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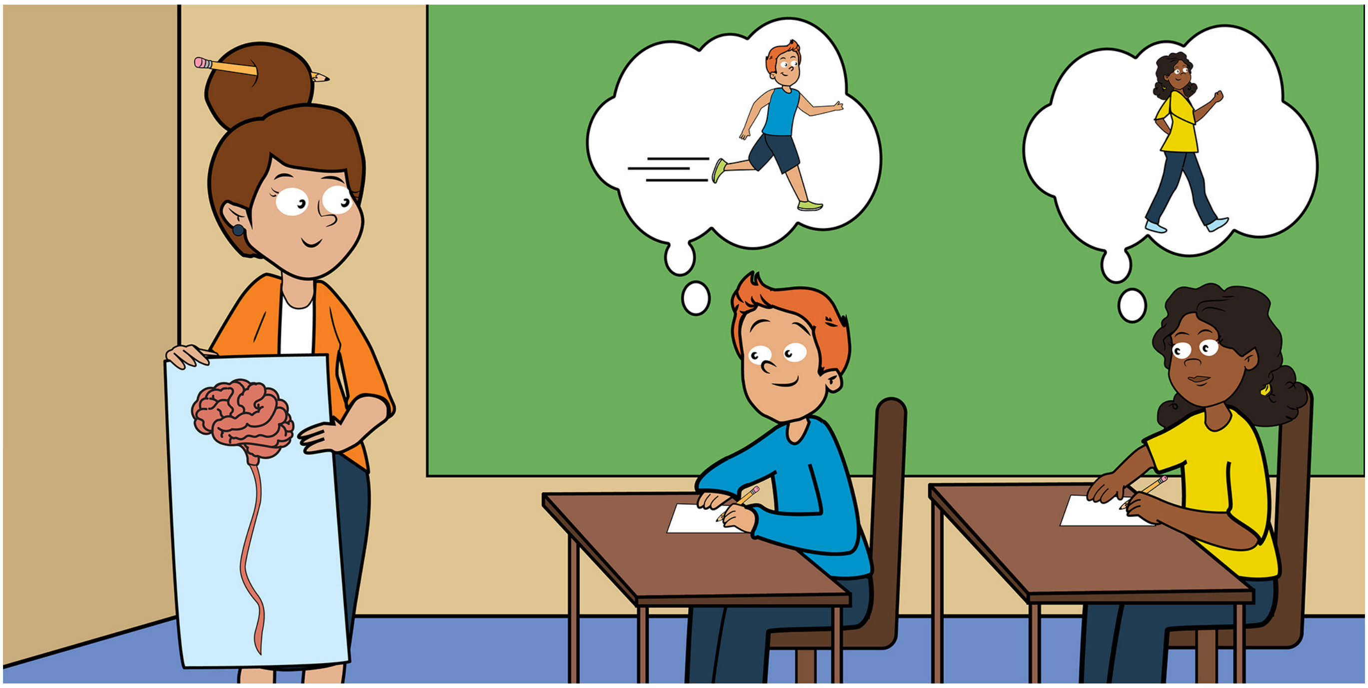

WHAT CAN A HEADLESS CHICKEN TEACH US ABOUT WALKING?

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YOUNG REVIEWERS:

ALINE
AGE: 14

ANNICA
AGE: 14

ISABELLA
AGE: 14

MAXWELL
AGE: 14

Unlike when you do your math homework, you do not usually have to *think about* walking—it just happens naturally. We master the ability to walk as children, but the control of walking is complex. To walk, many muscles must act together to produce smooth, coordinated movement of the arms and legs. We sometimes think about where we want to step, but sometimes we do not. We may also choose how fast and which direction we want to go, but we do not actually think about the individual movement of each limb—walking seems so simple and does not require much thought. Although our brains help supervise the control of walking, other parts of the nervous system are what make walking automatic. In fact, the basic pattern of walking is produced and adjusted by networks of cells within the spinal cord, known as central pattern generators.

Imagine yourself, on a beautiful sunny day, walking to your favorite ice cream shop for a refreshing snack. There are so many flavors to choose from! You spend the entire walk trying to decide which mouth-watering ice cream you will pick when you arrive. During your walk, how many times will you think about the individual movements required to walk to the shop? How many times do you think to yourself, "move my left foot first, now my right foot, and now my left foot again?" If you are like most people, you would answer that you do not think about these movements at all. That is because walking is not as reliant on the brain as you might think!

WALKING MIGHT SEEM EASY, BUT IT IS ACTUALLY COMPLEX!

As humans, we walk on two legs and move from one place to another with relative ease. Walking is considered an automatic movement. It is a skill that most of us learn and master as toddlers. But, while it seems quite easy, the movement patterns performed during walking are complex [1]. Walking involves rhythmic and alternating movements of the arms and legs in a series of repetitive forward steps. While one foot is on the ground, the other foot swings through the air as you step forward. Once the foot in the air contacts the ground, the other foot then "alternates" and swings through the air during the next step forward. One foot always remains on the ground, ensuring you do not topple over!

Just think about all the muscles in both legs that are involved in walking—it is a pretty complex movement. Muscles around our ankles, knees, and hips must work together, turning on and off at specific times to ensure we produce enough force so we can move. But, if walking is such a complex movement, why does it seem so easy? We can walk with such ease due to the efficiency with which the **central nervous system**, which consists of the brain, brainstem, and spinal cord, controls movement (Figure 1).

CENTRAL NERVOUS SYSTEM

The brain, brainstem, and spinal cord together.

DOES THE BRAIN CONTROL ALL MOVEMENT?

Most people think that the brain is responsible for producing and controlling all movement. After all, the brain is one of the most fascinating structures in the body. The brain is important for almost every thought, sense, and action we experience! The human brain is made up of millions of tiny cells called **neurons.** Neurons communicate by sending signals to one another, like sending text messages to your friends. Consider the example of raising your hand in class. To do this, signals sent from neurons in your brain travel down to your spinal cord. These signals then activate large cells in the spinal cord, called **motor neurons**. Motor neurons tell the muscles of your shoulder and arm to contract. When your muscles contract, they pull

NEURONS

One of the many cell types in the brain. Neurons communicate with one another by transmitting electrical signals.

MOTOR NEURONS

Cells located in the spinal cord that connect to our muscles and send signals telling them to contract.

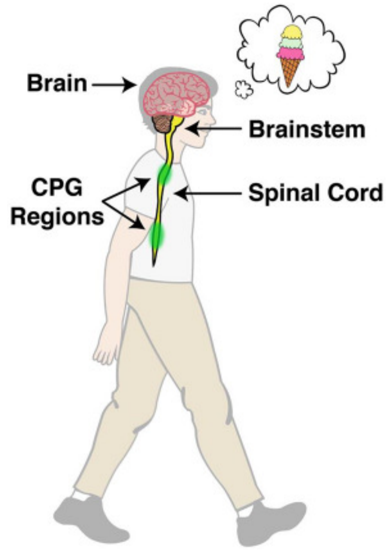

Figure 1

Figure 1

The approximate size and location of the brain, brainstem, and spinal cord, which collectively make up the central nervous system. The approximate regions where central pattern generators (CPGs) are located within the spinal cord are highlighted in green.

on your bones, which causes your arm to move and your hand to raise. However, some movements, such as walking, running, swimming, or cycling, can be performed with *only a little* input from the brain!

MIKE—THE HEADLESS CHICKEN WHO COULD WALK!

Have you ever heard the saying, "running around like a chicken with its head cut off"? This phrase is commonly used to describe the activities of someone who is in a panic or frenzy. Although it does not happen often, it *is* possible for a chicken to walk or run without a head! In fact, one very famous chicken, named Miracle Mike the headless wonder chicken, lived for nearly 2 years without a head and was able to walk around! You probably think there is no way this is true, but we promise you it is![1] Born in Fruita, Colorado, in the 1940s, Mike's head was removed, but a large part of his **brainstem** was left intact. The brainstem is part of the central nervous system that connects the brain and spinal cord and is essential for many important bodily functions, such as breathing and digesting food. Although Mike was a little clumsier than a normal chicken, he could still walk around! People around the world were fascinated with Mike's story, and soon his fame began to grow. He became so popular that he went on a cross-country tour, like a rockstar (Figure 2)! People paid money to see the remarkable headless chicken that could walk! Although Mike unfortunately passed away, his legacy remains. Every year in the city of Fruita, a weekend-long festival is held in his honor. There is even a statue to commemorate Mike's incredible story! You may be wondering how it is possible for a chicken with no head to walk! The answers lie within the spinal cord.

BRAINSTEM

Part of the central nervous system that connects the brain and spinal cord.

[1] If you would like to find out more about Mike the headless chicken, check out this link: https://www.miketheheadlesschicken.org/mike

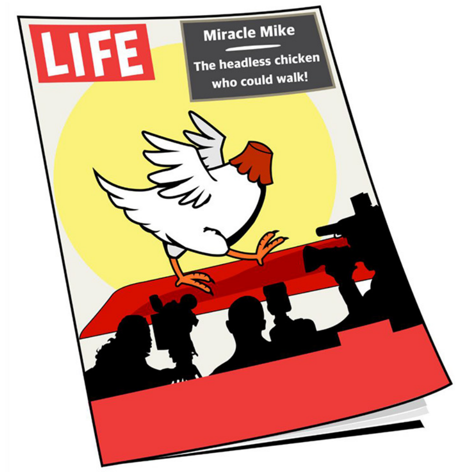

Figure 2

Figure 2

Miracle Mike lived for almost 2 years after having his head removed, and he was even able to walk around.

THE SPINAL CORD CAN PRODUCE MOVEMENT

Where is walking controlled, if not the brain? Many people think that the spinal cord simply acts as a pathway for signals traveling to and from the brain and the muscles. But this is not entirely the case. Although the spinal cord does relay information, it can also send information to the muscles without the brain's commands!

Have you ever stepped on a sharp object like a Lego block? If you have, you know how painful this can be. However, you did not have to think about lifting your foot away from the block as fast as you could. This is because stepping on something sharp results in an automatic reaction called the **crossed extensor reflex**. Spinal reflexes like this are controlled by neuron connections located entirely within the spinal cord. In this example, the sharp Lego is detected by sensors in your feet, and a signal is sent to neurons in your spinal cord. This signal then activates neurons that control the muscles of the leg that you stepped with, which allows you to lift your leg quickly and automatically away from the painful block. At the same time, this painful signal sent to the spinal cord activates neurons that control the muscles of your opposite leg, to ensure that you do not fall over. These movements occur within milliseconds of detecting the sharp object and are controlled entirely within the spinal cord. This means that you move your leg away from the painful Lego block before your brain even has a chance to send the necessary commands to move your leg!

CROSSED EXTENSOR REFLEX

Automatic reaction controlled by neurons in the spinal cord whereby a stimulus on one side of the body results in compensatory response to the other side of the body.

The spinal cord is also important for controlling more complicated movements. During walking, the basic movements are controlled by specialized groups of neurons within the spinal cord, called **central pattern generators** (CPGs) (Figure 1) [1, 2]. First discovered in non-human animals like Mike, it is now believed that human CPGs also help with walking and performing other rhythmic movements, such

CENTRAL PATTERN GENERATORS (CPGS)

Networks of neurons located in the spinal cord, responsible for producing the rhythmic and alternating movements of walking.

as swimming, running, and cycling [3, 4]. The highly capable spinal cord can produce the complex muscle contractions required to walk, which means the brain does not have to "think" about it. The brain, however, does turn on the CPGs for walking and helps us to avoid obstacles, like a crack in the sidewalk. In this way, the brain *supervises* our movements during walking, whereas the CPGs in the spinal cord *produce* the rhythmic and alternating movement patterns [2].

HOW DO CPGS WORK?

Researchers are still studying the details of the connections between neurons in spinal CPGs. However, we know that these connections are quite complex. One simple way to understand how CPGs work during walking is to think about the movement of a leg like a light switch turning on a light bulb (Figure 3). The "light switches" are located in the spinal cord and are a simple way to think about the neurons of the CPGs. When the light bulb is on, the leg swings forward. When the light bulb is off, the leg supports the weight of the body, ensuring we do not fall to the ground. The spinal cord receives information about when the step is complete and then flips the switches. This process

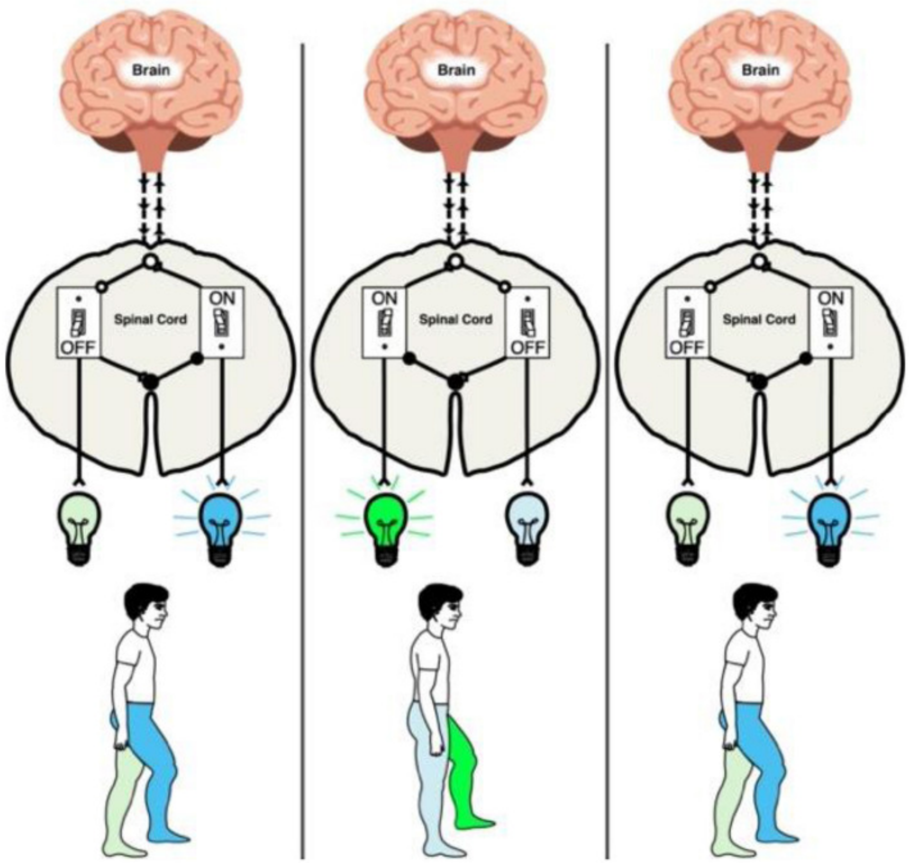

Figure 3

Figure 3

CPGs are like light switches. In this simplification, the light switches in the spinal cord represent networks of neurons that create a CPG. As you can see, when the light switch on the right side of the spinal cord is "ON," the blue light bulb lights up, and the right leg (blue) swings forward. When the step is finished, the light switch on the left side switches "ON" and the green light bulb lights up. This causes the left leg (green) to swing forward, completing the next step. This process is repeated until we choose to stop walking.

continues until we choose to stop walking. The CPGs create the basic left-right-left movement pattern of walking.

WHY IS UNDERSTANDING CPGS SO IMPORTANT?

If your school bus were to break down, would you know how to fix it? If you are like us, you probably do not know how the engine works, which means you would not know how to repair it. You can think of the central nervous system in the same way. If your central nervous system breaks down due to injury or disease, you would probably not know how to fix it. Scientists worldwide use their knowledge of CPGs to develop new technologies and training programs to help people regain the ability to walk after injuries. Scientists act like mechanics for the spinal cord!

Despite common belief, the brain does not produce all human movements. Although the brain is essential, we should not forget about the important role of the spinal cord in controlling movement! Hopefully, from reading this article, you have learned that networks of neurons in our spinal cords are essential for allowing us to walk. CPGs help us to walk without the need to think about the walking movements. Now, the next time you hear the saying, "running around like a chicken with its head cut off," you can wow people with your scientific knowledge. You can tell them that it *is* possible (at least for Miracle Mike the headless chicken), and you can really show them that you know your stuff by explaining that CPGs are the reason why!

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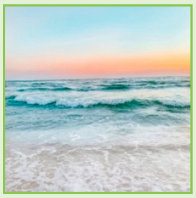
CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

ALINE, AGE: 14

My name is Aline, I am 14 years old. My favorite hobbies include theater, playing the clarinet, drawing and reading. I am fascinated with Greek mythology; my favorite books include the Harry Potter and the Percy Jackson series. At school, I really enjoy Maths and Science.



ANNICA, AGE: 14

My name is Annica and I am 14 years old. I grew up in Asia and now live in Switzerland. My hobbies include horse riding and cooking. I love traveling and discovering new cultures. My favorite subject in school is economy and science.

ISABELLA, AGE: 14

My name is Isabella and I am 14 years old. I was born in New York and I live in Switzerland. I love art, reading books, playing the piano and writing. I also have great interest in math, nature and science. In the future, I would like to be a medical doctor specialized in cancer or a civil rights lawyer. I am always very curious to learn more about our planet and in finding ways to help people all around the world.

MAXWELL, AGE: 14

I am interested in a lot of different things and I am curious about the world. I am humorous yet I can also be a bit dim at times.

AUTHORS

EVAN J. LOCKYER

I am a neuroscience Ph.D. candidate at Memorial University of Newfoundland, located on the east coast of Canada. I have been working in the field of human neurophysiology under the supervision of Dr. Kevin Power for the past 5+ years. Our lab investigates how the human nervous system produces the locomotor-like task of arm cycling. Currently, my research focuses on understanding the effects of aerobic exercise on changes within the central nervous system during arm cycling. Aside from science, I enjoy playing and watching many sports, going to the gym, and spending time with friends and family. *elockyer@mun.ca

GREGORY E. PEARCEY

I am an exercise neuroscientist and I study how the human nervous system controls movement and adapts to use and disuse. I received my Ph.D. in neuroscience under the supervision of Dr. E. Paul Zehr, which focused on how the neural connections between the arms and legs can help people improve their walking after stroke. Currently, I am a postdoctoral research fellow under the mentorship of Drs. C.J. Heckman and Zev Rymer at Northwestern University. I study how short periods of breathing air with low levels of oxygen, known as acute intermittent hypoxia, can improve recovery after spinal cord injuries and stroke. I love playing ice hockey, weightlifting, downhill skiing, and playing with my dogs!

KEVIN E. POWER

I have a Ph.D. in neurophysiology and am a professor in the School of Human Kinetics and Recreation at Memorial University of Newfoundland. As a child, I was very active and loved playing different sports and it was this love for sport that got me interested in understanding how the nervous system and muscles worked together to produce movement. In the Fall of 1999, I began doing research to better understand the neural control of movement and I have not stopped! In my leisure time, I enjoy coaching my son's hockey teams, running, spending time with family, and playing with my dog.