Mind & Muscle Maze Module

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Introduction

The future peripheral nervous system begins as a population of cells along the edges of the neural tube known as the neural crest. The output processes of these cells – the axons of developing neurons in the spinal cord- must find their way to a particular muscle in the body in order to make precise connections with those muscle cells for motor movement to be possible. This process, called axon migration, has been an area of intense research in the last 25 years, and neuroscientists have discovered much about how this amazing process occurs.

The first axons to develop and migrate in the embryo, whose tracts are used by later developing axons to migrate to their target (although not all late-growing axons project along such a pre-established pathway) are called pioneer axons. The tips of the growing axons form structures called growth cones. This structure moves in an ameboid-like fashion, with spikes or “toes” called filopodia extending in and out from the growth cone. They extend from the cone to explore the environment and may attach so the growth cone advances. The path of the growth cone is determined by the presence or absence of growth cues. These growth cues are, in actuality, adhesion molecules (proteins) in the extracellular matrix. Cues can be short-range (local) or long-range, and each can be positive (and attracting) or negative (and repelling). The cues are recognized by specific receptors on the growth cones. By following the layout of adhesion molecules in the embryonic environment, axons can be directed along a particular pathway to its ultimate destination. Guidepost cells assist by marking off the end of one pathway and the beginning of the next that developing axons use to migrate to their target.

Developing axons also undergo chemotropic guidance by responding to chemoattractants and chemorepellants. Chemoattractive factors are secreted by the targets of developing axons; the factors are diffusible and can attract the axons from a distance to help guide them to the correct site where synaptic contact should be made.

Chemorepellants are the opposite of attractants. Cells located near neurons may secrete a repellant to make sure the axons are “pushed” away in the right direction of their target organ. Another type of chemorepulsion occurs when factors deflect axons away from a particular target. Also, chemorepellant factors may assist in keeping the axon in the vicinity of the target organ and not grow beyond (or “overshoot”) the correct destination.

Once the axon has reached the target organ, and the appropriate cell selected with which to make a connection, the synapse must be established. Initially more synapses than needed will be produced. Later, a refinement process (in part depending on the activity of the target cell) to eliminate the excess synapses. How synaptic targets of regulate the development of the motor and sensory cells that innervate them is one of the most unique chapters in neuroscience history, and spotlights the work of Nobel prize winner Dr. Rita Levi-Montalcini.

Hands On-Activity

Purpose: This activity demonstrates developing nerve pathways used to reach muscles. By moving through the maze students will develop an understanding that a nerve must undergo a developmental process, navigating a few obstacles to become correctly connected to the muscle (or tissue) it innervates.

Guiding Documents

National Science Education Standards

Life Science Content Standard C: As a result of their activities in grades 5-8, all students should develop understanding of structure and function in living systems. Principles that underlie this standard include structure and functions of cells, tissues, organs, systems for movement, control, and coordination. A behavioral response requires coordination and communication at many levels, including cells, organ systems, and whole organisms. (pp. 155-157)

AAAS Benchmarks

By the end of 5th grade, students should know that the brain gets signals from all parts of the body telling what is going on there. The brain also sends signals to parts of the body to influence what they do. (p. 136)

Human Identity Grades 6-8: By the end of the 8th grade, students should know that human beings have body systems for providing coordination of body systems. (p. 129) "Students can now develop more sophisticated understandings of how organs and organ systems work together." This includes the carrying of messages by nerves to help the organism respond to its environment. "Asking 'What if?' questions such as 'What might happen if some other parts weren't there or weren't working?' can stimulate students to reflect on connections among organs." (p. 137) By the end of the 8th grade, students should know that interactions among the senses, nerves, and brain make possible the learning that enables human beings to cope with changes in their environment.

National Science Teachers Association Scope Sequence and Coordination

"At the 6-8 grade level, the curriculum should emphasize the human organism." (p. 48) Students should explore the different systems.

Nebraska Science Standards

"Grades 5-8 At the middle school level, students expand their scientific inquiry skills through knowledge, observations, ideas, and questions. Middle school students will begin to recognize the relationships between explanation and evidence. They understand that background knowledge and theories guide the design of investigations, the types of observations made, and the interpretation of data. Student investigations will shape and modify students' background knowledge. (p. 24)

"8.1 Unifying Concepts and Processes

"8.1.1 By the end of eighth grade, students will develop an understanding of systems, order, and organization.

Student demonstrations:

- Recognize and describe integral parts and functions of any system.
- Analyze and predict the interactions within a system and between systems.
- Create and use classification schemes.
- Interpret cause and effect relationships within and between systems."

p. 25

"8.4 Life Science

8.4.1 By the end of eighth grade, students will develop an understanding of the structure and function in living systems.

Student demonstrations:

- Investigate and describe the levels of organizations: cells, tissues, organs, organ systems, whole organisms, and ecosystems.

- Investigate and describe the specialized function performed by specialized cells, such as muscular and skeletal, in multicellular organisms.

- Investigate and describe the internal human body systems.

- Investigate and explain how disease affects the structure and/or function of an organism."

Safety

Direct students to walk through the maze carefully and in a spread out fashion, such as starting one student every 15 seconds. No running.

Students are not obligated to eat the M & M's. In the event that a student can not eat chocolate or sugar, alternate candy can be provided.

Objectives

Students will

- Simulate nerve pathway choices and consequences while moving through a maze

- Complete a puzzle which concretely demonstrates the nerve development process

- Participate in a learning module to reiterate the key points and apply what they have just learned

Science Content

- Nerve pathways develop through a process of trial and error

- Components of the nervous system must work together

Science Process Skills

- Making Connections
- Communicating
- Modeling
- Predicting
- Reasoning

Materials

- 250 ft. of PVC pipe (1 inch diameter is adequate)
- 10 elbows
- 22 T-shaped connectors
- 2 tri-pronged connectors
- 16 L-shaped connectors
- Duct tape
- Flat sheets
- Glue sticks
- Puzzle pieces
- Plain background paper
- Packages of M & Ms (or other candy)
- Safety pins

Key Vocabulary

Nerve growth factor

Axon

Target tissue ("muscle")

Median nerve

Ulnar nerve

Teacher Advanced Preparation

To construct the M-n-M maze, lay down 23 2.5 ft pieces of PVC pipe in the same shapes as in the diagram. This is the bottom layer. Connect the PVC pipe using joint connector pieces: L-shaped for the corners, elbow connectors for the ends of the sections, T-shaped for the straight lines and tri-pronged for the T-shaped joints. Starting at the end of one section, attach the 5 ft long vertical struts to the bottom layer at the connecting joints. Because some of the connecting joints do not have an opening for the vertical strut, those struts need to be attached to the bottom layer with duct tape. As you attach the vertical struts, begin constructing the top layer in the same way the bottom layer was constructed. For stability attach the top layer to the vertical struts. Again, you will need to use duct tape to attach the top to some struts.

At this point, your maze should consist of two free-standing sections. To increase the structural integrity of the maze, attach the two sections together using four 2.5 ft pieces of PVC pipe on the top layer. These pieces will need to be attached with duct tape and are for stability only. Once the stabilizing struts are attached, persons over 5 feet tall need to be careful when going through the maze so they do not hit their heads on the struts.

Once the maze structure is up and stable, roll a couple inches of the sheets over the top layer and secure with safety pins. The sheets should hang to the floor. Connect the sheets together with safety pins to prevent gapping. Once the sheets are hung and secured, attach envelopes containing puzzle pieces (photocopies) at regular intervals throughout the maze. The envelopes should not be in direct sight of each other in the maze and the pieces should be in sequential order. Attach the envelopes to the sheets with safety pins. Put an envelope with "wrong turn" pieces at the end of the dead end. These pieces should instruct the student to turn around and look for another way out.

Procedures

Initial discussion can ask the students questions about the nervous system. These include "What are nerves" and "What do nerves do?" The students are then instructed that in the following activity, they need to pretend that they are a nerve inside a baby's spinal cord. Their task? To correctly maneuver through the maze and "hook-up" with their muscle by looking for clues and landmarks (the puzzle pieces) along the way.

Students are directed to proceed through the maze, picking up puzzle pieces along the way. The starting point signifies the spinal cord. The end, the fingers. The pieces illustrate the anatomical regions the nerve passes through on its way.

If the student moves down a wrong pathway, he or she will have to backtrack. When the student successfully emerges from the maze, a brief education module is begun. The purpose of the Mind-n-Muscle maze education module is to define and exemplify the project's outcome objectives to the student participants. Reiterating the main educational objectives to the students after participation in the maze will serve to make these objectives not only more apparent, but also more memorable and applicable.

The procedure involved in the education module will begin with students gathering their collected puzzle pieces, and gluing them in the correct order onto a background piece of paper. Instructors will guide students in this process, while explaining the importance of gluing each piece in its proper place. After students have correctly connected the puzzle pieces, they will be instructed to pick up a bag of candy, and return to their seats.

Next, the instructor will explain (in an amount of detail appropriate to each age group) the process of nerve formation in the brain and spinal cord during fetal development. It is explained that each nerve has a specific destination, and must travel through the "maze of the body" to reach this destination. Nerves often use clues along the way (chemicals, electrical signals, etc.) to help direct them along the proper path. Children are asked to identify some of the clues they used in traveling through the maze. Instructors then explain what might happen if a nerve were to reach the wrong destination, or terminate growth before fully developing. Results of these circumstances may include paralysis, or uncoordinated movement.

Instructors then demonstrate two nerves that control hand musculature (median nerve and ulnar nerve) by drawing their paths in magic marker on their arms (or referring to a picture). While pointing to the median nerve, the instructor explains that this nerve connects with muscles surrounding the thumb, and helps the thumb to move. Similarly, the ulnar nerve connects to muscles around the pinky finger, and helps control its movement. Children are then instructed to observe and demonstrate how these nerves work in their own bodies by using their thumb and pinky fingers to pick up either their bag of candy or individual pieces of candy, and place them in their mouth. Finally, children are asked to explain what might happen if one, or both, of these nerves did not work, or were improperly connected.

This education module serves to increase the amount of new knowledge retained by the participants in many ways. First, explaining the learning objectives both before and after the maze activity will help children to both prepare for this new information, and remember the information after the activity. Second, demonstrating actual nerve pathways within the human body will allow children to more concretely visualize the process of nerve development, and utilization. Finally, allowing the children to demonstrate the actions of nerves within their own bodies provides for an increased understanding of the practical utility of this information, allowing children to understand its importance in their own lives.

Assessment

The student should be able to describe the nerve message pathway from the brain or spinal cord to the fingers. This includes being able to explain what might happen if that pathway is interrupted.

Background

Prior to the second World War, Levi-Montalcini was a research associate working in the laboratory of a famous histologist, Guiseppe Levi in Turin, Italy. She was investigating the effects of limb bud removal on the development of spinal ganglia in the chick embryo. In 1936 Mussolini issued the "Manifesto per la Difesa della Razza", signed by ten Italian 'scientists'; this was soon followed by the promulgation of laws barring academic and professional careers to non-Aryan Italian citizens. Levi-Montalcini and Levi went to Belgium to continue research. While Levi-Montalcini returned to Turin on the eve of the Nazi invasion of Belgium, Levi remained but later fled the Nazis and joined Levi-Montalcin in Turin. Because of the heavy bombing of Turin, in 1943 they left for Florence, where they remained in hiding (underground) until the end of the war. During this time, Levi-Montalcini continued her experiments, often eating the experiment afterwards for food. In 1946 Levi-Montalcini accepted an invitation to the United States and joined the laboratory of Viktor Hamburger in St. Louis. Hamburger had read a paper by Levi-Montalcini and Levi (though it had been published several years earlier in 1942), and excited by the seemingly different results from his own work, invited Levi-Montalcini to work with him so they could resolve these differences. They published their first paper in 1949, and it became a landmark in the field. By the 1950s, the beginnings of the neurotrophic theory had been established.

The neurotrophic theory postulates that neuron survival is dependant on their successful competition for neurotrophic factors (proteins secreted by the target organ (or, neighboring cells or from the neuron itself). Target organs provide limited survival factors for neurons; when synaptic contact is made between a developing axon and its target organ (such as a muscle fiber cell) the ability of the neuron to compete for the survival factor will determine whether it survives, or undergoes programmed cell death. As many as 50% of each class of neurons will be lost through a process of “programmed cell death”, or apoptosis.

For her work in establishing the neurotrophic theory, Levi-Montalcini was awarded the Nobel Prize in Physiology and Medicine in 1987 (sharing it with Stanley Cohen, a research colleague).

Vocabulary

Neural crest – a population of cells along the neural tube that later will form the peripheral nervous system

Growth cone - first described by Ramon y Cajal – ameboid specialization at the tip of a growing axon

Axon migration – the navigation of axons through the embryonic environment to reach a target (such as a muscle fiber)

Guidepost cells - mark off the end of one pathway and the beginning of the next that developing axons use to migrate to their target

Pioneer axons – the first axons to develop and migrate in the embryo, whose tracts are used by later developing axons to migrate to their target (although not all late-growing axons project along such a pre-established pathway)

Growth cues - the axon migrates in a step-wise, segmental pattern along their trajectory through the coordinate action of growth cues, which are actually extracellular molecules located in the extracellular matrix. Cues can be short-range (local) or long-range, and each can be positive (and attracting) or negative (and repelling). The cues are recognized by specific receptors on the growth cones.

Chemotropic guidance mechanisms - cell migration directed by diffusible chemoattractants and repellants

Chemoattraction - factors are secreted by the targets of developing axons; the factors are diffusible and can attract the axons from a distance to help guide them to the correct site where synaptic contact should be made.

Chemorepulsion – the opposite of chemoattraction; cells located near neurons may secrete a repellant to make sure the axons are "pushed" away in the right direction of their target organ. Another type of chemorepulsion occurs when factors deflect axons away from a particular target; or, factors may assist in keeping the axon in the vicinity of the target organ and not grow beyond (or "overshoot") the correct destination.

Neurotrophic theory – More neurons than are needed for innervation of a target are formed during the developmental program. Many of these neurons (estimated to be as much as 50% of each class of neurons) will be lost through a process of "programmed cell death", or apoptosis. Target organs provide limited survival factors for neurons; when synaptic contact is made between a developing axon and its target organ (such as a muscle fiber cell) the ability of the neuron to compete for the survival factor will determine whether it survives, or undergoes programmed cell death. The theory that neuron survival is dependant on their successful competition for neurotrophic factors (proteins secreted by the target organ (or, neighboring cells or from the neuron itself) is known as the neurotrophic theory.

Resources and Links

Rita Levi-Montalcini – Nobel Lecture

Neuroscience Education

The Brain Connection

I am your Child