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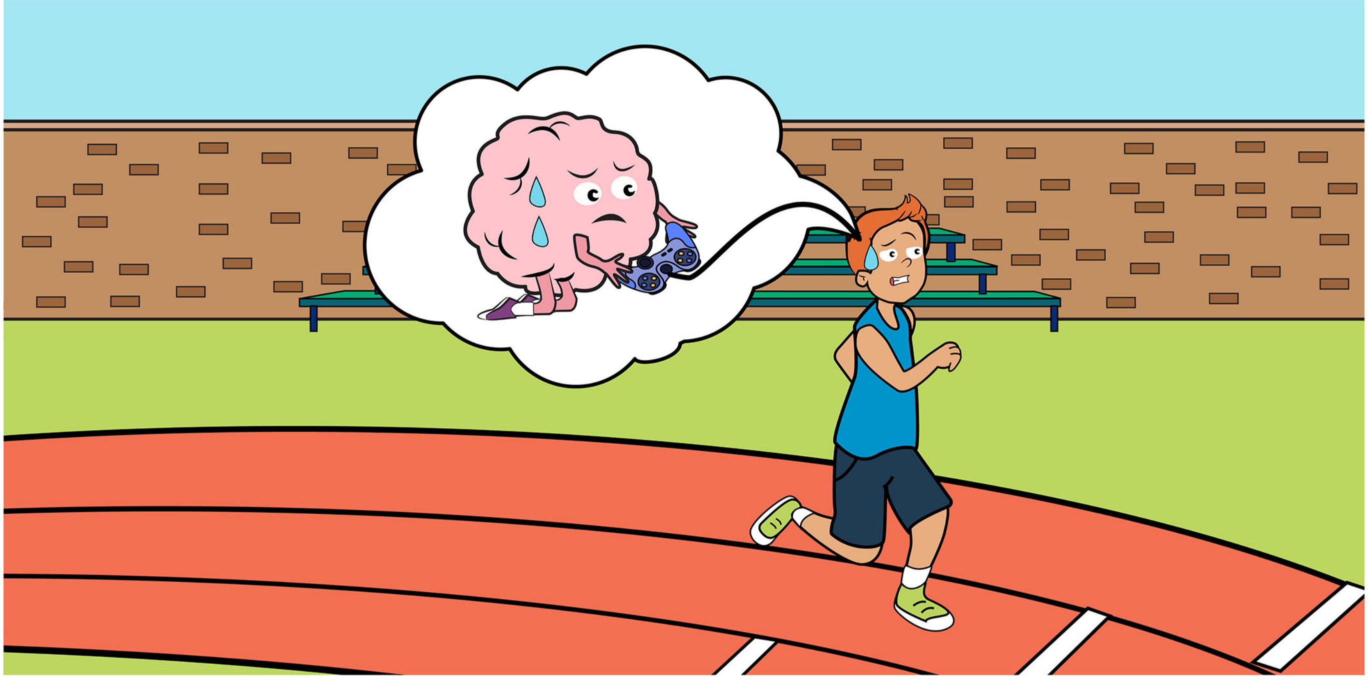

MOVING IS NOT AS SIMPLE AS YOU MAY THINK

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YOUNG REVIEWERS:

DANIELLE
AGE: 12

MAIZY
AGE: 15

An athlete who runs. A child who grasps a piece of candy. A teacher who talks. A person who eats. What do all these people have in common? They are producing movements, often without even thinking about them. Moving seems easy. However, it might surprise you, but there is still a lot to learn about the way we produce movement. Producing movement is a complex process that involves many structures in the body. Did you know that grasping a piece of candy requires your brain to send electrical impulses to many different muscles? These impulses tell each of your muscles when and how hard to contract. Muscles need to contract in a coordinated way. If not, you will not grab your preferred piece of candy. Understanding how movement is produced will help doctors to assist people with movement disorders, and this understanding could also help to develop training strategies for athletes.

MOVEMENT IS IMPORTANT, BUT WE (STILL) KNOW LITTLE ABOUT IT

Think for a moment about actions that require movement. Maybe you think about sports-related movements, such as running, catching, or kicking a ball. Movement is indeed the key to success in many sports. But did you also think about chewing, writing, and talking? These are also actions that require movement. Actions such as talking allow your brain to communicate with the world. When movement is compromised, a person's health may degenerate. Understanding how movement is produced is important, because it can help coaches to develop training strategies for athletes and it can help doctors to assist people who have movement disorders.

It might surprise you, but there is still a lot for us to learn about movement. For example, we have created computers capable of solving math problems much more quickly than you can. But we are still unable to build a robot that can move as well as a child can. In this article, we will talk about **voluntary movement**, which is intentional movement. Involuntary movements, such as the reflex of withdrawing your hand from a hot object, involve a different process that we will not talk about. Voluntary movement is a complex process that involves many structures in the human body. Did you know that producing voluntary movements requires that you use your brain, your spinal cord, your nerves, and your muscles?

VOLUNTARY MOVEMENT

Intentional movement.

PRODUCING A MOVEMENT INVOLVES MANY STRUCTURES AND PROCESSES

Let us imagine that you decide to walk or to grasp a piece of candy from a bowl on the table. To do either of these things, the brain must send messages to the correct muscles, telling them to contract. Once the muscles receive the correct information, they contract and pull on the tendons that connect them to bones, which then allows our joints to move. Figure 1 shows this process for walking.

The messages sent from the brain to the muscles are electrical impulses, called **action potentials**. These action potentials travel along and between nerve cells that lie within the brain and spinal cord. The nerve cells that connect the spinal cord to the muscles are called **motor neurons**. Did you know that there are tens to thousands of motor neurons that connect the spinal cord with each muscle? And that each muscle in your body is made of thousands of muscle fibers? Each motor neuron connects with a small group of muscle fibers within a muscle. Together, the motor neuron and muscles fibers are called a **motor unit**. The number of muscle fibers connected to each motor neuron can vary. For example, muscles that are used for fine movement, like blinking, have only 10–20 fibers in each motor unit. However, muscles that need to produce high forces, such as those

ACTION POTENTIAL

Change in electrical potential due to the passage of an electrical impulse along a nerve or a muscle fiber.

MOTOR NEURON

A nerve that conducts action potentials to a muscle.

MOTOR UNITS

A motor neuron together with the muscle fibers to which it is connected.

that are needed to kick a ball, could have more than 1,000 fibers in each motor unit (Figure 2).

When the action potentials from the brain reach the muscles, the electrical impulses spread along the muscle fibers. This causes the muscle fibers to contract. When muscle fibers contract and shorten, this can change our joint angles. For example, some muscle fibers in the back of your upper arm need to shorten for your elbow angle to increase, to allow you to stretch out your arm and reach for that piece of candy (Figure 2).

But it gets more complicated! If you only needed to activate one muscle to grasp the candy, the process would be quite simple. However, to pick up the right piece of candy, you need to create movements around your finger, wrist, elbow, and shoulder joints. All these movements require the extremely coordinated use of many muscles. Think about rowers in a boat: if they do not row in a coordinated way, the boat does not move. Your muscles are similar: your nervous system needs to decide which muscles to use, in which order, and how much of the muscle is needed. It is even *more* complex, because we have multiple muscles that can perform the same action. For example, to do a simple movement like bend the elbow, we have three muscles to choose from. We could bend the elbow using only one of these three muscles, or any combination of them. In other words, there are many different ways to use your muscles to produce a given movement.

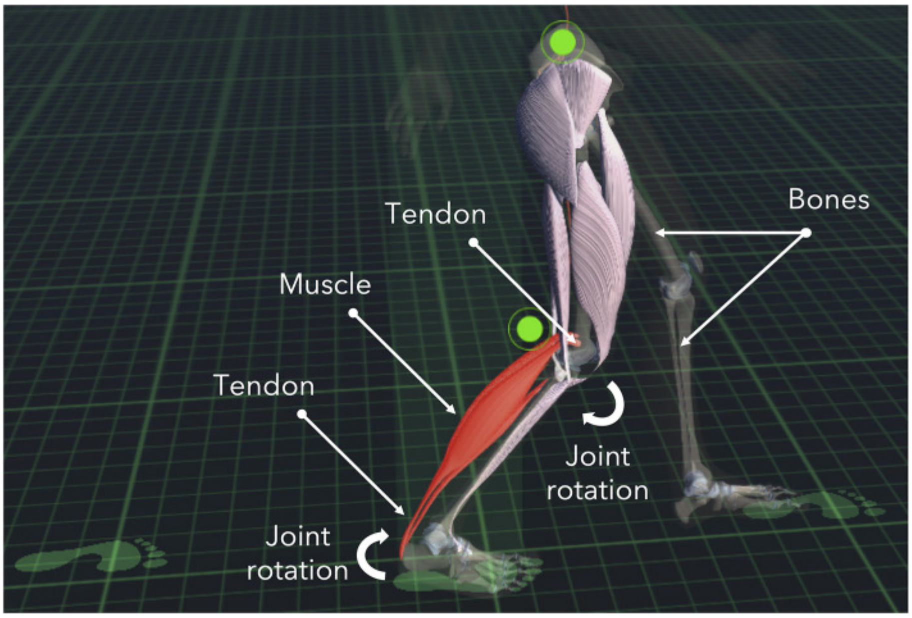

Figure 1

Figure 1

Action of the calf muscles during walking. The calf muscle contracts, which pulls the heel up and flex the knee to allow forward movement. (Image credit from an 3-D interactive application: http://brule.co/lab/Neuro-marche/englishTempVersion/). This interactive 3-D application also provides a detailed diagram of the different regions of the brain involved in movement production.

Figure 2

Main structures involved in the production of voluntary movements. The brain sends messages to the muscles through action potentials, which travel along the spinal cord and the motor neurons. Each motor neuron connects with a group of muscle fibers, which together are called a motor unit. Two motor units are shown in the right panel.

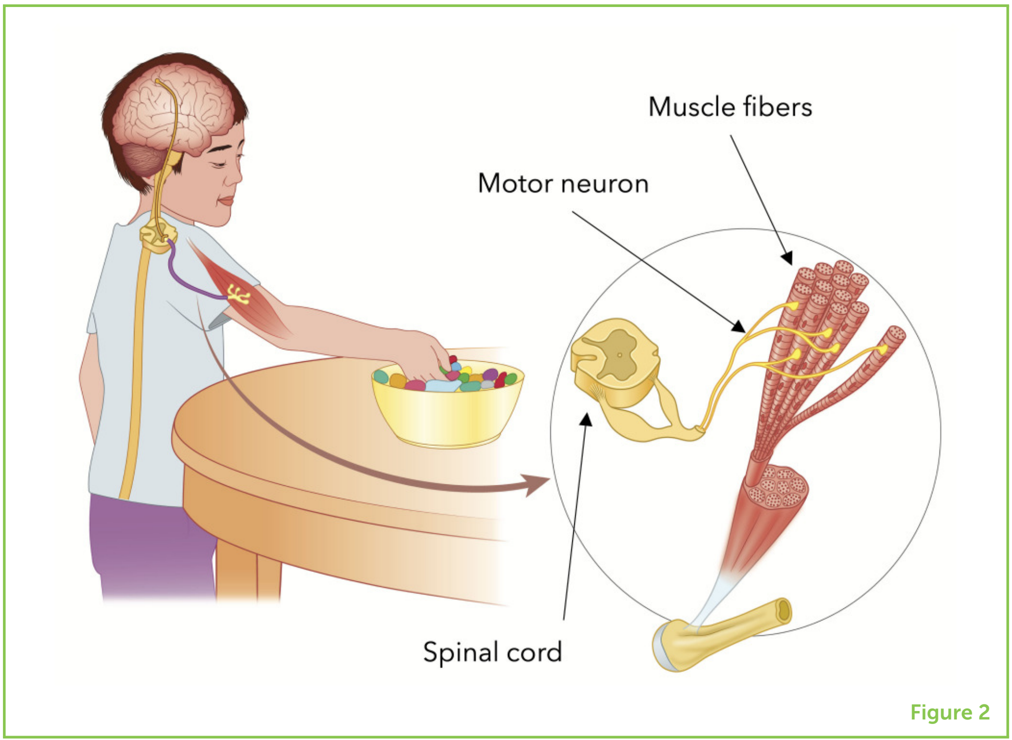

Figure 2

HOW CAN WE STUDY HUMAN MOVEMENT?

There are many ways to combine the actions of our muscles to produce a given movement. But why do we choose a specific combination of muscles among the many available solutions? To understand this, we need information about the force produced by each muscle. Unfortunately, we cannot insert sensors into human muscles to measure force. So, we must rely on other tools.

ELECTROMYOGRAPHY

Technique to record the electrical activity that is generated as action potentials travel along muscle fibers.

ELECTRODE

Substance which is a good conductor of electricity. They are usually patches filled in with conductive gel/paste, which sticks to the skin.

MOTION CAPTURE

Technique to track and record movement, using reflective markers placed on the skin that are tracked by cameras.

Since muscles produce force in response to action potentials that spread along the muscle fibers, one way to study which muscles are working together is to measure the electrical activity generated by these action potentials. This can be done using a technique called **electromyography** (Figures 3A,B). This technique involves placing sensors called **electrodes** on the skin above the muscle(s) we want to measure. By recording the muscle activity, we can determine when a muscle is active and the amount of muscle activity. We can determine if the muscle works close to its maximum level, like when your finger muscles are holding on tight to a tree branch, so you do not fall, or operating at a submaximal level, like when your finger muscles are holding, but not squishing, a delicate ladybug.

Information about muscle activity is not quite enough to provide a complete understanding of movement. It is also important to understand how people move different parts of their bodies. For example, how much do your knee and ankle joints move while you walk? We can record this information using a technique called **motion capture** (Figures 3C,D). Did you know that motion capture is also used

Figure 3

Two techniques to study human movement. **(A)** In electromyography, electrodes are placed at the surface of the skin directly above the muscles we want to measure. **(B)** The electrical activity of three muscles, measured using electromyography during pedaling. From these signals, it is possible to determine when the muscles are active and their amount of activity. **(C)** In motion capture, reflective markers are placed on the skin. **(D)** From tracking these markers as a person moves, a computer can construct an image of the lower limbs.

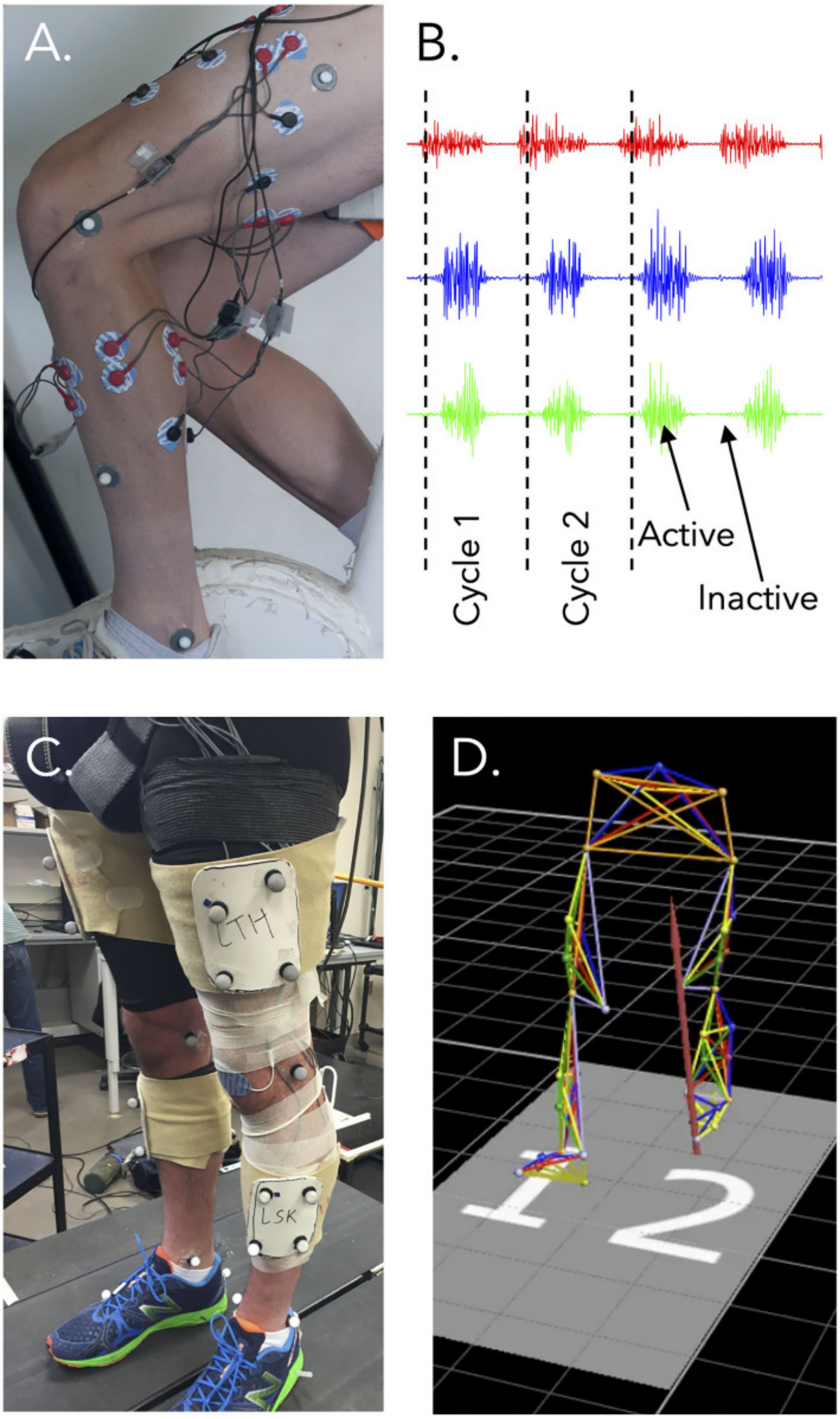

Figure 3

in filmmaking and video game development, to animate characters? In animation, the movements of real humans are first measured using motion capture. Dozens of reflective markers are placed on the skin. Then, the position of these markers is tracked by cameras while the person performs various movements. All this motion information is used to animate the digital characters, so that their movements look just like real human movements. Motion capture is used in a very similar way by researchers, to measure and describe movements.

HAVE YOU EVER RECOGNIZED A FRIEND BY THEIR WALK?

Movement requires many muscles to work together in a coordinated way. But do we all move in exactly the same way? In a recent exciting discovery, a computer was able to recognize people solely by the way they walk [1]! The researchers recruited 57 healthy men and women and placed 62 reflective markers on each person's skin. Then, they used motion capture to measure the body movements of the volunteers as they walked. Finally, the researchers used a **machine-learning** software, which works a bit like the software that recognizes faces or fingerprints on new mobile phones. This machine-learning software was trained to recognize each volunteer's walking style. After this training phase, the researchers observed that the software was able to recognize each participant only by the way they walked.

MACHINE-LEARNING

An application of artificial intelligence in which computers can learn from data.

The researchers then wondered whether we also have unique ways of using our muscles [2]. They attached electrodes to eight muscles of the right leg. They found that a machine-learning software program could identify each person based on their muscle activation patterns. This suggests that the way we coordinate our muscles to walk is as unique to us as our fingerprints!

WHY IS THIS IMPORTANT?

Why is it useful to know that each of us has a unique movement signature? First, it could help coaches and therapists to personalize exercise programs. Unique movement patterns could also be used for identification purposes. Companies are developing security systems that will recognize a person based on the way he or she walks. Face or fingerprint recognition requires that a person to stop to look at a camera or to place a finger on a scanner. The advantage of movement recognition is that people do not need to stop. Therefore, this kind of technology could be useful to speed up passage through places like airport security checkpoints. Maybe one day you will be recognized at the airport just by the way you walk, without the need to stop and show your passport. But do not worry, this technique is not yet developed, so nobody can identify you while you are grasping that piece of candy!

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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

DANIELLE, AGE: 12
Hello! My name is Danielle. I am most interested in clinical and computational neuroscience. In addition to these areas of neuroscience, I am also extremely interested in the overlap between coding and the brain (e.g., deep neural networks). My favorite movie is "The Imitation Game" because I greatly admire Alan Turing for his contributions to early computer science and the way he introduced the concept of brain/computer parallels, thus paving the way for brain-computer interfaces.

MAIZY, AGE: 15

Maizy has a passion for animals, music, history, and neuroscience. She loves to travel, and her favorite pastime is reading. She enjoys learning about history and cultures. She participates in Filipino martial arts and Kajukenbo self-defense.

AUTHORS

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François Hug, Ph.D., is a professor at Université Côte d'Azur (France) and a junior fellow of the Institut Universitaire de France (IUF). He has a background in human movement sciences. His research focuses on the control of movement in health and disease. Specifically, using an approach that combines neurophysiology (study of the functioning of the nervous system) and biomechanics (study of the mechanics of living bodies), he aims to understand the origin of individual muscle coordination strategies (or signatures) and their role in the development/persistence of musculoskeletal disorders. *francois.hug@univ-cotedazur.fr

KYLIE TUCKER

Kylie Tucker, Ph.D., is an associate professor in the School of Biomedical Sciences at the University of Queensland (Australia). She was awarded her Ph.D. in 2006 from Adelaide University (Australia). Her research aims to understand more about how movement control adapts during typical and atypical development (childhood), aging, and in musculoskeletal diseases and pain. She is interested in postural control, meaning what keeps individuals upright and standing, or able to correct their posture after being knocked; and voluntary control, such as how we control our muscles to grab a piece of candy.

TAYLOR J. M. DICK

Taylor Dick, Ph.D., is a lecturer in the School of Biomedical Sciences at the University of Queensland (Australia). She was awarded her Ph.D. in 2016 from Simon Fraser University (Canada). Her research aims to unveil the mechanisms of how muscles work in the body; how muscle-tendon structures adapt to external challenges such as size, age, and disease; and how emerging wearable robotic technologies, such as exoskeletons and prosthetics, interact with musculoskeletal structures to improve movement.