Motor Adaptation

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Lesson Objectives:
By the end of this workshop, teachers should be able to:

- Explain feed forward and feedback control
- Understand basic circuitry of the basal ganglia and cerebellum, and related disorders
- Provide examples of the ways that the brain can adapt to sensory input
- Illustrate motor adaptation using prism goggle, inversion goggles, and mirror-drawing activities

Activity Summary
There are two activities that you can use to demonstrate motor learning. The first activity involves the use of prism goggles (which offset vision by 10 degrees) and inversion goggles (which flip vision upside down). Students will try various motor tasks while wearing the goggles, such as catching and throwing beanbags with a partner or building with tinker toys. The second activity involves the use of a mirror, cardboard boxes, and star-shaped tracing patterns. The cardboard boxes will be used as barriers so that students can only see their hand by looking in the mirror, and they will attempt to trace the outline of a star. Whether the students are wearing prism/inversion goggles or performing the mirror drawing task, their ability to perform motor actions accurately will be compromised due to the change in visual input. As the brain adapts to the new input, accuracy will quickly begin to improve.

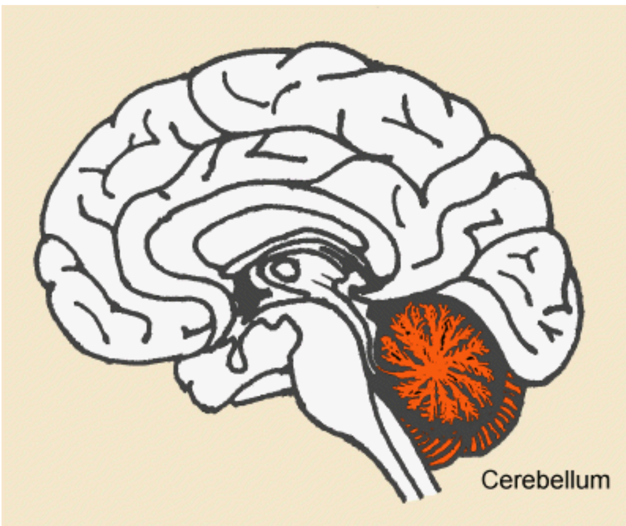
The Brain Can Adapt!
People often compare the brain to a computer – it can store information and make calculations. One distinct advantage of the brain over the computer is its ability to adapt and change in response to sensory stimuli. This adaptation is accompanied by physical changes in the connections between neurons; new connections are made or strengthened, and others are lost. We refer to this ability of neural networks to adapt as "**plasticity**". Plasticity is best described in the context of learning. The plastic nature of your brains allows you to make new connections between neurons when you learn something new. Since learning a new skill can take a while to master, some might think that plasticity only happens after days and days of practice. This is only partially true. The motor learning activities will provide examples of motor adaptation that occurs within minutes.

Motor Learning: Feed forward and Feedback Control
Have you ever tried to develop a new motor skill, like learning an instrument, drawing, or playing a sport? You are always told to practice to improve your skills, but why? How can practice lead to improvement? Your brain allows you to improve your ability to make voluntary movements through two mechanisms: by **correcting** you if you've made an error, and by **anticipating** potential obstacles that might affect your ability to move correctly. These strategies can also be called **feedback correction** and **feed forward control**, respectively.

When you first learn a new piece of music, or a new dance move, you often make a lot of errors and your body might not move the way you want it to. How do you get better? **Feedback correction** is when the brain receives sensory information from the body, telling the brain what the limbs are doing. The brain then compares this information to a desired state - what it *wants* the body to do. The brain then uses this comparison to change what it is telling the limbs - "a little more to the left, a little faster here" - and the movement hopefully gets better and better the more that you practice. Feedback correction is a constant task, and it applies even to seemingly insignificant movements. When you hold an object in your hands, like an egg you are constantly adjusting the amount of force needed to hold the egg in order to keep it steady without crushing it.

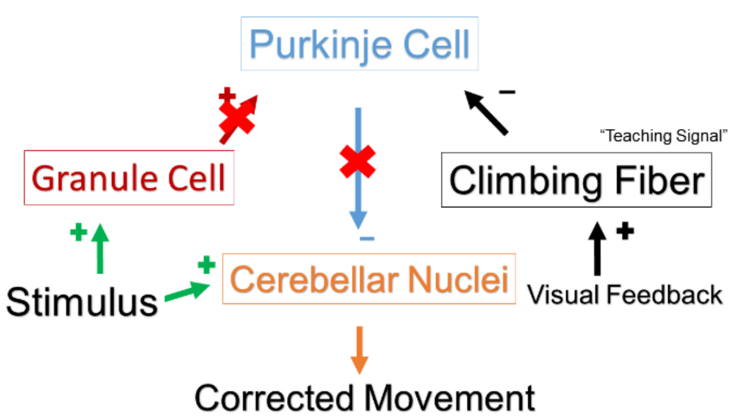
Feed forward control, by comparison, does not correct errors, but *anticipates* them. When a football quarterback is about to throw the ball, he has to take all sorts of factors into account before making that throw, such as how strong the wind is, the position of his body, what direction and how far the ball needs to be thrown. The quarterback receives information on all these parameters from sensory signals like visual cues, sounds and sensations, and he adjusts the way he will throw the ball in anticipation of those perturbations. At the other end of the field, the person receiving that throw is *also* using feed forward control. He anticipates the direction of the throw and the speed of the ball by watching the way the ball moves, and he anticipates the amount of muscle force needed to catch the ball without dropping it.

The Cerebellum



The **cerebellum** (Latin for "little brain") is the brain structure responsible for both feedback and feed forward control. The cerebellum is a small, wrinkled structure at the very back of the brain. The cerebellum can be separated into three function regions. 1) The **vestibulocerebellum** consists of the flocculonodular lobe that sits underneath the main body of the cerebellum. It is the most primitive part of the cerebellum and receives vestibular (balance and spatial orientation) input and controls balance and vestibular reflexes. 2) The **spinocerebellum** is comprised of the midline (vermis) and the intermediate hemispheres of the cerebellum and appeared later in evolution. It receives somatosensory and proprioceptive input from the spinal cord and controls the muscles of the body and limbs to maintain posture and execute locomotion. 3) The **cerebrocerebellum** is comprised of the lateral parts of the cerebellar hemispheres and appeared most recently in evolution. The inputs and outputs of the cerebrocerebellum are to the cerebral cortex, most specifically to the motor and premotor areas and is important for planning and executing movement.

Cerebellar circuitry, the connections between neurons in the cerebellum are very plastic, and special types of neurons in the cerebellum are important for motor learning. The major neuron classes of the cerebellum are the **Purkinje cell** and the **granule cell**. The granule cells make up the deepest layer of the cerebellar cortex and they provide input to the Purkinje cells. The Purkinje cells make up the middle layer of the cerebellum. The Purkinje cells are the largest neuron in the brain due to their extensive branching. **Climbing fibers** from the spinal cord and the cerebral cortex also innervate Purkinje cells. The Purkinje cells innervate the **deep cerebellar nuclei**, which provide the major output of the cerebellum. Purkinje cells are interesting because rather than causing the cells they innervate to fire more action potentials (i.e. excitatory), they cause the cells to fire *fewer* action potentials (i.e. inhibitory).



Question: What is an advantage of being inhibitory?

Answer: Inhibitory output eliminates unnecessary movement and only allows necessary information to exit the cerebellum.

The cerebellar circuitry (left) is also very important for **motor learning**. Motor learning is a type of implicit learning, which is unconscious learning. It can manifest as improvement in a task without conscious awareness of how.

Question: What are some examples of implicit/motor learning?

Answer: Learning to ride a bike or Prism Goggles Task

When a certain stimulus requires a certain movement, visual feedback from the executed movement goes to the Purkinje cells via the climbing fibers. The climbing fiber has the job of suppressing incorrect movement. The climbing fibers therefore serve as a "teaching signal." Eventually, a new pattern of activity emerges from the granule cells, which can allow for the corrected movement to occur.

Damage to the cerebellum results in four characteristic symptoms:

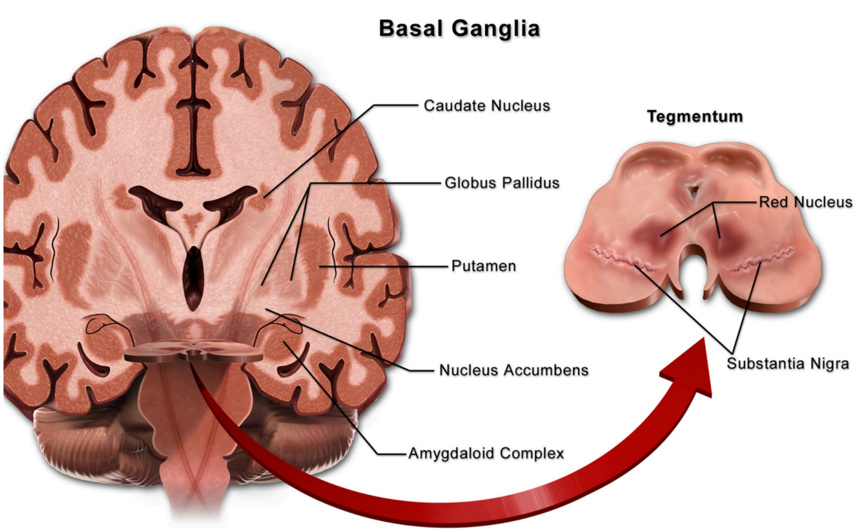
- Hypotonia: diminished resistance to passive limb displacements, as a result of low muscle tone
- Astasia-Abasia: inability to stand or walk in a normal manner (astasia: the inability to stand upright; abasia: lack of motor coordination in walking). When sitting or standing, cerebellar patients will compensate by spreading their feet to stabilize balance.
- Ataxia: abnormal execution of voluntary movement, characterized by a lack of coordination
- Tremor: Corrections to movement fail repeatedly and the hand oscillates irregularly around the target in a tremor

One very distinct feature of cerebellar damage is the loss of the automatic, unconscious nature of movement. When the cerebellum is taken offline, the cerebral cortex must be engaged for controlled movement.

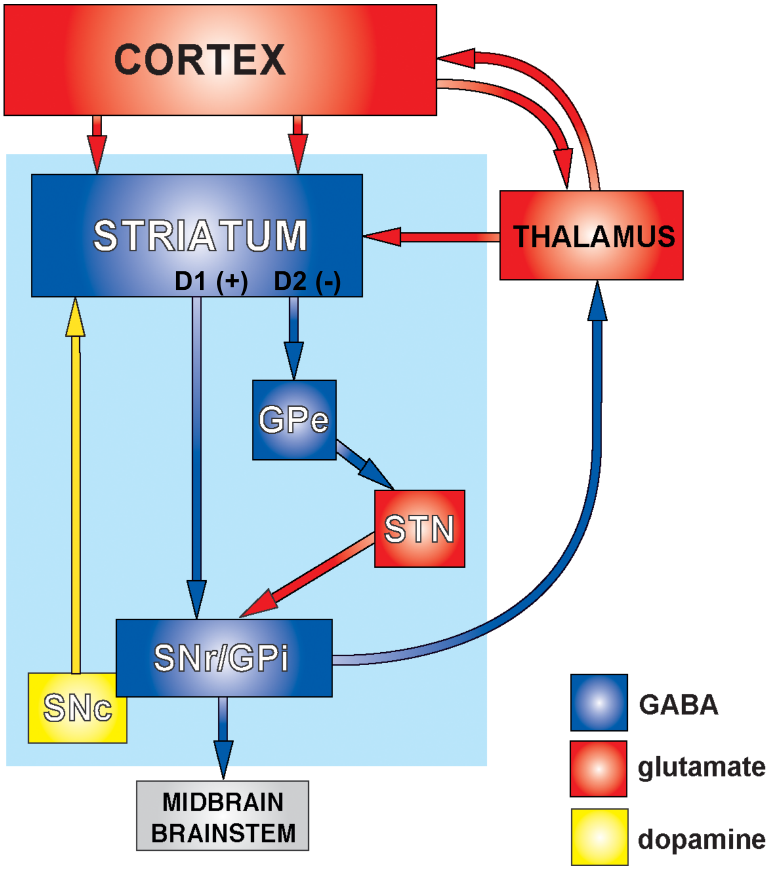
Cerebellar disorders can come in the form of lesions or damage to the cerebellum, or they can come in the form of a hereditary disease known as spinocerebellar ataxia (SCA). SCA is a hereditary, progressive neurodegenerative disorder that leads to atrophy of the cerebellum. SCA comes in multiple types. Symptoms appear in mid-adulthood and worsen. Walking becomes impossible and speech becomes incomprehensible. Patients eventually have difficulties swallowing and breathing and this becomes fatal.

The Basal Ganglia

The **basal ganglia** compromises multiple different brain regions located at the base of the cortex. The basal ganglia is highly connected to other brain regions and it is important for control of voluntary movements, procedural learning, and emotion. The brain areas important for motor control in the basal ganglia are: striatum (in humans the caudate and putamen), substantia nigra pars compacta (SNc), substantia nigra par reticulata (SNr), globus pallidus internal segment (GPi), globus pallidus external segment (GPe), subthalamic nucleus (STN), thalamus and cortex.



There are two main pathways for controlling movement within the basal ganglia. There is the **direct pathway** overall yielding movement initiation, and the **indirect pathway** that inhibits movement. Ultimately the direct pathway is excitatory and the indirect pathway is inhibitory. In general glutamate is an excitatory neurotransmitter while GABA is inhibitory and dopamine can act as both depending on what receptor is present on the neuron. Many neurons in the brain fire action potentials in order to signal other neurons, however, there are small populations of neurons that are consistently firing or tonically active neurons. Addition of neurotransmitters to tonically active neurons modulates the firing rate by either increasing or decreasing the rate, in this case glutamate (excitatory) will increase the firing rate while GABA (inhibitory) will decrease the firing rate.



Dopamine acts as a modulator of the basal ganglia circuitry. Dopaminergic neurons are located in the substantia nigra pars compacta, and axons are sent to the striatum. In the striatum there are two main types of dopamine receptors D_1 and D_2, and they have opposing functions. The D_1 receptors are excitatory and the D_2 receptors are inhibitory. The D_2 receptors have a higher affinity for dopamine, therefore small amounts of dopamine allow for the inhibition of movement.

Two neurological disorders highlight the different pathways in the basal ganglia, **Parkinson's disease (PD)** and **Huntington's disease (HD)**. PD is the second most common movement disorder in the USA, after resting tremor, and the incidence rate increases with age. PD is characterized by decrease in spontaneous movement, gait difficulty, problems initiating movement, postural instability, rigidity and tremor. In PD the dopamine producing neurons in the SNc die, with the loss of dopamine the D_1 receptors are most affected because they require more dopamine for activation compared to the D_2 receptors. Since D_2 receptors are more active and part of the indirect (inhibitory) pathway of the basal ganglia there is a loss of movement. Current treatments for PD focus on dopamine replacement and deep brain stimulation of the GPi to regulate movement.

HD is a genetic disorder caused by a trinucleotide repeat expansion in the gene *HTT* (protein huntingtin) this CAG repeat codes for glutamine and HD is one of many polyglutamine disorders. HD is inherited in an autosomal dominant manner, and the severity of the disease increases with repeat expansion number. As opposed to PD patients with HD have a surplus of uncontrolled movement or chorea, and as the disease progresses cognitive symptoms manifest along with complete loss of movement. In the striatum most neurons (>90%) express only D_1 or D_2 dopamine receptors, not both. In HD neurodegeneration first occurs in the D_2 receptor expressing neurons, removing the inhibitory indirect pathway allowing for a surplus of movement. As the disease progresses the D_1 receptor expressing neurons are lost and at this stage there is no movement.

<u>Activity: Prism Goggles, Inversion Goggles, and Mirror Drawing</u>

Materials needed:

- Prism goggles ($15 each at http://psychkits.com/perception_goggles.html)
- Small balls or beanbags for tossing
- Inversion goggles ($25 each at http://psychkits.com/inversion_goggles.html)
- Tinker toys or another activity that involves fine precision movements
- Mirror
- Cardboard box with hole cut for hand
- Shape outlines (see attached for star outline)
- Pens or markers

The purpose of these activities is to show how quickly the brain can adapt to changes in the sensory information it is receiving. For the prism/inversion goggles activity, it should take students 5 to 10 minutes to adapt to altered sensory information

Try out different kinds of movements with your goggles!

- Catching or throwing a ball
- Throwing darts at a target
- Giving somebody a handshake
- Giving somebody a high-five
- Be creative!

Once the students remove the goggles, since the brain has already compensated for accuracy by shifting movements by 10 degrees, their movements should be inaccurate all over again! The brain will have to compensate again to restore the visual field to its original orientation. Students should be back to their normal accuracy within another 5 to 10 minutes.

Try out different kinds of movements with mirror drawing!

- Trace the outline of a brain
- Try to trace a path through a maze
- Write your name

Questions you can ask your students as they do the activity:

1. What areas of the brain do you think are important for this activity? (cerebellum, but other correct answers are visual system, motor cortex, etcetera)
2. What do you think will happen when you remove the prism goggles? What would happen if you wore the prism goggles for a whole week? (we would adapt to the prism world, and once we removed the goggles we would have difficulty re-adjusting for awhile, but would eventually learn to move again without making mistakes)
3. What do you think the word adaptation means?
4. Why do you think we get better at doing things that we practice?
5. Is it good for us to make mistakes? Why?
6. What sports do you think this activity relates to?
7. Is it good for our brains to be able to change so easily? Why? What are examples where this could be good for us?

Run your own Experiment!

Are there age differences or gender differences in ability to adapt quickly? Grab a couple of stopwatches and time how long it takes for students to correctly trace a star in the mirror drawing task. You could also time how long it takes for students to recover their ability to throw a beanbag accurately after putting on the prism goggles. Or, you could make teams of students and see which team can build a structure out of tinker toys the fastest while wearing inversion goggles.

The bigger picture:

The cerebellum is essential for the motor adaptation you see in the prism/inversion goggles activity and in the mirror drawing activity. There are people who suffer from particular diseases that result in cerebellar degeneration, such as dyspraxia, cerebellar ataxia, or hypertrophic olivary degeneration. These people make very abnormal movements, and are **unable to adapt to new sensory input.**