

# Brain Intelligence and Artificial Intelligence

## 人脑智能与机器智能

Lecture 8 – Motor System 1

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# Recall Lecture 7 – Somatosensory System

- **Introduction to somatic sensation:** touch, pain, temperature, proprioception
- **Touch**
  - Mechanoreceptors of the skin: cell types, receptive fields,
  - Primary Afferent Axon
  - The Spinal Cord
  - The Dorsal Column–Medial Lemniscal Pathway
  - The Trigeminal Touch Pathway
  - Somatosensory Cortex
  - Diseases in Somatosensory System
- **Embodied Intelligence 具身智能**
- **Electronic skin**

# Lecture 8 – Motor System 1

- **Muscles:** skeletal muscle; smooth muscle; cardiac muscle
- **Control of movement:** Spinal & Brain
- **The lower motor neuron**
  - Segmental organization of lower motor neurons
  - Alpha Motor neurons
  - Motor Units & Motor Unit Pool
  - Myotatic stretch reflex & Inverse myotatic reflex
  - Reciprocal inhibition
  - Flexor reflex & Crossed-extensor reflex
- **Musculoskeletal model (for simulation)**
- **Bio-inspired Bipedal Robots**
- **Exoskeleton**

# Movements

- Locomotion (walking, swimming)
- Breathing
- Gastrointestinal motility
- Eye movements
- Prehension (reach and grasp)
- Speech
- ....

## Questions:

- Is our brain **necessary** for these movement control?
- Is our brain involved in **all** of these movement control?

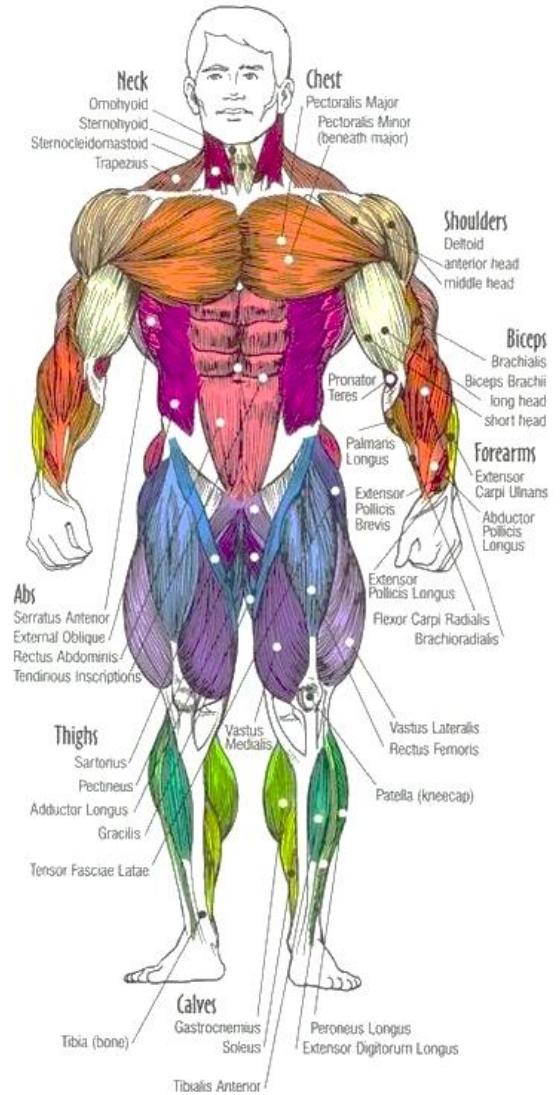
**运动控制的生物学基础：  
神经系统如何控制肌肉收缩，产生运动**

# Muscles

“To move things is all that mankind can do ...  
for such the sole executant is **muscle**, whether  
in whispering a syllable or in felling a forest.”

--Charles Sherrington (1857–1952)  
Nobel Prize in 1932

<https://baike.baidu.com/item/%E6%9F%A5%E5%B0%94%E6%96%AF%C2%B7%E6%96%AF%E7%A7%91%E7%89%B9%C2%B7%E8%B0%A2%E7%81%B5%E9%A1%BF/451704> 百度百科（查尔斯·斯科特·谢灵顿）



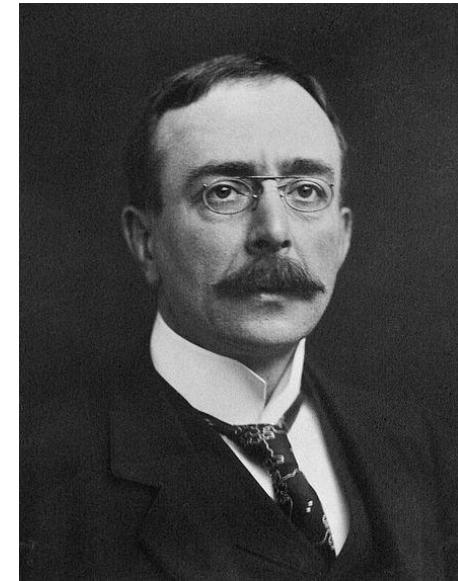
# Charles Scott Sherrington, 1932年诺贝尔生物医学奖。

他在 Cajal 创立的神经元学说的基础上，于 1897 年 提出使用 [突触](#) (synapse) 来描述一个神经元与另一个神经元之间的接触部位，并认为神经元与神经元之间在这个部位进行信息沟通。

Sherrington 在 [脊髓反射](#) 的研究中具有诸多建树，他非常准确地将脊髓前角 [运动神经元](#) 称为运动传出的 final common pathway，并于 1925 年提出使用 [运动单位](#) (motor unit) 来命名运动功能的基本单位，即一个运动神经元和它所支配的一群肌纤维。

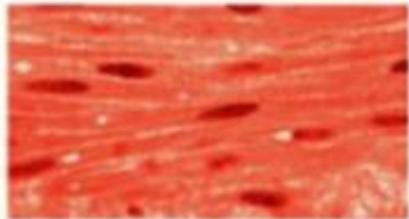
他是最早认识到 [感觉传入信息](#) 在调节运动中具有重要作用的少数几个人之一。1894 年他发现支配肌肉的神经含有感觉神经纤维和引起肌肉收缩的运动神经纤维。在此之前，他于 1893 年就已发现 [肌肉](#)、[肌腱](#) 和 [关节](#) 等处具有感觉功能，并提出了 [本体感觉](#) (proprioception) 这一术语。他认为 [本体感觉](#) 的信息由 [传入神经纤维](#) 传至 [中枢](#) 后可决定肌肉的紧张度。1900 年他指出 [小脑](#) 是本体感受系统的中枢。

他最早体会到 [牵张反射](#) 在姿势调节中的重要性，从而奠定了研究运动和姿势调节的反射基础。他还把 [牵张感受器](#) 称为 [本体感受器](#) (proprioceptive receptor)。在考虑躯体感觉传入对步行运动的作用中，Sherrington 提出本体感受器和外感受器的区别，本体感受器是肌肉和关节内的并可被躯体运动所兴奋，来自本体感受器的传入信息与步行运动的自动调节有关。外感受器则位于皮肤，其主要功能是通过接受外部刺激对步行运动的调节。



# Three Types of Muscles

Smooth muscle



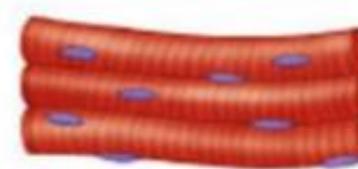
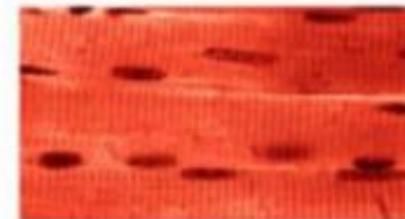
Internal organs

Cardiac muscle



Heart

Skeletal muscle



Arms/Legs

involuntary

voluntary

平滑肌：位于消化道和动脉管壁等部位，受到自主神经系统的神经纤维支配，参与消化道蠕动和血压的控制。

横纹肌：分为心肌(在没有任何神经支配的情况下可发生节律性收缩)和骨骼肌(skeletal muscle)。

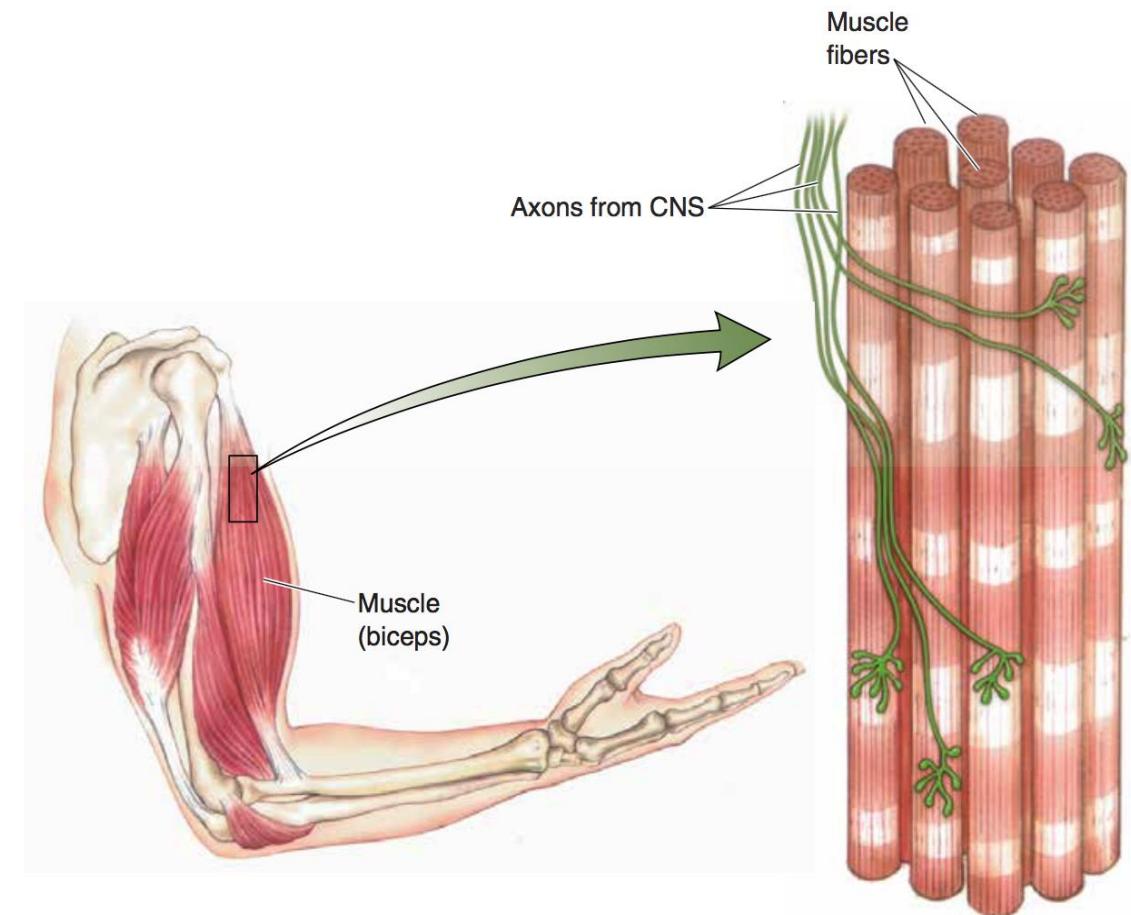
Skeletal muscles are attached directly to the bones in the skeleton.

# Skeletal Muscle

Within each muscle are hundreds of ***muscle fibers***, the cells of skeletal muscle.

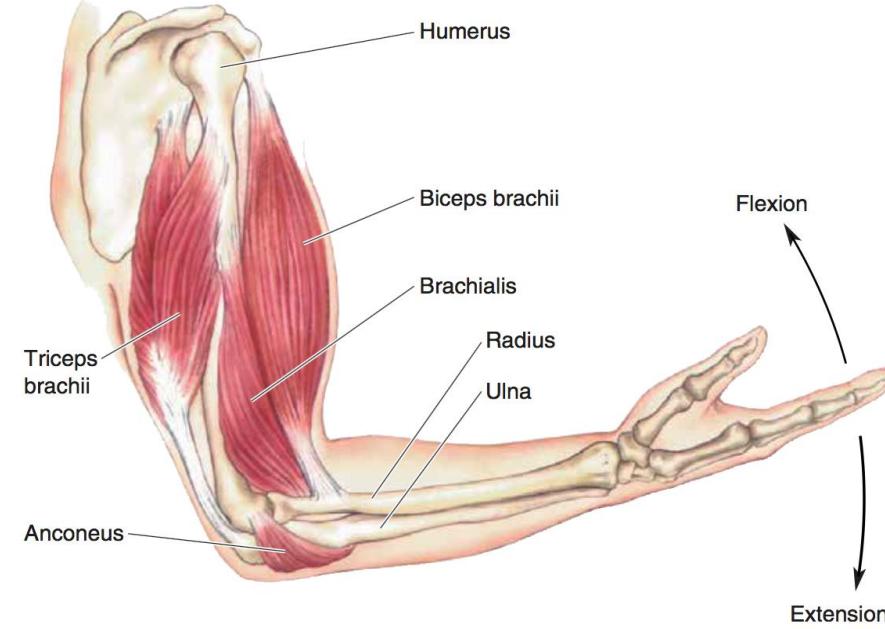
**Each fiber** is innervated by a **single** axon branch from the central nervous system (CNS) .

There are around **600** muscles in the human body, but an exact number is hard.



The structure of skeletal muscle

## Major muscles of the elbow joint

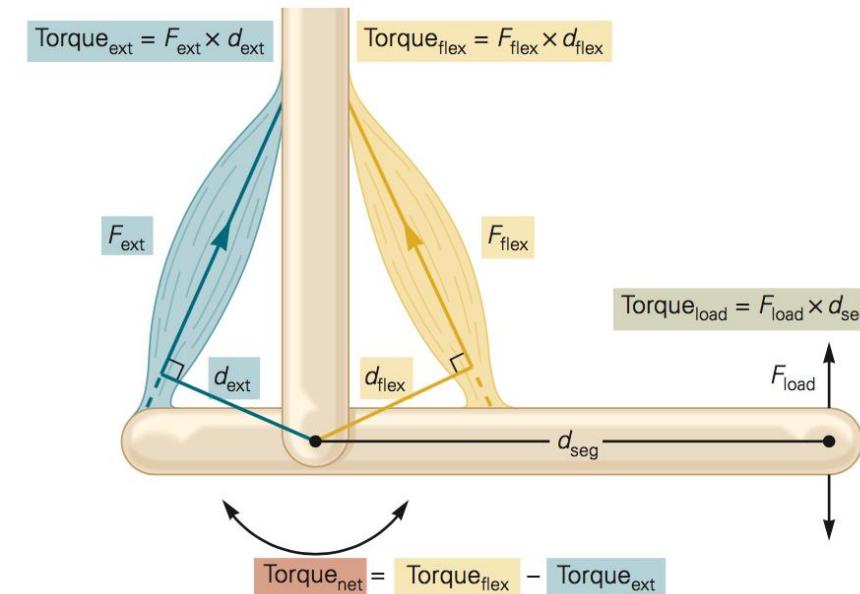
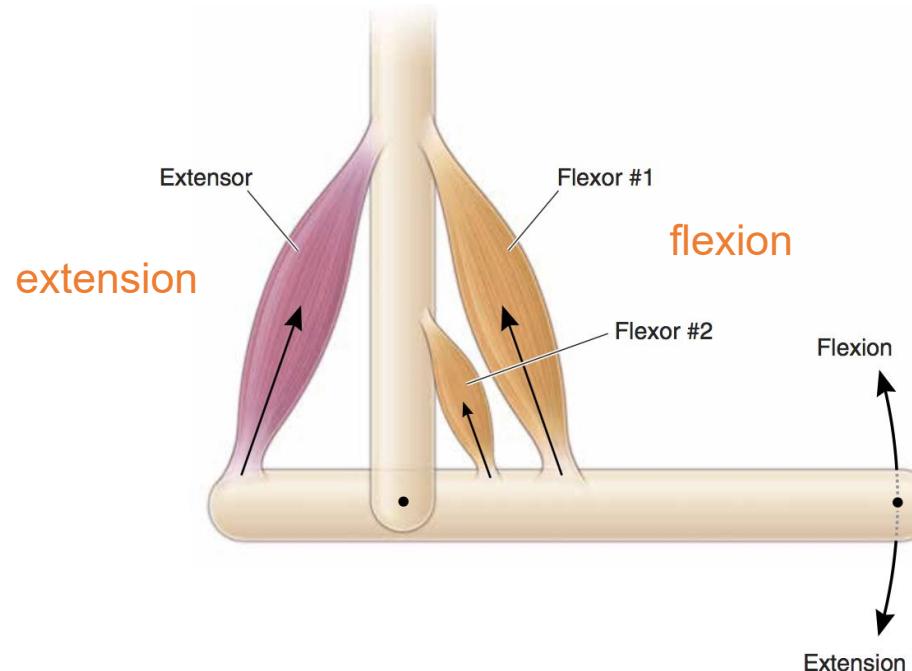


# Skeletal Muscle

Note that muscles only pull on a joint; they cannot push.

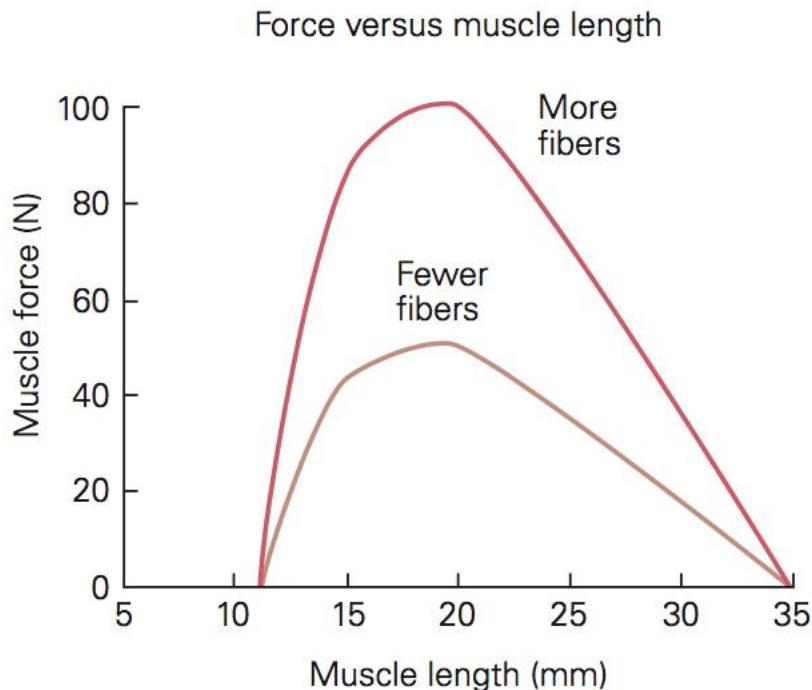
- Flexion
- Extension

Flexion and extension are **antagonist**.

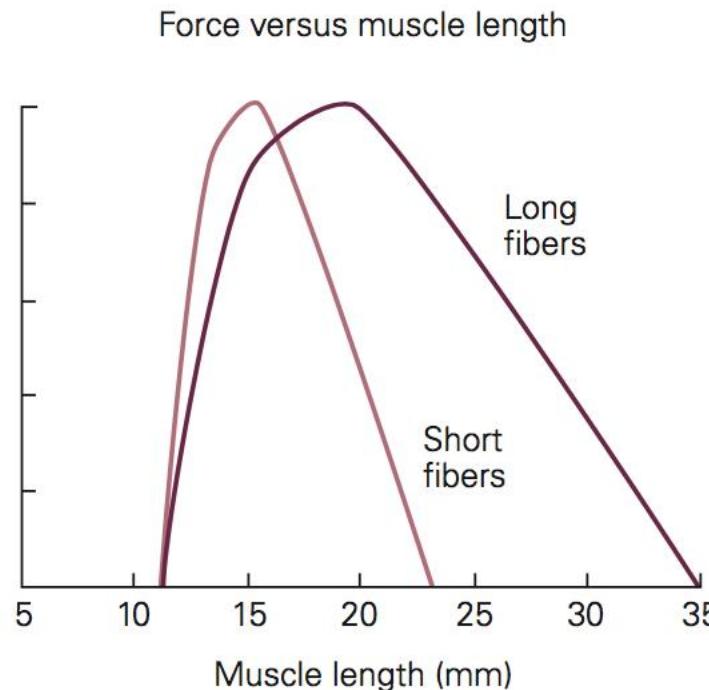


# Diversity of Muscles

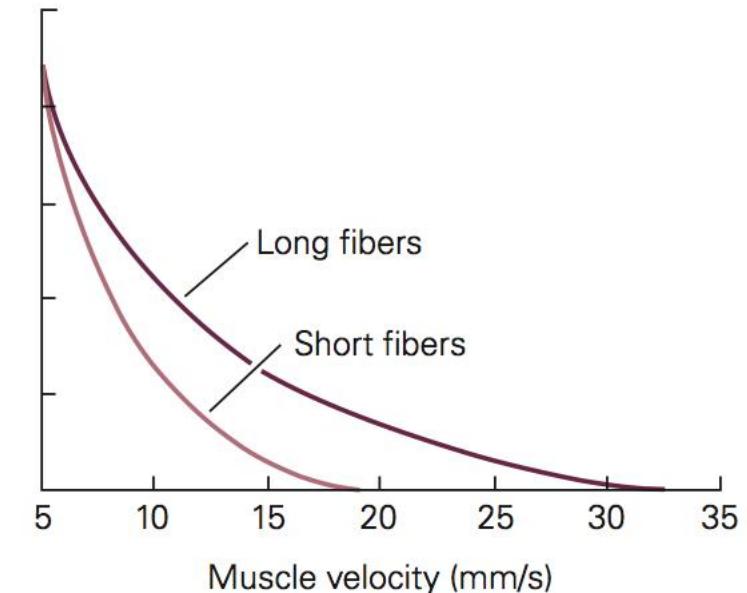
A Different number of fibers



B Different fiber lengths



Force versus muscle velocity



A. Two muscles with similar fiber lengths but different numbers of muscle fibers (**different cross-sectional area**). The muscle with twice as many fibers exerts **greater** force.

B. Muscle force at various muscle lengths for two muscles with the **same cross-sectional area** but different fiber lengths. The muscle with longer fibers has an **increased** range of motion (left plot). It also has a **greater** maximal shortening velocity and exerts greater force at a given absolute velocity (right plot).<sup>11</sup>

# Control of movement

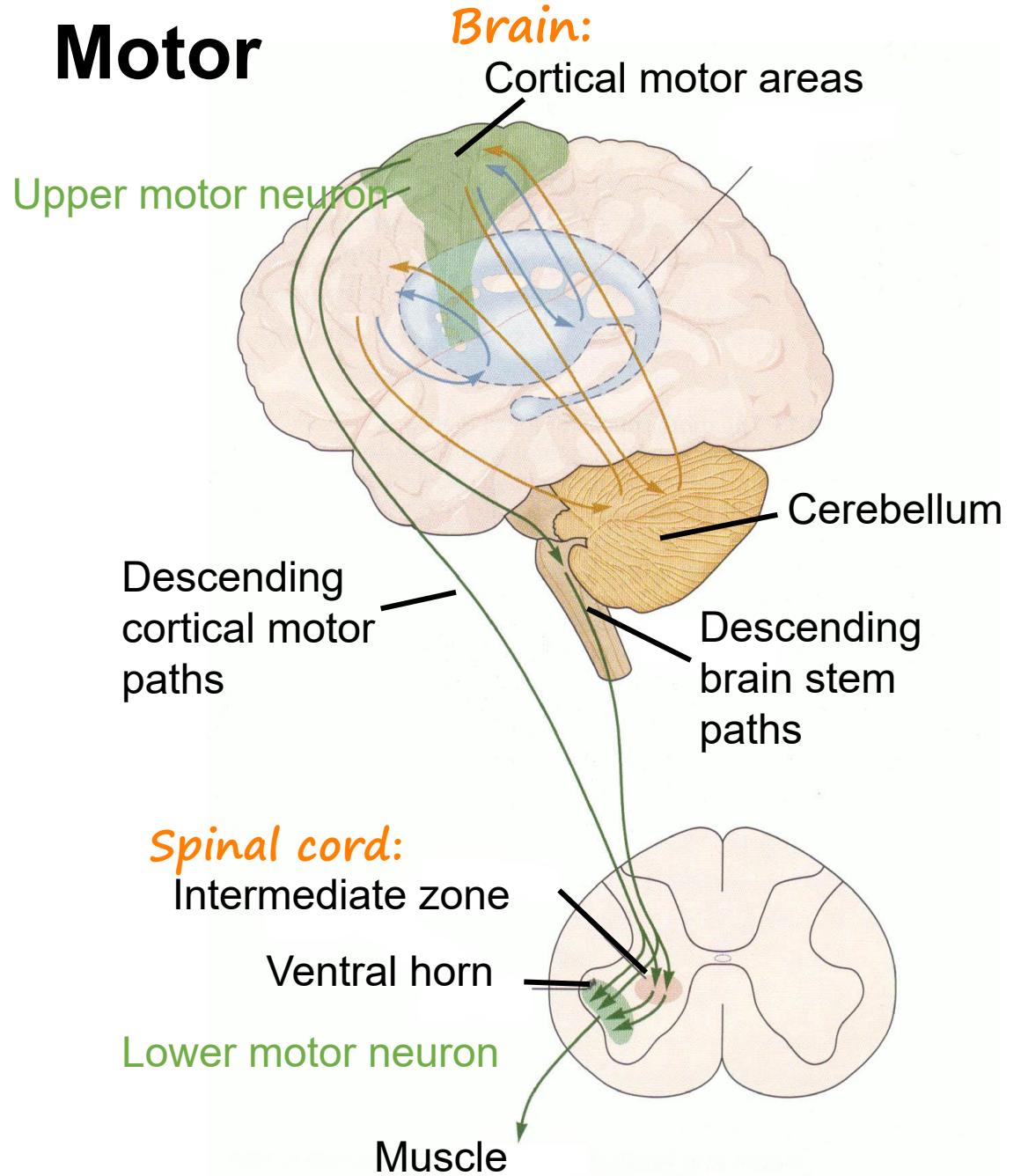
- **Spinal control of movement**

- Fast
- Inaccurate
- Rigid
- Localized
- Unconscious
- Automatic

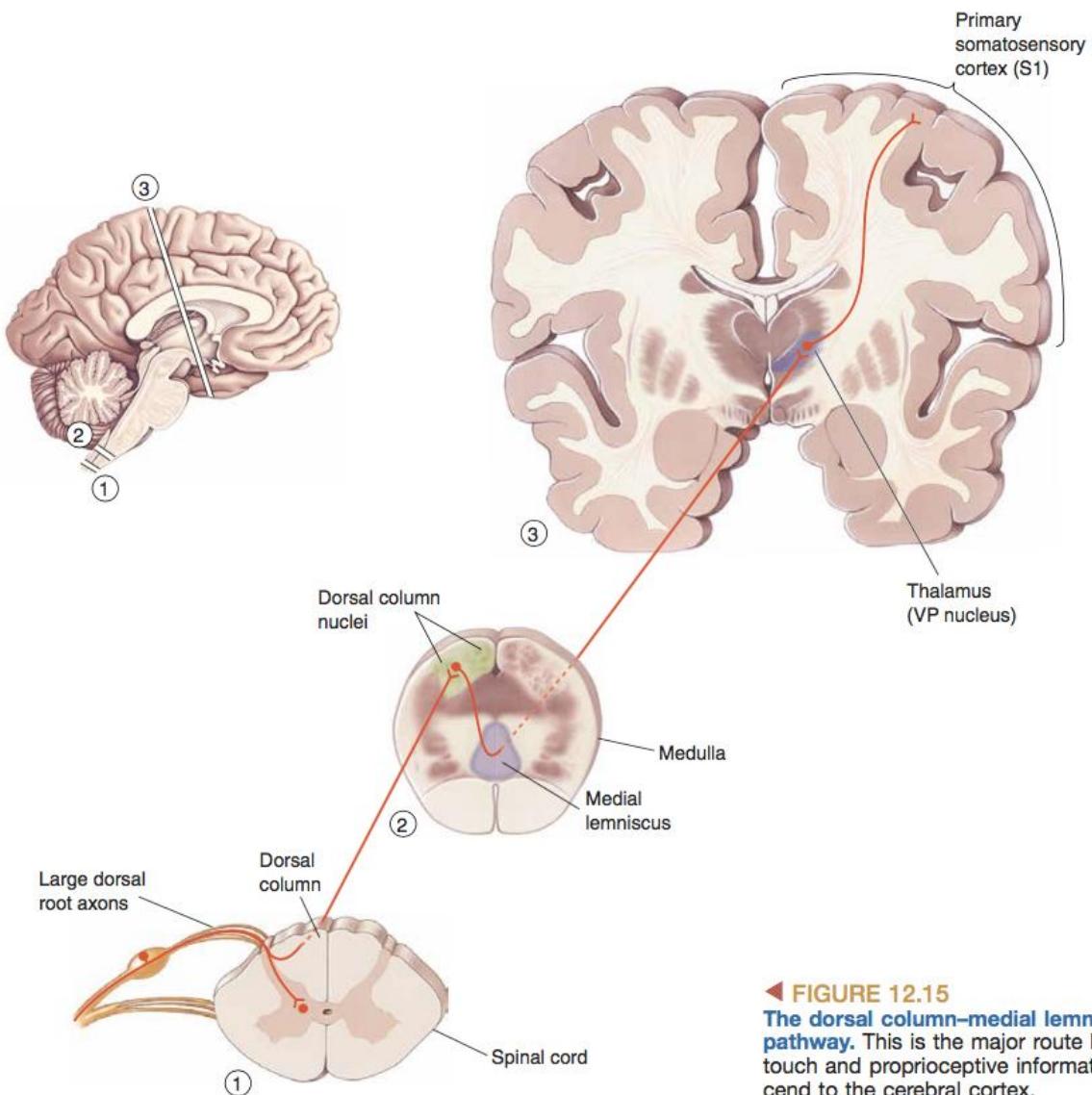
- **Brain control of movement**

- Slow
- Accurate
- Flexible
- Centralized
- Conscious
- Deliberate

## Motor

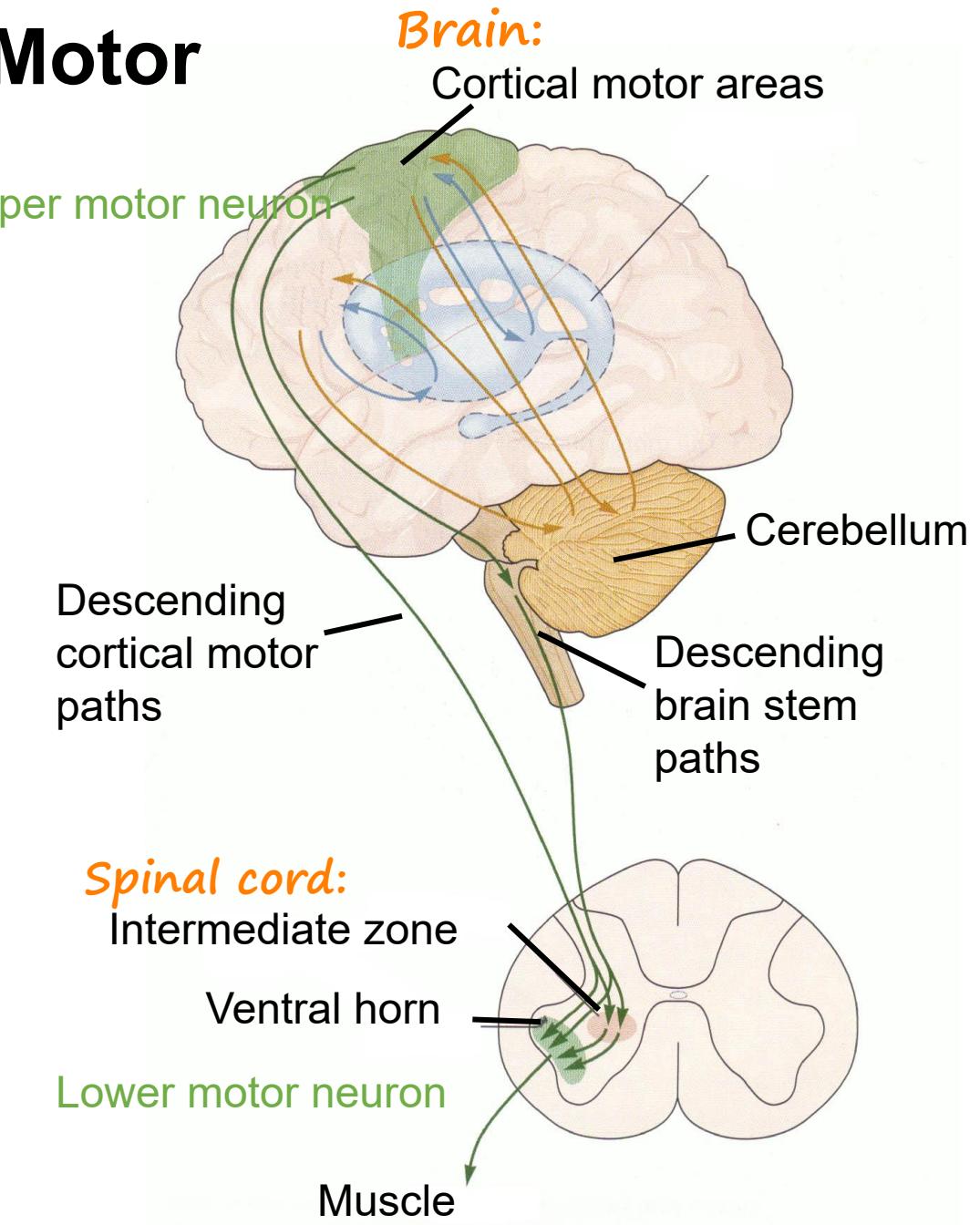


# Somatosensory



◀ FIGURE 12.15  
The dorsal column-medial lemniscal pathway. This is the major route by which touch and proprioceptive information ascend to the cerebral cortex.

# Motor



# **Reflex Layer**

Fast  
Inaccurate  
Rigid  
Localized  
Unconscious  
Automatic

Unstable real dynamics

# **Planning Layer**

Slow  
Accurate  
Flexible  
Centralized  
Conscious  
Deliberate

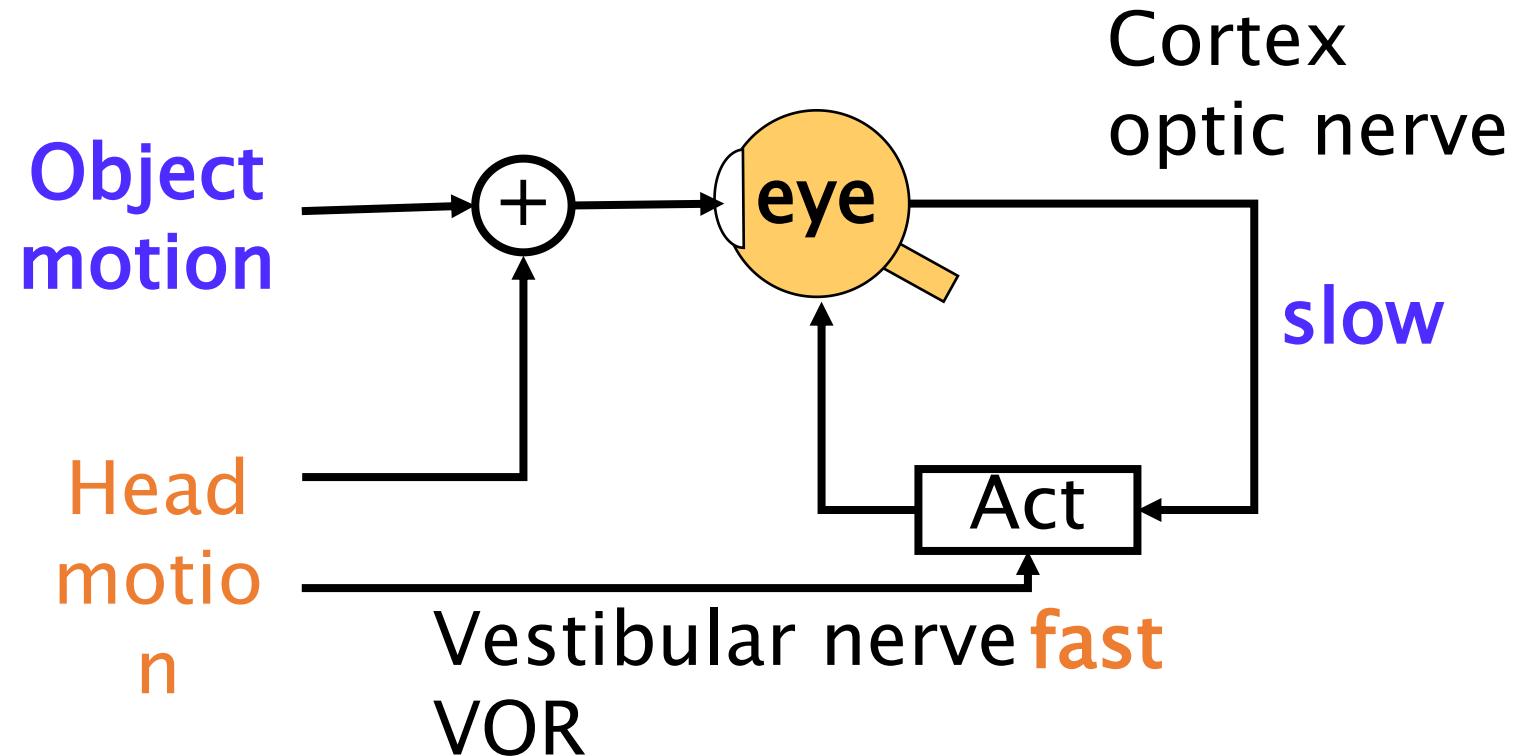
Stable virtual dynamics  
Vision

# A simple test to feel the diversity in two layers

## System level

Task 1: Reading a moving word

## Hardware level

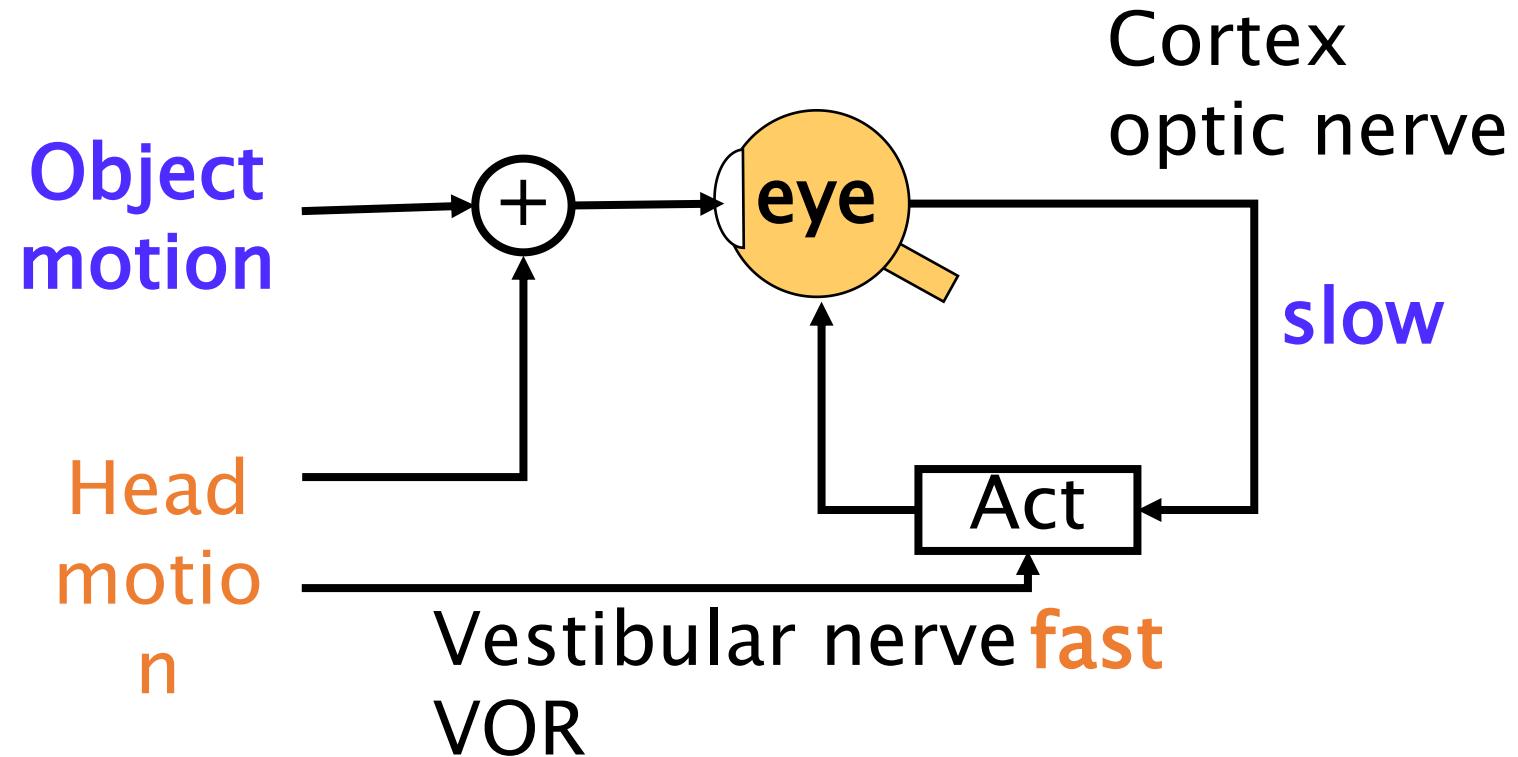


# A simple test to feel the diversity in two layers

## System level

Task 1: Reading a moving word

## Hardware level

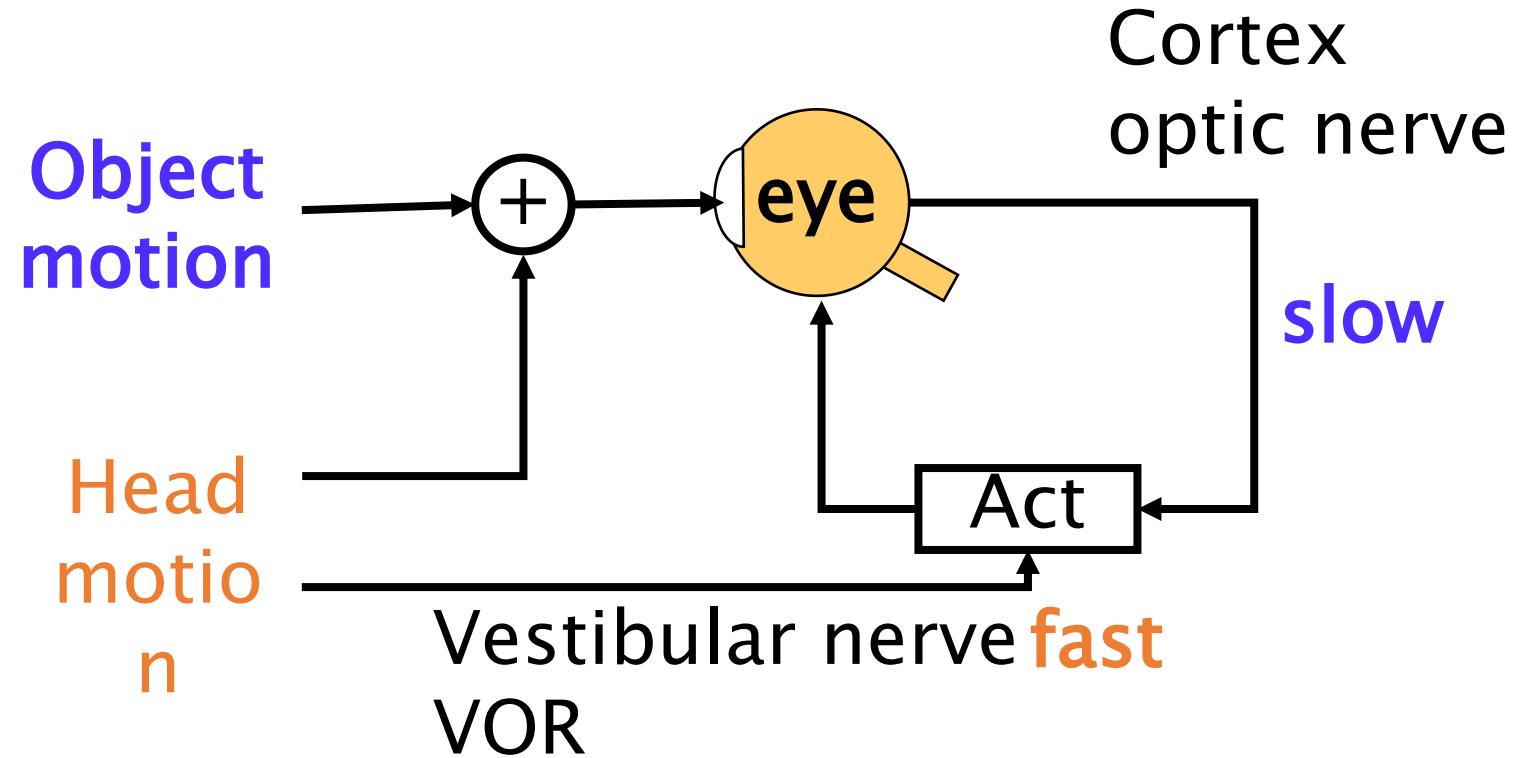


# A simple test to feel the diversity in two layers

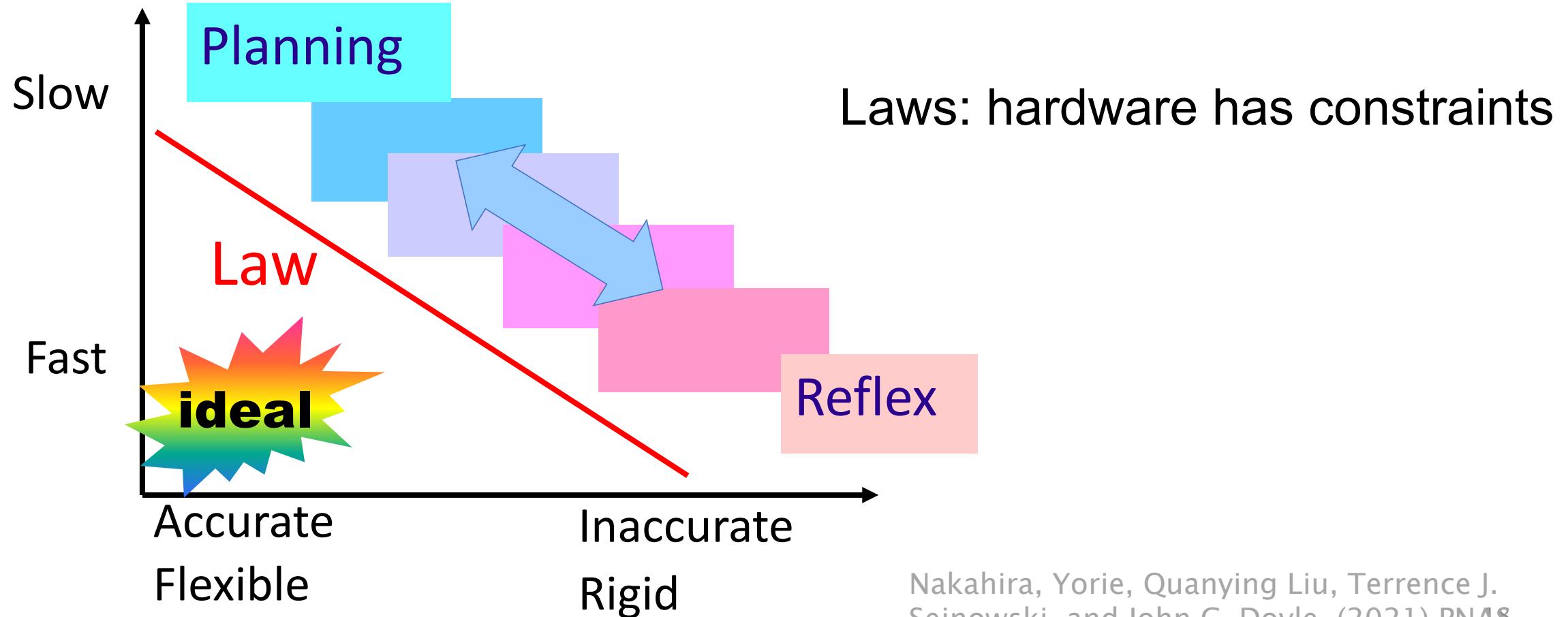
System level

Task 2: Reading under  
head  
motion

Hardware level



# A theory is needed!



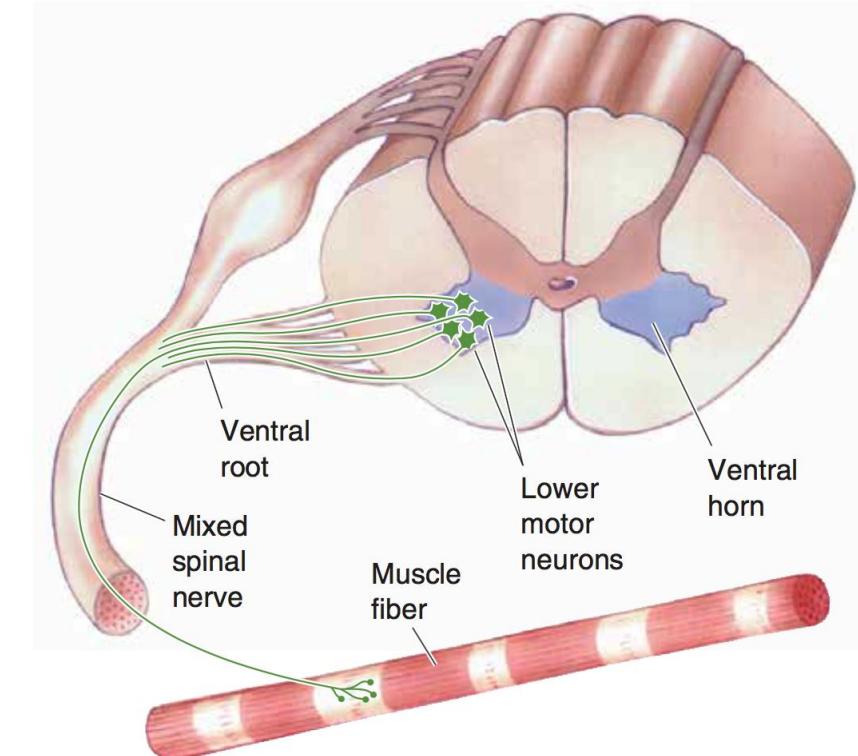
# Lower Motor Neuron

The somatic musculature is innervated by the *lower motor neurons* (*alpha/gamma motor neurons*) in the ventral horn of the spinal cord.

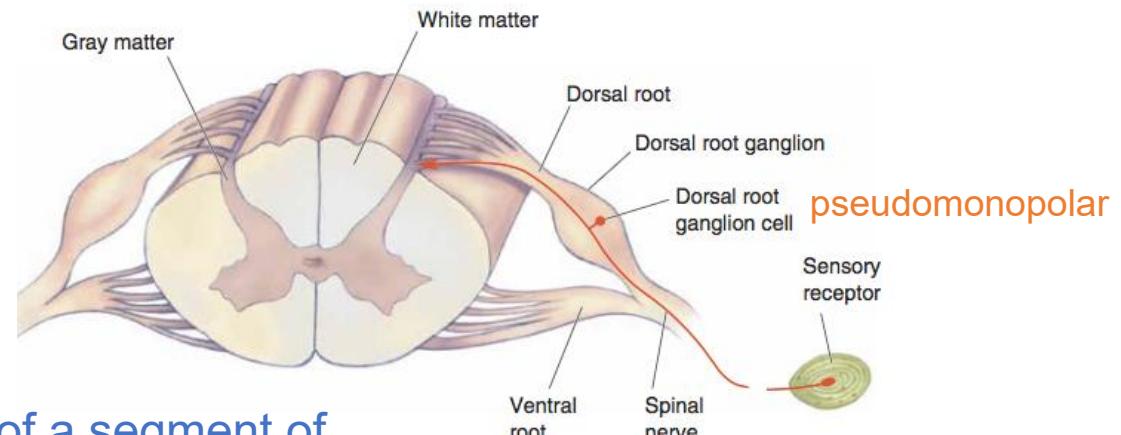
Remember, **only** the lower motor neurons **directly** command muscle contraction.

Alpha motor neurons directly trigger the generation of force by muscles.

Recall the *dorsal root ganglion cell* in somatosensory system



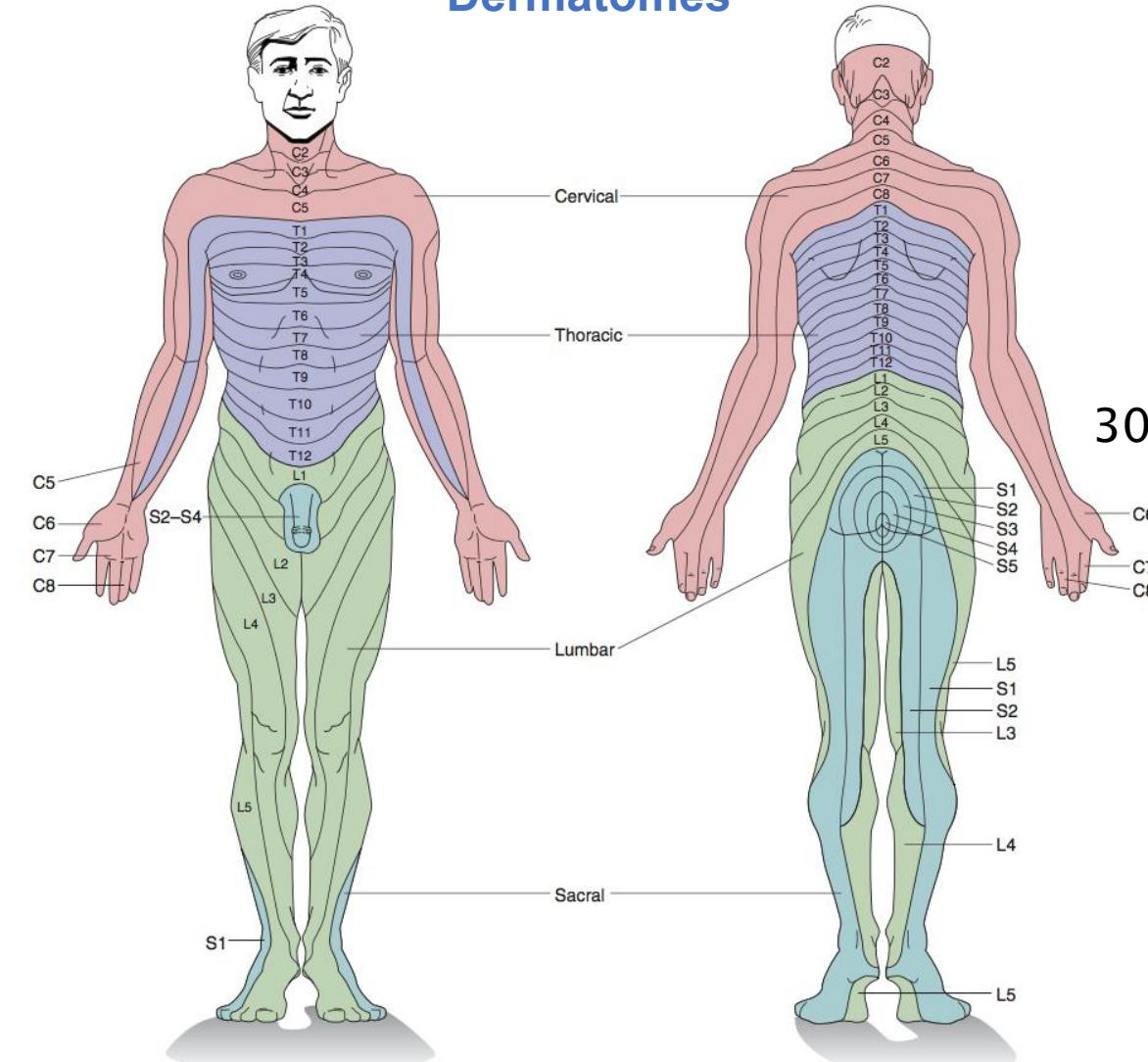
Muscle innervation by lower motor neurons



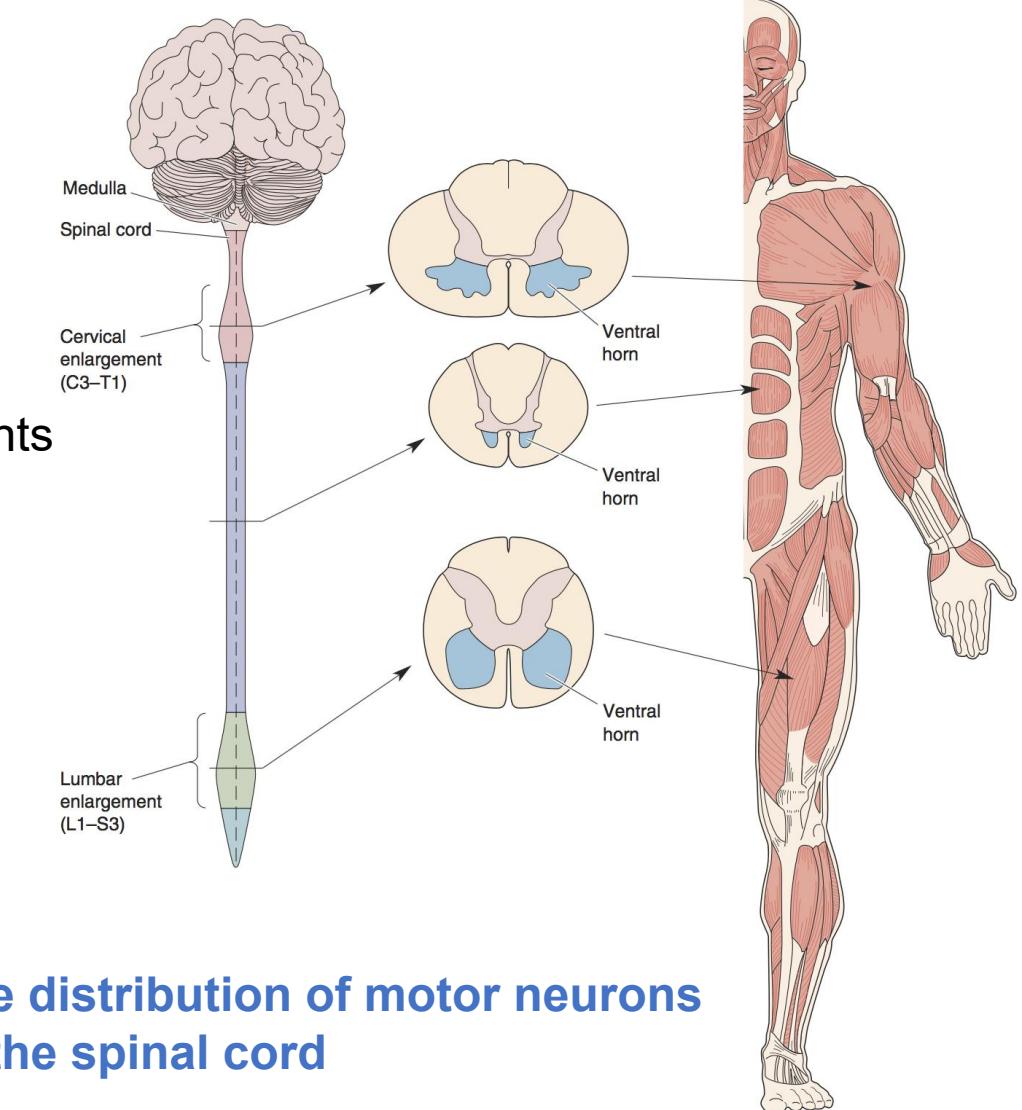
The structure of a segment of the spinal cord and its roots.

# The Segmental Organization of Lower Motor Neurons

## Dermatomes



30 spinal segments



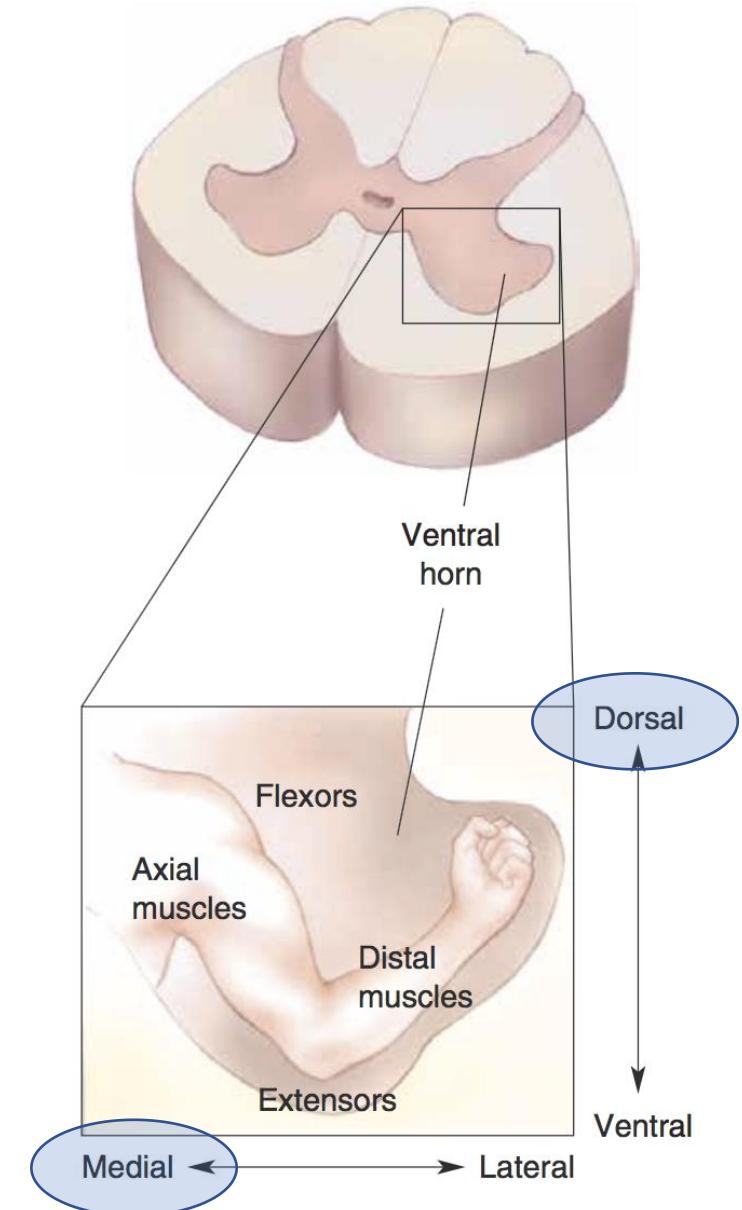
The distribution of motor neurons  
in the spinal cord

# Lower Motor Neurons in Ventral Horn

The lower motor neurons are also **distributed** within the *ventral horn* at each *spinal segment* in a predictable way, depending on their function.

The cells innervating the axial muscles are **medial** to those innervating the distal muscles.

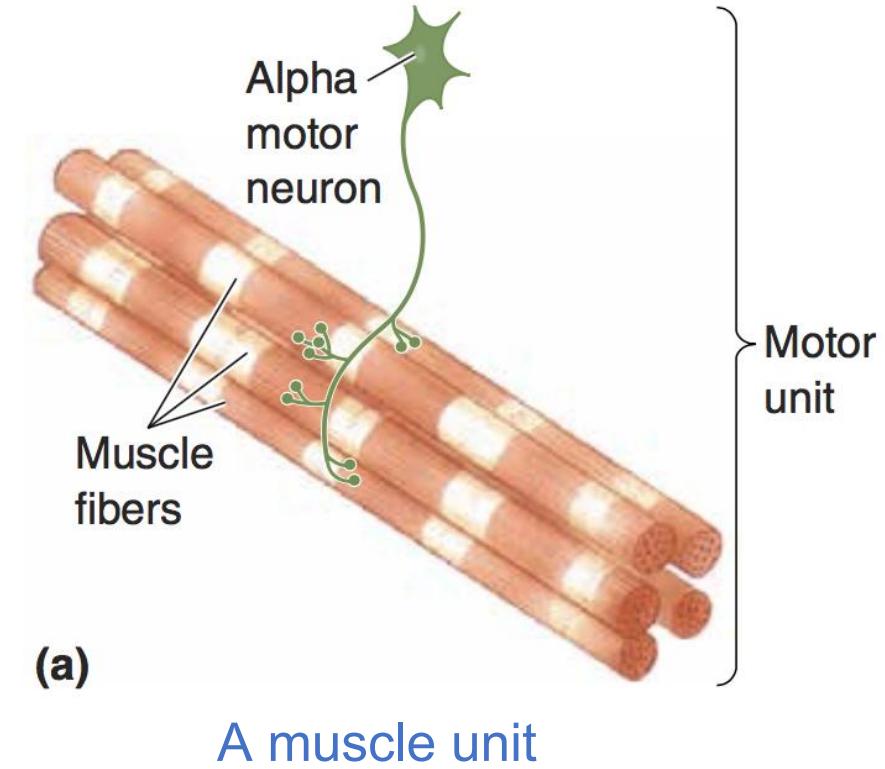
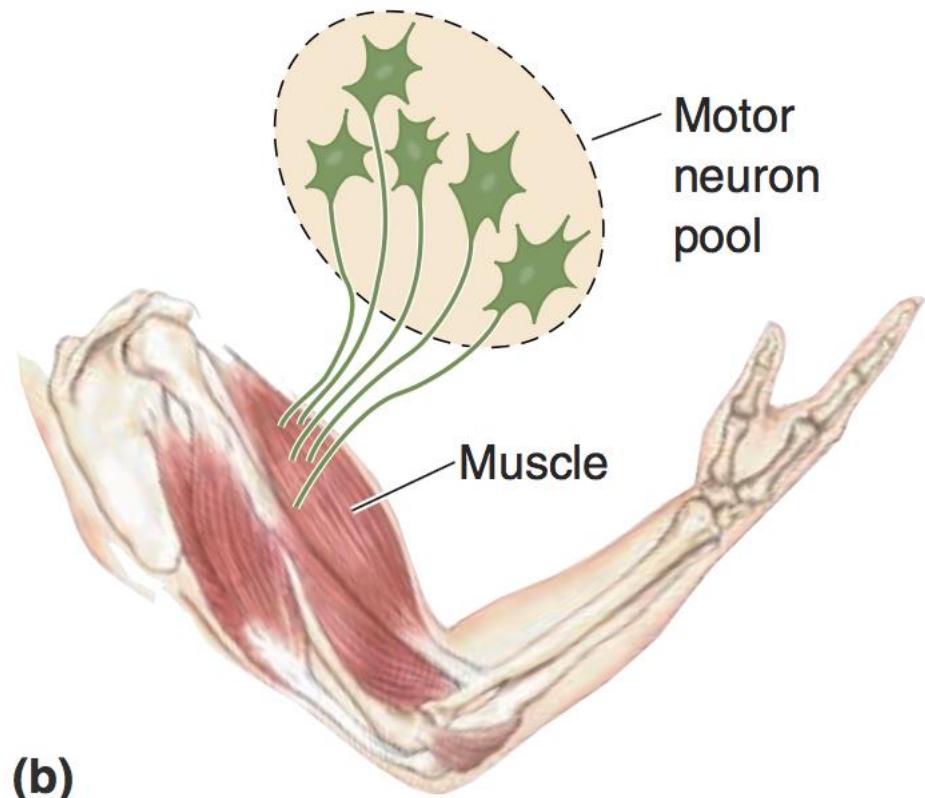
The cells innervating flexors are **dorsal** to those innervating extensors.



The distribution of lower motor neurons in the ventral horn.

# Motor Unit & Motor Unit Pool

A *motor unit* is **an alpha motor neuron** and **all the muscle fibers** it innervates.



A *motor neuron pool* is all the alpha motor neurons that innervate one muscle (such as biceps).

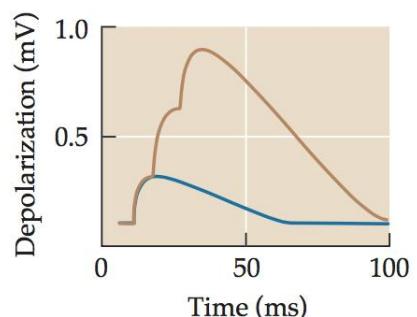
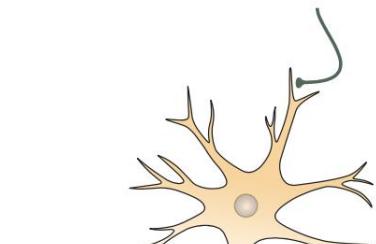
# Graded Control of Muscle Contraction

## Temporal summation and spatial summation

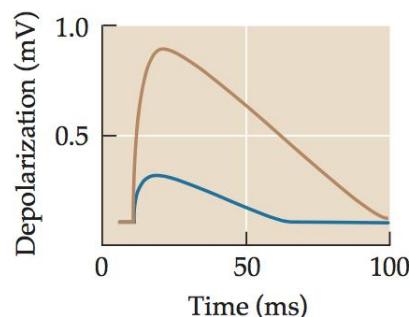
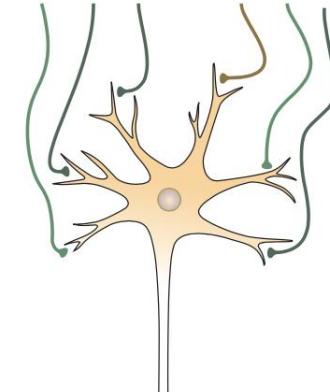
A **single** action potential in Ia afferent produce an EPSP on motoneuron.

How about **three** action potentials in Ia afferent?

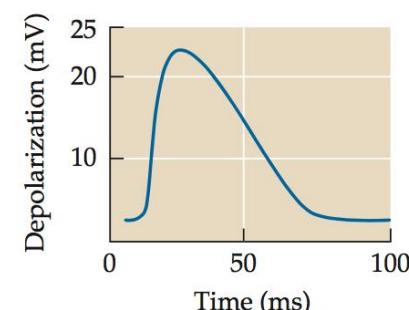
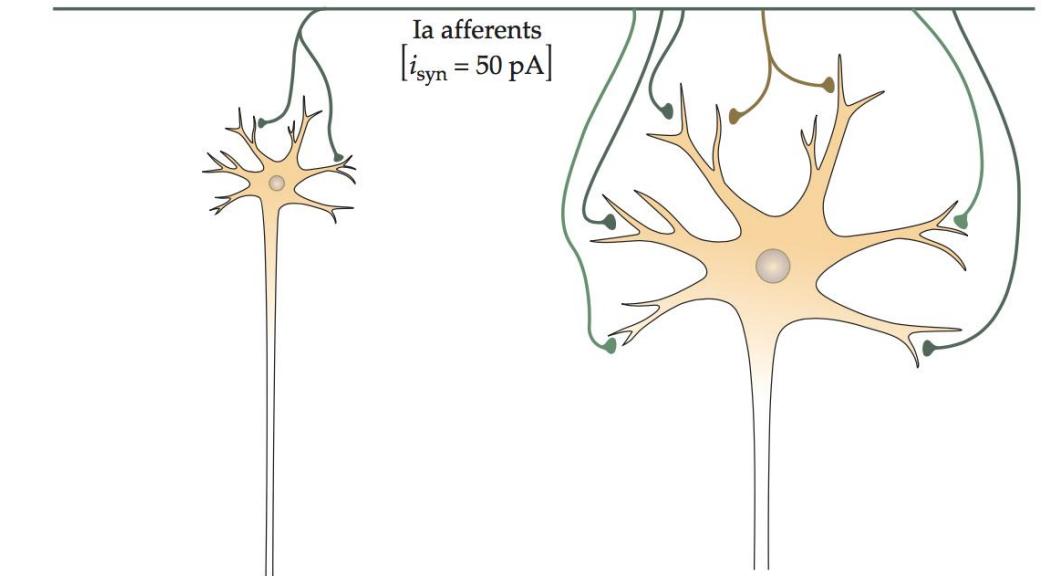
(A) Temporal summation



(B) Spatial summation

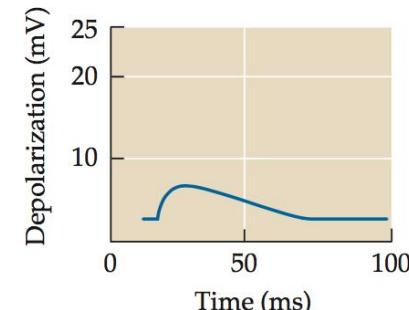


## The Size Principle



$$R_{\text{input}} = 500 \text{ M}$$

$$\Delta V_{\text{syn}} = 25 \text{ mV}$$



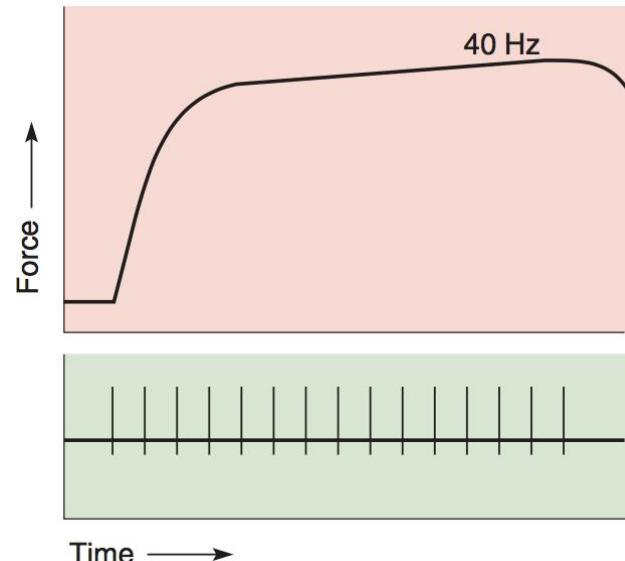
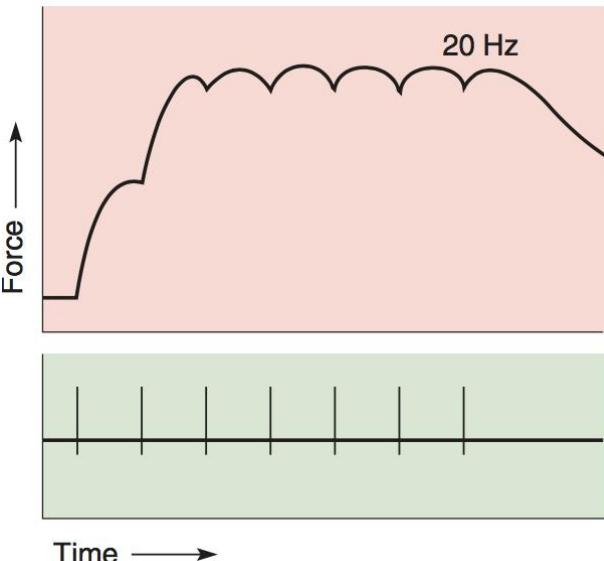
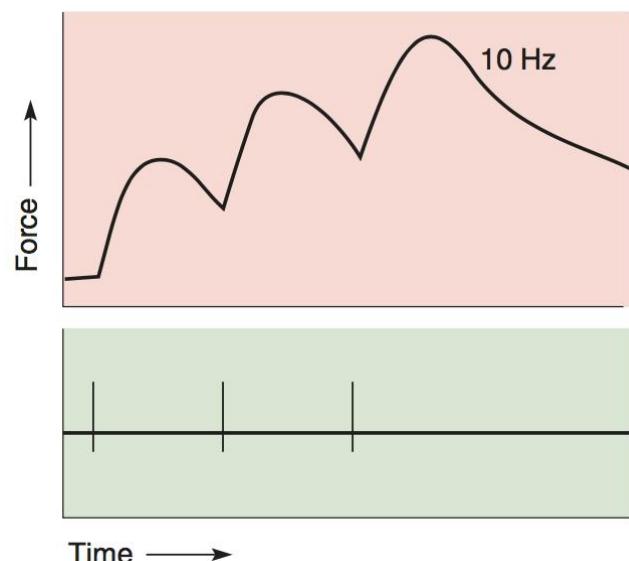
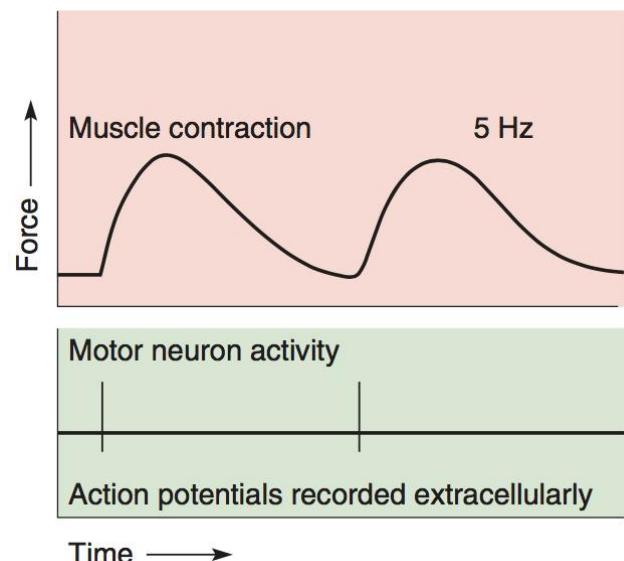
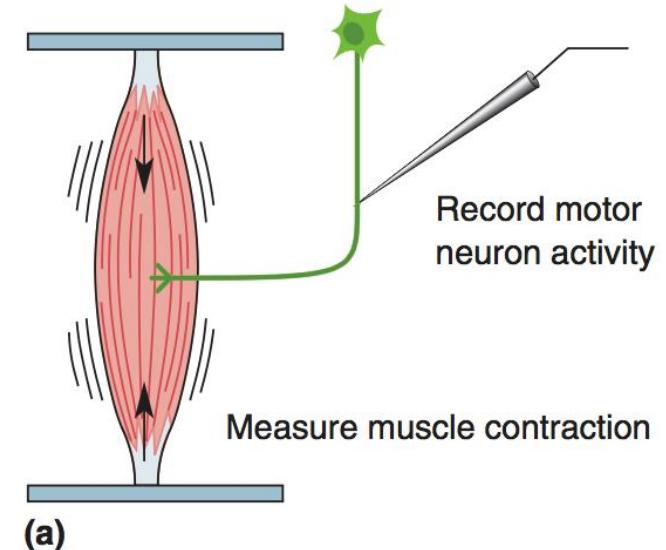
$$R_{\text{input}} = 100 \text{ M}$$

$$\Delta V_{\text{syn}} = 5 \text{ mV}$$

# Graded Control of Muscle Contraction

(a) A single action potential in an *alpha motor neuron* causes the muscle fiber to **twitch**.

(b) The *summation of twitches* causes a **sustained contraction**, as the number and frequency of incoming action potentials increase.



# **From motor neuron activity to muscle fiber activity**

Once *synaptic input* depolarizes the membrane potential of a **motor neuron** above threshold, the neuron generates an **action potential** that is propagated along the axon to its terminal in the **muscle**.

The action potential releases **neurotransmitter** at the neuromuscular synapse, and this causes an **action potential** in the sarcolemma of the **muscle fibers**.

A muscle fiber has electrical properties similar to those of a large-diameter, unmyelinated axon, and thus action potentials propagate along the sarcolemma.

Because the action potentials in all the muscle fibers of a motor unit occur at approximately the same time, they contribute to extracellular currents that sum to generate a **field potential** near the active muscle fibers.

Most muscle contractions involve the activation of **many** motor units, whose currents **sum** to produce signals detected by **electromyography** (EMG).

The *timing* and *amplitude* of EMG activity, therefore, reflect the activation of muscle fibers by the motor neurons.

# From motor neuron activity to muscle fiber activity



请解释一下 motor neuron activity 怎么产生 muscle fiber activity.



参考 4 条网页信息源 ^

1 运动神经环路

知乎 知

2 Modulation of motoneuron activity by serotonin

百度学术 学

3 健身基础知识--窥探组成肌肉的肌纤维

腾讯网 网

4 【BI&AI】Lecture 9-Motor system 1\_肌纤维被单个动作电位激活后、临界阻...

CSDN软件开发网 网

运动神经元活动 (Motor Neuron Activity) 产生肌肉纤维活动 (Muscle Fiber Activity) 的过程是一个复杂的神经肌肉传导过程，涉及多个环节和参与者。以下是对这一过程的详细解释：

## 一、运动神经元的结构与功能

运动神经元是负责将大脑或脊髓的运动指令传递到肌肉纤维的神经元。它们位于脊髓的腹角，并向下延伸至肌肉，形成神经肌肉接头。运动神经元包括 $\alpha$ 运动神经元和 $\gamma$ 运动神经元等，其中 $\alpha$ 运动神经元直接负责产生肌力。

## 二、神经冲动的产生与传导

神经冲动的产生：当大脑或脊髓中的上位运动神经元发出运动指令时，这些指令会沿着下行脊髓束（如皮质脊髓束）传递到脊髓中的运动神经元。运动神经元接收到这些指令后，会产生神经冲动。

神经冲动的传导：神经冲动沿着运动神经元的轴突向下传导，直至到达神经肌肉接头。

## 三、神经肌肉接头的传递

神经递质的释放：当神经冲动到达神经肌肉接头时，运动神经元的轴突末端会释放神经递质（如乙酰胆碱）。这些神经递质会扩散到突触间隙，并与肌肉纤维上的受体结合。

肌肉纤维的激活：神经递质与肌肉纤维上的受体结合后，会引起肌肉纤维的膜电位变化，即去极化。当去极化达到一定程度时，会触发肌肉纤维内部的钙离子释放，进而引发肌肉收缩。

## 四、肌肉纤维的收缩与放松

肌肉收缩：肌肉纤维的收缩是由肌原纤维的收缩引起的。肌原纤维包括粗肌丝和细肌丝，它们之间的相互作用会产生收缩力。当钙离子释放到肌肉纤维内部时，它会与细肌丝上的肌钙蛋白结合，导致细肌丝向粗肌丝滑动，从而产生收缩力。

肌肉放松：肌肉放松的过程是肌肉收缩的逆过程。当神经冲动停止或神经递质被清除时，肌肉纤维的膜电位会恢复，钙离子也会被重新吸收到肌浆网中，导致肌肉纤维放松。

## 五、总结

综上所述，运动神经元活动产生肌肉纤维活动的过程是一个涉及神经冲动产生、传导、神经肌肉接头传递以及肌肉纤维收缩与放松的复杂过程。这个过程需要多个环节的协同作用，包括运动神经元的兴奋、神经递质的释放、肌肉纤维的激活以及钙离子的释放等。这些环节共同决定了肌肉纤维的活动状态和收缩力的大小。<sup>37</sup>

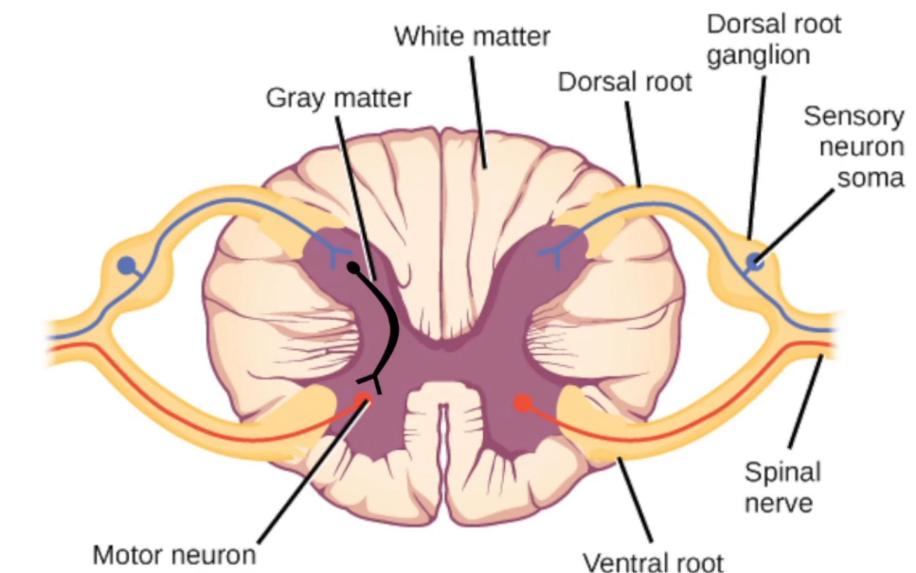
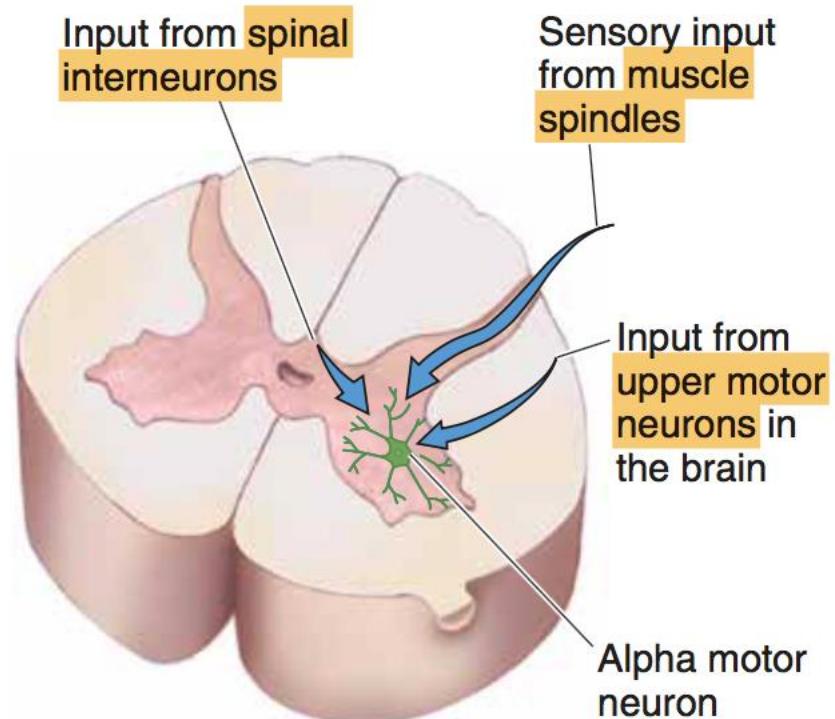
# 3 Inputs to Alpha Motor Neurons

Lower motor neurons are controlled by synaptic inputs in the *ventral horn*.

(1) The first source is *dorsal root ganglion cells* with axons that innervate a specialized sensory apparatus embedded within the muscle known as a *muscle spindle*. This input provides feedback about muscle length.

(2) The second source of input to an alpha motor neuron derives from *upper motor neurons* in the motor cortex and brain stem. This input is important for the initiation and control of voluntary movement (see our next lecture).

(3) The third and largest input to an alpha motor neuron derives from *spinal interneurons* in the spinal cord. This input may be excitatory or inhibitory and is part of the circuitry that generates the spinal motor programs.



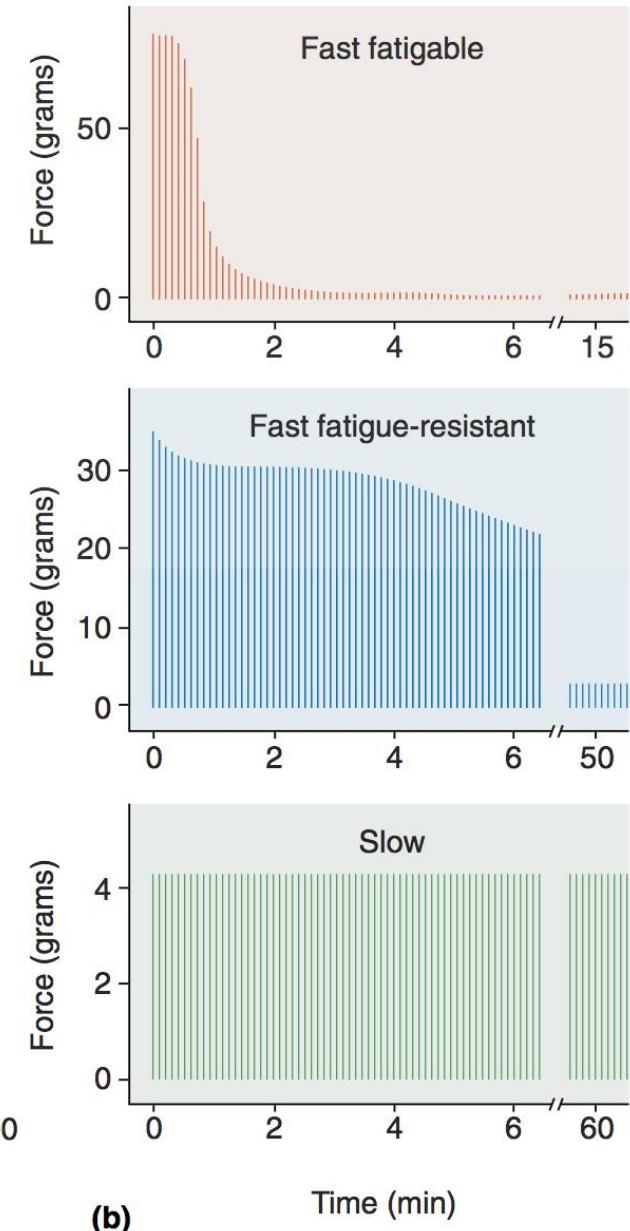
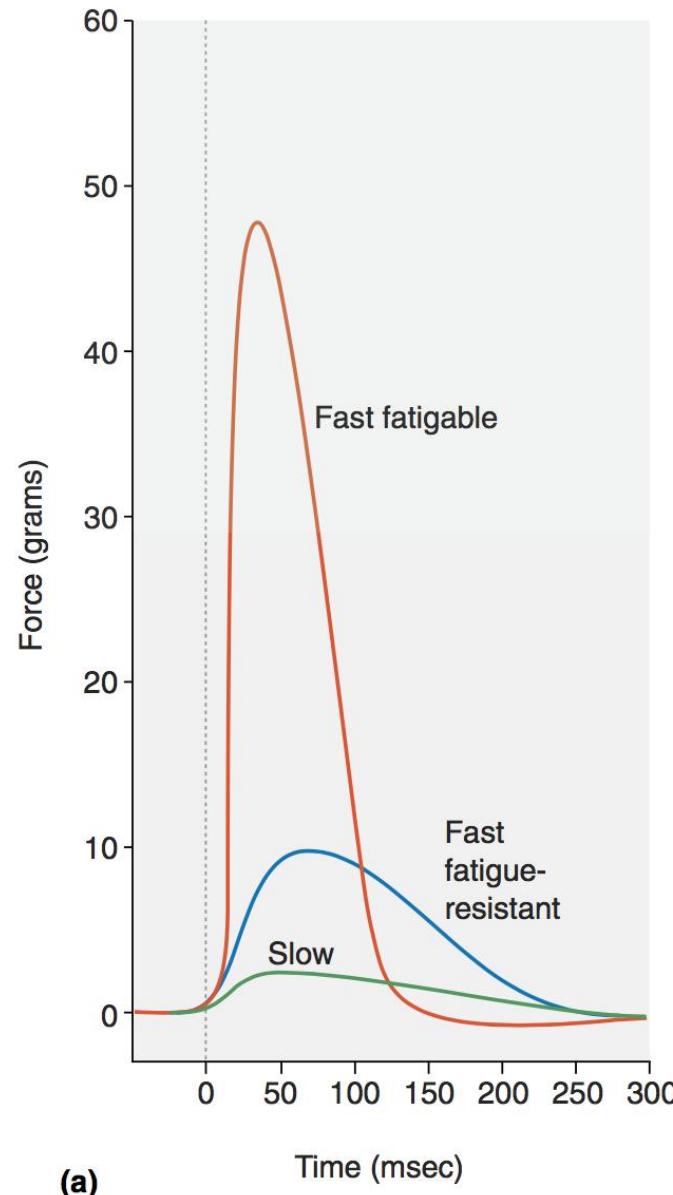
# Three types of Motor Units

(a) A **single** action potential triggers contraction strengths of **different** force and time-course in each of the *three* types of motor units.

(b) **Repeated trains** of action potentials at 40 Hz over many minutes lead to different rates of **fatigue** in the three types of motor units.

(Source: Adapted from Burke et al., 1973.)

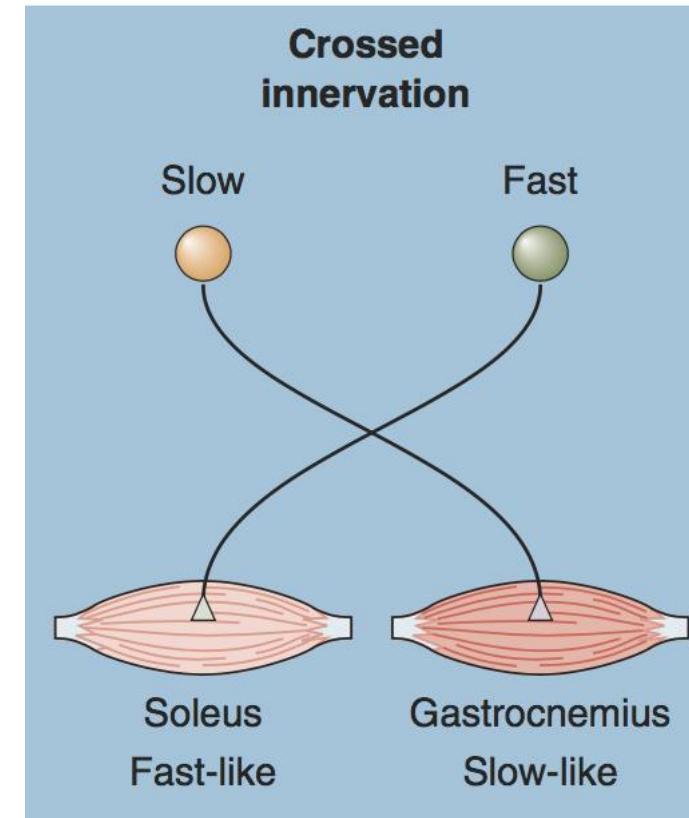
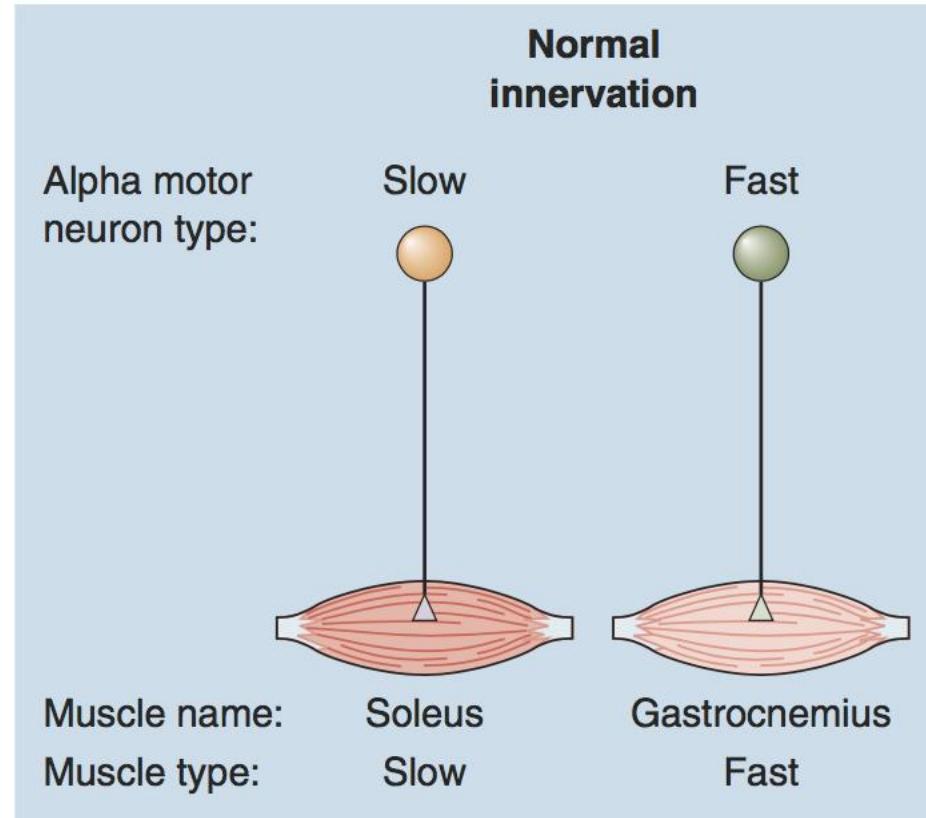
**WHY design in such way?**



# A cross-innervation experiment

Slow alpha motor neuron innervate slow muscle fiber.

**How about a slow muscle fiber receives a synaptic contact from a fast motor neuron?**



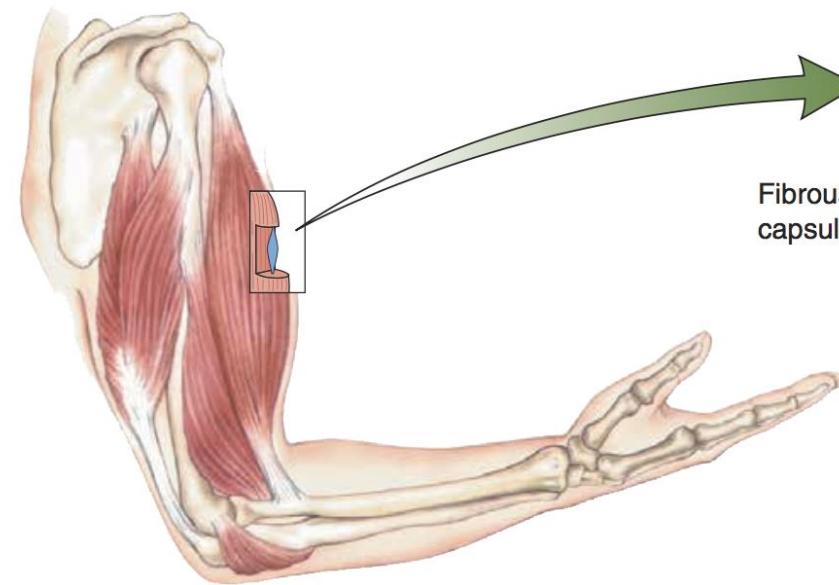
The properties of the muscle are determined solely by the type of innervation it gets.

# Proprioception from Muscle Spindles

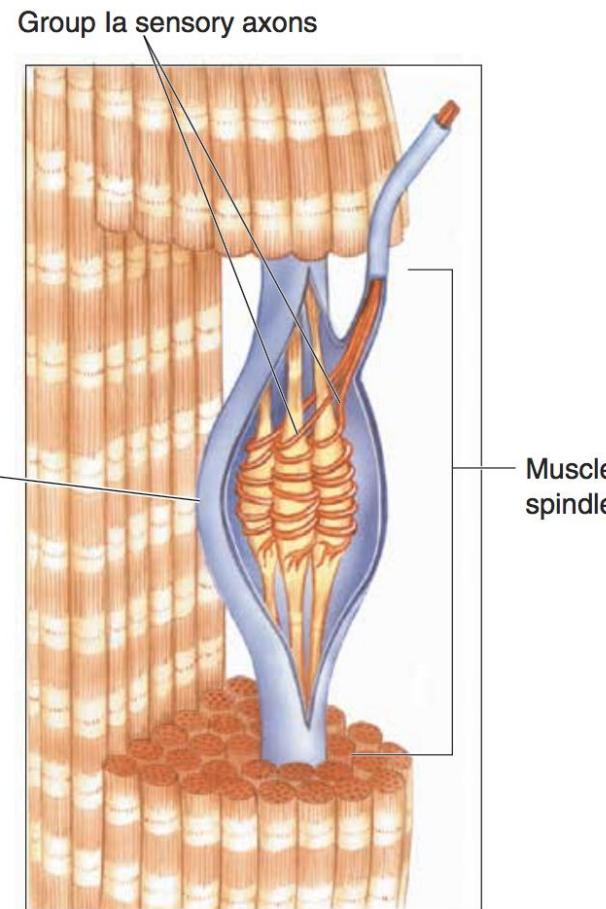
Deep within most skeletal muscles are specialized structures called ***muscle spindles*** (also called ***stretch receptor***).

***Group Ia sensory axons*** wrap around the muscle fibers of the spindle.

The ***spindles*** and their associated ***Ia axons***, specialized for the detection of changes in muscle length (stretch), are examples of **proprioceptors**.



▲ FIGURE 13.17  
A muscle spindle and its sensory innervation.



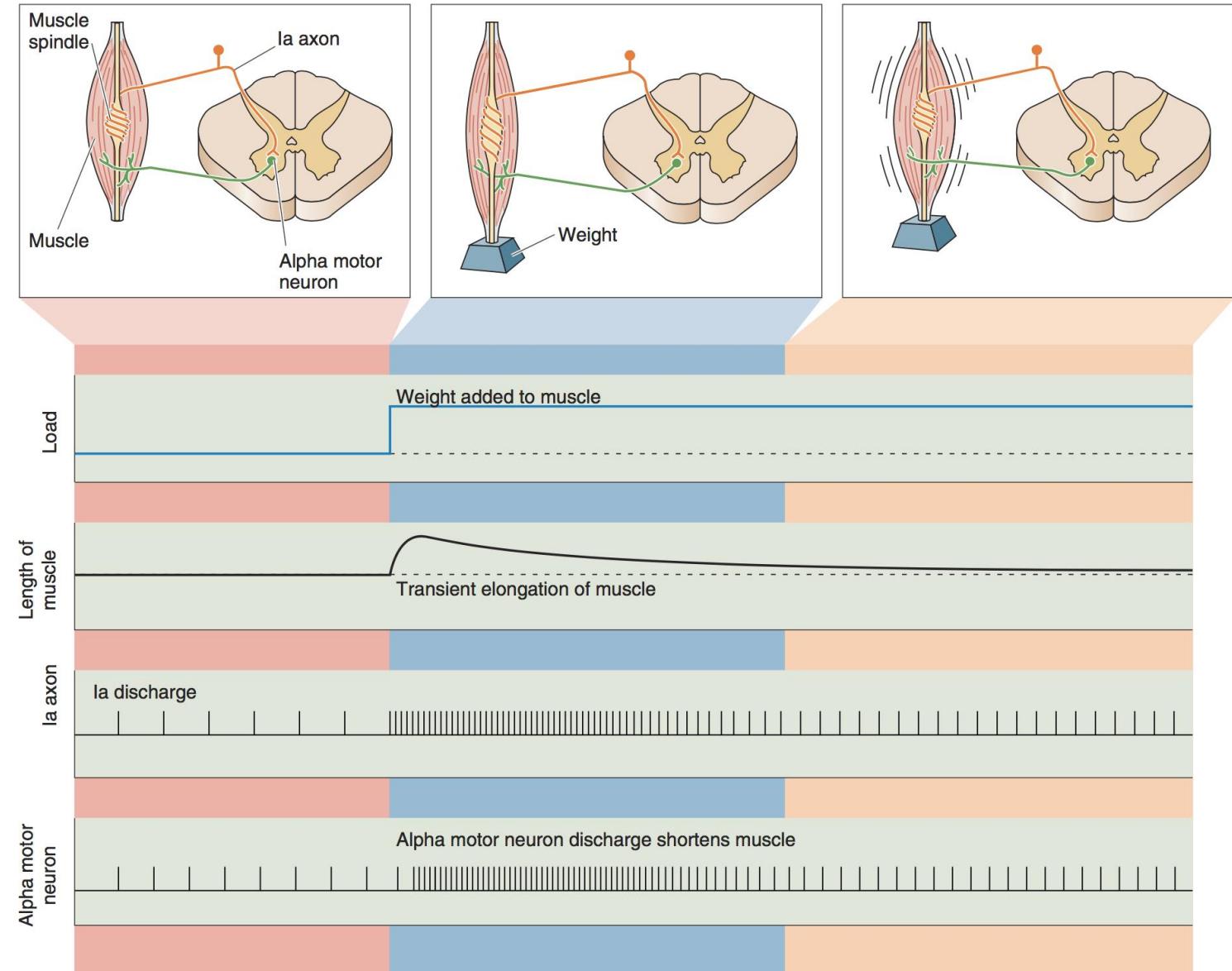
# Stretch Reflex

## (Myotatic stretch reflex)

The *Ia axon* and the *alpha motor neurons* on which it synapses constitute the **monosynaptic stretch reflex arc** -- “monosynaptic” because only **one** synapse separates the primary sensory input from the motor neuron output.

(rapid, <1ms)

This causes the muscle to contract, thereby shortening it.



The response of an *Ia axon* and a *motor neuron* to the sudden addition of weight that stretches the muscle

# The knee-jerk reflex, a specific stretch reflex

The knee-jerk reflex is one example of the stretch reflex.

The knee jerk reflex test is used to check for nerve damage in the nerve system as a whole (**not for brain**).

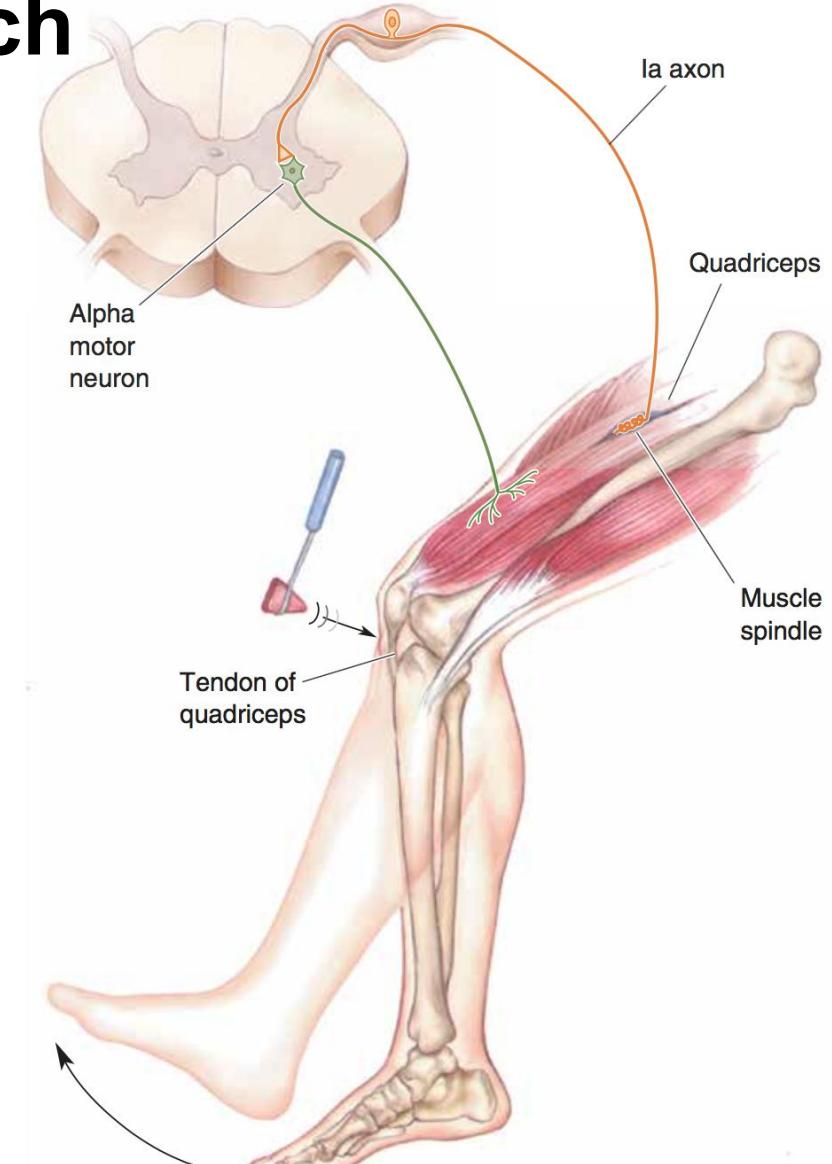
Legs that **do not jerk** at all or that **jerk continuously** after being struck are considered **abnormal**.

Complete lack of a knee jerk reflex can be a sign of several nerve conditions and is referred to as "**Westphal's sign**". It can be a sign of spinal damage, injury to the *femoral nerve*, or *multiple sclerosis*.

牵张反射具有重要的生理意义。

首先，它有助于维持身体的姿势和平衡。当身体某个部位受到外力作用时，牵张反射可以使相关肌肉产生收缩反应，从而保持身体的稳定。

其次，牵张反射可以保护肌肉免受过度拉伸的损伤。当肌肉受到过度牵拉时，牵张反射可以迅速激活肌肉收缩，从而减轻或避免肌肉撕裂等损伤。



▲ FIGURE 13.19  
The knee-jerk reflex.

# Nerve Re/Degeneration

A severe disruption in the neural circuitry controlling muscle movement, potentially linked to conditions, like **aging** or **neurodegenerative diseases**, like Parkinson's Disease, Alzheimer's Disease, amyotrophic lateral sclerosis (ALS, 肌萎缩侧索硬化症), may **lose** 70% of *Ia synapses* on the proximal dendrites of motor neurons.

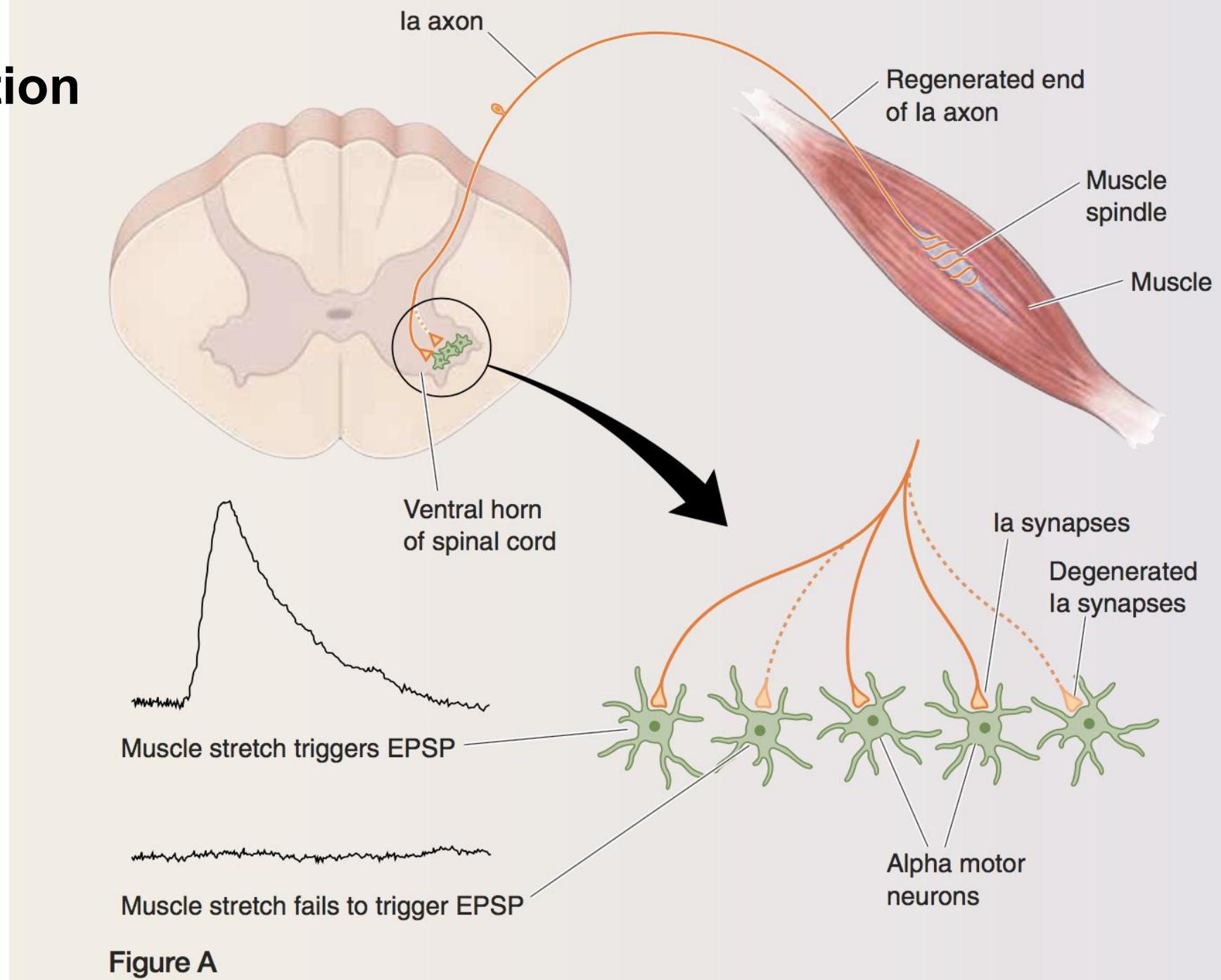


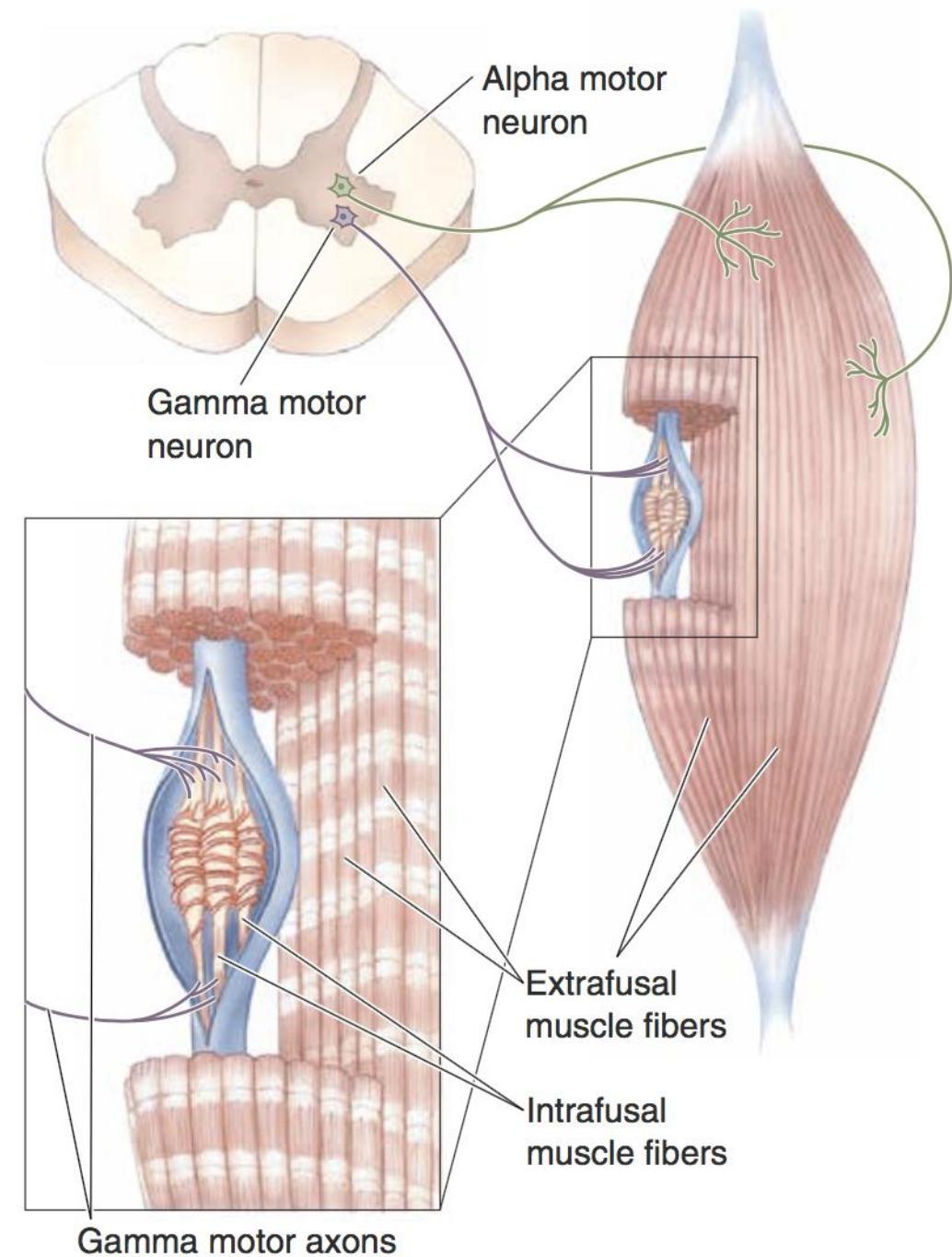
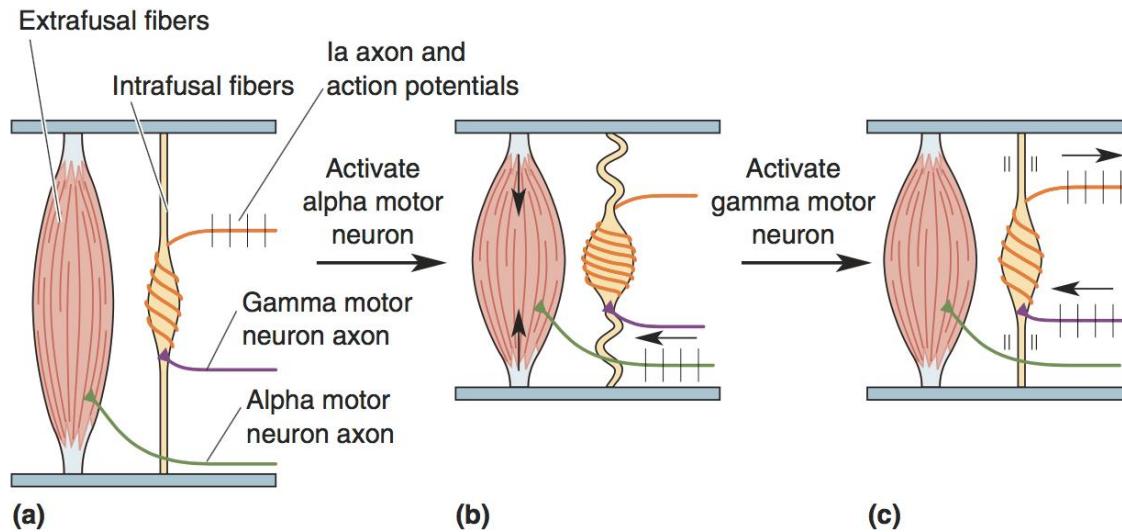
Figure A

# Alpha/Gamma motor neurons

Extrafusal fibers are innervated by alpha motor neurons.

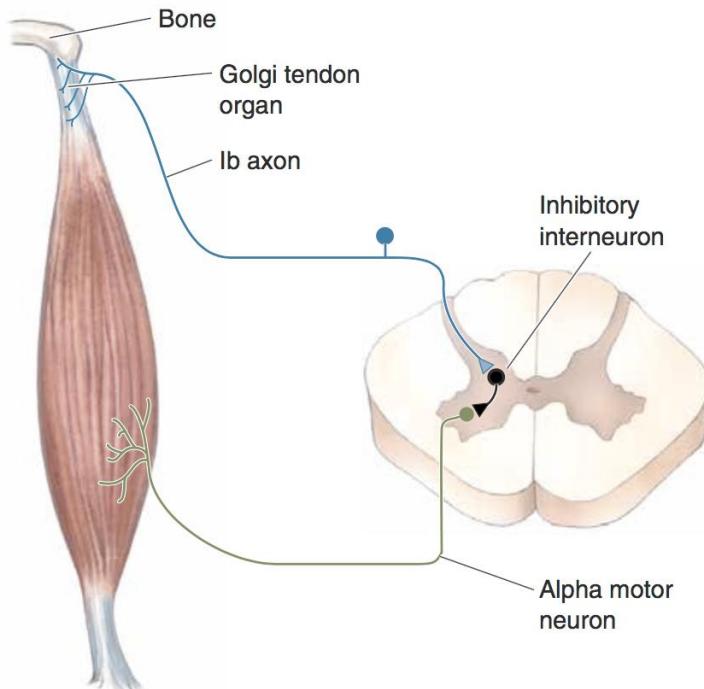
Intrafusal fibers receive their motor innervation by gamma motor neurons.

Notice that the activation of alpha and gamma motor neurons has opposite effects on Ia output; **alpha** activation alone **decreases** Ia activity, while **gamma** activation alone **increases** Ia activity.

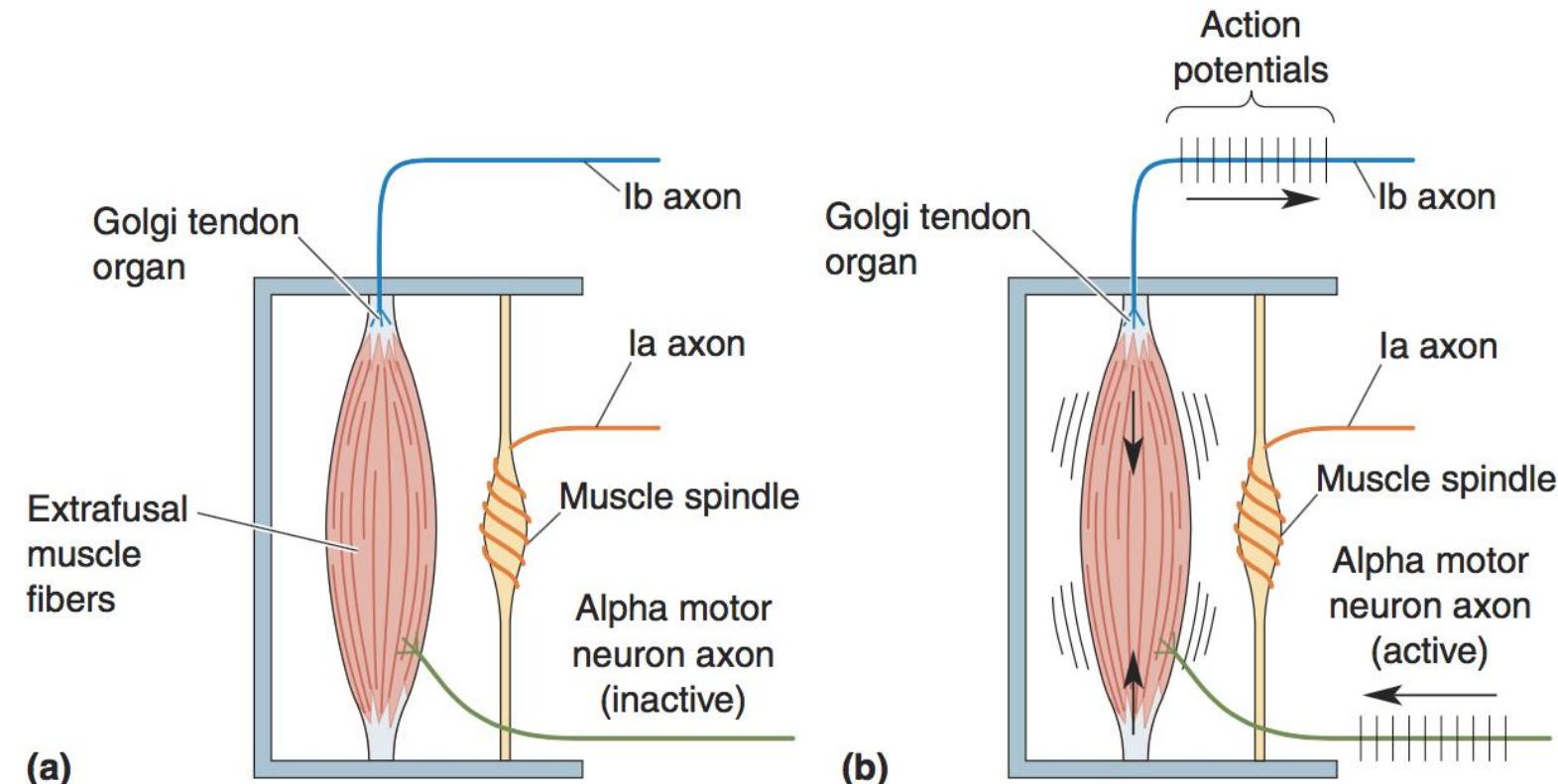


# Proprioception from Golgi Tendon Organs

The **Ia activity** from the spindle encodes **muscle length** information, while **Ib activity** from the Golgi tendon organ encodes **muscle tension** information.



**Golgi tendon organ circuit.** To regulate muscle tension within an optimal range.

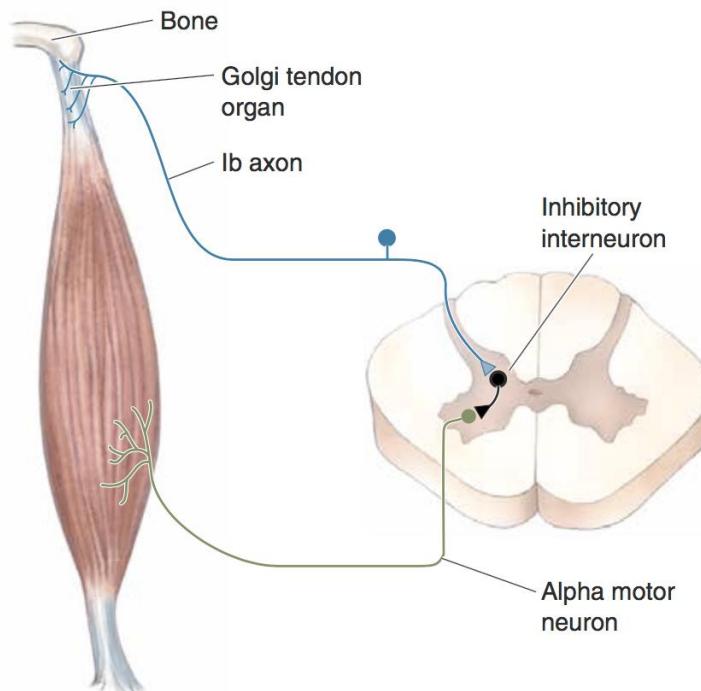


▲ FIGURE 13.23

**The organization of muscle proprioceptors.** (a) Muscle spindles are arranged parallel to the extrafusal fibers; Golgi tendon organs lie in series, between the muscle fibers and their points of attachment. (b) Golgi tendon organs respond to increased tension on the muscle and transmit this information to the spinal cord via group Ib sensory axons. Because the activated muscle does not change length, the Ia axons remain silent in this example.

# Proprioception from Golgi Tendon Organs

The *Ia activity* from the spindle encodes *muscle length* information, while *Ib activity* from the Golgi tendon organ encodes *muscle tension* information.



**Golgi tendon organ circuit.** To regulate muscle tension within an optimal range.

## 高尔基腱器官在本体感觉中的作用

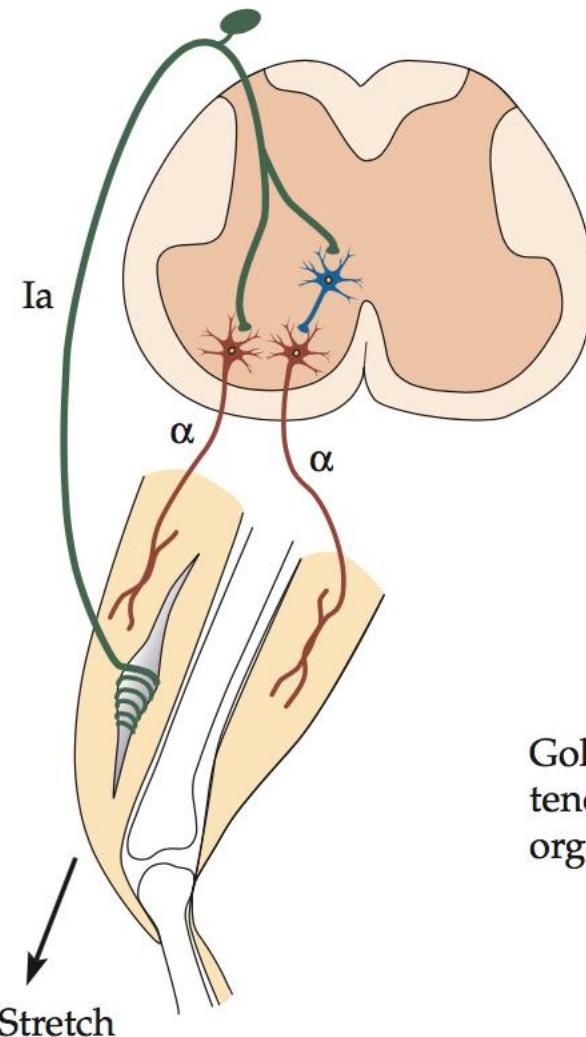
- 1) **提供肌肉张力信息:** 高尔基腱器官能够感知肌肉的张力变化，并将这些信息传递给中枢神经系统。这对于维持身体的姿势和平衡至关重要。
- 2) **调节肌肉收缩:** 高尔基腱器官通过反馈机制调节肌肉的收缩。当肌肉张力过高时，高尔基腱器官会发送抑制性神经冲动到脊髓的运动神经元，抑制肌肉的进一步收缩，从而避免肌肉过度紧张或损伤。
- 3) **参与运动控制:** 高尔基腱器官提供的信息对于精细运动控制至关重要。例如，在进行需要精确控制的运动时，高尔基腱器官能够感知肌肉的微小张力变化，并帮助调整肌肉收缩的强度和速度。

## 高尔基腱器官与运动训练的关系

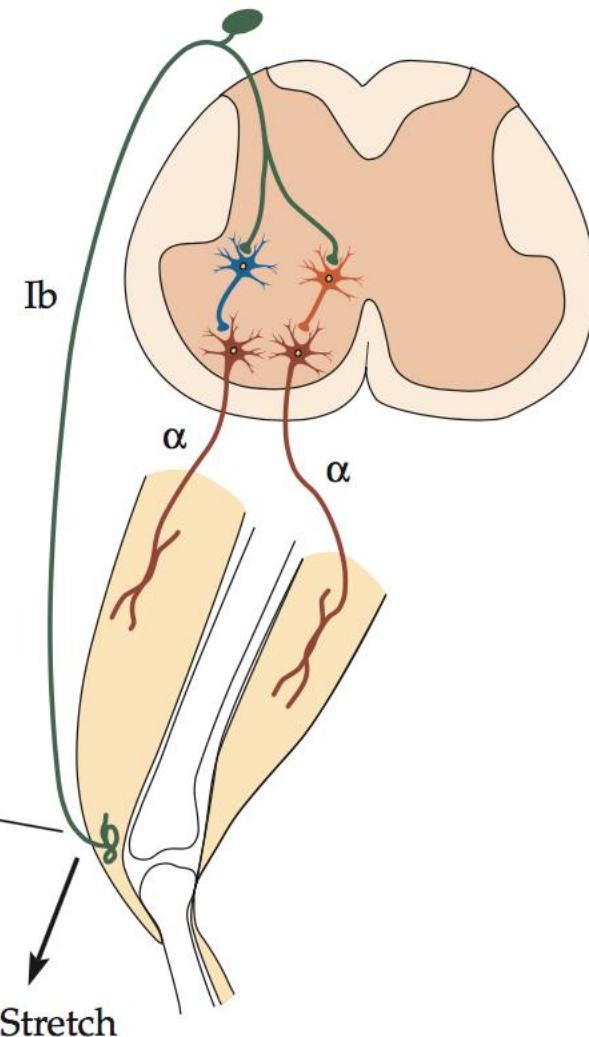
在高强度或长时间肌肉活动中，高尔基腱器官可能会受到过度刺激，导致肌肉疲劳或紧张。因此，在进行运动训练时，合理的休息和放松对于保护高尔基腱器官和维持良好的本体感觉至关重要。

# Myotatic reflex (肌伸张反射) vs Inverse myotatic

(A) Myotatic reflex



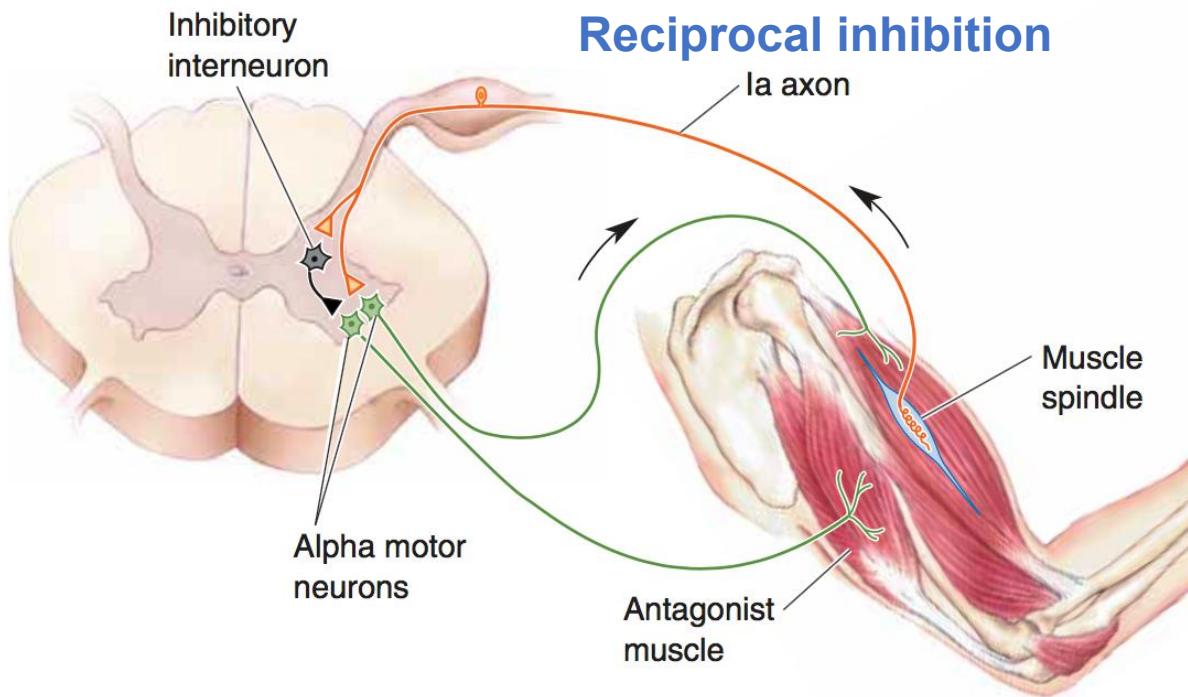
(B) Inverse myotatic reflex



(A) In the myotatic reflex, stretch of the muscle spindle generates impulses that travel along group Ia afferent fibers to the spinal cord and produce monosynaptic **excitation** of alpha motoneurons to that same muscle. Impulses also excite interneurons that, in turn, **inhibit** motoneurons supplying the antagonist muscles. 肌伸张反射是指当肌肉受到外力牵拉而使肌梭感受装置被拉长时，会引起的被牵拉的同一肌肉发生收缩的反射。它是单突触反射，其感受器是肌梭，传入纤维是I<sub>a</sub>和II类神经纤维，基本中枢位于脊髓前角，传出纤维是α和γ纤维，效应器是被牵拉的同一肌肉。这种反射是脊椎动物在进化过程中形成的一种保护机制，有助于维持身体的姿势和平衡。

(B) Stretch or contraction of the muscle pull on the tendon and generate impulses in the Golgi tendon organ's Ib afferent fiber. Ib fibers **inhibit** motoneurons that supply the same muscle.

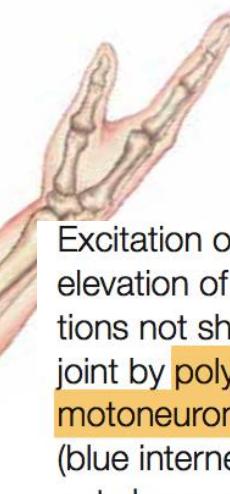
# Inhibitory Interneurons



▲ FIGURE 13.25  
Reciprocal inhibition of flexors and extensors of the same joint.

# Excitatory Interneurons

## Flexor reflex



Excitation of A $\delta$  pain fibers results in elevation of the thigh (synaptic connections not shown) and flexing of the knee joint by polysynaptic excitation of flexor motoneurons and inhibition of extensors (blue interneurons are inhibitory). Also not shown are contralateral connections that subserve extension of the opposite leg for support.

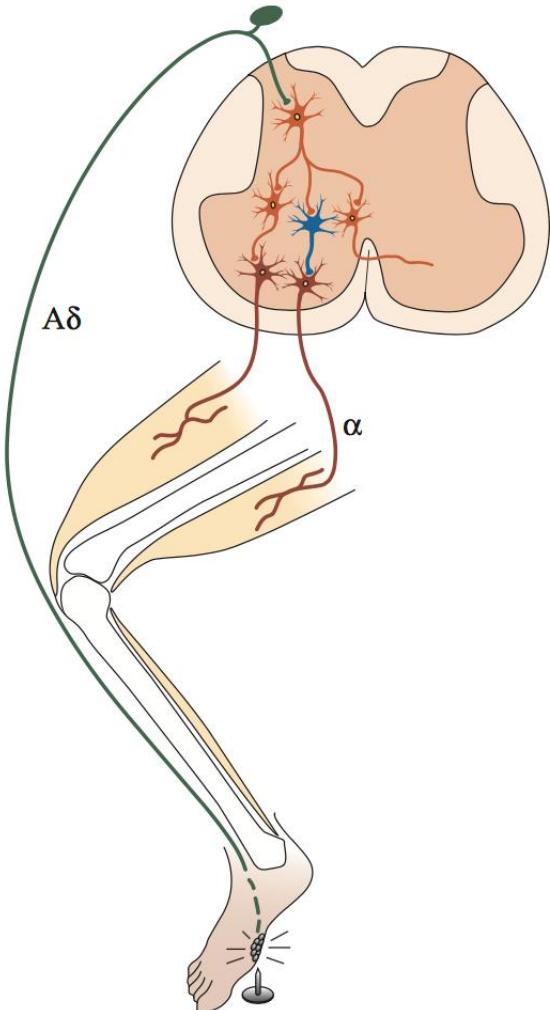


FIGURE 24.9 The Flexor Reflex is  
39

Consider the stretch reflex. Compensation for the lengthening of the flexors of the elbow involves contraction of the flexors via the stretch reflex but also requires relaxation of the antagonist muscles, the extensors.

This process is called **reciprocal inhibition**, the **contraction** of one set of muscles accompanied by the **relaxation** of their antagonist muscles.

# Crossed-extensor reflex (对侧伸肌反射)

You're walking around barefoot, and you step on a tack.

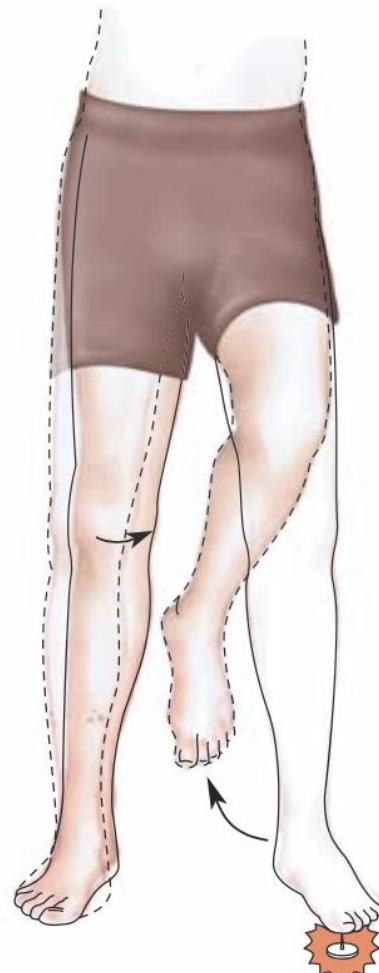
Due to *the flexor reflex*, you reflexively yank your foot up.

But where would that leave the rest of your body if nothing else happened? Falling to the floor, most likely.

Luckily, an additional component of the reflex is recruited:

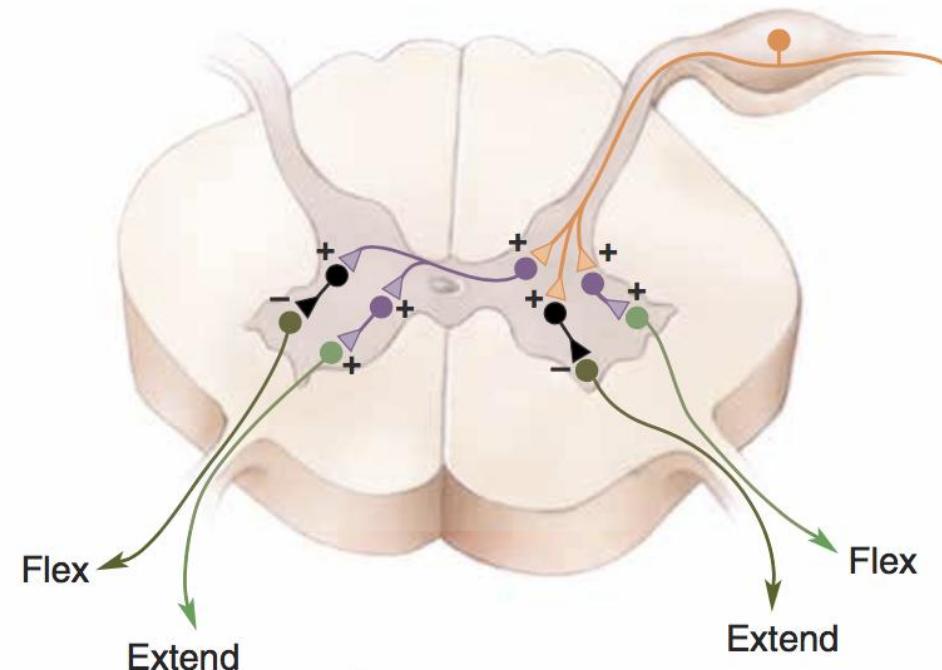
- 1) the *activation* of extensor muscles;
- 2) the *inhibition* of flexors *on the opposite side*.

This is called the *crossed-extensor reflex*, and it is used to compensate for the extra load imposed by limb withdrawal on the antigravity extensor muscles of the opposite leg.



当肢体皮肤受到伤害性刺激（如针刺、热烫等）时，该肢体的屈肌会强烈收缩，伸肌舒张，使该肢体出现屈曲反应，这是屈肌反射作用。

如刺激强度足够大，不仅在同侧肢体发生屈肌反射，对侧肢体也会出现伸直的反射活动，这种反射即称为对侧伸肌反射。



Circuitry of the cross-extensor reflex

# Modeling and control of movement

- *Realistic musculoskeletal model of the human*
  - 1) *Building a human musculoskeletal model requires detailed quantitative knowledge of anatomy and physiology.*
  - 2) *The muscle control parameter space is complex, where over 600 skeletal muscles control hundreds of joints, leading to high dimensionality and redundancy of the system.*
  - 3) *The dynamical property of neuro-muscle actuators is non-linear and inconstant.*
- *End-to-end training in robotics*

## MuJoCo

MuJoCo stands for Multi-Joint dynamics with Contact. It is a general purpose physics engine that aims to facilitate research and development in robotics, biomechanics, graphics and animation, machine learning, and other areas that demand fast and accurate simulation of articulated structures interacting with their environment.



MuJoCo (Multi-Joint dynamics with Contact) 和OpenSim是两个用于生物力学和机器人模拟的开源软件工具，但它们在功能和应用领域上有所不同。

### MuJoCo

#### 1. 定义:

- MuJoCo是一个物理引擎，专注于复杂多关节动态系统的模拟，特别适用于机器人、仿生学和控制研究。

#### 2. 主要特点:

- 高效的物理计算：利用连续动力学模型进行高效的碰撞检测和模拟，适合实时应用。
- 灵活的建模：用户可以定义复杂的动力学模型，包括接触和摩擦。
- 广泛应用：被广泛用于强化学习和机器人控制的研究。

#### 3. 应用领域:

- 机器人技术、运动控制、仿生机器人、物理模拟和强化学习。

<https://mujoco.readthedocs.io/en/stable/overview.html>

## OpenSim

OpenSim is a freely available, user extensible software system that lets users develop models of musculoskeletal structures and create dynamic simulations of movement. OpenSim 4.5 includes the GUI, published Conda and Docker packages, additional Moco functionality, and FunctionBasedPath for function-based muscle wrapping.

### OpenSim

#### 1. 定义:

- OpenSim是一个开源软件平台，用于创建和分析生物力学模型，特别关注人类运动和肌肉骨骼系统的动态模拟。

#### 2. 主要特点:

- 生物力学建模：允许用户构建详细的人体运动模型，模拟肌肉、骨骼和关节的相互作用。
- 运动分析：提供工具用于分析运动数据，如步态分析和肌肉力量计算。
- 可视化和可交互性：用户可以可视化模型并进行实时交互，支持运动学习和控制策略开发。

#### 3. 应用领域:

- 生物力学研究、康复工程、运动科学、假肢和支具设计。

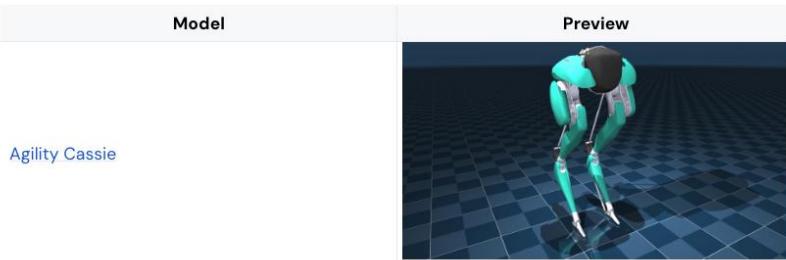
<https://simtk.org/projects/opensim>

- MuJoCo 主要用于实时物理模拟和机器人控制，适合对动态行为进行高效建模和仿真。
- OpenSim 则更侧重于生物力学分析和肌肉骨骼建模，适合研究人体运动和相关的生物力学问题。

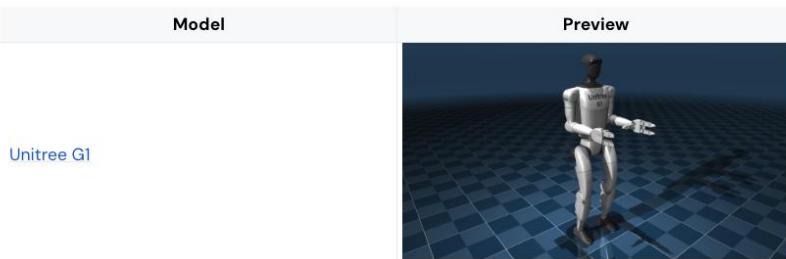
## MuJoCo

A physics simulator is only as good as the model it is simulating, and in a powerful simulator like MuJoCo with many modeling options, it is easy to create “bad” models which do not behave as expected. The goal of MuJoCo Menagerie is to provide users with a curated collection of well-designed models that work well right out of the box.

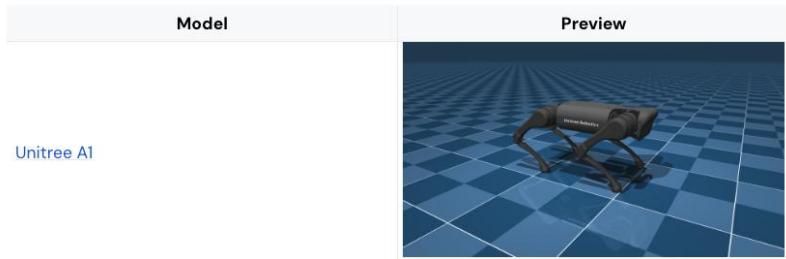
### Bipeds



### Humanoids



### Quadrupeds



## OpenSim

OpenSim Moco produces the optimal motion and muscle behavior for an OpenSim musculoskeletal model, given goals to achieve during the motion and reference data. Moco provides a library of **goals**, such as minimizing effort, deviation from marker data (or generalized coordinate data), and joint loading. **Reference data** for the motion (markers or generalized coordinates), external forces (from force places), and muscle activity (from electromvoaranhv) are optional.



仿真效果：

<https://www.bilibili.com/video/BV1rw411T7qw>

[https://github.com/rabfiras/moco\\_mujoco](https://github.com/rabfiras/moco_mujoco)

*A musculoskeletal model* (MS-Human-700) with 90 body segments, 206 joints, and 700 muscle-tendon units, allowing simulation of full-body dynamics and interaction with various devices.

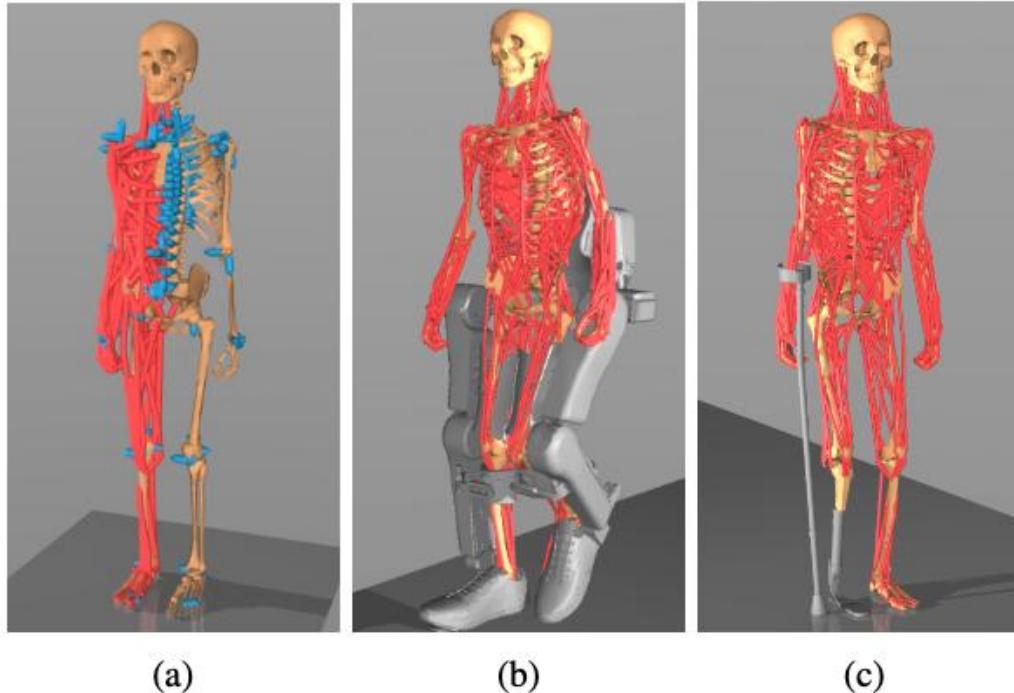


Fig. 1: (a) MS-HUMAN-700: full-body musculoskeletal model. Blue arrows represent joint axes, red lines represent muscle-tendon units (right half). (b) The model interacting with an exoskeleton in simulation. (c) The model with a prosthetic leg and a crutch.

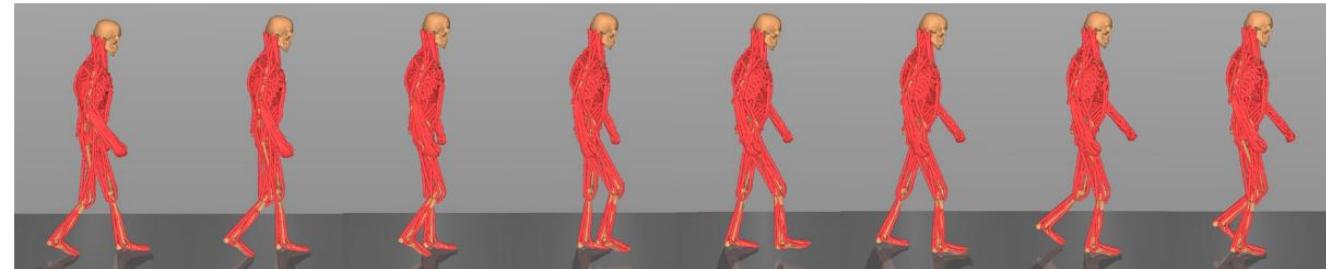


Fig. 2: Learning to walk with MS-HUMAN-700 via Two-Stage Hierarchical Training (TSHT).

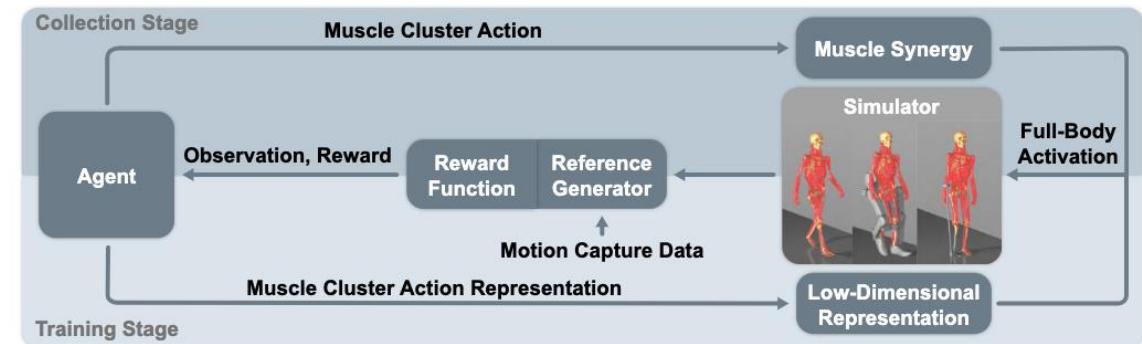


Fig. 4: Two-Stage Hierarchical Training (TSHT). In the collection stage, the agent determines muscle cluster actions. Muscle Synergy function then maps these muscle cluster actions into full-body muscle activation, leveraging prior physiological knowledge. Meanwhile, the reference generator generates the desired joint states based on motion capture data and computes corresponding rewards. Once a sufficient number of sub-optimal trajectories are collected, low-dimensional representations are extracted by encoder-decoder architecture and utilized for the training stage.

锻炼特定肌肉群需要针对性的训练计划。以下是一些常见肌肉群及其锻炼方法：

### ### 1. 胸部肌肉

- \*\*卧推\*\*：可使用杠铃或哑铃，平躺在长椅上进行。
- \*\*俯卧撑\*\*：自身体重训练，适合各种水平。
- \*\*飞鸟\*\*：用哑铃在平躺姿势下展开双臂，强调胸部肌肉的拉伸。

### ### 2. 背部肌肉

- \*\*引体向上\*\*：锻炼背阔肌和上背部。
- \*\*划船\*\*：使用哑铃或杠铃进行划船动作，目标是背部中部。
- \*\*超人式\*\*：趴在地上，抬起手脚，强化下背部。

### ### 3. 腿部肌肉

- \*\*深蹲\*\*：锻炼大腿前侧、臀部和核心。
- \*\*硬拉\*\*：强化下背部、大腿后侧和臀部。
- \*\*腿举\*\*：在腿举机上进行，专注于大腿肌肉。

### ### 4. 肩部肌肉

- \*\*肩推\*\*：使用哑铃或杠铃，增强肩部力量。
- \*\*侧平举\*\*：用哑铃训练侧肩部，增加肩部宽度。
- \*\*前平举\*\*：强调前肩部，用哑铃向前抬起。

### ### 5. 腹部肌肉

- \*\*卷腹\*\*：经典的腹部锻炼，主要针对腹直肌。
- \*\*平板支撑\*\*：增强核心稳定性，训练全腹部。
- \*\*俄罗斯转体\*\*：坐姿转体，主要锻炼侧腹。

### ### 训练建议

- \*\*目标重复次数和组数\*\*：每个动作建议进行3-4组，每组8-12次。
- \*\*逐渐增加负重\*\*：随着力量提升，逐渐增加训练重量。
- \*\*适当休息\*\*：每个肌肉群间隔48小时再进行锻炼，确保肌肉有足够时间恢复。

结合有氧运动和力量训练，营养均衡，能提升整体效果。

刘泉影的一个值钱的idea：[个体化的运动仿真及分析软件](#)

1) 运动轨迹分析；2) 个体化肌肉骨骼建模；3) 针对性训练特定肌肉目标，利用RL设计最优的健身动作

# idmatch Bike Fitting, 50–60万RMB



idmatch Bike Fitting is a set of high-tech tools to make cyclist analysis and evaluation simple but scientifically reliable and accurate.

# idmatch Bike Fitting, 50–60万RMB



idmatch Bike Fitting is a set of high-tech tools to make cyclist analysis and evaluation simple but scientifically reliable and accurate.

idmatch Analysis System  
Is an innovative analysis software

Thanks to 3D scanning, it can analyse the cyclist while pedalling without the support of markers and process possible solutions by modifying the Smart Bike setting in real time

[Discover more](#)

将强化学习技术与肌肉骨骼模型结合，可以通过以下方式**个体化地优化训练动作**：

### ### 1. \*\*数据收集\*\*

- **生理数据监测**：利用传感器收集用户在训练过程中的生理数据（如心率、肌肉电活动）。
- **动作捕捉**：使用摄像头或运动捕捉系统记录用户的动作表现，以获得精确的运动轨迹。

### ### 2. \*\*建立模型\*\*

- **肌肉骨骼模型**：基于收集的数据，创建个性化的肌肉骨骼模型，模拟用户的运动特征和肌肉功能。
- **强化学习算法**：运用强化学习算法，定义**奖励机制**（如**肌肉激活度**、**激活持续时间**等），训练模型进行优化。

### ### 3. \*\*优化训练动作\*\*

- **模拟和预测**：利用强化学习模型预测不同训练动作对特定肌肉群的激活效果，通过模拟找到最佳动作组合。
- **个性化建议**：根据用户的运动表现和目标，生成个性化的训练计划，调整动作的难度、强度和频率。

### ### 4. \*\*实时反馈\*\*

- **动态调整**：在训练过程中，实时监测用户的表现，强化学习算法可根据实时反馈自动调整训练计划，以优化效果。
- **用户界面**：提供可视化的反馈，帮助用户理解当前动作的有效性，并指导其调整姿势或力度。

### ### 5. \*\*长期跟踪\*\*

- **进展分析**：定期分析用户的训练数据，评估其进展，并根据变化的需求不断调整个性化计划。
- **适应性学习**：强化学习系统可根据用户的适应性，自动更新训练动作，以确保持续的挑战和进步。

通过这种结合，用户不仅能获得科学的训练建议，还能在每次训练中不断优化动作，从而更有效地达成健身目标。

# 刘泉影的一个烧钱的idea：真人动捕/游戏/动画，武打动作引擎

1) 骨骼系统；2) 武打动作前向仿真；3) 武打动作反向优化

## 3D动画引擎有哪些？基于什么肌肉骨骼模型来实现的？

3D动画引擎有许多种，常用的包括：

### 1. Unity

- 特点：广泛应用于游戏开发和虚拟现实，支持多种平台。
- 肌肉骨骼模型：支持Mecanim动画系统，可以利用Skinned Mesh Renderer来实现肌肉骨骼动画。

### 2. Unreal Engine

- 特点：高质量的图形渲染，适用于大型游戏和视觉效果。
- 肌肉骨骼模型：使用Skeletal Mesh组件，支持复杂的物理模拟和动画系统，如Control Rig。

### 3. Blender

- 特点：开源的3D创作工具，适用于建模、动画、渲染等。
- 肌肉骨骼模型：通过Armature系统和Rigging工具，能够实现详细的骨骼动画和肌肉模拟。

### 4. Maya

- 特点：专业的3D建模和动画软件，广泛用于影视和游戏。
- 肌肉骨骼模型：使用HumanIK系统，支持复杂的骨骼绑定和动画制作。

### 5. Cinema 4D

- 特点：易于使用的动画和建模软件，适合动态图形。
- 肌肉骨骼模型：通过角色动画工具，可以创建和控制骨骼动画。

### 6. Havok

- 特点：主要用于游戏物理和动画系统，特别是在大型游戏中。
- 肌肉骨骼模型：结合Havok动画系统，可以实现高效的骨骼和物理交互。

### 7. Daz 3D

- 特点：专注于人物模型和动画的创建。
- 肌肉骨骼模型：使用Genesis平台，能够实现详细的肌肉和骨骼动画。

## 肌肉骨骼模型的实现

这些引擎通常通过以下方式实现肌肉骨骼模型：

- 骨骼系统：利用骨骼结构（骨骼和关节）来驱动角色的运动。
- 权重绘制：将模型的顶点与骨骼关联，定义各个骨骼对顶点移动的影响程度。
- 动画插值：使用关键帧动画和插值方法，平滑地转换不同姿势。
- 物理模拟：一些引擎还支持肌肉和皮肤的物理模拟，增加真实感。

通过结合这些技术，开发者可以创建复杂的3D动画，模拟肌肉的运动和反应。

# 这里面有中国的模型吗？

是的，中国也有一些3D动画引擎和相关模型，以下是几个 notable 的例子：

## 1. Cocos Creator

- 特点：开源的游戏引擎，适合2D和轻量级3D游戏开发。
- 肌肉骨骼模型：支持骨骼动画系统，可以创建角色动画。

## 2. Godot Engine

- 特点：开源且社区活跃，支持2D和3D游戏开发。
- 肌肉骨骼模型：内置的动画系统支持骨骼动画和蒙皮。

## 3. ByteX

- 特点：国产的3D引擎，专注于游戏和虚拟现实应用。
- 肌肉骨骼模型：支持骨骼动画和动态物理效果。

## 4. 华为的HUAWEI AR Engine

- 特点：专注于增强现实应用的引擎。
- 肌肉骨骼模型：支持动画和骨骼模型，可以用于AR场景中的人物动画。

## 5. 阿里巴巴的Mocap

- 特点：用于动作捕捉的技术，常用于动画和游戏开发。
- 肌肉骨骼模型：通过动作捕捉技术，将真实动作转化为骨骼动画。

这些引擎和模型在游戏开发、影视制作和虚拟现实等领域都得到了应用，推动了中国在3D动画和建模技术的发展。



# 这里面有中国的模型吗？

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2000年-2004年，冯骥就读于华中科技大学生命学院**生物医学工程专业**。

2005年，入职游戏公司任职游戏策划岗位，踏上游戏开发的道路，网名为“yocar”（尤卡，又被称为卡总）。

2008年，冯骥加入腾讯量子工作室，担任腾讯PC网游《斗战神》主策划，该游戏前期一度成了经典。

2014年，冯骥从腾讯离职，与杨奇等原《斗战神》的核心主创组建成立了游戏科学的关联公司深圳市游科互动科技有限公司，并担任CEO。

2016年底，其率领团队推出了即时战略游戏《战争艺术：赤潮》。

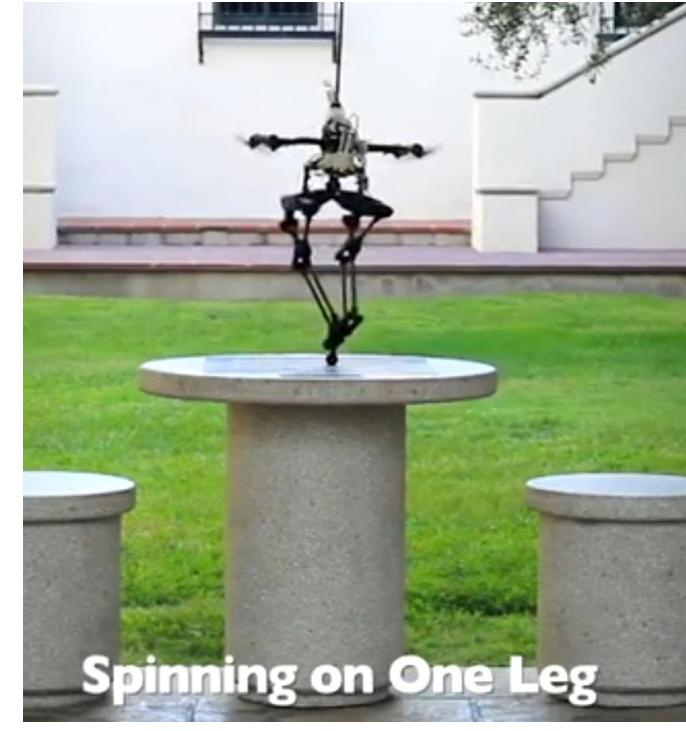
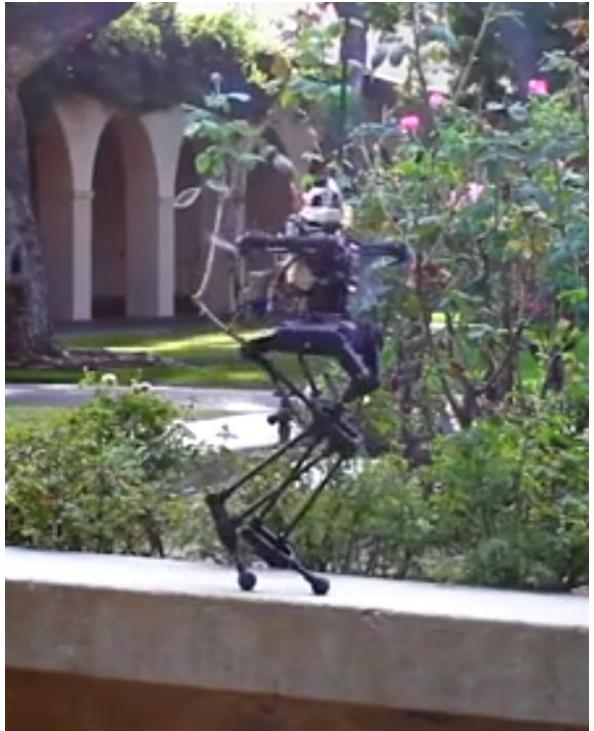
2017年5月，冯骥和游戏科学获得了英雄互娱的天使轮以及A轮融资。

2024年8月20日，《黑神话：悟空》正式在全球上线，首日在线玩家突破170万。

# Bipedal robots

Caltech – Leonardo

Synchronized Aerial & Legged Robot

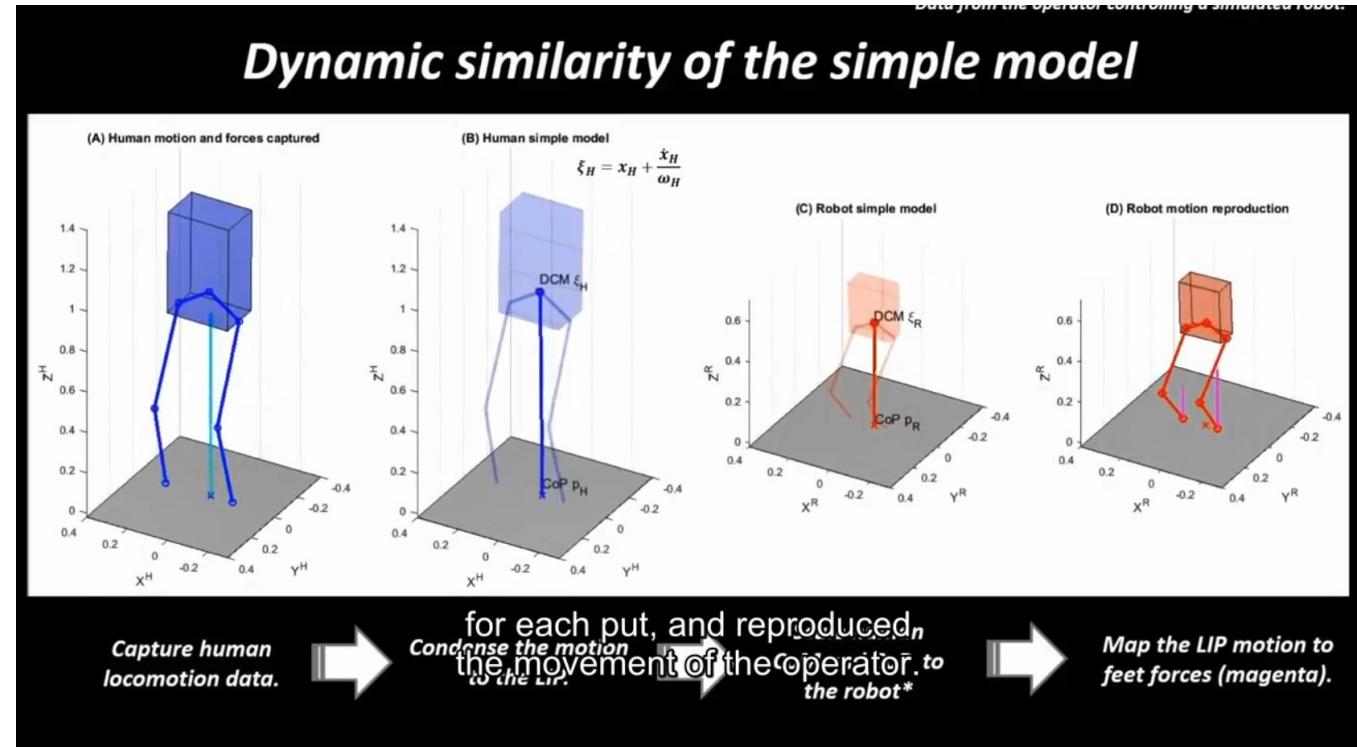


<https://www.bilibili.com/video/BV1KE411f7mu>

# Bipedal robots

Engineers at UIUC and MIT have designed a new lightweight bipedal robot.

Dynamic locomotion synchronization of bipedal robot and human operator via bilateral feedback teleoperation



<https://www.bilibili.com/video/BV1eJ411y7n7>

# Quadruped robots

SUSTech

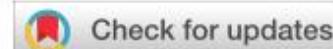
CLEAR lab (南科大, 张巍老师组)



<https://www.bilibili.com/video/BV1YE411b7qG>



<http://www.wzhanglab.site/dynamic-obstacle-avoidance-for-quadruped-robot/>

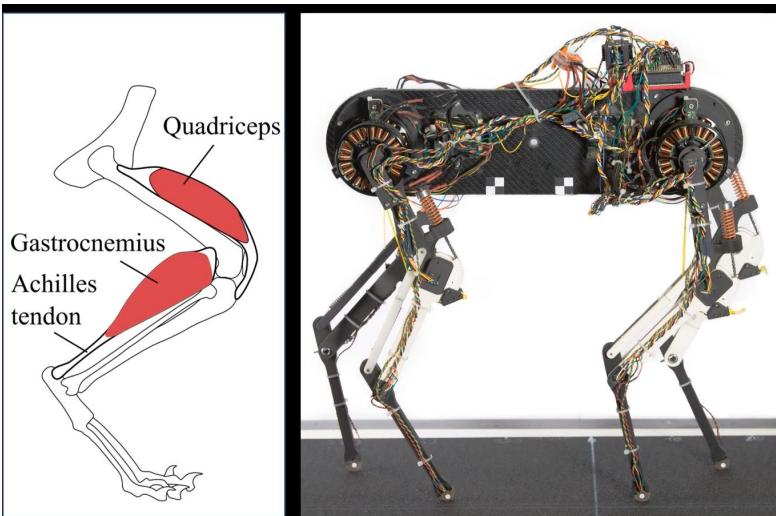


OPEN

# Learning plastic matching of robot dynamics in closed-loop central pattern generators

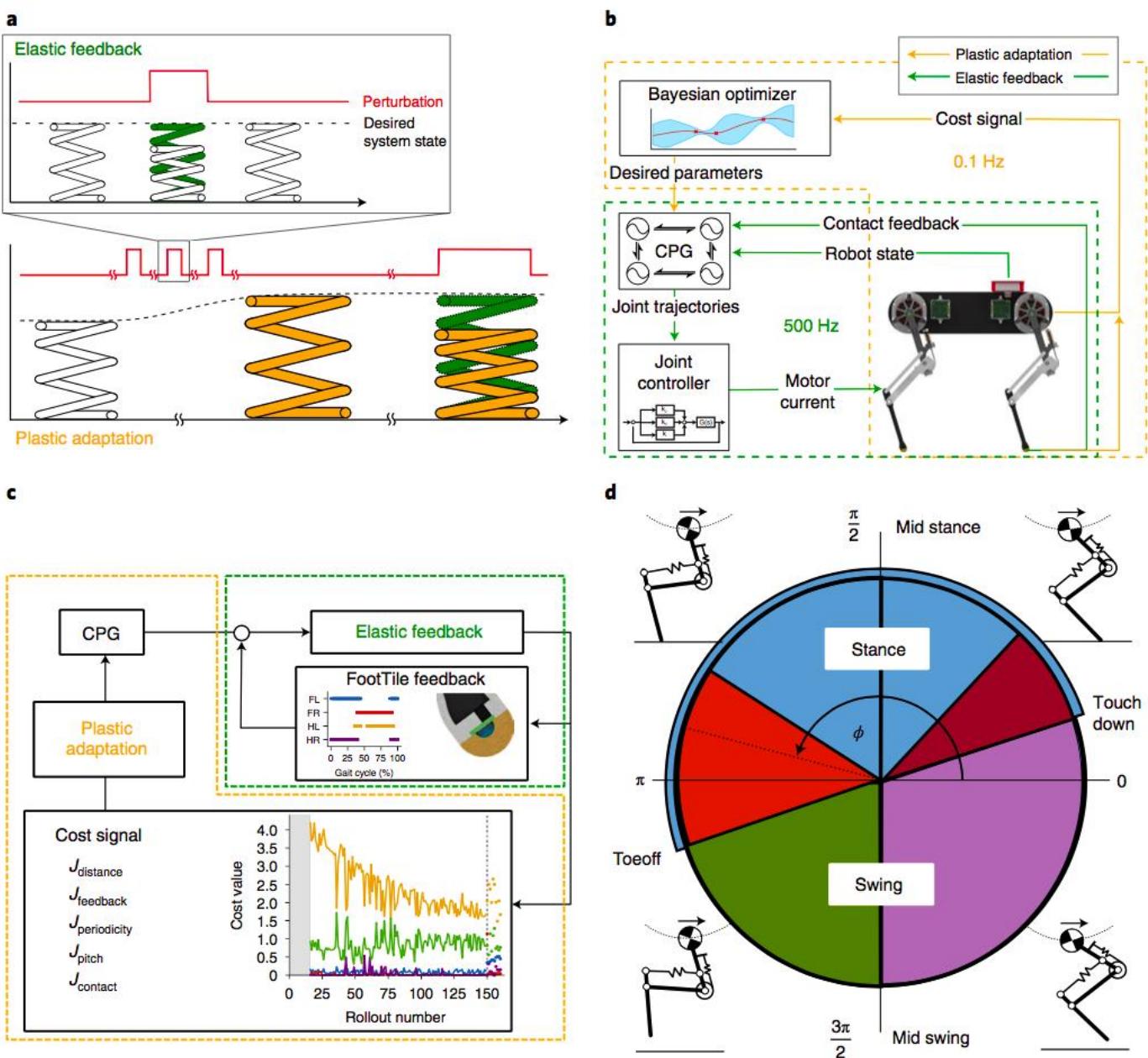
Felix Ruppert and Alexander Badri-Spröwitz

Animals achieve agile locomotion performance with reduced control effort and energy efficiency by leveraging compliance in their muscles and tendons. However, it is not known how biological locomotion controllers learn to leverage the intelligence embodied in their leg mechanics. Here we present a framework to match control patterns and mechanics based on the concept of short-term elasticity and long-term plasticity. Inspired by animals, we design a robot, Morti, with passive elastic legs. The quadruped robot Morti is controlled by a bioinspired closed-loop central pattern generator that is designed to elastically mitigate short-term perturbations using sparse contact feedback. By minimizing the amount of corrective feedback on the long term, Morti learns to match the controller to its mechanics and learns to walk within 1 h. By leveraging the advantages of its mechanics, Morti improves its energy efficiency by 42% without explicit minimization in the cost function.



[https://static-content.springer.com/esm/art%3A10.1038%2Fs42256-022-00505-4/MediaObjects/42256\\_2022\\_505\\_MOESM3\\_ESM.mp4](https://static-content.springer.com/esm/art%3A10.1038%2Fs42256-022-00505-4/MediaObjects/42256_2022_505_MOESM3_ESM.mp4)

Ruppert and Badri-Spröwitz (2022)  
Nature Machine Intelligence



**Fig. 2 | Schematic depiction of the elasticity and plasticity framework.** **a**, Short-term elastic feedback (top) and long-term plasticity (bottom). Elastic feedback (green) mitigates stochastic short-term perturbations (red), such as pot holes, that disturb the system (spring) from its desired state (dashed line). Elastic activity is reversible and only active when a perturbation is present, just as a spring only deflects as long as an external force is active and then returns to its initial state. Plasticity (yellow) changes the system behaviour permanently to adapt to long-term active stimuli from the environment.

# 2022年的国产动画片《黑门》

提醒：需要B站大会员

<https://www.bilibili.com/bangumi/play/ss35215>

技术：机械外骨骼、脑机接口、神经修复、群体意识共享与进化。。



## ARTICLE

<https://doi.org/10.1038/s41467-021-23020-3>

OPEN

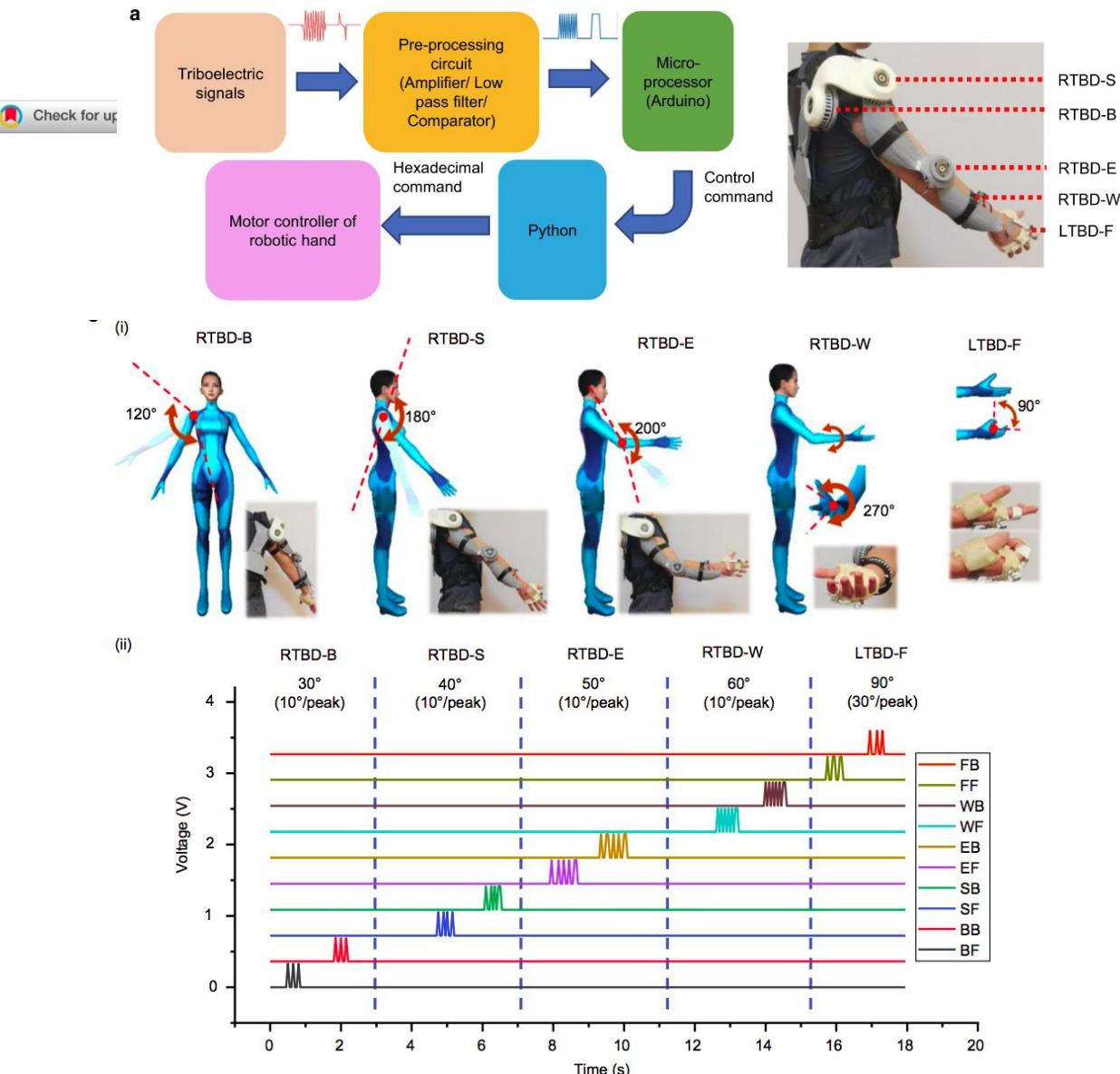
# Low cost exoskeleton manipulator using bidirectional triboelectric sensors enhanced multiple degree of freedom sensory system

Minglu Zhu<sup>1,2,3,4</sup>, Zhongda Sun<sup>1,2,3,4</sup>, Tao Chen<sup>1,2</sup> & Chengkuo Lee<sup>1,2,3,4,6</sup>

Rapid developments of robotics and virtual reality technology are raising the requirements of more advanced human-machine interfaces for achieving efficient parallel control. Exoskeleton as an assistive wearable device, usually requires a huge cost and complex data processing to track the multi-dimensional human motions. Alternatively, we propose a triboelectric bi-directional sensor as a universal and cost-effective solution to a customized exoskeleton for monitoring all of the movable joints of the human upper limbs with low power consumption.

The corresponding movements, including two DOF rotations of the shoulder, twisting of the wrist, and the bending motions, are detected and utilized for controlling the virtual character and the robotic arm in real-time. Owing to the structural consistency between the exoskeleton and the human body, further kinetic analysis offers additional physical parameters without introducing other types of sensors. This exoskeleton sensory system shows a great potential of being an economic and advanced human-machine interface for supporting the manipulation in both real and virtual worlds, including robotic automation, healthcare, and training applications.

2021年

<https://www.nature.com/articles/s41467-021-23020-3>


# Personalizing exoskeleton assistance while walking in the real world

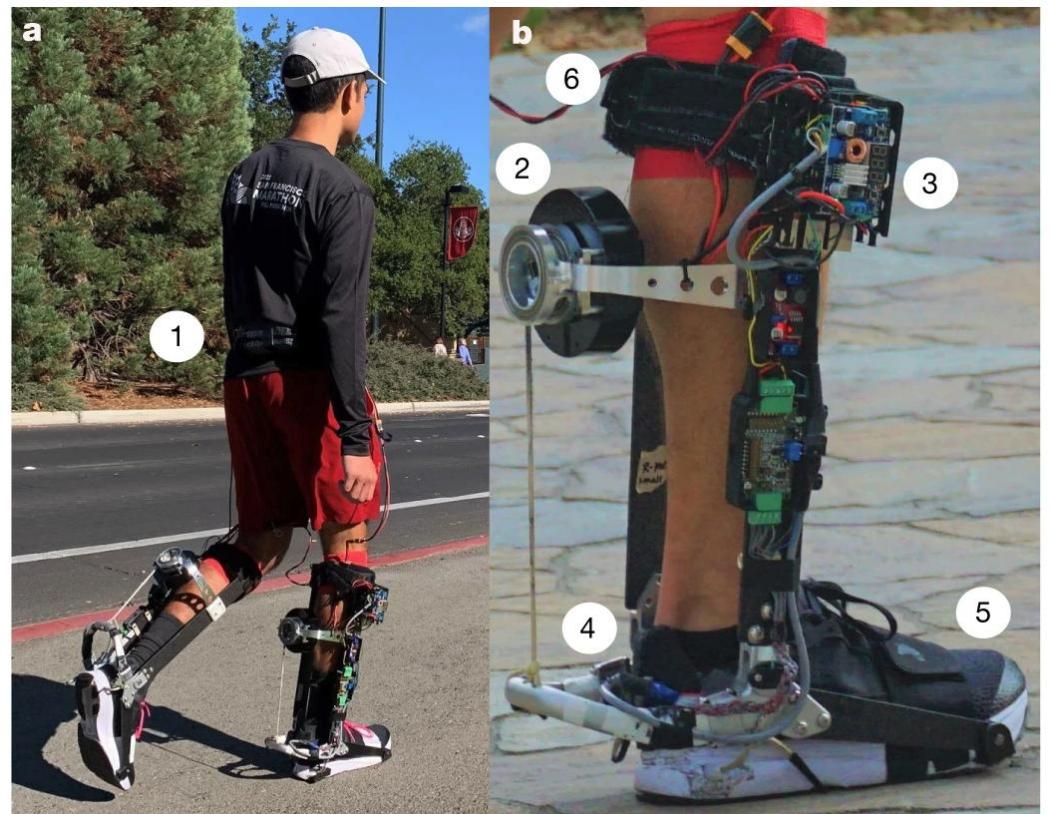
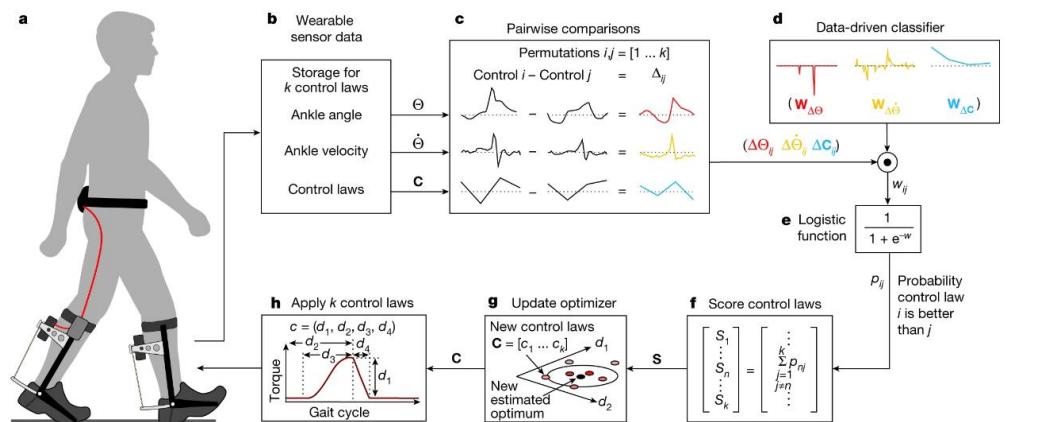
Patrick Slade, Mykel J. Kochenderfer, Scott L. Delp & Steven H. Collins 

[Nature](#) **610**, 277–282 (2022) | [Cite this article](#)

31k Accesses | 34 Citations | 1361 Altmetric | [Metrics](#)

## Abstract

Personalized exoskeleton assistance provides users with the largest improvements in walking speed<sup>1</sup> and energy economy<sup>2,3,4</sup> but requires lengthy tests under unnatural laboratory conditions. Here we show that exoskeleton optimization can be performed rapidly and under real-world conditions. We designed a portable ankle exoskeleton based on insights from tests with a versatile laboratory testbed. We developed a data-driven method for optimizing exoskeleton assistance outdoors using wearable sensors and found that it was equally effective as laboratory methods, but identified optimal parameters four times faster. We performed real-world optimization using data collected during many short bouts of walking at varying speeds. Assistance optimized during one hour of naturalistic walking in a public setting increased self-selected speed by  $9 \pm 4\%$  and reduced the energy used to travel a given distance by  $17 \pm 5\%$  compared with normal shoes. This assistance reduced metabolic energy consumption by  $23 \pm 8\%$  when participants walked on a treadmill at a standard speed of  $1.5 \text{ m s}^{-1}$ . Human movements encode information that can be used to personalize assistive devices and enhance performance.



当前的外骨骼（exoskeleton）技术与人工智能（AI）的结合正在快速发展，主要体现在以下几个方面：

### 1. 智能控制

- 实时反馈：AI可以处理来自传感器的数据（如肌肉活动、身体姿态），实时调整外骨骼的运动以适应用户的需求。
- 自适应控制：通过机器学习算法，外骨骼可以根据用户的活动模式和环境变化自我调整，以优化性能和舒适性。

### 2. 用户个性化

- 运动模式识别：AI可以分析用户的运动习惯，个性化设置外骨骼的控制策略，满足不同用户的需求（如康复、工业作业等）。
- 用户学习：外骨骼可以通过用户的反馈和数据学习，逐渐优化自身的辅助效果。

### 3. 增强人机交互

- 自然交互：结合自然语言处理技术，用户可以通过语音命令控制外骨骼，提升使用便利性。
- 情感识别：AI可以通过情感识别技术分析用户的情绪状态，调整外骨骼的反应，提高用户体验。

### 4. 数据分析与优化

- 性能监控：利用AI分析用户的运动数据，评估外骨骼的性能，发现潜在的问题，并提供改进建议。
- 康复效果评估：在康复治疗中，AI可以分析患者的进展，调整外骨骼的使用方案，优化康复效果。

### 5. 安全性和可靠性

- 故障预测：AI可以监测外骨骼的工作状态，预测可能的故障，进行预防性维护。
- 环境感知：结合计算机视觉技术，外骨骼可以识别周围环境，避免障碍物，确保用户的安全。

### 6. 集成与互操作性

- 多设备协作：AI可以协调外骨骼与其他设备（如轮椅、传感器等）的协同工作，提高整体系统的效率。

通过这些结合，外骨骼技术不仅能提升用户的身体能力，还能提供更智能、更个性化的使用体验，推动康复、工业和军事等领域的发展。

刘泉影的一个稀松平常的idea：**AI牵引的主动康复训练机械外骨骼**

- 1) 外骨骼系统； 2) Imitation learning学习正常人的动作控制；
- 3) 将学习到的正常人的外骨骼运动方法，应用于中风患者的主动康复训练

2023年

# EUREKA: HUMAN-LEVEL REWARD DESIGN VIA CODING LARGE LANGUAGE MODELS

Yecheng Jason Ma<sup>1 2</sup>✉, William Liang<sup>2</sup>, Guanzhi Wang<sup>1 3</sup>, De-An Huang<sup>1</sup>, Osbert Bastani<sup>2</sup>, Dinesh Jayaraman<sup>2</sup>, Yuke Zhu<sup>1 4</sup>, Linxi “Jim” Fan<sup>1</sup>✉, Anima Anandkumar<sup>1 3</sup>†

<sup>1</sup>NVIDIA, <sup>2</sup>UPenn, <sup>3</sup>Caltech, <sup>4</sup>UT Austin; †Equal advising

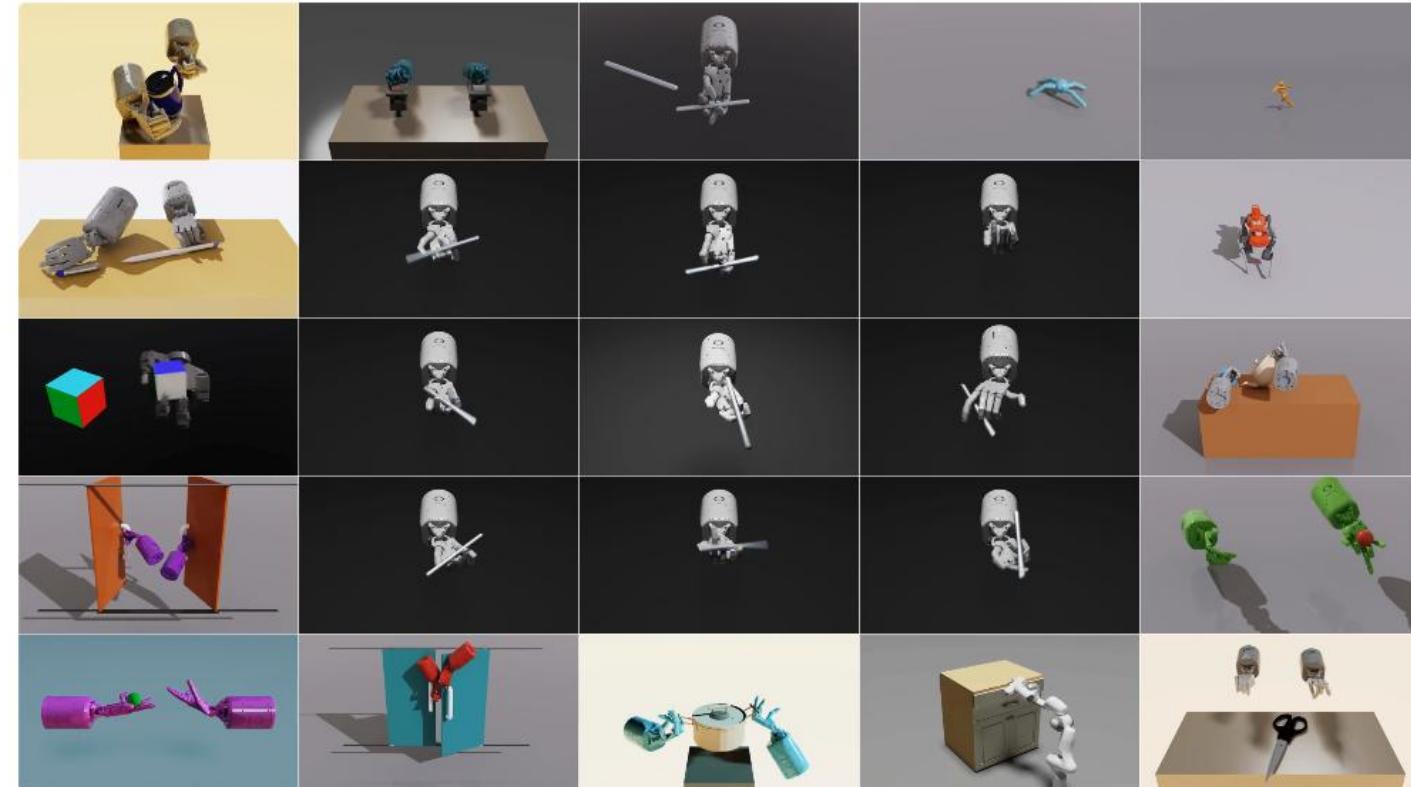
<https://eureka-research.github.io>

详细视频 <https://eureka-research.github.io/>

用LLMs学习reward设计，  
从而学会Low-level manipulation tasks

## ABSTRACT

Large Language Models (LLMs) have excelled as high-level semantic planners for sequential decision-making tasks. However, harnessing them to learn complex low-level manipulation tasks, such as dexterous pen spinning, remains an open problem. We bridge this fundamental gap and present EUREKA, a human-level reward design algorithm powered by LLMs. EUREKA exploits the remarkable zero-shot generation, code-writing, and in-context improvement capabilities of state-of-the-art LLMs, such as GPT-4, to perform evolutionary optimization over reward code. The resulting rewards can then be used to acquire complex skills via reinforcement learning. Without any task-specific prompting or pre-defined reward templates, EUREKA generates reward functions that outperform expert human-engineered rewards. In a diverse suite of 29 open-source RL environments that include 10 distinct robot morphologies, EUREKA outperforms human experts on **83%** of the tasks, leading to an average normalized improvement of **52%**. The generality of EUREKA also enables a new gradient-free in-context learning approach to reinforcement learning from human feedback (RLHF), readily incorporating human inputs to improve the quality and the safety of the generated rewards without model updating. Finally, using EUREKA rewards in a curriculum learning setting, we demonstrate for the first time, a simulated Shadow Hand capable of performing pen spinning tricks, adeptly manipulating a pen in circles at rapid speed.



斯坦福大学教授李飞飞创立的初创公司WorldLabs，成功获得了2.3亿美元的融资。

WorldLabs的核心使命是**构建一种大型世界模型**，利用图像和其他数据对三维世界进行决策。

李飞飞在多次公开演讲中强调，当前的AI模型，如生成式AI，主要依赖文本、音频和视频进行交互，而人类本质上是在三维空间中生活和体验的。因此，**开发具有空间智能的AI，能够理解物体、地点和交互的物理规则**，将为多个行业带来革命性的影响。这一技术不仅对艺术家和设计师至关重要，还有助于开发者和工程师创新他们的工作方式。

根据李飞飞的表述，这项技术的潜力是巨大的。

未来的应用场景涵盖了从**增强现实（AR）**到**机器人技术（Robotics）**的广泛领域。

WorldLabs计划在2025年推出首款产品，初期阶段将专注于建立对三维性、物理性及其与时间概念的深入理解。

随着产品的逐步完善，预计将支持**更多交互式应用**，甚至能够实现对现实世界的实时学习和反应。

这种技术潜力的多样性引发了业界的广泛期待，业界普遍认为，WorldLabs有可能为包括游戏公司和电影制片厂在内的众多领域提供变革性解决方案。

# Summary of Lecture 8 – Motor System 1

- **Muscles:** skeletal muscle; smooth muscle; cardiac muscle
- **Control of movement:** Spinal & Brain
- **The lower motor neuron**
  - Segmental organization of lower motor neurons
  - Alpha Motor neurons
  - Motor Units & Motor Unit Pool
  - Myotatic stretch reflex & Inverse myotatic reflex
  - Reciprocal inhibition
  - Flexor reflex & Crossed-extensor reflex
- **Musculoskeletal model (for simulation)**
- **Bio-inspired Bipedal Robots**
- **Exoskeleton**

# Reading materials

- *Neuroscience: Exploring the brain* (3<sup>rd</sup> ed), **Chapter 12 – Spinal Control of Movement**, pp453-481
- *From Neuron to Brain* (5<sup>th</sup> ed), **Chapter 24 – Circuits controlling reflexes, respiration, and coordinated movement**, pp497-511
- 【杜克大学】Medical Neuroscience 运动神经元  
<https://www.bilibili.com/video/BV1AE411F7kN>
- 【清华大学】A musculoskeletal model (**MS-Human-700**): 90 body segments, 206 joints, and 700 muscle-tendon units  
<https://linsgroup.cc/research/MS-Human-700>

# Suggested videos

崔翯，大脑如何控制我们身体的运动？

<https://www.bilibili.com/video/BV1ZP411D7KF/>

崔翯：大脑如何控制我们身体的运动？ | 科学家请出镜

597 0 2023-06-06 10:04:20 未经作者授权，禁止转载



眭亚楠，构建具身的意识

<https://www.bilibili.com/video/BV1QS411w7WL/>

A video thumbnail for a conference presentation. The top bar says 'BAI 6th CONFERENCE 北京智源大会'. The main title is '意识与通用人工智能' and the subtitle is '研究方向 : Learning to Move'. A box highlights '面向具身智能和脑机交互的 神经-肌肉-骨骼系统建模与强化学习 (在算法上关注安全约束、偏好反馈、结构化决策空间的优化)'. Below it, the English title is 'neuro-musculo-skeletal modeling and reinforcement learning for human motion control and interactive robotics' with a subtitle 'with algorithmic focus on optimization with safety constraints, preference feedback, and structured decision spaces'. The Bilibili logo is in the bottom right corner.

# Homework 1: 写一个AI和运动控制相关的business plan

## 举个栗子

如果我想用强化学习来做动画引擎，应该怎么写Business plan?

撰写一个关于利用强化学习的动画引擎的商业计划时，可以遵循以下结构：

### 1. 执行摘要

- **项目简介**: 简要介绍你的动画引擎项目，强调使用强化学习的创新点。
- **目标市场**: 描述你的目标用户（如游戏开发者、影视制作公司等）。
- **财务摘要**: 概述资金需求和预期收入。

### 2. 市场分析

- **行业概述**: 分析动画和游戏行业的发展趋势，特别是在使用人工智能和强化学习方面的需求。
- **竞争分析**: 列出主要竞争对手，分析他们的优势和劣势。
- **目标客户**: 明确你的目标客户群体，包括他们的需求和痛点。

### 3. 产品描述

- **技术概述**: 详细描述你的动画引擎的功能，特别是如何使用强化学习来优化动画效果。
- **独特卖点**: 强调与现有引擎的不同之处，例如更高效的动画生成、更智能的角色行为等。

### 4. 实施计划

- **开发阶段**: 划分项目开发的阶段，包括原型开发、测试和最终发布。
- **技术需求**: 列出所需的技术资源和工具，包括强化学习框架、3D建模工具等。

### 5. 营销策略

- **品牌定位**: 确定品牌形象和市场定位。
- **推广渠道**: 列出潜在的营销渠道（如社交媒体、行业展会、线上广告等）。
- **合作伙伴**: 考虑与游戏开发公司、教育机构等合作，以推动产品推广。

### 6. 财务计划

- **预算和融资**: 详细列出启动资金需求和主要开支，包括开发、市场营销和运营成本。
- **收益预测**: 基于市场分析，制定收入预测，考虑不同的收入模型（如订阅、一次性购买等）。
- **风险评估**: 识别潜在的商业风险及其应对策略。

### 7. 团队构成

- **核心团队**: 介绍团队成员的背景和专业技能，包括技术、市场和运营方面的经验。
- **外部顾问**: 如有必要，列出相关领域的顾问或合作伙伴。

### 8. 结论

- **项目愿景**: 重申项目的长远愿景和目标。
- **号召行动**: 呼吁投资者或合作伙伴的支持，提供联系方式。

通过上述结构，你可以全面展示项目的潜力和可行性，吸引投资者和合作伙伴的关注。确保每个部分清晰、简洁且有说服力。

# Homework 1: 写一个AI和运动控制相关的BP

- 组队: 3-5人

请TA王淞，在QQ群里发腾讯excel共享文档。填写人员，产品名称，主题，融资金额

DDL: 本周三 (Oct, 16, 2024) , 7pm

- 提交BP的PPT, email给TA钱富元

DDL: 下周一 (Oct, 21, 2024) , 7pm

- Oral Presentation

时间: 下周三 (Oct, 23, 2024) , 7pm