cortex allocated to it.

The primary motor cortex generates electrical movement commands, again in the form of action potentials, which travel down the spinal cord, through the nerves, and arrive at the muscles. When muscles receive the movement commands, the muscles contract which produces body movement. In our example of turning around in response to a shoulder tap, the subregions of the primary motor cortex that controls the muscles in our torso and trunk are generating the electrical movement commands which allow us to turn our bodies.



The sensorimotor nervous system isn't restricted to just the primary somatosensory cortex and the primary motor cortex. Other senses besides touch, like vision, sound, smell, and taste are conveyed in a very similar manner but use different areas of the brain which then interacts with the primary motor cortex to produce movements.



<u>Sensory systems of the brain</u>:
1) Touch - Primary Somatosensory Cortex
2) Vision – Primary Visual Cortex
3) Sound - Primary Auditory Cortex
4) Smell - Olfactory Bulb
5) Taste - Primary Gustatory Cortex

<u>Activity: Exploring the sensorimotor nervous system of the *Blaberus discoidalis* cockroach</u>

The *Blaberus discoidalis* cockroach has a sensorimotor nervous system very similar to that of humans which also communicate using electric, action potential signals. The cockroach legs contain sensory neurons that convert touch and wind flow into action potentials which are then sent to the cockroach brain for interpretation. The sensory neurons that detect wind help the cockroach escape from predators that are trying to catch it (no wonder it's so hard to catch them!). Once the cockroach brain perceives the sensory stimuli, the information is sent to the area of the cockroach brain that controls body movements which in turn, generates commands to move its body. The electrical movement commands are sent to the cockroach leg muscles which cause the muscles to contract and enable the little critter to scurry away!

1) <u>Part I. "eavesdropping" on the electrical action potential signals generated by sensory neurons in the cockroach leg:</u>

Using a low-cost, do -it-yourself neurophysiology amplifier called a **Spikerbox** (from Backyard Brains, co), we will record and “eavesdrop” on the action potentials that are generated by the sensory neurons in the cockroach leg that detect touch and air flow. We will amputate a leg of a living cockroach and insert recording electrodes which are connected to the Spikerbox. Every time the cockroach leg is touched, a burst of popping sounds will be heard from the Spikerbox. The sounds are “sensory evoked <u>spikes</u>,” or an auditory representation of the electrical action potential signals generated by sensory neurons (which are still alive) in the cockroach leg in response to touch. These are the signals that are normally being sent to the cockroach’s brain for interpretation but instead are being sent to the speaker on the Spikerbox for us to hear.

2) <u>Part II. Sending electric "movement commands" to the cockroach leg:</u>

Although the cockroach leg is severed from the rest of the body and no longer connected to its brain, can we make it move? Yes! The action potentials generated by the brain is the same energy as the electric signals that power our every-day electronic devices like the speakers in our ipods and laptops. Therefore, we can pretend to be the cockroach's brain and send artificial, electric "movement commands" to the leg and cause it to move. This will be done by using a music playing device (e.g. laptop) that’s playing music, splitting the electric signals coming from the headphone jack into two parallel signals, and having one going to the speakers (for us to hear the music) and having the other going to the electrodes inserted in the cockroach leg.

Materials:

- *Blaberus discoidalis* cockroach - ($24.00 http://backyardbrains.com/products/cockroaches)
- Spikerbox kit ($129.99 http://backyardbrains.com/products/spikerboxkit). Includes recording electrodes and stimulation cables
- Y-adaptor ⅛" stereo jacks & ⅛" stereo plug ($5.49 Catalog #: 274-375 http://www.radioshack.com/product/index.jsp?productId=2102691&numProdsPerPage=60)
- Cup of ice water (for anesthetizing the cockroach)
- Precision scissors
- Probe (e.g. Q-tips, coffee stirrer)
- Tweezers
- Music playing device (laptop, iPod, CD players, etc.)
- Computer speakers with ⅛" stereo jack cable

Procedures

Part I. "eavesdropping" on the electrical action potential signals generated by sensory neurons in the cockroach leg

1) "Anesthetize" a cockroach by dunking it into ice water. Wait a few minutes for it to stop moving.
2) Once the cockroach stops moving, cut one of the hind legs off at the coxa, near the body.
3) Put the cockroach back into its cage (the cockroach will survive the amputation. If the cockroach is still a juvenile, it will regenerate a new leg).
4) Place the leg onto the cork platform on the spikerbox and let the leg hang off a little.
5) Insert one recording electrode into the coxa of the leg and the other into the femur.
6) Turn on the spikerbox. You should hear popping sounds which are spontaneous action potentials generated by the sensory neurons in the cockroach leg.
8) Touch the leg with a probe. What do you observe? You should hear an increase in the frequency of the popping sounds when you touch the leg. These are the nerve signals that are being generated by the sensory neurons in the cockroach's leg.

* From backyardbrains.com

Spin-off experiments you can do with your students: Every living organism has an optimal temperature range in which it can survive. For most, colder temperatures cause the metabolism of the organism to slow down. Test the effect of various temperatures on the ability of the sensory neurons in the cockroach leg to generate action potentials (e.g., bring the spikerbox setup outside during winter, put it in the freezer, bring it to an air-conditioned/heated room).

Part II. Sending electric "movement commands" to the cockroach leg:

1) Turn off the spikerbox.
2) Plug the ⅛" stereojack of the stimulation cable (included in the spikerbox kit) into one of the plugs in the Y-adaptor.
3) Plug the ⅛" stereojack coming from your computer speakers into the other plug of the Y-adaptor
4) Plug the Y-adaptor stereojack into the headphone jack of your music playing device.
5) On the other end of the stimulation cable (away from the Y-adaptor), there should be 2 clips. Attach one of the clips onto one of the electrodes inserted into the cockroach leg. Attach the other clip onto the other electrode.
6) Select a song with a lot of bass on your music player (Hip hop and R&B songs work the best). Turn the volume up half-way. While the song is playing, slowly increase the volume. At some point, the leg should begin to twitch.

Spin-off experiments you can do with your students: Students should notice that if the volume is too high, the leg may stop moving. This is because the leg is being over-stimulated with electricity (high volume = more stimulation) that the muscles have no time to relax (tetanus - prolonged muscle contraction). Students should also notice that the leg often twitches to the bass of the music. This is possibly due to the frequency of the bass being similar to the natural firing frequency of the neurons that innervate the cockroach leg muscles. Using a tone generator program (free download: Audacity) on a laptop to stimulate the leg with instead of music, and using the volume control on the laptop, test for the optimal stimulation frequency and volume that elicits leg movement (e.g., 20Hz, 100Hz, 200Hz, 1000Hz etc. at 1/4 volume, 1/2 volume, 3/4 volume, full volume).

Activity: Sensorimotor Nervous System: Human to Human Interface

Every action or movement we produce is generated by a specific firing pattern of neurons in our cerebral cortex. Consequently, if we could understand or predict what kind of patterns will produce certain types of movements, we could conceivably use this information to help disabled populations control prosthetic limbs by merely thinking about the movement they wish to perform. Although controlling a prosthetic limb with your thoughts may seem like something straight out of science fiction, it is actually already being successfully performed in a variety of patient populations. But how does it actually work?

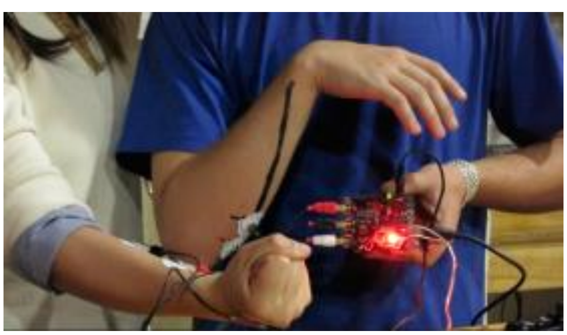
When we go to perform a movement, neurons in the motor cortex and surrounding motor associated areas fire in a specific pattern depending on the characteristics of the movement (direction, velocity, force, etc.). We can measure the firing patterns of these neurons invasively, using electrode arrays that are implanted directly on the cortex, or noninvasively, using electrodes on the skin. However, these signals are incredibly small (especially when measured noninvasively), and therefore must be amplified in order to be usable. Additionally, these signals are incredibly noise, making it difficult to piece out what information is important, and what information is random. Therefore, the noise must be filtered from the signal so that we are left only with the important information. You then train a computer to recognize the patterns of different movements by repeating simple movements such as a grasp over and over until the computer has a recognizable pattern to look for each movement. Now when the subject performs the movement and the signal is sent to the computer, the computer decodes the signal by comparing the pattern of the incoming signal to the different patterns associated with each type of movement. Once it categorizes the pattern of the signal as a specific movement, the computer then sends a signal to the robotic limb (or computer cursor) to perform that movement. It's easy to see how this becomes more difficult as you add in more movements, especially when considering that all of this processing must be done in real-time with minimum delay. However, with modern day computing, this process is being successfully used with increasingly complex movements to control sophisticated robotic limbs.

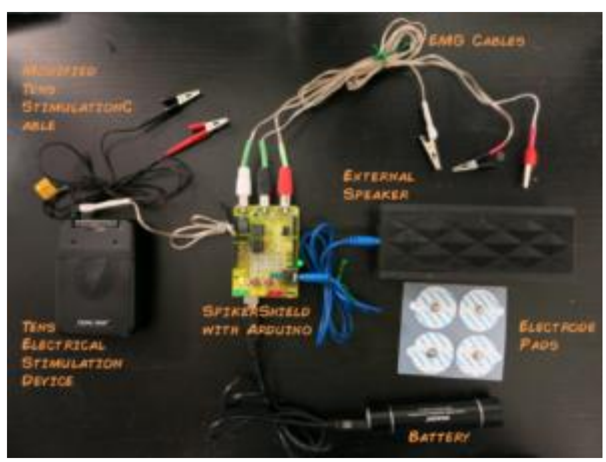
Objectives:
- Understand the principle that the brain uses electrical signals to communicate:
    - electrical signals containing information about touch are sent from sensors in our skin to the brain for interpretation
    - the brain sends movement commands in the form of electrical signals that our muscles to allow body movement
- Understand that muscles give off small electrical signals that can be amplified and recorded via electromyograms (EMGs)
- Introduce the idea of electrical tools such as Brain Computer Interfaces (BCI), Brain Machine Interfaces (BMI), and neuroprosthetics, for restoration of motor control in different types of disabilities including spinal cord injury or amputation.

Materials:
- Human to Human Interface: Available from Backyard brains (https://backyardbrains.com/products/HHI) $259.99 includes TENS 3000, necessary cables, and 100 electrodes.

DIY instructions and raw materials available at backyardbrains.com
- Muscle electrodes (as many as needed): 29.99 per 100 https://backyardbrains.com/products/emglargeelectrodes

Procedures:
Detailed procedures can be found at:
https://backyardbrains.com/experiments/humanhumaninterface



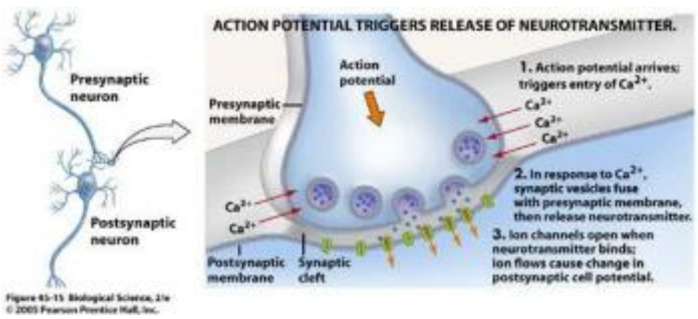


Questions you can ask your students

1. What are some examples of the sensorimotor nervous system in action?
2. What are the parts of your body that produce the sense of touch? What are the parts of your body that produce movement? What is similar or different about them?
3. How is the sensorimotor system of the cockroach similar or different than that of humans?
4. What actually produces the sounds resulting from touching the cockroach leg while it is hooked up to the Spikerbox?
5. What are some similarities or differences between the sense of touch and other senses (i.e. vision, audition, smell, taste)?
6. Given the materials used in these experiments, what changes could you make to this set up and what differences do you think would result?

Does the brain only use electrical signals to communicate?

The brain actually uses both chemical and electrical signals to communicate. The brain is made of billions of cells called neurons. Neurons within and between regions form connections ("friendships") with one another and communicate with each other at special connection points called *synapses*. At each synapse, one neuron is the sender of messages, or "pre-synaptic" neuron, and the other is the receiver, or "post-synaptic" neuron. A pre-synaptic neuron, acting as the sender, first generates action potentials which are electric. These electric signals travel down its axon, a slender projection of the neuron that terminates near the post-synaptic neuron. At the end of the axon, the action potential causes the pre- synaptic neuron to release chemicals called *neurotransmitters* which are then taken up by the post-synaptic neuron. Different types of neurotransmitters can have different effects on the post-synaptic neuron. Some neurotransmitters will cause the receiving post-synaptic neuron to generate action potentials which allow for the propagation of the signal to the next neuron. Other neurotransmitters can cause the post- synaptic neuron to become less active by preventing the generation of action potentials, thereby ending the propagation of the signal. Although these chemical signals can exert different effects on the recipient, they are quite slow for neurons to communicate with its neighbors (when you fart in a room, how long does it take before someone at the opposite end of the room smells it?) so it's not a great way for neurons to communicate over long distances. Electrical signals on the other hand are fast and can travel long distances (when you flip on the light switch, how long does it take for the light to go on?) therefore, they are great for neurons to communicate over long distances, such as between brain regions in the sensorimotor nervous system.



Understanding the sensorimotor system allows scientists and doctors to augment brain function.

Everyday neuroscientists use sophisticated equipment to record from areas of the brain that control the senses, movement, memory and even cognition. These experiments are performed in a wide variety of species, from rodents to humans. Sometimes scientists record from individual neurons, other times they record from large groups of neurons. The goal of these experiments is to understand how information is stored and processed in the brain. By understanding this process, researchers can develop treatments for a variety of neurological disorders and conditions like Alzheimer's disease, Parkinson's disease, blindness, deafness, and paralysis.

For example, consider the case of a quadriplegic, a heavily paralyzed individual. Normally, these individuals have great difficulty completing daily tasks that we all take for granted, such as eating. However, recent research has enabled a paralyzed individual to control a robotic arm with her thoughts. This patient has recording electrodes implanted in her primary motor cortex which "eavesdrops" onto the electrical impulses generated by the neurons in the area. A computer decodes and interprets the electrical impulses and sends the commands to a robotic arm. As such, this patient can now pick up and move objects with the robotic arm simply by thinking about moving the objects. This robotic arm is an example of a *brain machine interface*, a direct communication between the brain and a machine. These brain machine interfaces can augment, or enhance, the natural functions of the brain, and many interfaces have been developed for highly varied purposes. For example, implants can be placed deep into the brain to ameliorate some of the symptoms of Parkinson's disease. Cochlear implants can help to restore the sense of sound to deaf individuals. Recent research has even given rodents the ability to "feel" infrared light, which is normally invisible to rodents and humans. Also, retinal implants have been developed which aim to restore vision in blind individuals. All of these, and other, amazing technologies would be impossible without first understanding how neurons communicate with each other.

Additional Links

- Quadriplegic woman feeds herself with a robotic arm controlled by her brain: http://www.guardian.co.uk/science/2012/dec/17/paralysed-woman-robotic-arm-pittsburgh
- Quadriplegic man controls computer cursor with his thoughts: http://www.youtube.com/watch?v=TJJPbpHoPWo
- Retinal implant partially restores blindness: http://www.youtube.com/watch?NR=1&v=Bh3MaoPVdNM&feature=endscreen - http://www.youtube.com/watch?v=gPPWjn2nZxY http://www.youtube.com/watch?v=8U-xLaAGSV0