Motor Control

WEEK 7, LECTURE 1

Instructor: Erin Horowitz

Alright everyone, welcome back! I hope you all had a good exam – or as good as it can be, given that you had to take an exam.

We're now in week 7 (I can't believe how fast the quarter has gone by!), and we're going to start the first of our last four lecture series. This week's topic is on motor movements.

And again, I apologize for having to write out notes to you all instead of giving the lectures verbally. This isn't ideal for any of us, but I wouldn't be doing it this way if I didn't absolutely have to. With that in mind, I'm going to try and make these notes as clear and conversational as possible.

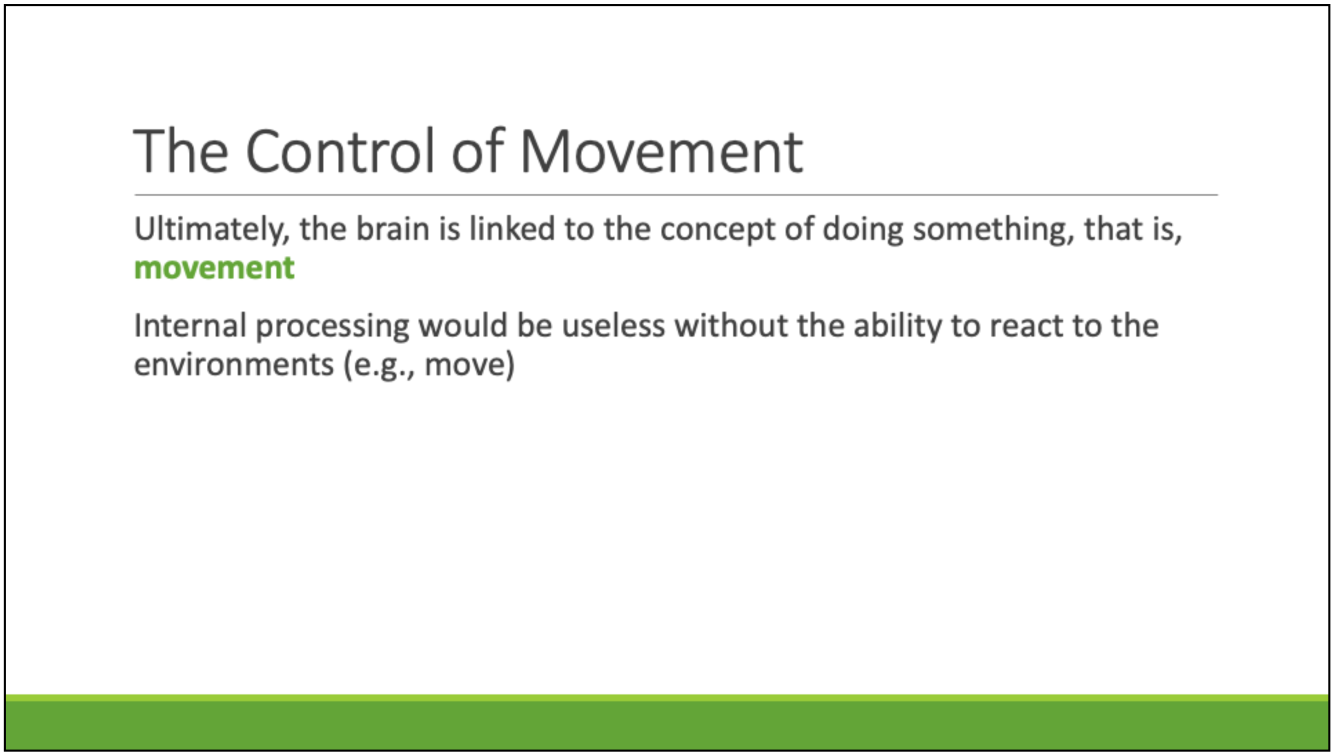
This lecture series will cover…

Motor control

Brain mechanisms involved in movement

Movement disorders

Here’s what’s on the agenda for this week. We’ll be covering how our muscles work and connect to our brains, how our brain coordinates various sensory and motivational processes to execute movements, and also what happens when movements malfunction. So let’s get started!



[read through the slide]

Basically, the function of the brain is to interact with the world, and we need movement to do that. Our brains have another important function that we've been talking about these past two weeks – to provide a coherent picture of the world, which is provided via our sensory organs and the systems that integrate that information… but what do we do with sensory information once we have it? We use it to move about successfully – to obtain food, to find mates, to avoid dangers – essentially, to survive.

So I think you can make a strong argument for movement being one of the primary functions of the brain.

Muscles and Their Movements

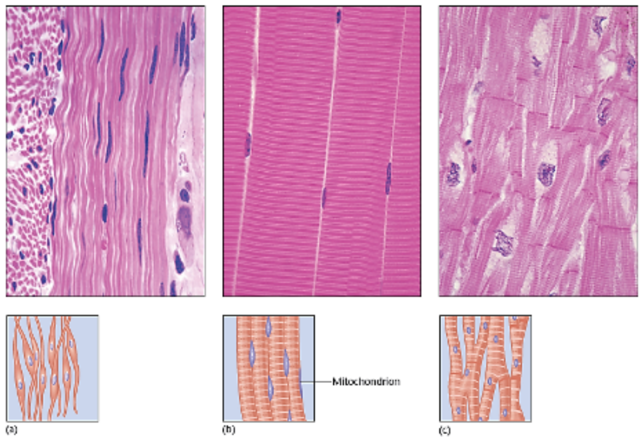
All animal movement depends on muscle contractions of one of three (or a combination of) types of muscles…

- **Smooth muscles**: control the digestive system and other organs
- **Skeletal**/**striated muscles**: control movement of the body in relation to the environment
- **Cardiac muscles**: heart muscles that have properties of skeletal and smooth muscles

The first thing we should talk about when we talk about movement is the different structures that allow us to move. This is mainly accomplished by muscles. And in animals, all movement depends on muscle contractions, which you can think of as the tensing up of muscles. All animals' muscles can be divided into three types, and all animals use different combinations of these three types to move in different ways.

[read through the different types]

Three Categories of Vertebrate Muscles



Smooth Skeletal/Striated Cardiac

This is a really nice picture that delineates the three different types of muscle:

- Smooth muscle, which is found in the intestines and other organs, consists of these long, thin cells.
- Skeletal or striated muscle consists of long cylindrical fibers with stripes – hence the term striated, which is another term for “linear marks” or “stripes.”
- And finally we have cardiac muscle, which is found solely in the heart, and which consists of fibers that fuse together at various points. Because of these fusions, cardiac muscles contract together rather than independently.

Muscle Fibers

Muscles are composed of many individual fibers

- Each muscle fiber receives information from only one axon, but a single axon may innervate many muscle fibers
- The fewer number of fibers that are innervated by an axon, the more precise the movements (e.g., eye muscles)
- The greater number of fibers that are innervated by an axon, the less precise the movements (e.g., bicep muscles)

So let’s drill down further and look at what muscles are made of. Go ahead and read through the slide to get an idea of how these structures are broken down into their component parts.

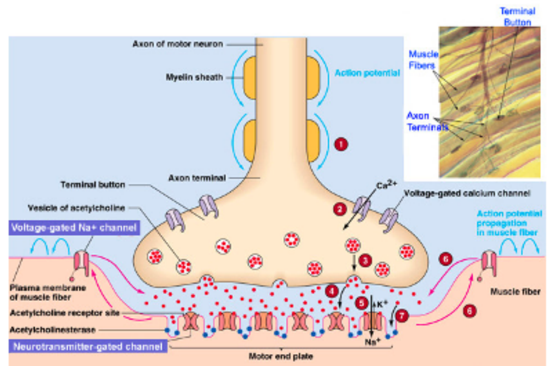
Speaking to these last two bullet points, why is it like that? Think about the fovea, and how one cone connects to one bipolar cell, and that one bipolar cell connects to one midget ganglion cell, and so on. The fact that a single cone has a direct route to the brain means that there’s no interference coming from other neurons – so visual information from the fovea ends up being very precise. The same is true for muscle fibers: fewer connections means less interference, which enables more precision in movement.

Muscle Fibers

A **neuromuscular junction** is a synapse between a motor neuron axon and a muscle fiber

Release of acetylcholine causes the muscle to contract

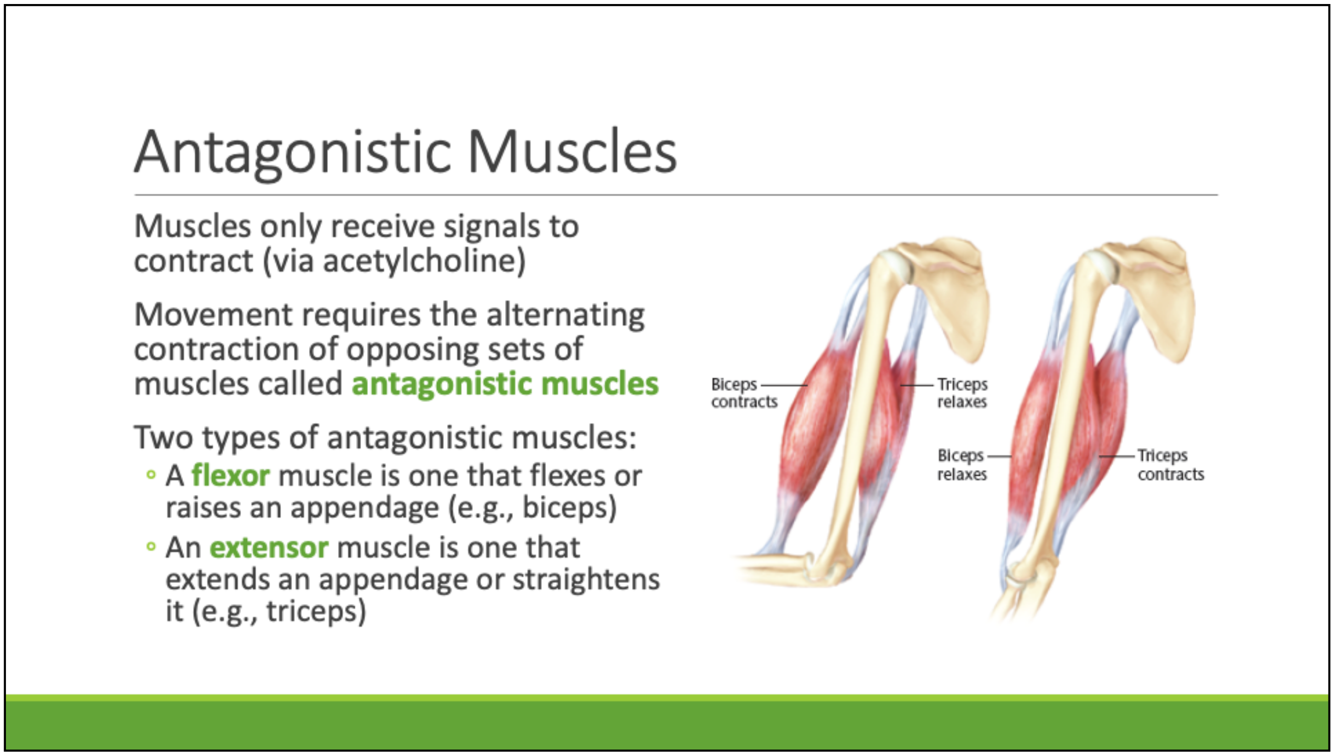
The Neuromuscular Junction



Motor neurons are connected to muscle fibers, and the synapse between them is known as a neuromuscular junction.

Motor neurons release acetylcholine into the neuromuscular junction, and when acetylcholine binds to receptors on the muscle, it causes a contraction.

Now, I'm *definitely* not expecting you to know any of the processes here, but I think this diagram is worth taking a moment to study. Ask yourself how this reaction is similar to what you know about action potentials and the release of neurotransmitters in the synapse. At this point in the class, it's probably a little overwhelming to look at at first, but the more you look at it, the more it should start to seem familiar to you. Look how much progress we've made! ☺



Muscles *only* receive signals to contract, which as I said previously is accomplished through the transmission of acetylcholine. And they relax in the absence of this signal.

Similarly, there are no signals which tell muscles to move in the opposite direction – this is accomplished through the *contraction of opposing sets of muscles* which are called antagonistic muscles.

There are two types of antagonistic muscles, which you can read about on this slide.

Fast and Slow Muscles

Skeletal muscle types range from:

- **Fast-twitch**: fibers produce fast contractions, but fatigue rapidly
- **Slow-twitch**: fibers produce less vigorous contractions, without fatigue

Muscles themselves are made up of muscle fibers, and in skeletal muscles, this produces two types of muscles: fast- and slow-twitch. You can read brief descriptions of these above.

Fast and Slow Muscles

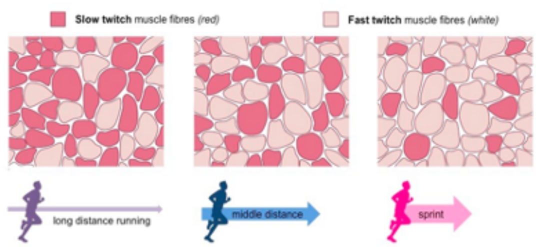
People have varying percentages of fast-twitch and slow-twitch muscles

Slow-twitch fibers are aerobic (requires oxygen during movement) and therefore do not fatigue

- Nonstrenuous or sustained activities utilize slow-twitch and intermediate muscle fibers

Fast-twitch fibers are anaerobic (do not require oxygen during movement, but need it to recover), resulting in fatigue

- Behaviors requiring quick movements utilize fast-twitch fibers



From BioNinja

[read through the slide first]

Both of these fibers use oxygen like currency, but slow-twitch fibers use oxygen as they're active, so they can be sustained for a lot longer. Fast-twitch fibers don't use oxygen when they're active, but they'll need oxygen to replenish themselves eventually. So they typically occur in short, strong bursts of movement.

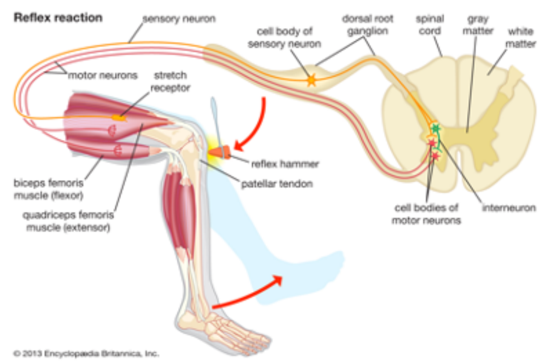
Muscle Control by Proprioceptors

Proprioceptors: receptors that detect the position or movement of a part of the body

Muscle spindles are proprioceptors parallel to the muscle that responds to a stretch → cause a contraction of the muscle

A **stretch reflex** occurs when muscle proprioceptors detect the stretch and tension of a muscle and send messages to the spinal cord to contract it

- Example: Knee-jerk reflex



From Encyclopedia Britannica

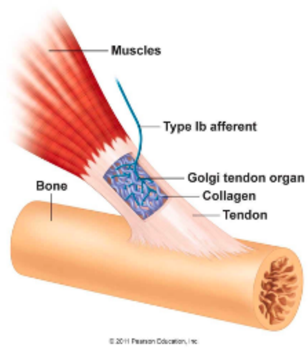
We have an ability to automatically and unconsciously make adjustments to our bodies in response to small physical changes in this environment. This is accomplished by proprioceptors, which are receptors that continually detect the position of your body relative to its surroundings.

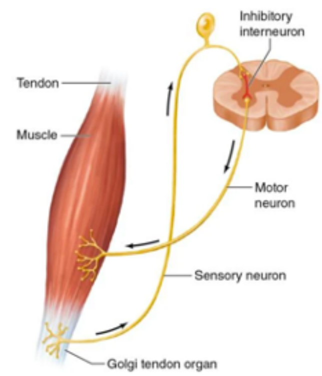
One type of proprioceptor is called a muscle spindle. Muscle spindles lie parallel to the muscle that responds to a stretching motion. Whenever a muscle is stretched, the muscle spindle sends a message to a motor neuron in the spinal cord, which in turn sends a signal that triggers the opposing muscle to contract. This keeps us from over-extending our muscles when we move. This broad set of movements is known as a stretch reflex. A knee-jerk reflex is a type of stretch reflex: when something hits our knee at just the right place, our knee will make a small jerking motion, but won't extend our leg all the way out. This is a stretch reflex in action.

Muscle Control by Proprioceptors

The **Golgi tendon organ** is another type of proprioceptor that responds to increases in muscle tension

- Located in the tendons at the opposite ends of the muscle
- Acts as a "brake" against excessively vigorous contraction by sending an impulse to the spinal cord where motor neurons are inhibited





From Human Kinetics

Another type of proprioceptor, the Golgi tendon organ, responds to increases in muscle tension. It's located in a very small area, at opposing ends of a muscle, in the tendons. And its function is to essentially prevent muscles from over-contracting.

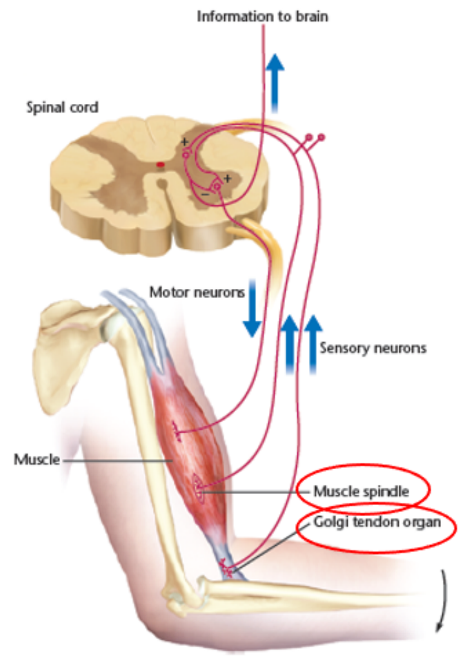
So basically, when a muscle contracts, Golgi tendon organs send signals to the spinal cord, and these signals activate inhibitory neurons. This stops the muscle from contracting too much, which could potentially cause a lot of damage.

So both muscle spindles and Golgi tendon organs function to keep muscles from over-exerting themselves. This is very important, because a lot of muscle movements are reflexive – meaning they tend to occur automatically. So we need something in place to *automatically* keep these reflexes from being too vigorous.

Two kinds of proprioceptors regulate muscle contractions

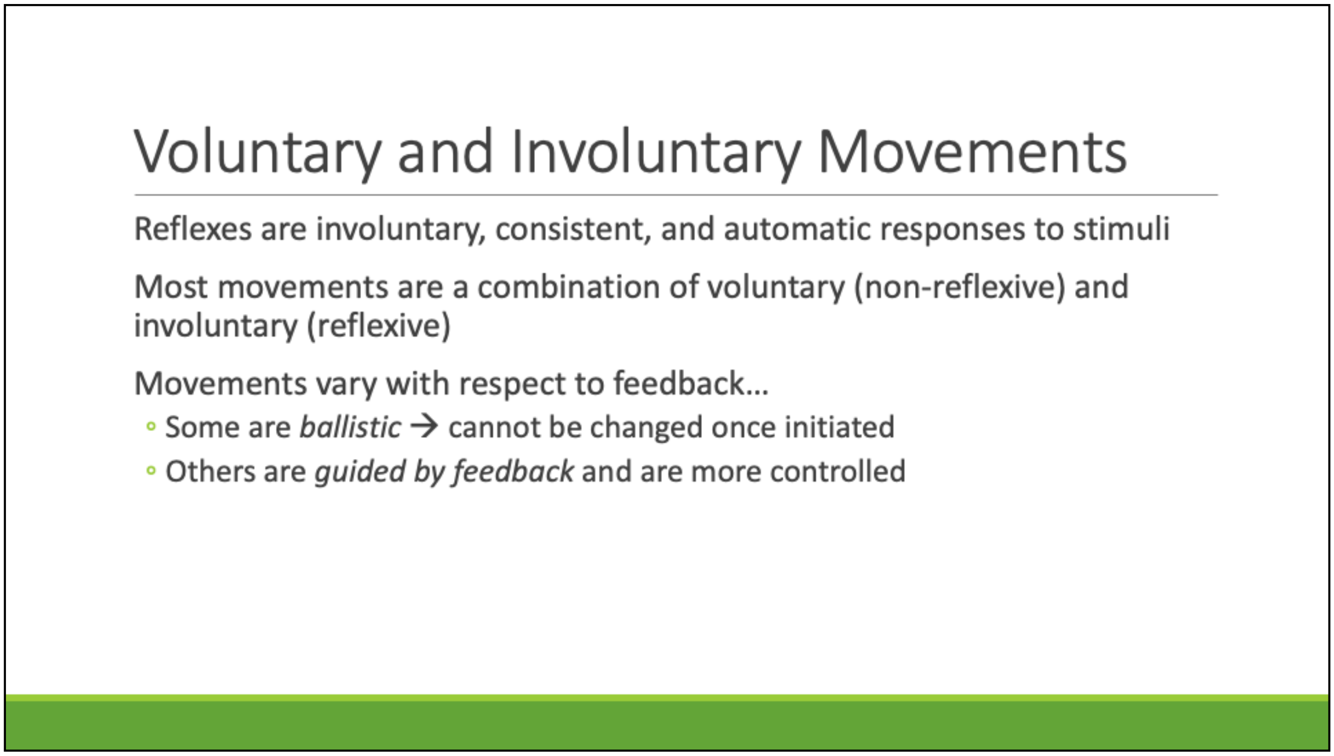
Muscle is stretched → nerves from muscle spindles stimulate contraction of the muscle

Once muscle is contracted → Golgi tendon organ keeps contraction from being too quick/extreme



This is a nice depiction of how these two types of proprioceptors work in tandem.

When a muscle is stretched, nerves from the muscle spindles, which are located on muscles transmit impulses that lead to contraction of the muscle. When a muscle is contracted, that stimulates the Golgi tendon organ, which is located here on the muscle tendon. The organ acts as a brake or shock absorber to prevent a contraction that is too quick or extreme. You can follow the pathways of each, and in the spinal cord you can see that the muscle fibers have an excitatory effect (indicated by the plus signs in the spinal cord), which the Golgi tendon organs have an inhibitory one (indicated by the minus signs in the spinal cord).



So that's how different muscles interact with motor neurons. Let's talk about movement more generally.

Movement can roughly be divided into two types: voluntary and involuntary. Reflexes – which are what we've been talking about so far – are involuntary. They're also consistent, in that they respond the same way to the same type of stimulation every time. And they are also automatic, meaning they occur in response to a stimulus without interference (although they can be interrupted).

Importantly - even though you can divide up movement into voluntary and involuntary, *most movements are a combination of both.*

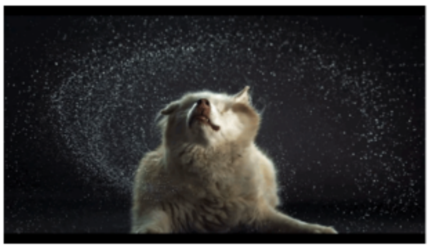
Movements also vary with respect to feedback from the environment. Some are "ballistic," meaning once they start, you can't stop them. This includes most reflexes. Others are more sensitive to feedback and are thus more under voluntary control. Your book uses an example of threading a needle – this is something that requires feedback from the environment to tell you whether you need to adjust the position of the thread, the needle, or both.

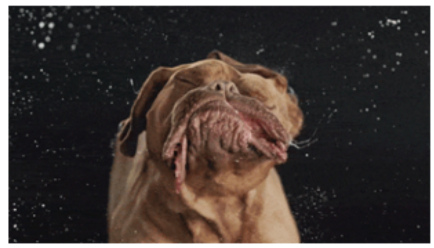
Sequences of Behaviors

Many behaviors consist of rapid sequences of individual movements

Central pattern generators → neural mechanisms in the spinal cord that generate rhythmic patterns of motor output

- Example: wing flapping in birds or "wet dog shake"





[read through this slide first]

In terms of central pattern generators, the thing that causes them to do their thing does not control how fast it's done once it starts. Unless there's something wrong, a given dog will always shake at the same frequency once that behavior is initiated.

I looked up "wet dog shake" to give you some visuals, and it *really* paid off – although I'm sad you won't be able to see these as gifs, because they're really magnificent. Dogs are very floppy, apparently. But importantly! This is an example of a motion pattern that will always occur at the same frequency once initiated. The motion pattern itself is generated in the spinal cord, and interestingly, this pattern will be initiated even if the neurons involved are isolated from the brain or the muscles involved are paralyzed. The shake may ultimately look different, but the pattern will still be initiated regardless. It's like executing a computer program, even if they underlying hardware isn't capable of performing it.

Sequences of Behaviors

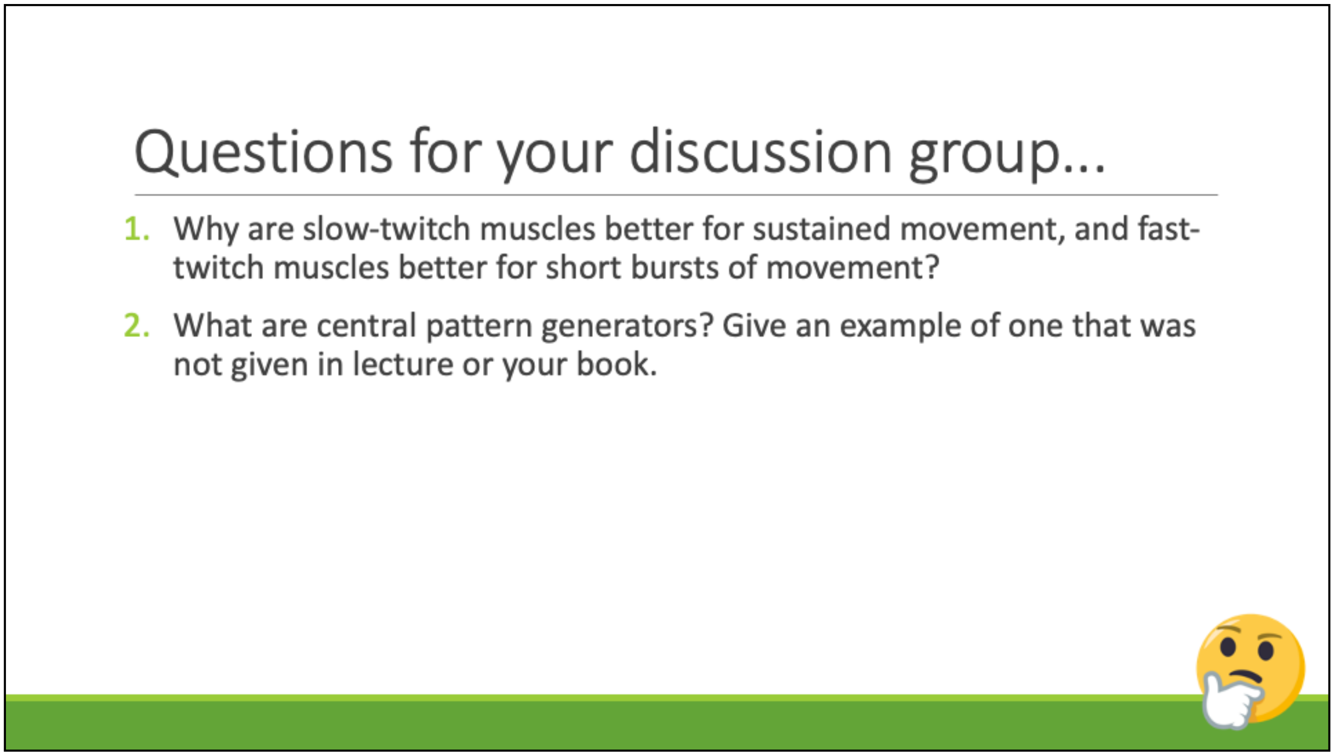
Many behaviors consist of rapid sequences of individual movements

A **motor program** refers to a fixed sequence of movements that is either learned or built into the nervous system

- Once begun, the sequence is fixed from beginning to end
- Automatic, but thinking or talking about it can interfere with the action
  - Examples: mouse grooming itself; yawning

One specific type of central pattern generator is called a motor program. This refers to a fixed sequence of movements – and it can either be learned, or "innate" (side note: I actually don't like using the term innate because it's often misunderstood, but I think it works here).

A central pattern generator is a type of motor program that is mainly initiated in the spinal cord. But there are many other types of motor programs out there. For *any* motor program, though, once it begins, the sequence is fixed. Your book has a great example of a cat scratching: once initiated, a cat will scratch at roughly the same frequency, for roughly the same duration. Other examples include yawning (in all animals that yawn) or grooming patterns in mice. And as a side note: many of these patterns are initiated automatically, but can also be interrupted once started. You can, for example, interrupt someone in the middle of yawning – they might not like you for doing it, but you can do it nonetheless.



Okay, that does it for this lecture! Hopefully reading my notes hasn't been too bad ☺

I have two discussion questions for you here, and then we'll move on to the next lecture: brain mechanisms of movement. See you there!