

Brain Intelligence and Artificial Intelligence

人脑智能与机器智能

Lecture 7 – Somatosensory System

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Recap Lecture 3 – Auditory System

- **Sound:** frequency (Hz) & intensity (dB)
- **Ear**
 - Structure of human ear: outer ear, middle ear, inner ear
 - Cochlea; Organ of Corti; Hair cells
- **Central auditory process**
 - Auditory pathways: SG, (VCN, SO, IC, MGN), A1
 - Encoding sound intensity and frequency
 - Mechanisms of sound localization
 - Auditory cortex
- **Neural representation & plasticity in auditory cortex**
- **Deep learning for auditory processing:** encoding, decoding, interpreting

Recap Lecture 4 – Language processing

- **What is language**
- **The language system in brain**
- **Aphasia**
 - Broca's Aphasia
 - Wernicke's aphasia
- **Decoding language from the neural data**
 - ECoG-based decoding
 - EEG-based decoding
- **NLP in machines v.s. NLP in human brain**
 - NLP models
 - Representation of semantics
 - Brain-AI alignment
- **Linguistic stimuli to modulate the brain activity**

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**

Somatic sensation

Somatic sensation enables our body

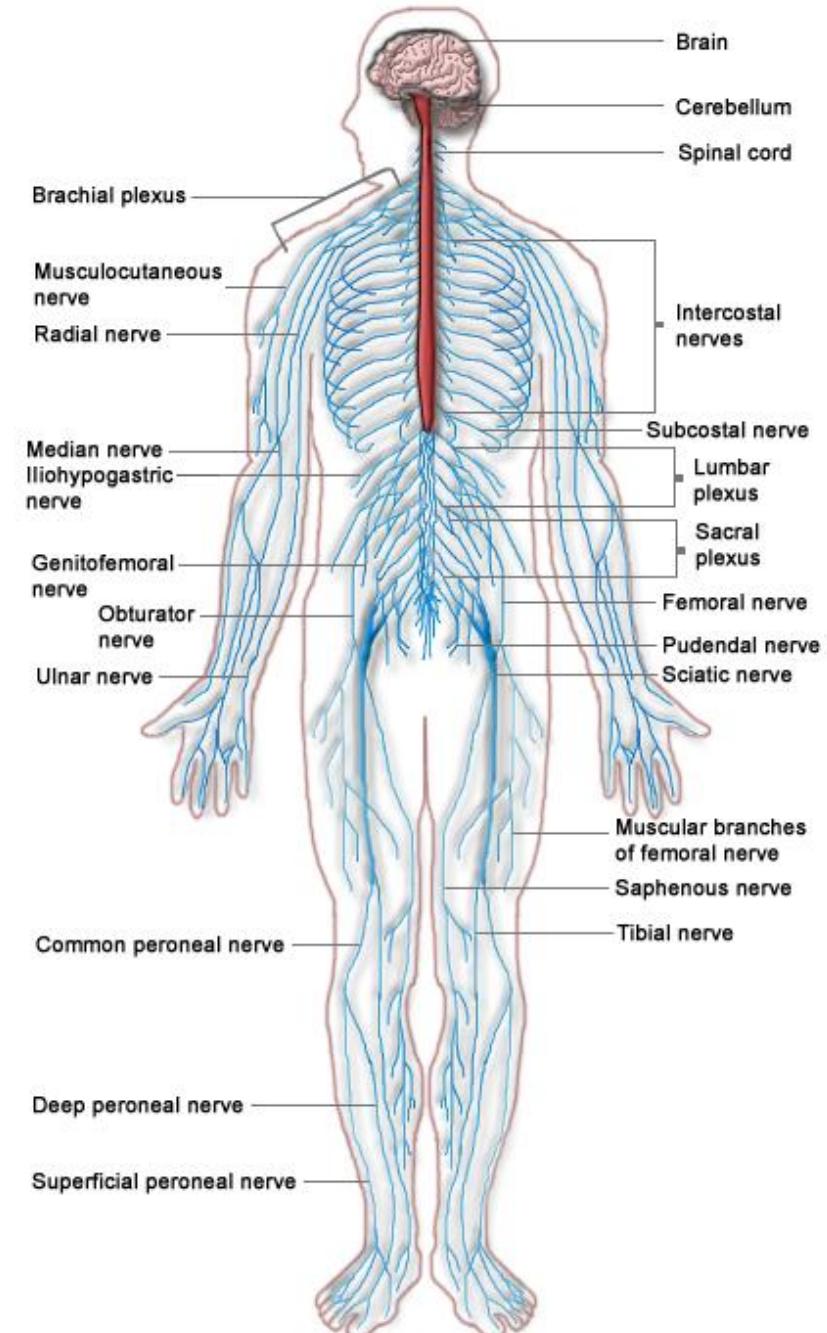
- to feel
- to ache
- to chill
- to know what its parts are doing

These sensory receptors are **not** localized to a specific organ, such as the eye, ear, tongue or nose.

Instead they cover our skin, epithelial tissues, our skeletal muscles, our bones and joints, and our internal organs.

Somatosensory system receive inputs from many sensory **receptors**:

- Mechanoreceptors, 机械感受器
(mechanical → action potential)
- Thermoreceptors, 热感受器
- Photoreceptors, 光感受器
- Chemoreceptors, 化学感受器



Somatosensory system

Somatic sensation includes many feelings, such as *pressure*, *skin stretch*, *vibration*, *temperature*.

- ❖ **Mechanoreception** ➤ touch
- ❖ **Thermoception** ➤ temperature
- ❖ **Nociception** ➤ pain
- ❖ **Proprioception** ➤ body movement

In this lecture, we will learn

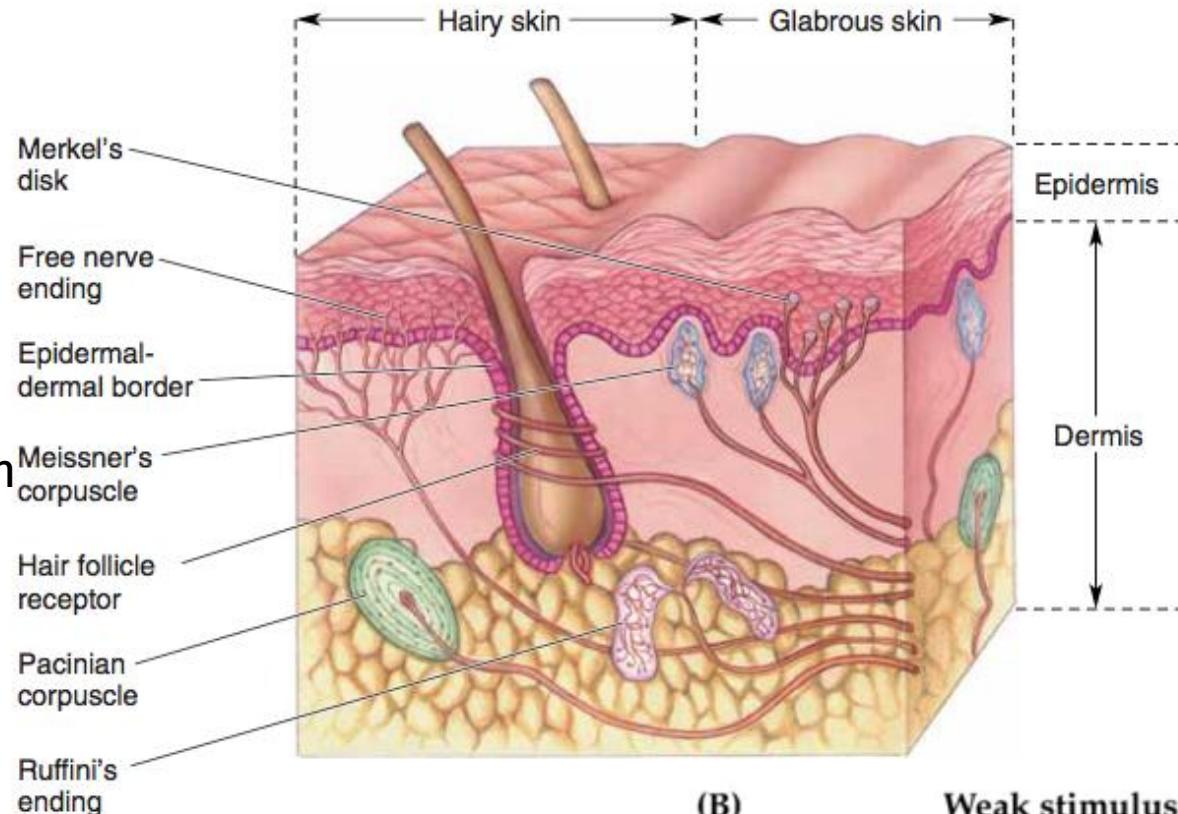
- (i) how a touch of the skin is transduced into neural signals,
- (ii) how these signals make their way to the brain,
- (iii) how the brain makes sense of them.

The sensation of touch begins at the **skin**.

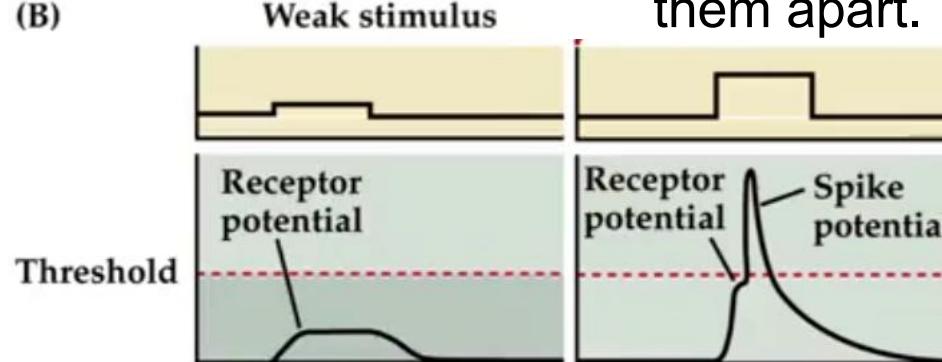
- Skin performs an essential *protective* function, and it prevents the evaporation of body fluids into the dry environment we live in.
- Skin also provides most direct contacts with the world, as the largest *sensory organ* we have.

Somatic sensory receptors in the skin

heat
touch



Each type of fiber is activated by a **specific** stimulus and leads to a characteristic sensation.



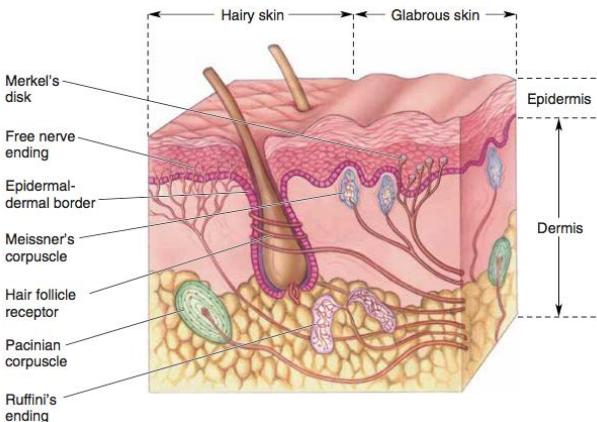
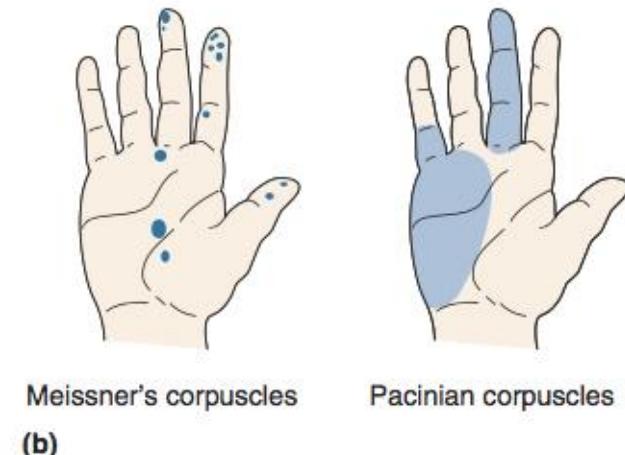
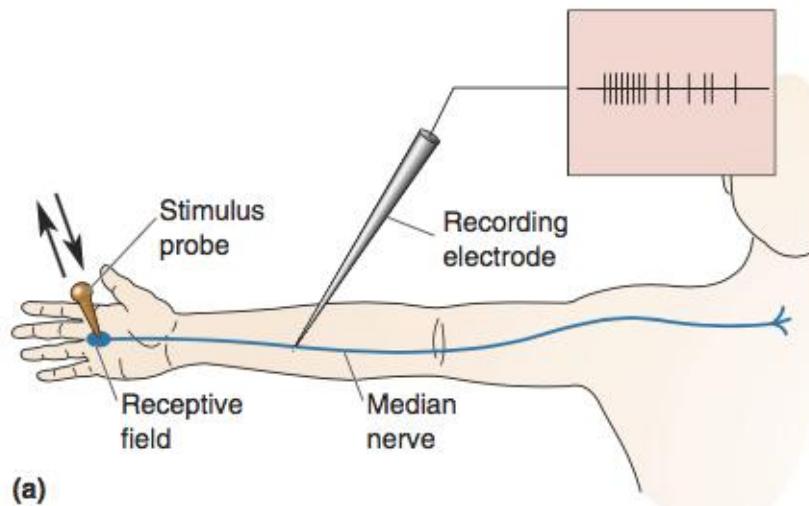
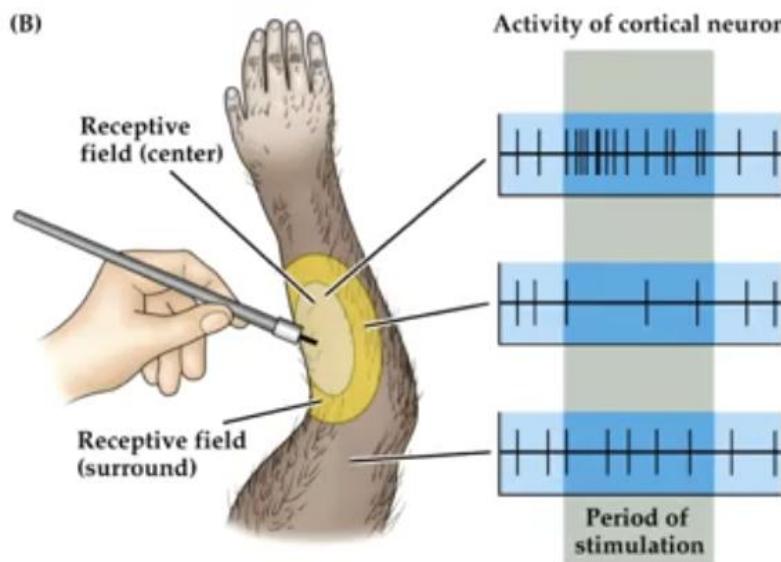
Hairy skin and glabrous skin have a variety of sensory receptors within the dermal and epidermal layers.

Each receptor has an axon and, except for *free nerve endings*, all of them have associated non-neuronal tissues.

Skin can be vibrated, pressed, pricked, and stroked, and its hairs can be bent or pulled. These are quite different kinds of mechanical energy, yet we can feel them all and easily tell them apart.

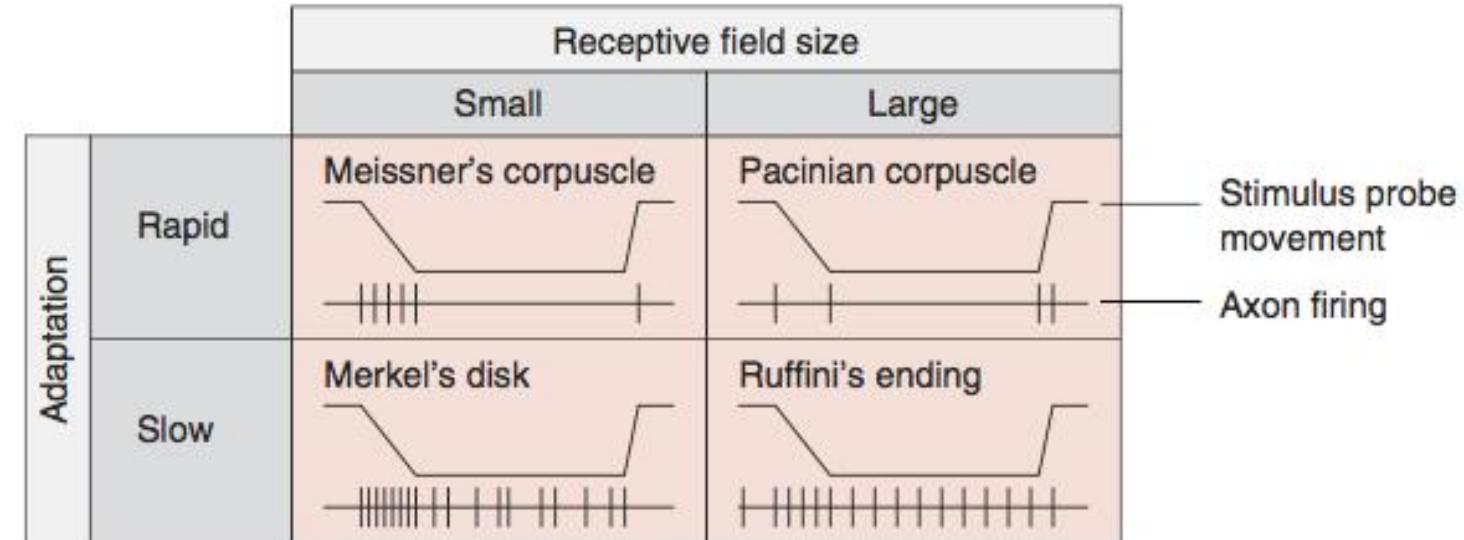
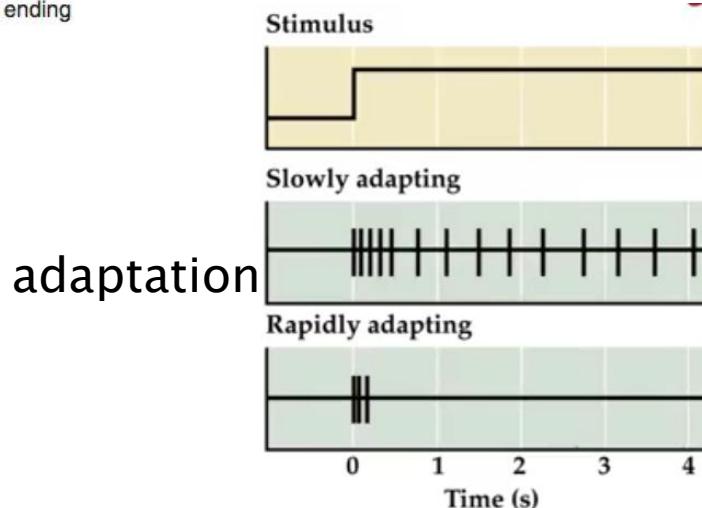
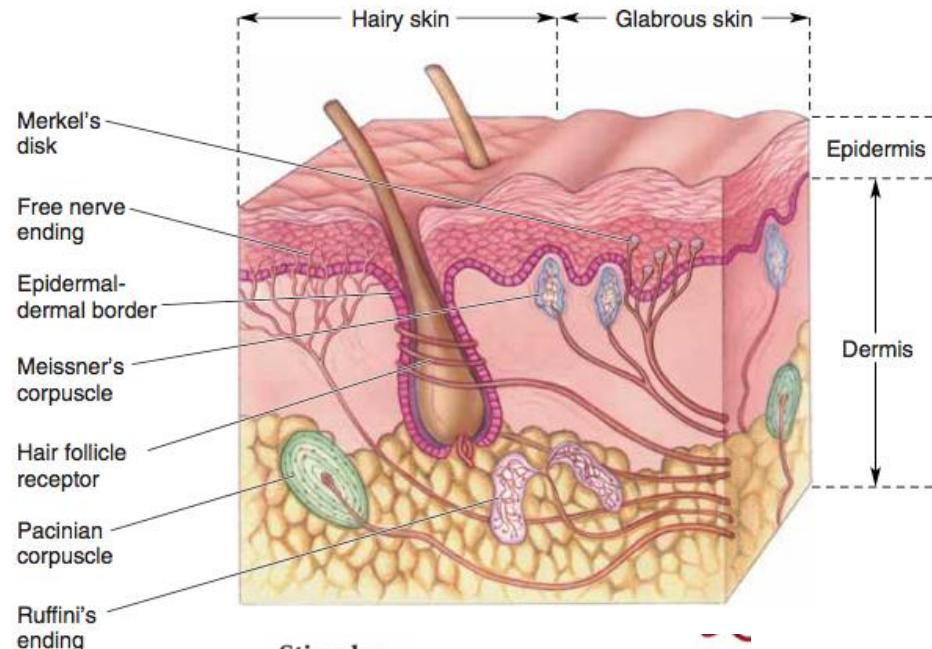
We have mechanoreceptors that referred stimulus frequencies, and receptive field sizes.

Receptive fields of human sensory receptors

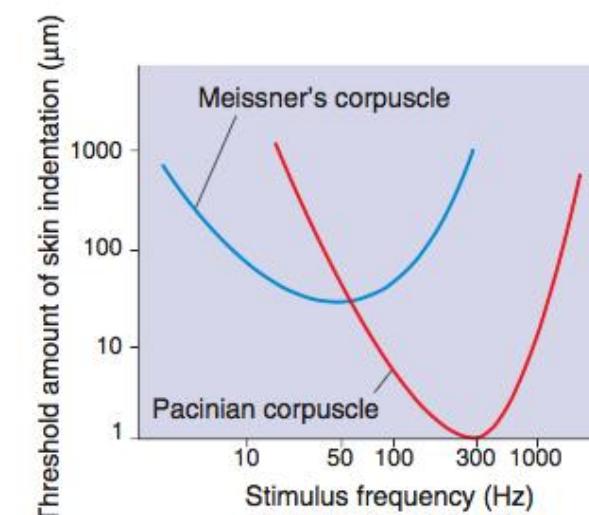


- (a) By introducing a *microelectrode* into the median nerve of the arm, it is possible to record the action potentials from a **single** sensory axon and **map its receptive field** on the hand with a fine *stimulus probe*.
- (b) Results show that *receptive fields* are either relatively small (as in Meissner's corpuscles), or large (as in Pacinian corpuscles).

Diversity in receptive field size and adaptation

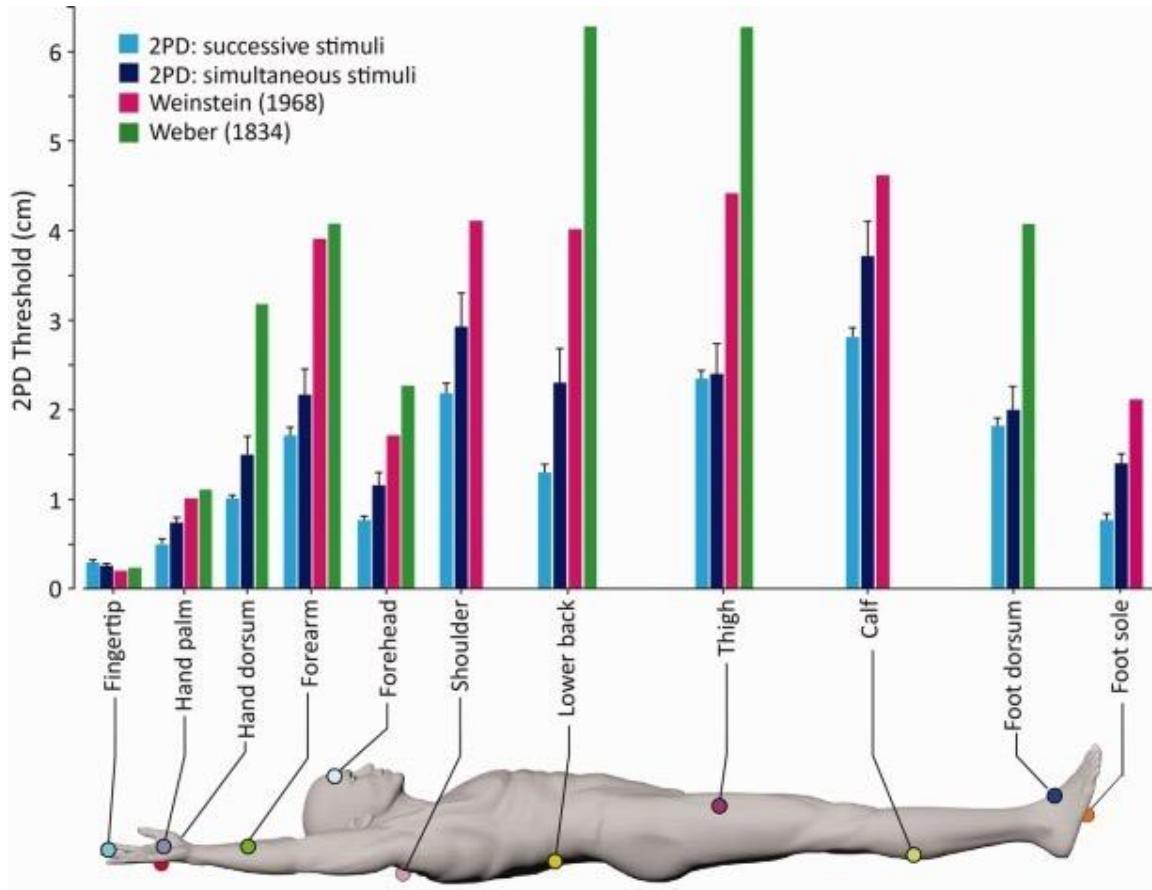


The different mechanical sensitivities of mechanoreceptors mediate different sensations.



Two-Point Discrimination

Let's do an experiment.



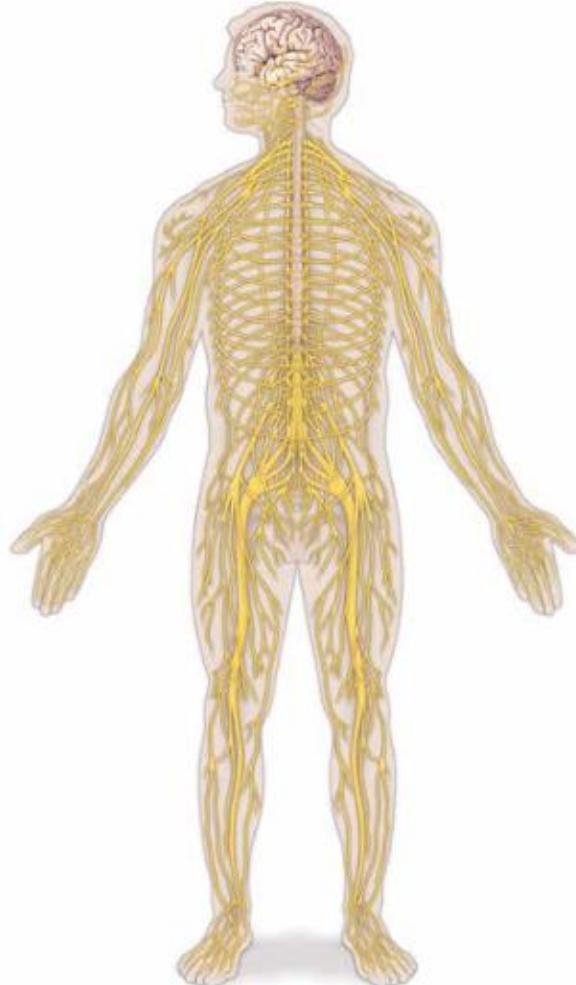
Our ability to discriminate the detailed features of a stimulus varies tremendously across the body.

WHY? and HOW?

Several reasons explain why the fingertip is so much better than other body surface:

- (1) There is a much higher density of mechanoreceptors in the skin of the fingertip than on other parts of the body,;
- (2) the fingertips are enriched in receptor types that have small receptive fields (e.g., Merkel's disks);
- (3) there is more brain tissue (and thus more raw computing power) devoted to the sensory information of each square millimeter of fingertip than elsewhere;
- (4) there may be special neural mechanisms devoted to high-resolution discriminations.

Primary Afferent Axons

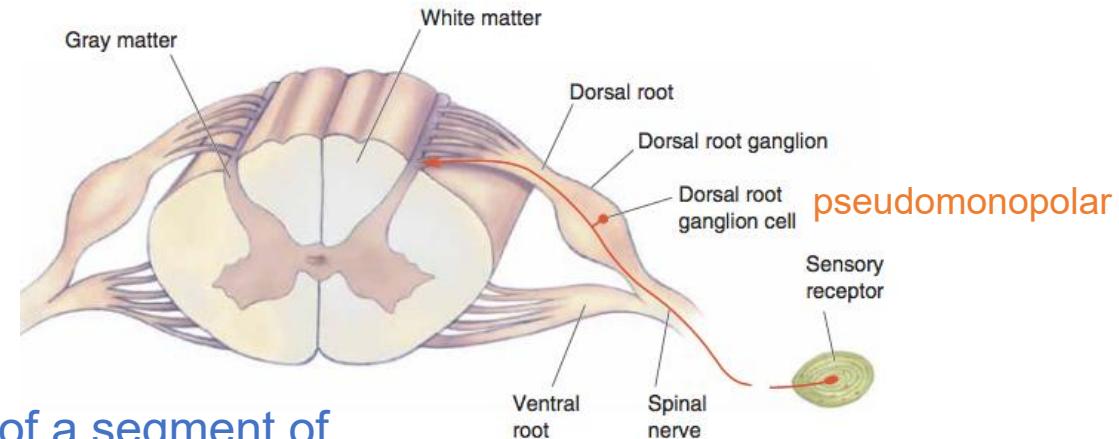


Peripheral nerves

The skin is richly innervated by axons that course through the vast network of **peripheral nerves** on their way to the CNS (see the left Figure).

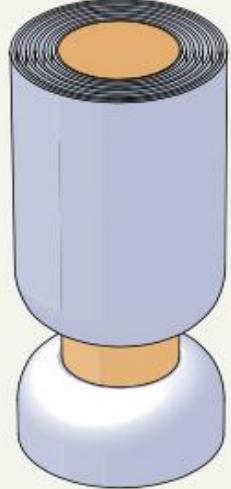
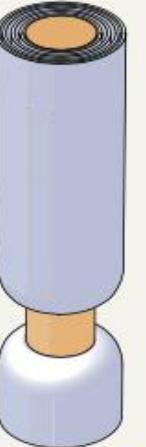
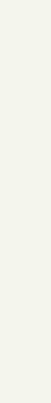
Axons bringing information from the somatic sensory receptors to the spinal cord or brain stem are the **primary afferent axons** of the somatic sensory system.

The primary afferent axons enter the **spinal cord** through the **dorsal roots**; their cell bodies lie in the dorsal root ganglia.



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

Diverse sizes of primary afferent axons

Axons from skin	A α Group I	A β II	A δ III	C IV
Axons from muscles				
Diameter (μm)	13–20	6–12	1–5	0.2–1.5
Speed (m/sec)	80–120	35–75	5–30	0.5–2
Sensory receptors	Proprioceptors of skeletal muscle	Mechanoreceptors of skin	Pain, temperature	Temperature, pain, itch

Primary afferent axons have widely varying diameters, and their size correlates with the type of sensory receptor to which they are attached.

The diameter of an axon, together with its myelin, determines its **speed** of action potential conduction.

C fibers mediate pain, temperature sensation, and itch, and they are the slowest of axons, conducting at about 0.5–1 m/sec.

WHY are they designed in this huge diversity?

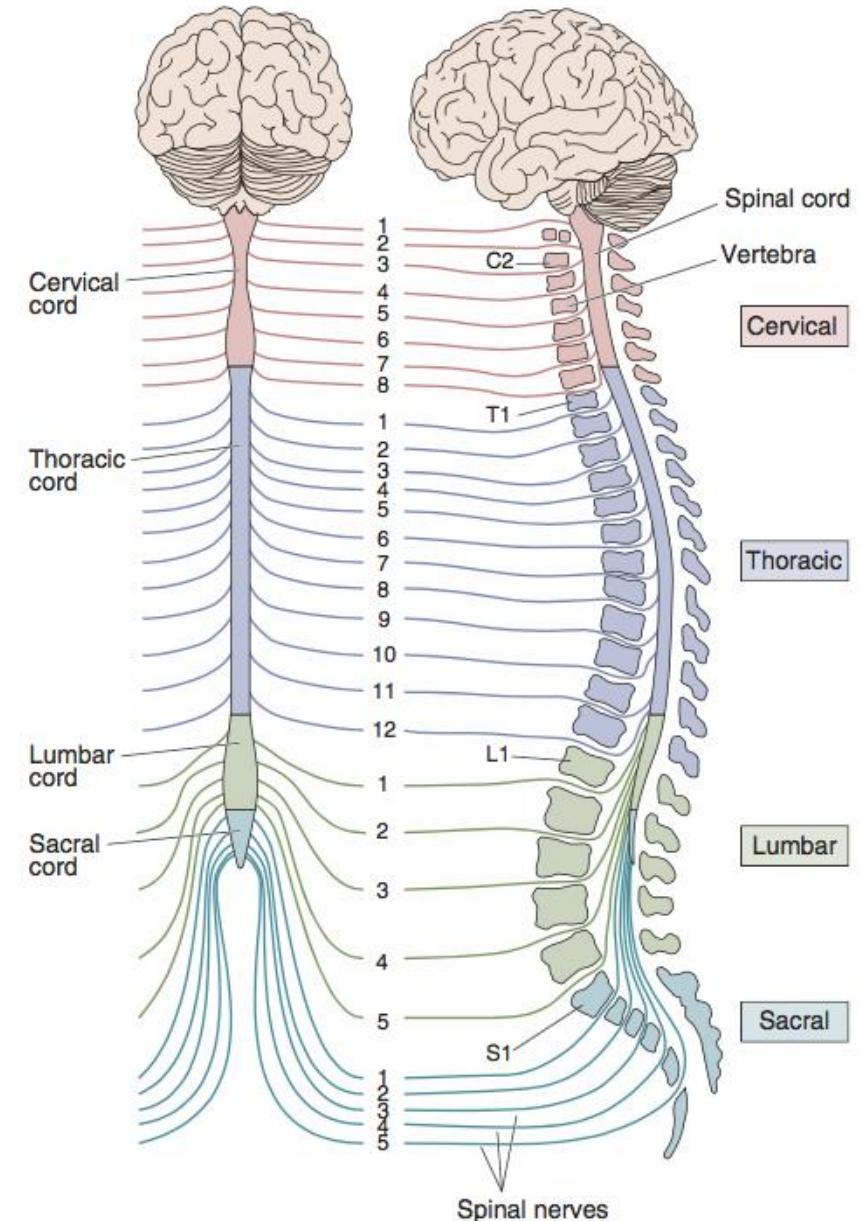
Receptor type	Muscle spindle	Merkel, Meissner, Pacinian, Ruffini cells	Free nerve endings	Free nerve endings (unmyelinated)
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The Spinal Cord

Most peripheral nerves communicate with the CNS via the spinal cord.

Humans have 31 spinal segments, categorized as follows:

- 8 cervical segments (C1-C8)
- 12 thoracic segments (T1-T12)
- 5 lumbar segments (L1-L5)
- 5 sacral segments (S1-S5)
- 1 coccygeal segment (Co1)



30 Segments of the spinal cord

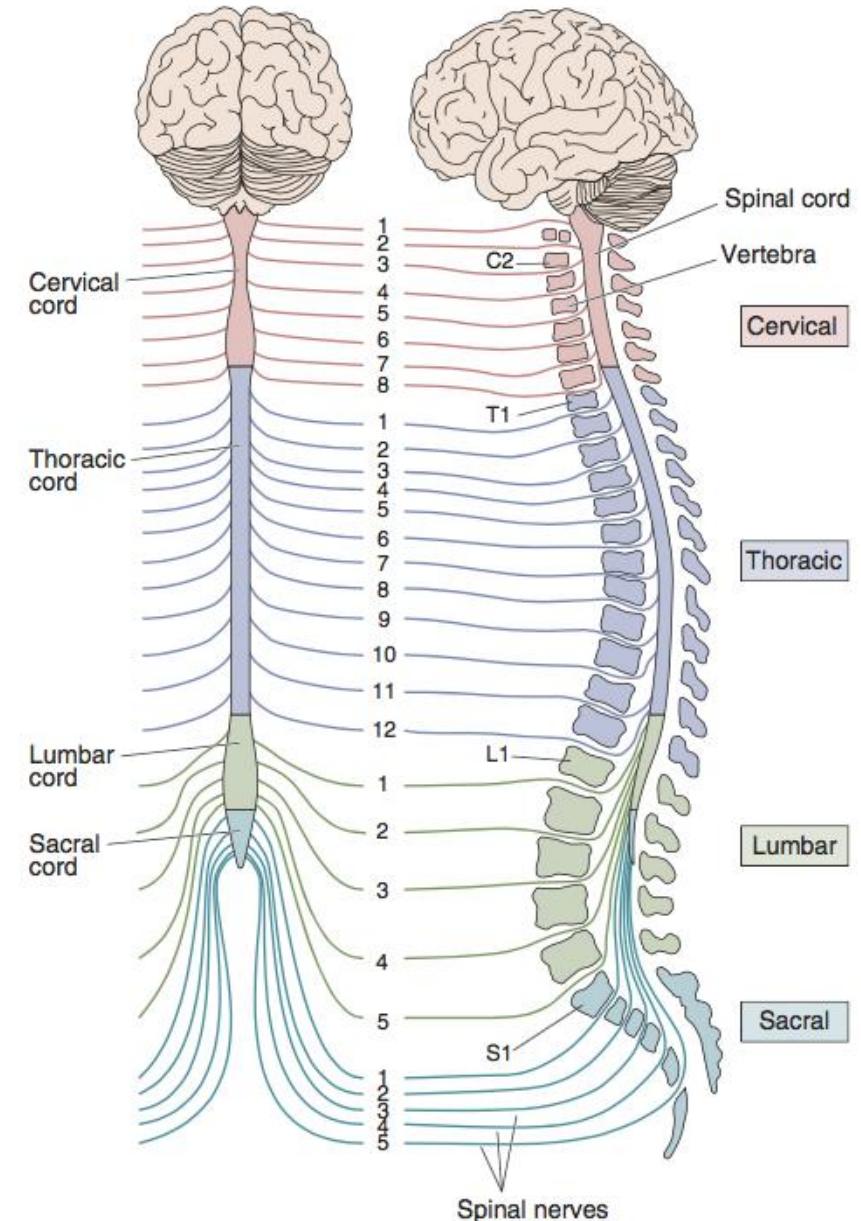
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The Spinal Cord

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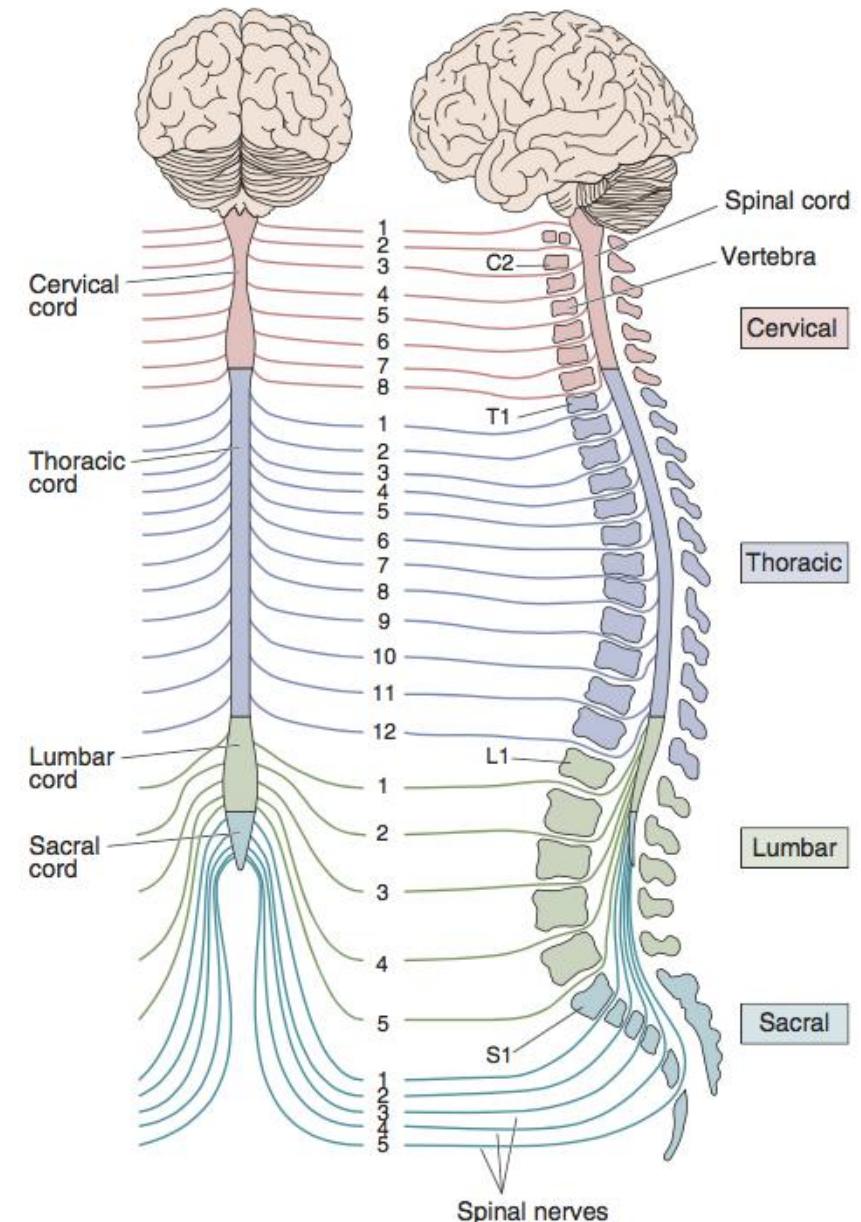
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How about the giraffe?

Their total number of spinal segments is **similar**, though there can be small variations among species. Most giraffes have:

- 7 cervical segments (C1-C7)
- 14-15 thoracic segments
- 5 lumbar segments
- 5 sacral segments

This gives giraffes around 31-32 spinal segments in total.



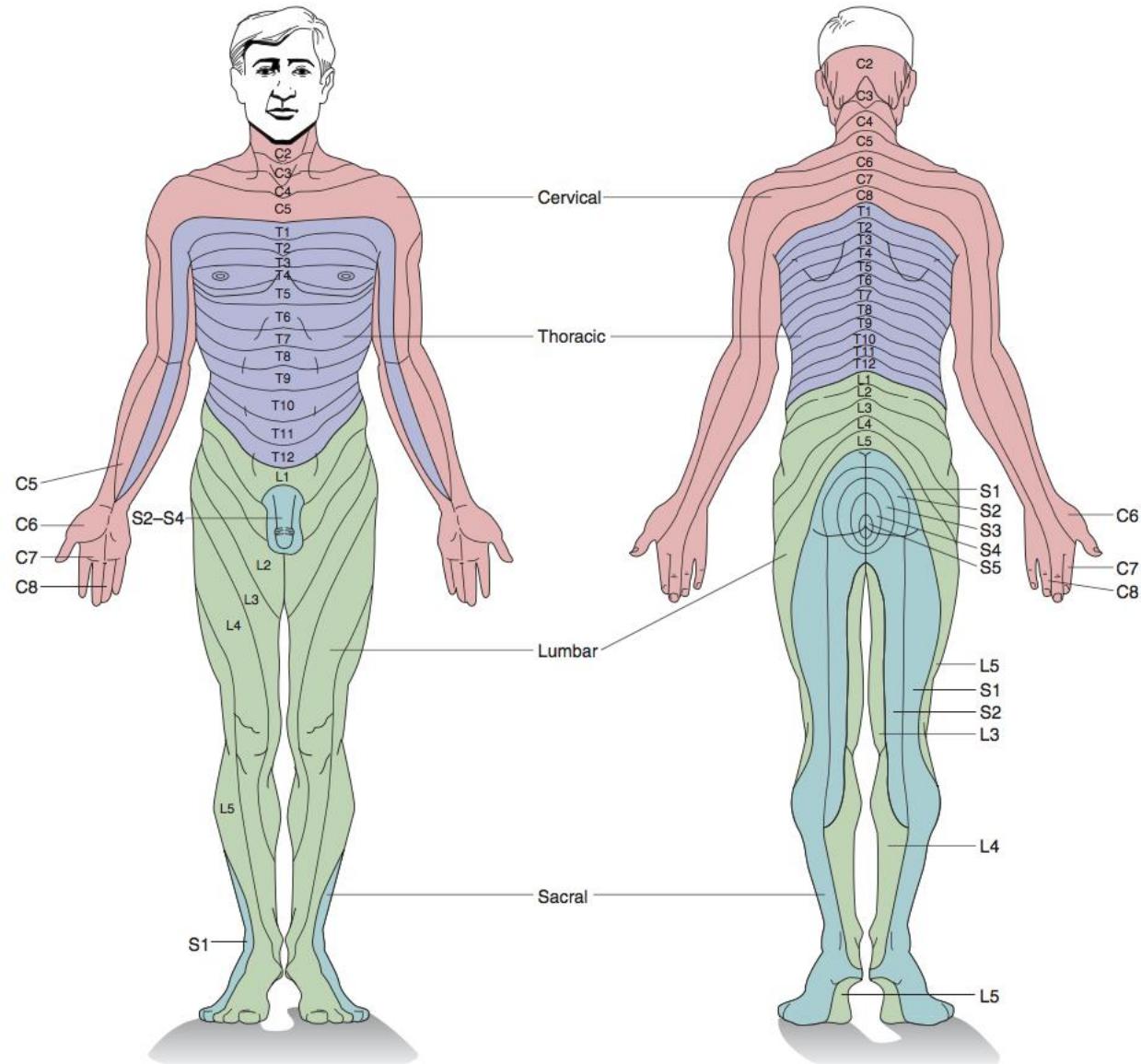
30 Segments of the spinal cord

Dermatomes

The area of skin innervated by the right and left dorsal roots of a single spinal segment is called a **dermatome**; thus, there is a **one-to-one correspondence** between dermatomes and spinal segments.

When a dorsal root is cut, the corresponding dermatome on that side of the body does **NOT** lose all sensation. The residual somatic sensation is explained by the fact that the adjacent dorsal roots innervate overlapping areas.

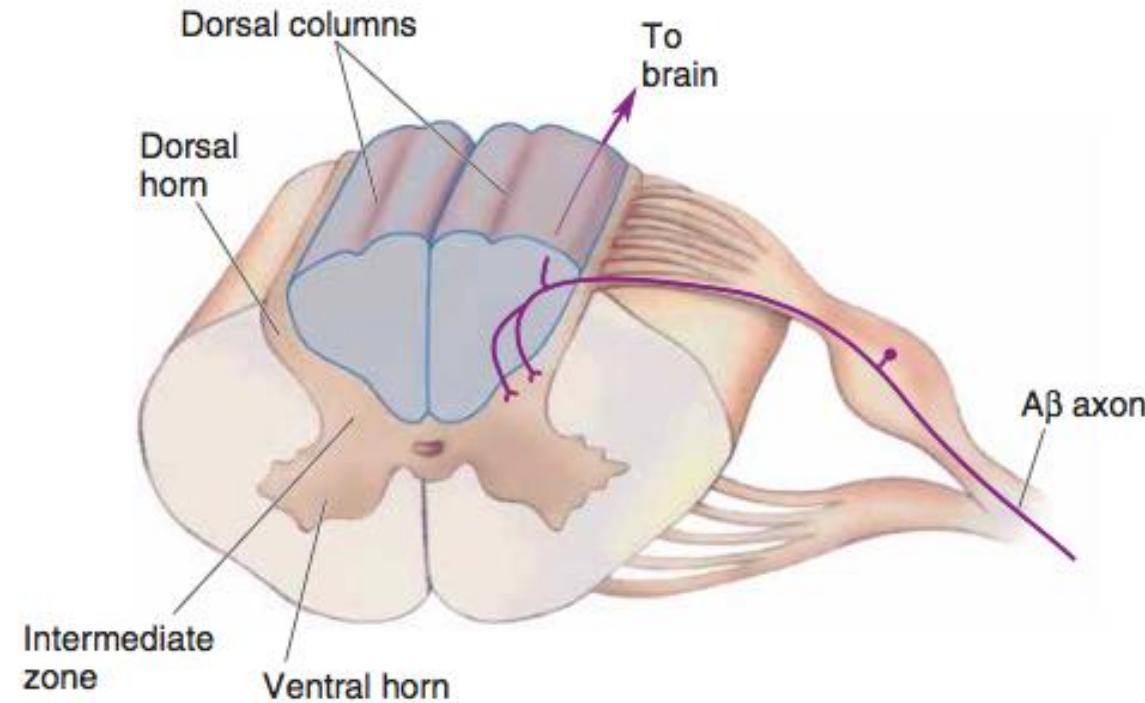
To lose all sensation in one dermatome, therefore, 3 adjacent dorsal roots must be cut.



Sensory organization of the spinal cord

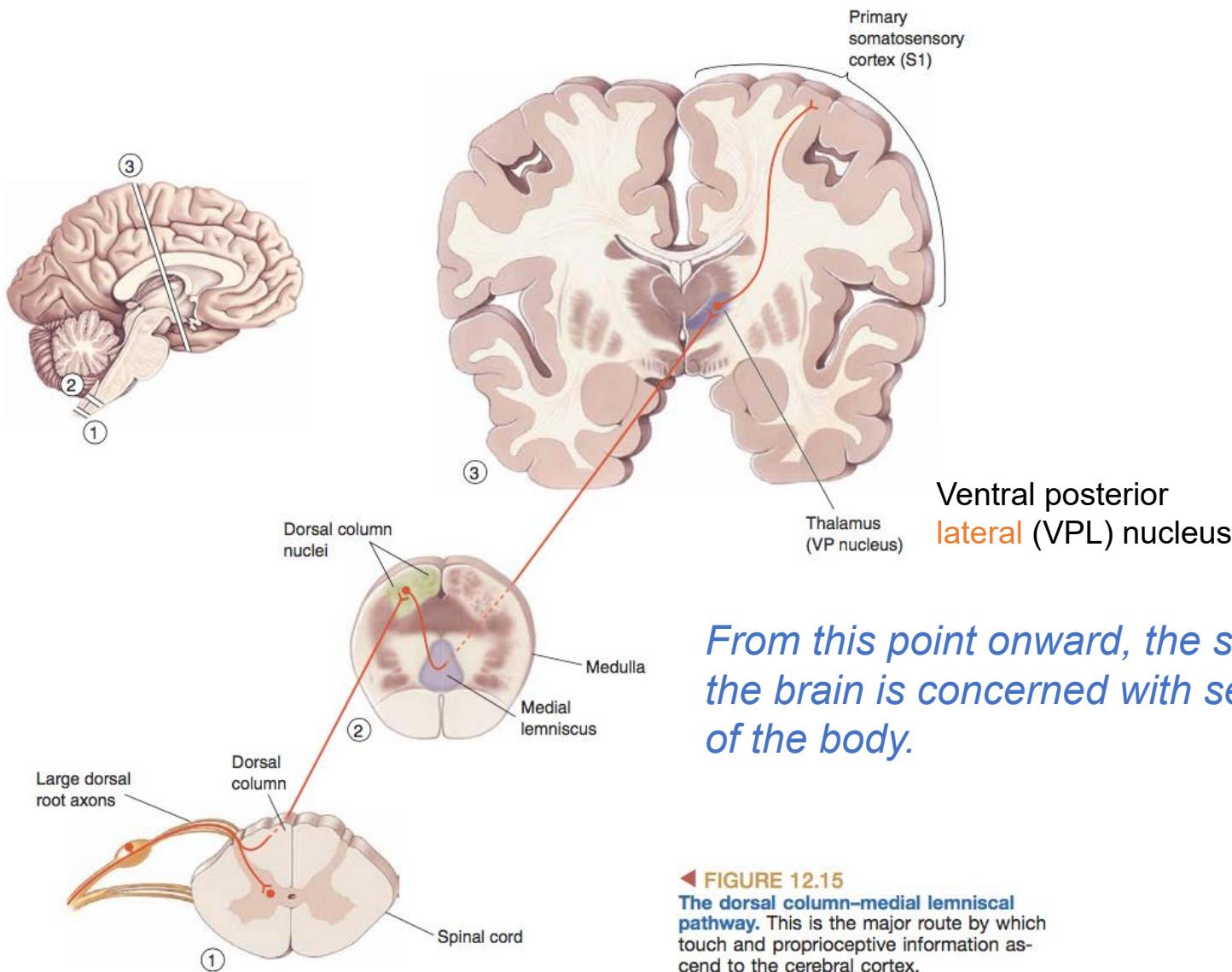
The large, myelinated **A β axons** conveying information about a touch to the skin enter the dorsal horn and branch.

- One branch synapses in the deep part of the dorsal horn on **second-order sensory neurons**. These connections can initiate or modify a variety of rapid and **unconscious reflexes**.
- The other branch of the A β primary afferent axon ascends straight to the **brain**. This ascending input is responsible for perception, enabling us to form **complex judgments** about the stimuli touching the skin.



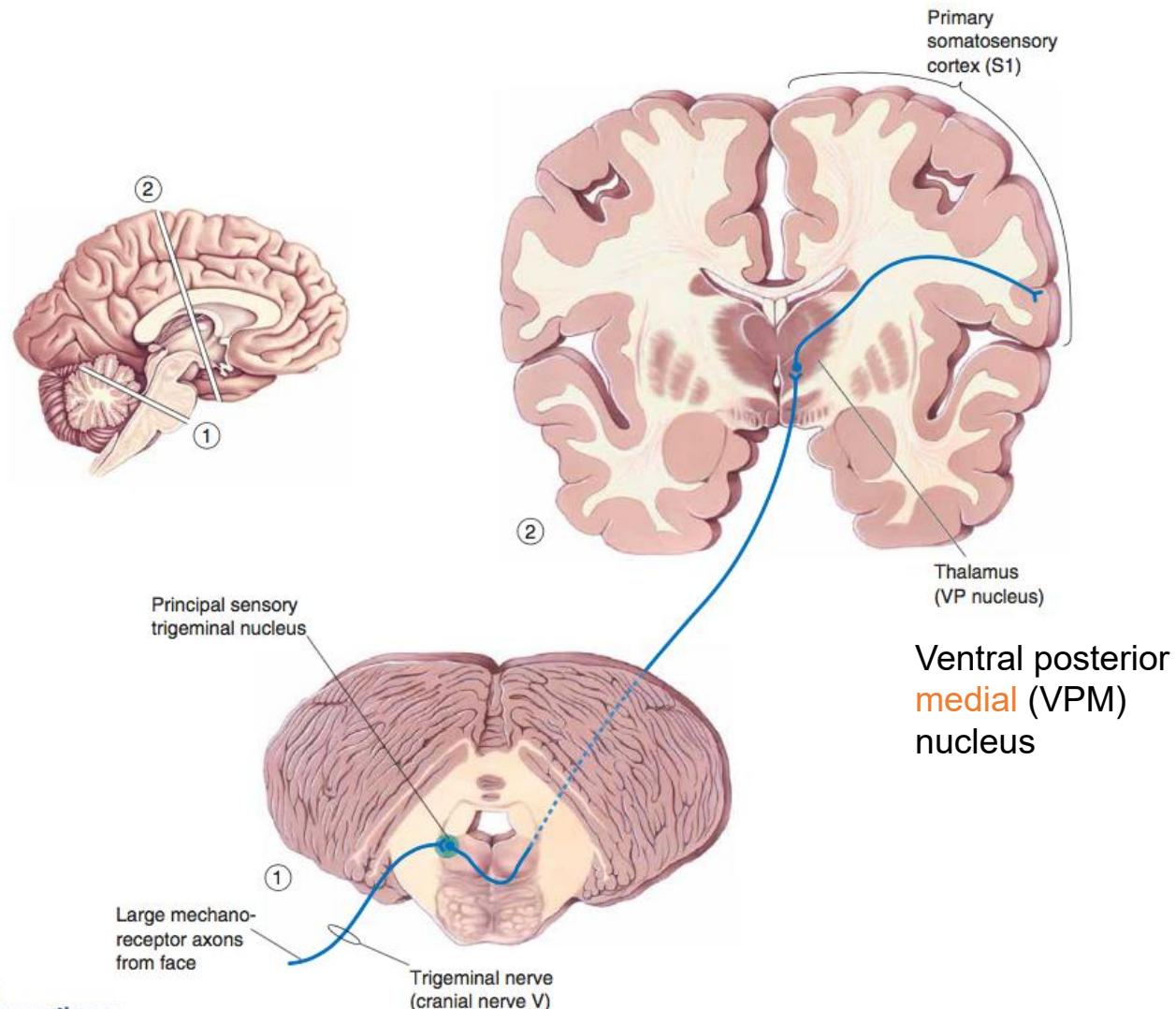
The trajectory of the touch-sensitive A β axons in the spinal cord.

The Dorsal Column–Medial Lemniscal Pathway



From this point onward, the somatic sensory system of one side of the brain is concerned with sensations originating from the other side of the body.

The Trigeminal Touch Pathway

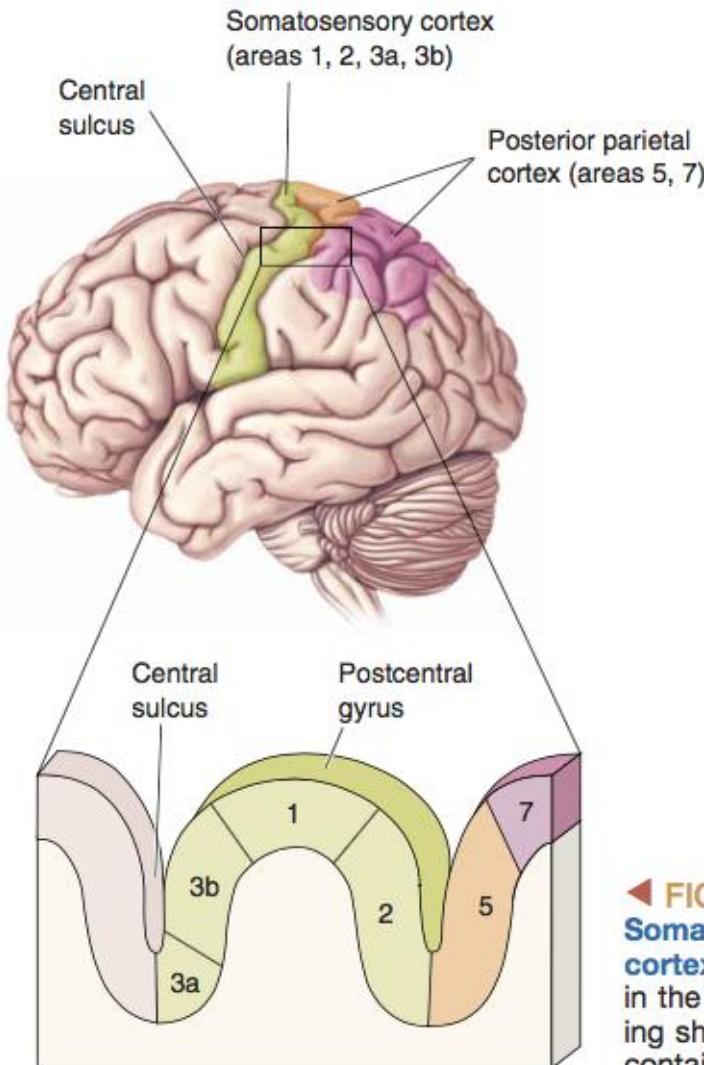


► FIGURE 12.16
The trigeminal nerve pathway.

There are twin trigeminal nerves, one on each side, and each breaks up into three peripheral nerves that innervate the face, mouth areas, the outer two-thirds of the tongue, and the dura mater covering the brain.

Additional sensation from the skin around the ears, nasal areas, and pharynx is provided by other cranial nerves: the facial (VII), glossopharyngeal (IX), and vagus (X).

Somatosensory Cortex



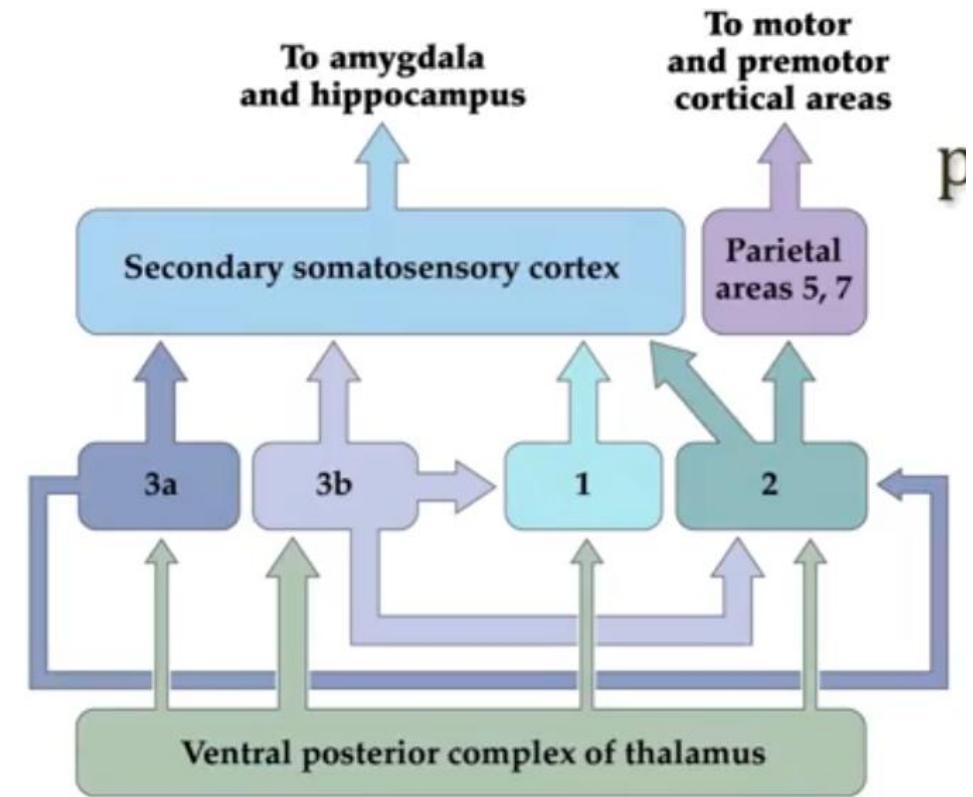
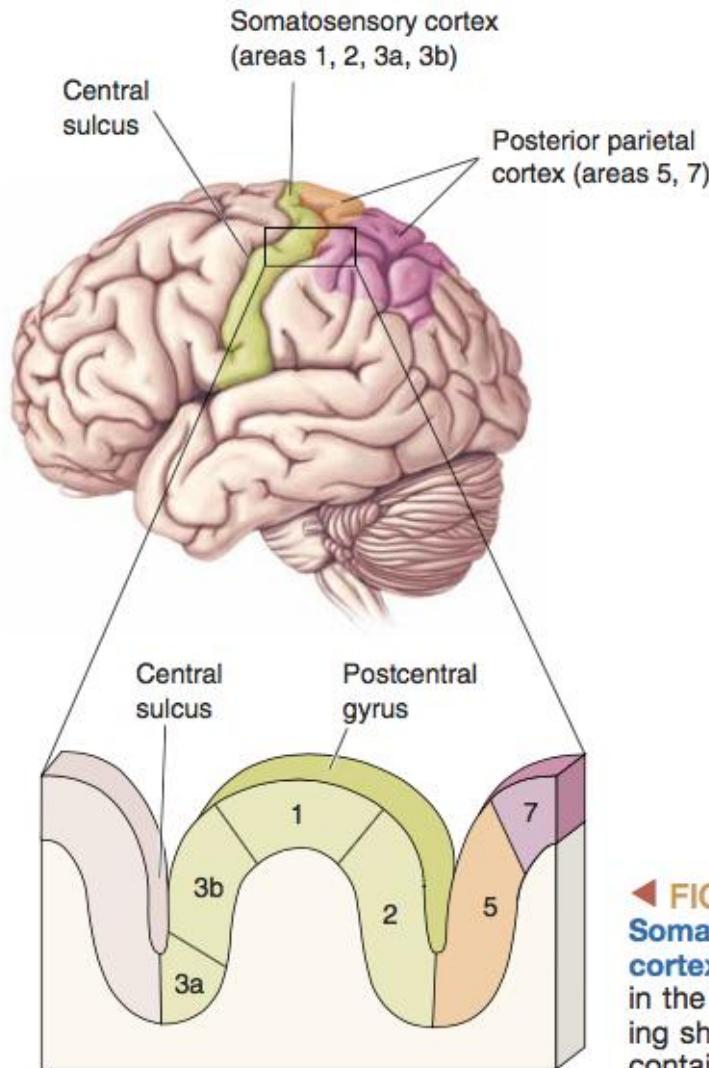
Area 3b is the primary somatic sensory cortex because

- (1) it receives dense inputs from the VP nucleus of the **thalamus**;
- (2) its neurons are very responsive to **somatosensory stimuli** (but not to other sensory stimuli);
- (3) lesions here impair somatic sensation;
- (4) when electrically stimulated, it evokes somatic sensory experiences.

Area 3a also receives a dense input from the **thalamus**; however, this region is concerned with the **sense of body position** rather than touch.

◀ **FIGURE 12.17**
Somatic sensory areas of the cortex. All of the illustrated areas lie in the parietal lobe. The lower drawing shows that the postcentral gyrus contains S1, area 3b.

Somatosensory Cortex



Areas 1 and 2 receive dense inputs from area 3b.
The projection from 3b to **area 1** sends mainly **texture** information, while the projection to **area 2** emphasizes **size and shape**.

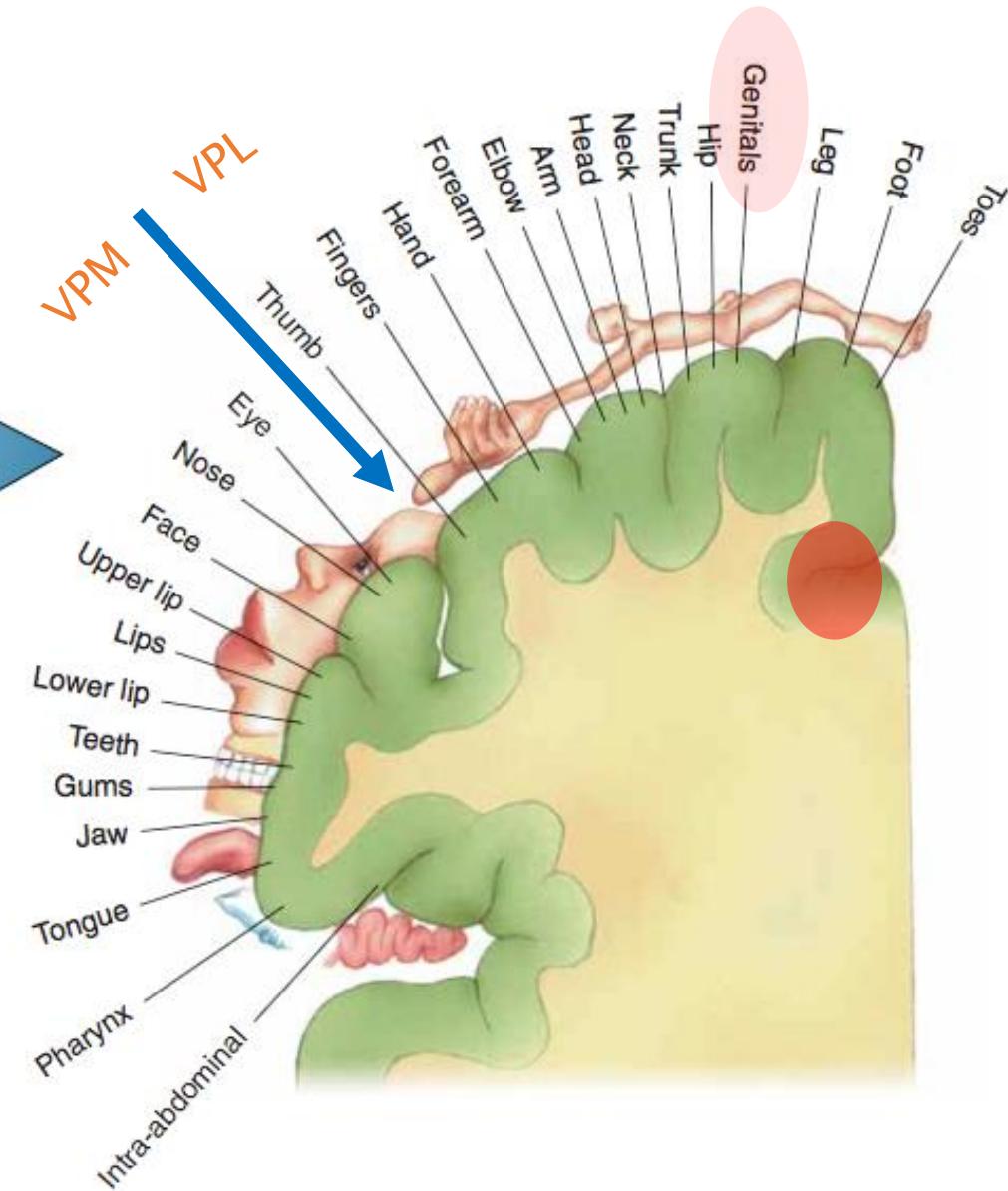
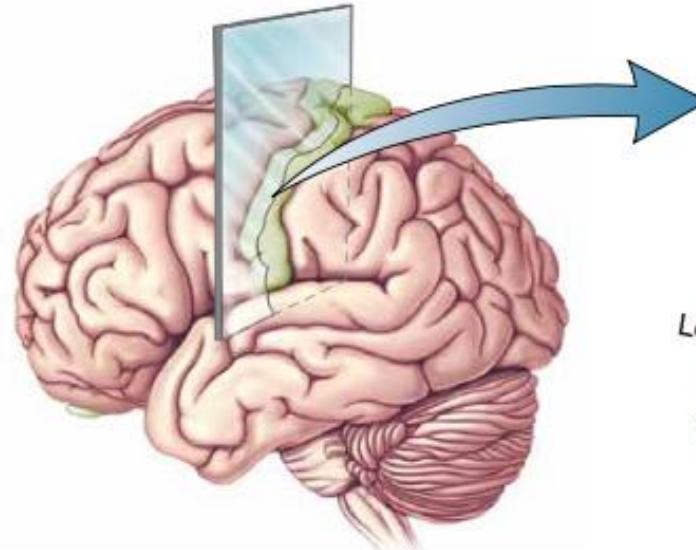
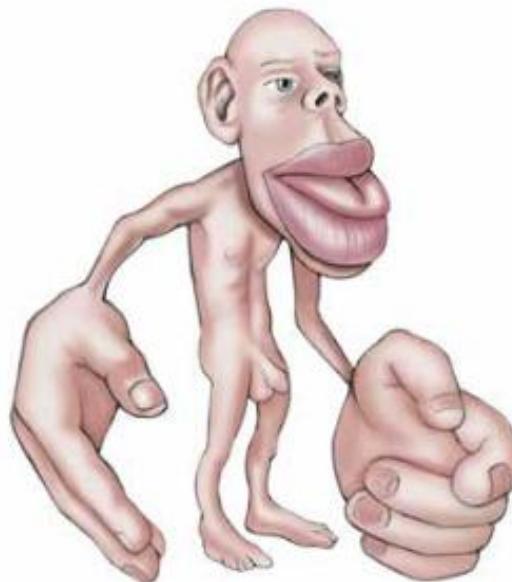
Small lesions in area 1 or 2 produce predictable deficiencies in discrimination of texture, size, and shape.

Cortical Somatotopy of human

Tonotopy → audition

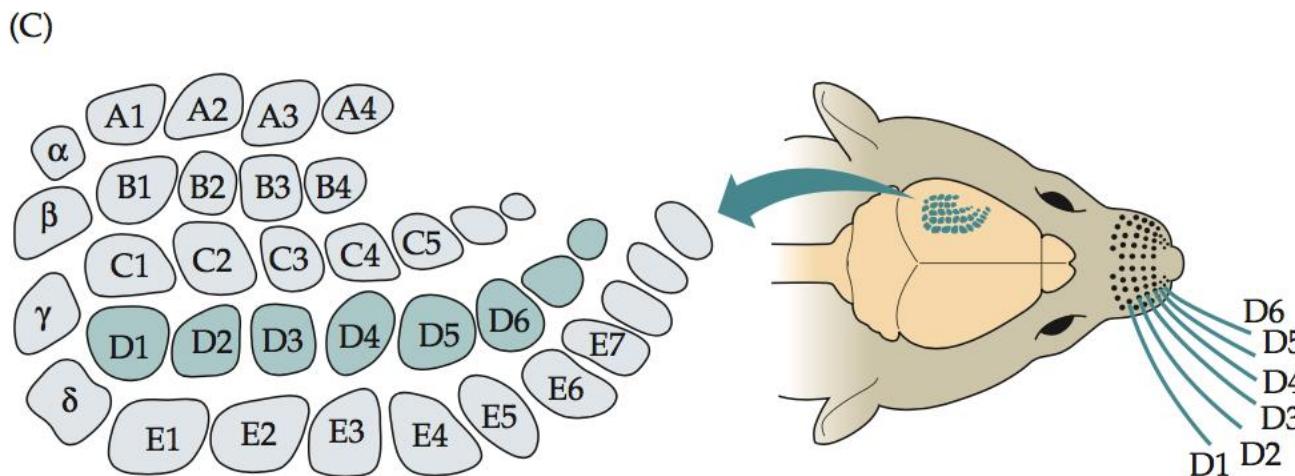
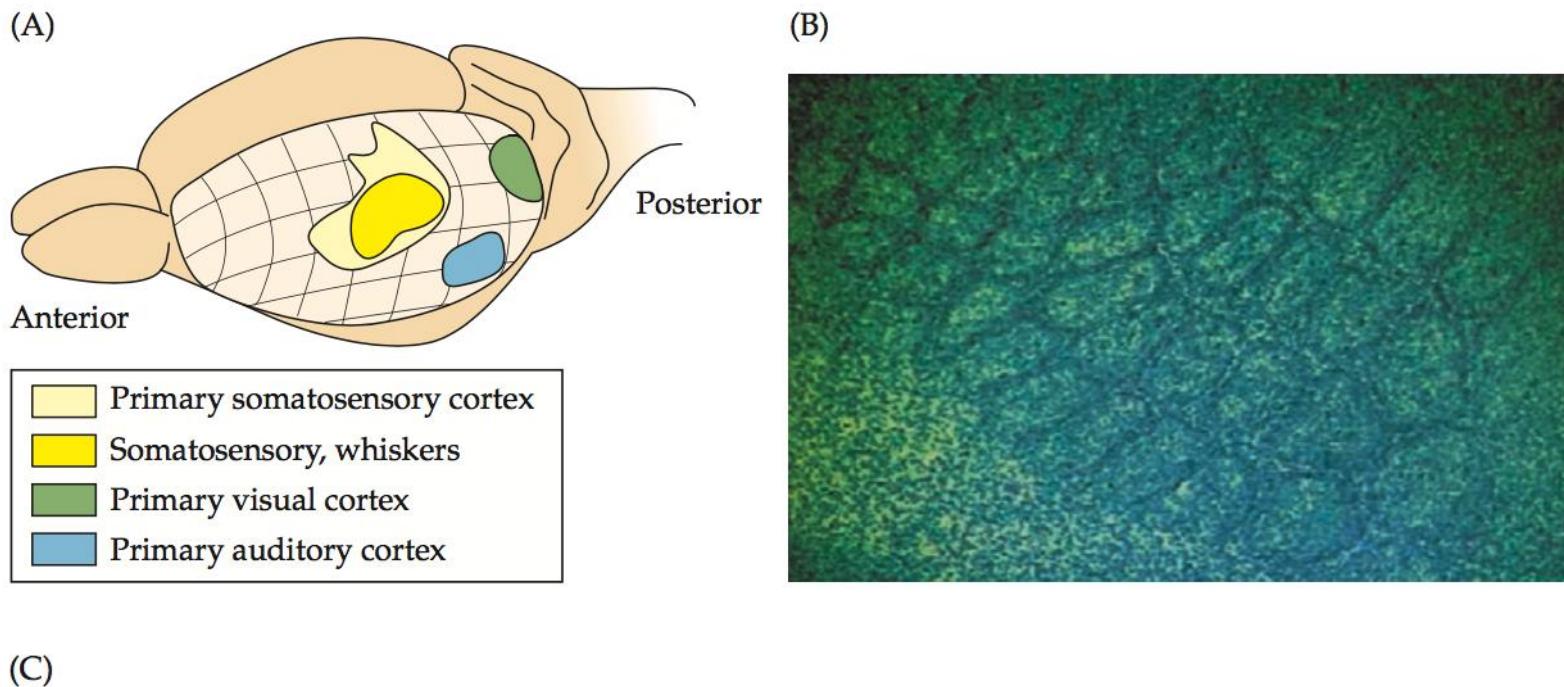
Retinotopy → vision

Somatotopy → somatosensory

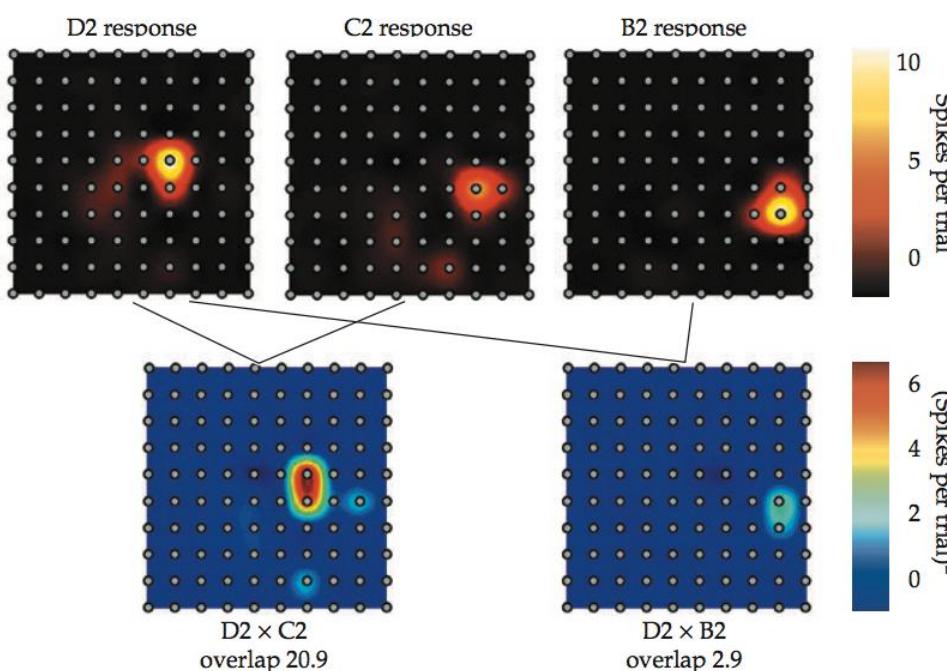
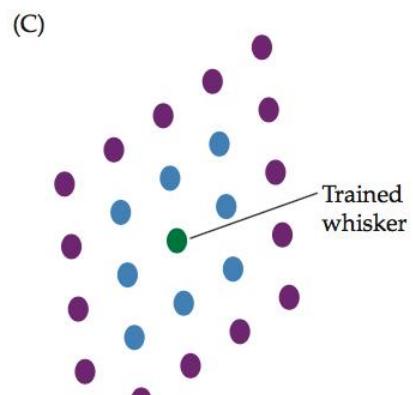
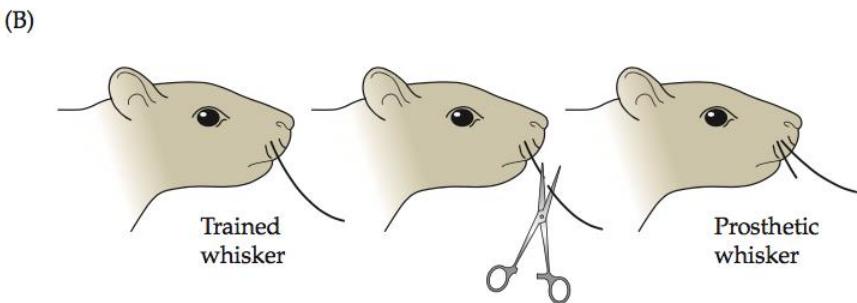
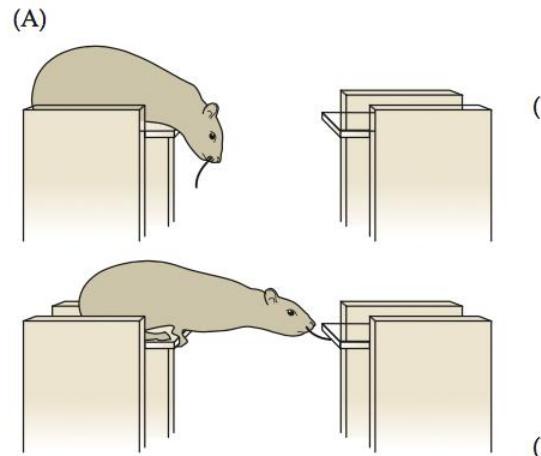


A somatotopic map of the body surface onto primary somatosensory cortex.

Cortical representation of whiskers in rats and mice



Role of the Cortical Whisker Map in Sensory Learning



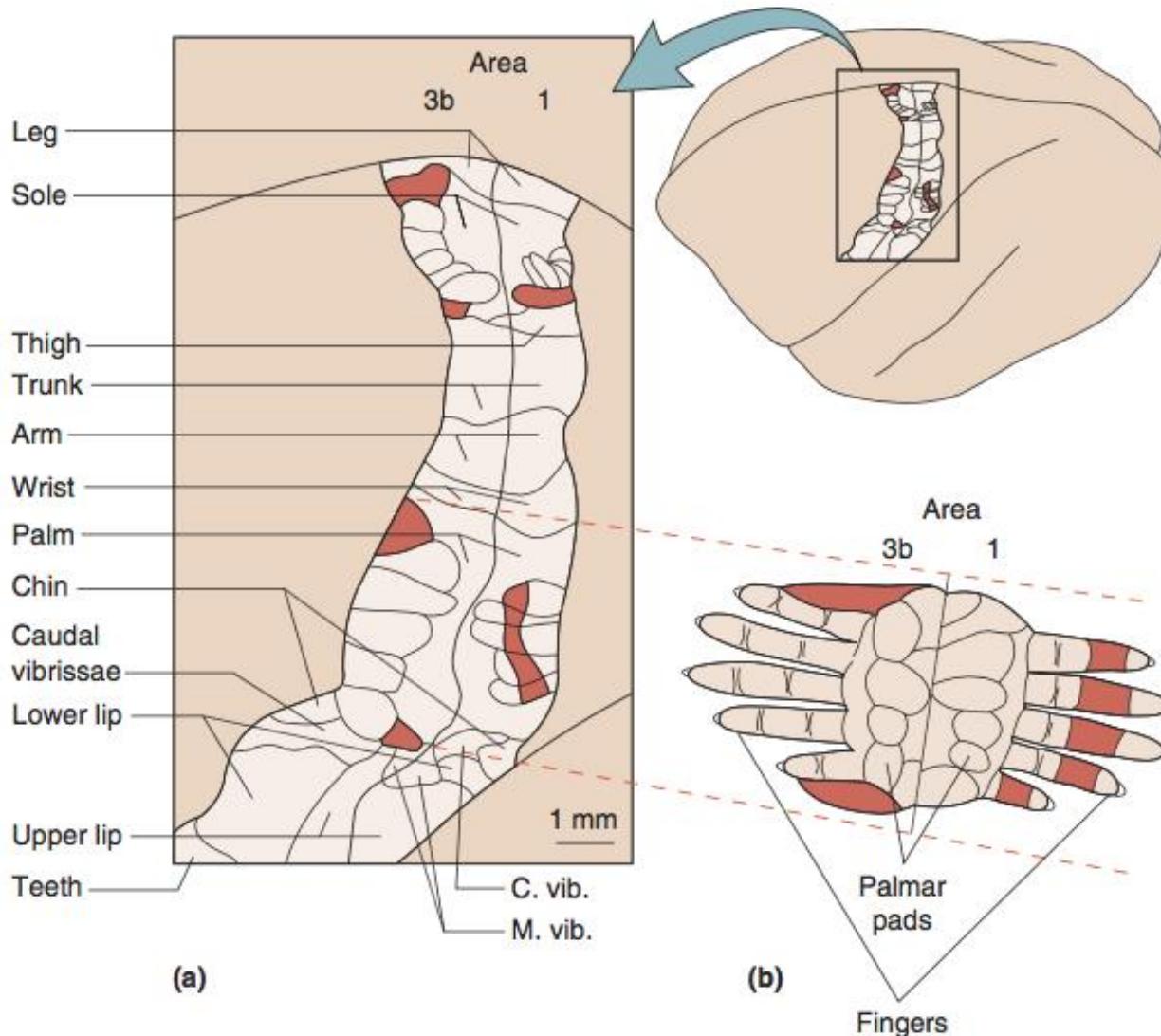
(A) In the gap-crossing task. First it leans into the gap (upper sketch) and then it extends forward to reach the target (lower sketch).

(B) The trained whisker (left) was clipped off (middle) and a different whisker was fixed to a whisker stump some specific distance from the stump of the trained whisker (prosthetic whisker, right).

(C) Schematic depiction of the whisker grid. The speed at which the rat relearned the gap-crossing task depended on the distance from the site of the trained whisker to the site of attachment of the new whisker, indicating that learning was localized.

(D) In the upper three plots, the number of action potentials evoked by separate movements of three different whiskers is illustrated.

Multiple somatotopic maps



Recordings were made from **areas 3b** and **areas 1** of an owl monkey.

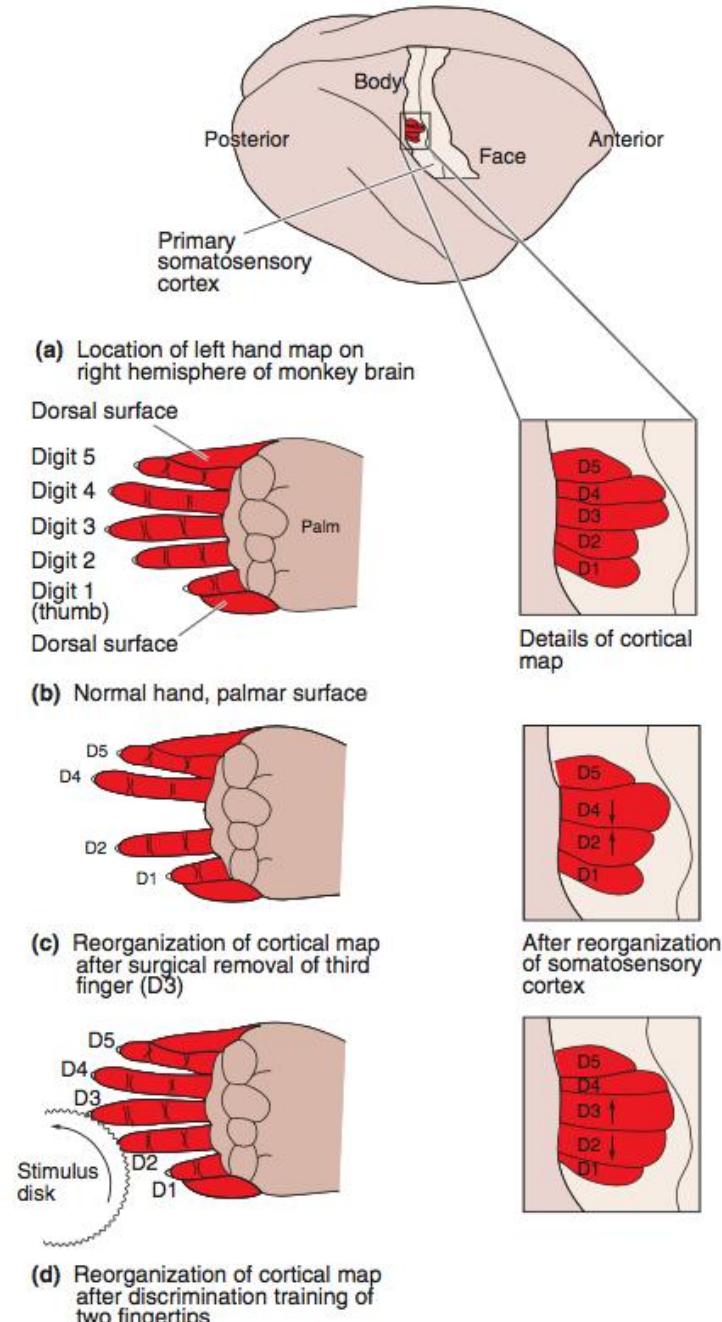
- (a) Results show that each area has its own somatotopic map.
- (b) Detailed examination of the hand area shows that the two maps are **mirror images**. Shaded regions represent the dorsal surfaces of the hands and feet, unshaded regions the ventral surfaces. (Source: Adapted from Kaas et al., 1981.)

Plasticity of somotopic map

Question: What happens to the somatotopic map in cortex when an input, such as the finger, is removed?

Does the “finger area” of cortex simply go unused? Or is this tissue taken over by inputs from other sources?

- (a) The fingers of the hand of an owl monkey are mapped onto the surface of S1 cortex.
- (b) If digit 3 is removed, over time, the cortex reorganizes so that the representations of digits 2 and 4 expand.
- (c) If digits 2 and 3 are selectively stimulated, their cortical representations also expand.



感知觉系统的神经表征确实受到自下而上（bottom-up）和自上而下（top-down）处理的影响。以下是这两种处理方式的概述及其对神经表征的影响，以及相关的证据。

自下而上（Bottom-up）处理

- 定义：自下而上处理指的是从感官输入开始，逐步向高级认知过程传递信息。这种处理通常依赖于感知信号的物理特性。
- 影响：感知觉系统的神经表征首先会反映外部刺激的特征，比如形状、颜色、运动等，经过多个处理层次逐步构建更复杂的表征。
- 证据：
 - 神经元活动研究：研究发现，在初级视觉皮层（V1）中，神经元对不同视觉刺激的反应特征表明，它们的活动模式是由刺激的物理属性驱动的。
 - ERP（事件相关电位）研究：使用ERP技术观察到，感知信息的处理始于刺激呈现后的几个毫秒内，显示出感知过程的快速反应。

自上而下（Top-down）处理

- 定义：自上而下处理指的是认知过程对感知的影响，比如预期、注意力和经验。这种处理方式常常依赖于已有知识或背景信息。
- 影响：自上而下的加工可以改变对感知信息的解读，影响神经表征。例如，个体的注意力或期望可以使某些刺激的神经表征变得更加突出。
- 证据：

- 注意力研究：研究表明，当个体集中注意力于某一特定刺激时，相关的神经区域（如视觉皮层）表现出更强的活动，显示出注意力对神经表征的调节作用。
- 心理学实验：通过改变刺激的上下文或期望，实验者能够显著影响参与者的感知体验，相关的神经成像研究（如fMRI）显示了不同的神经活动模式。

结合的作用

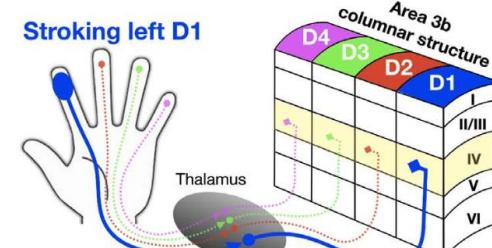
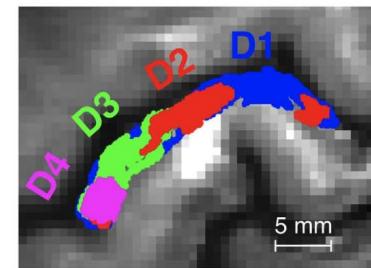
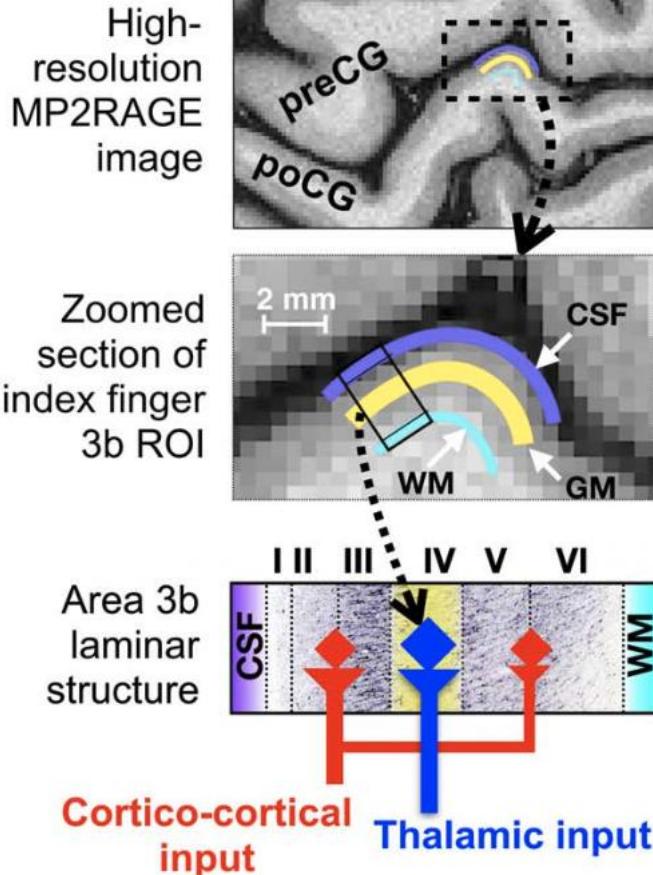
- 相互影响：自下而上和自上而下的处理方式并不是孤立的，而是相互作用的。在感知过程中，底层的感官输入可以受到高级认知过程的调节，反之亦然。
- 证据：
 - 跨模态研究：在不同感官之间的交互中（例如，视觉和听觉），发现自下而上的感知信息和自上而下的上下文信息共同影响了感知觉系统的整合和表征。
 - 神经网络模型：一些计算模型表明，结合自下而上和自上而下的处理方式可以更好地解释复杂的感知现象。

总结

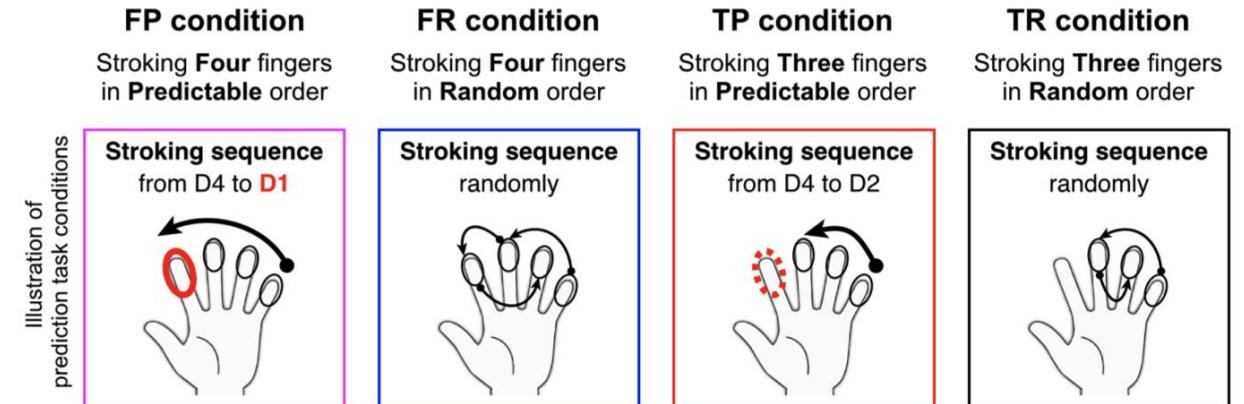
感知觉系统的神经表征受到自下而上和自上而下处理的双重影响。相关的神经活动研究、行为实验和计算模型都为这一观点提供了支持，表明两种处理方式在感知过程中相辅相成，促进了对环境的全面理解和适应。

Bottom-up & top-down

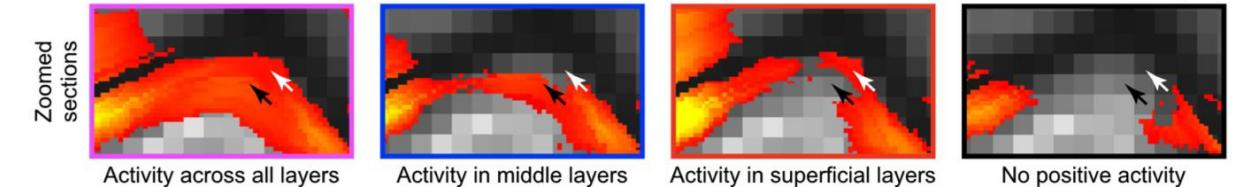
A Human area 3b (index finger)



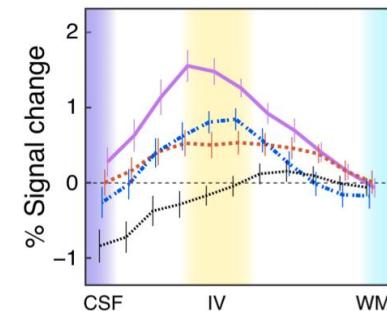
A Representative participant's BOLD activity maps of four prediction task conditions



B Zoomed sections of D1 ROI

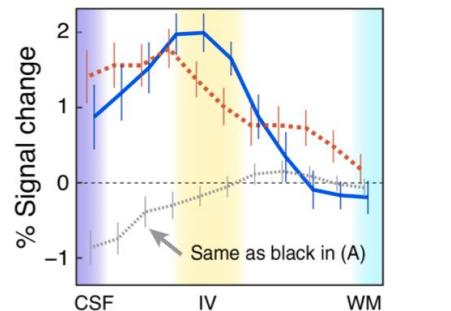


A Averaged ($n = 10$) activity profiles for the four conditions in D1 ROI



- FP: Stroking Four fingers in Predictable order
- FR: Stroking Four fingers in Random order
- TP: Stroking Three fingers in Predictable order
- TR: Stroking Three fingers in Random order

B Sensory input vs. top-down feedback in D1 ROI



- Top-down feedback (FP-FR) + (TP-TR)
- Sensory input (FP-TP) + (FR-TR)
- No input nor top-down feedback (TR)

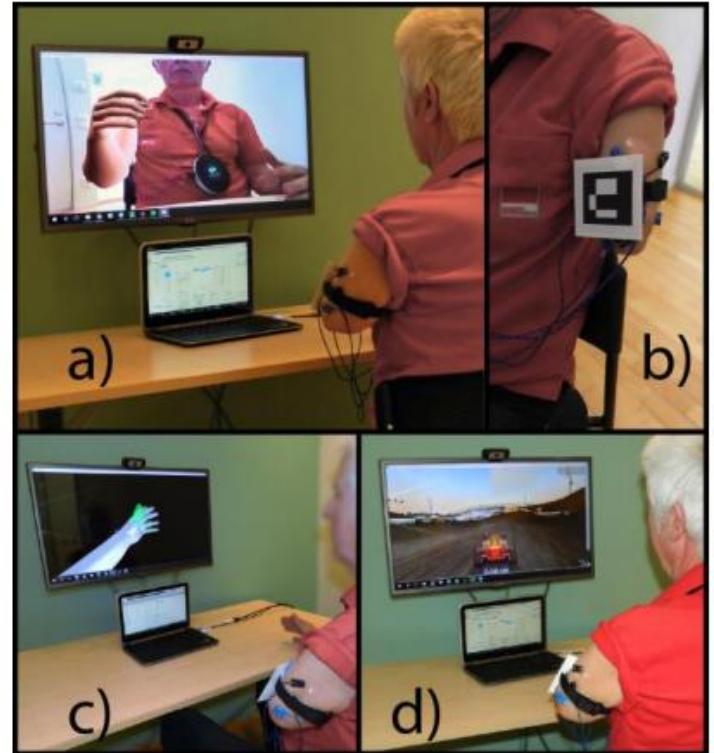
“Phantom limb” sensations in amputees

The “phantom limb” sensations are the perception of sensations coming from the missing limb when other body parts are touched.

Sensation: The “phantom limb” sensations usually evoked by the stimulation of skin regions whose somatotopic representations border those of the missing limb; for example, feeling can be evoked in a phantom arm by stimulating the face.

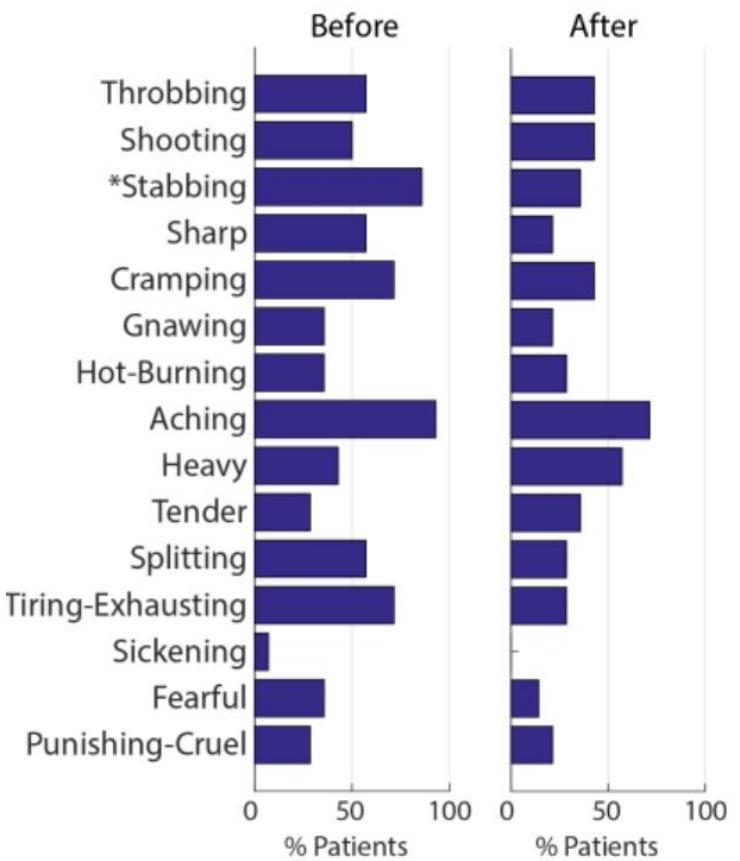
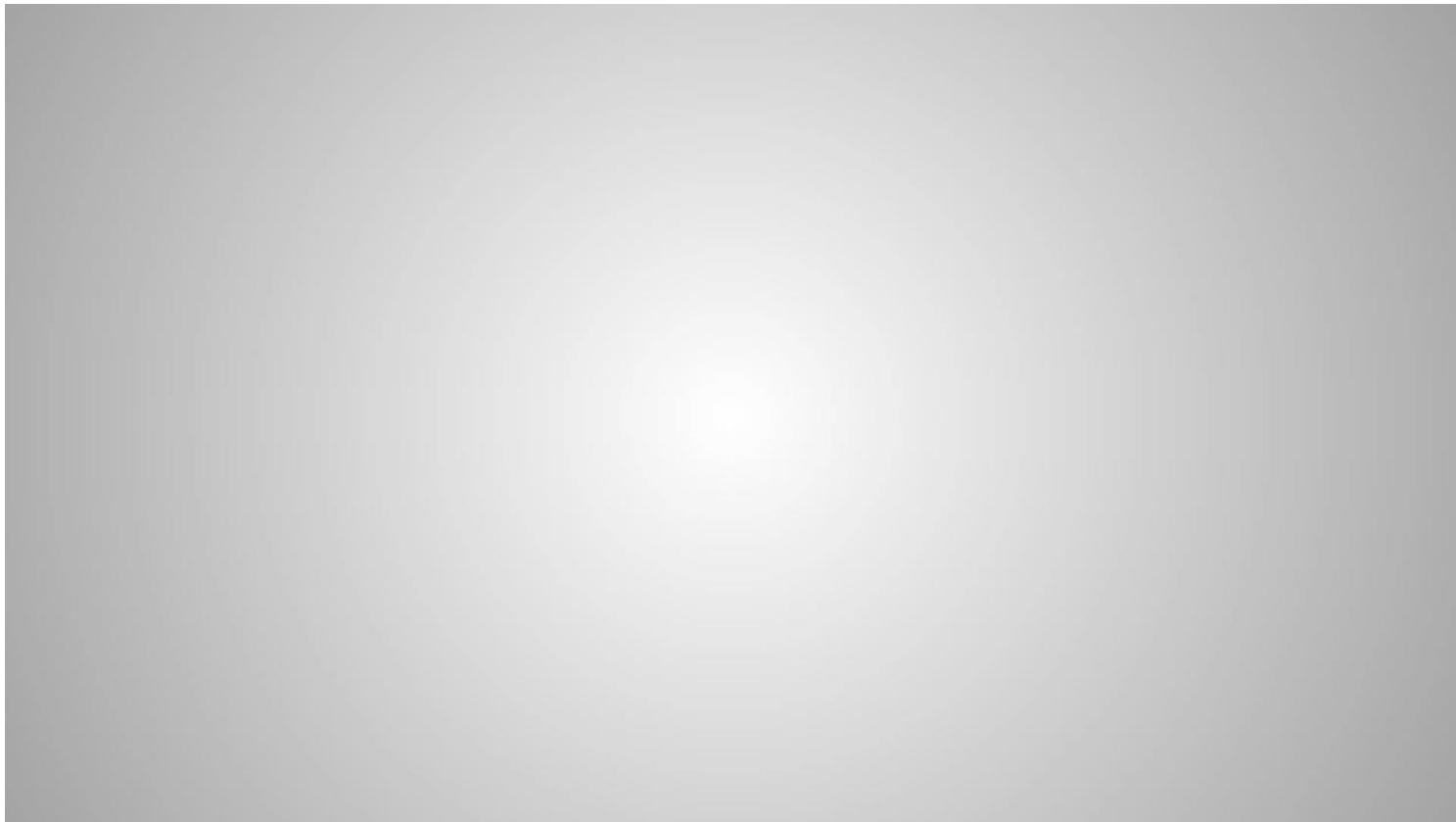
Brain activity: Functional brain imaging reveals that the cortical regions originally devoted to the missing limb are now **activated** by stimulating the face.

Explanation: While this plasticity may be adaptive in the sense that the cortex does not go unused, the **mismatch** between sensory stimulation and perception in amputees shows that it can lead to confusion on how signals from S1 should be interpreted.



Phantom motor execution
facilitated by machine learning and
augmented reality as treatment for
phantom limb pain

“Phantom limb” sensations in amputees



The incidence of fifteen qualities of pain as recorded by the Pain Rating Index are presented before and after treatment.

Damage to posterior parietal areas

astereognosia 是什么疾病？主要是什么脑区的问题？

The posterior parietal cortex seems to be essential for the perception and interpretation of spatial relationships, accurate body image, and the learning of tasks involving coordination of the body in space.

Damage to posterior parietal areas can yield some bizarre neurological disorders. Among these is **agnosia** (失认症, 感知无能), the inability to recognize objects even though simple sensory skills seem to be normal. People with **astereognosia** (触觉失认症) cannot recognize common objects by feeling them (e.g., a key), although their sense of touch is otherwise normal and they may have no trouble recognizing the object by sight or sound. Deficits are often limited to the side contralateral to the damage.



Asterognosia (触觉失认症) 是一种感觉障碍，患者在没有视觉帮助的情况下，无法识别和辨认通过触觉所感知的物体。尽管患者能够感知触觉刺激，但无法将触觉信息与已知物体的形状或功能进行关联。

主要脑区

Asterognosia 主要与以下脑区的损伤有关：

1. 顶叶 (Parietal Lobe) :

- 特别是后顶叶皮层 (posterior parietal cortex) 是触觉处理和空间感知的关键区域。损伤此区域会导致触觉信息无法有效整合，从而影响物体识别。

2. 初级感觉皮层 (Primary Somatosensory Cortex) :

- 初级感觉皮层位于顶叶，负责处理来自身体各部位的触觉信息。损伤可能导致触觉感知受损，进而影响物体识别能力。

3. 颞叶 (Temporal Lobe) :

- 尽管主要负责听觉和记忆，但颞叶的一些区域与物体的识别和语义记忆有关。它可能在触觉信息的语义处理和存储中发挥作用。

总结

“ ”

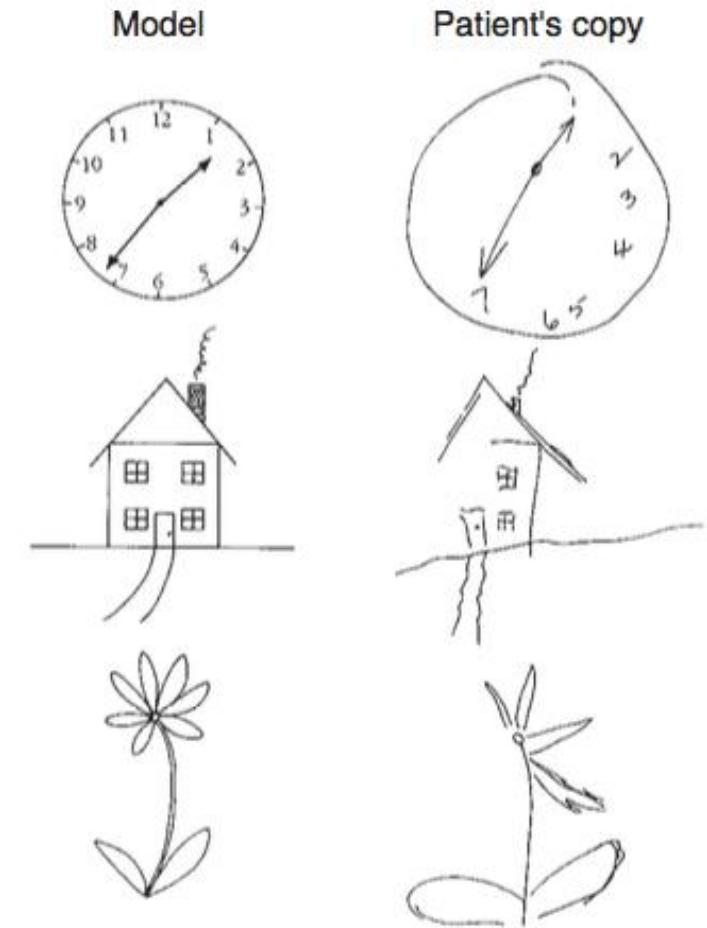
Asterognosia 主要与后顶叶皮层及其连接区域的损伤有关，影响触觉信息的整合与识别。这种疾病的发生通常与中风、脑外伤或其他神经系统疾病相关。

Damage to posterior parietal areas

The **posterior parietal cortex** seems to be essential for the perception and interpretation of spatial relationships, accurate body image, and the learning of tasks involving coordination of the body in space.

Damage to posterior parietal areas can yield some bizarre neurological disorders. Among these is **agnosia** (失认症, 感知无能), the inability to recognize objects even though simple sensory skills seem to be normal. People with **astereognosia** (触觉失认症) cannot recognize common objects by feeling them (e.g., a key), although their sense of touch is otherwise normal and they may have no trouble recognizing the object by sight or sound. Deficits are often limited to the side contralateral to the damage.

Parietal cortical lesions may also cause a **neglect syndrome** (忽视综合征), in which a part of the body or a part of the world (the entire visual field left of the center of gaze, for example) is ignored or suppressed, and its very existence is denied.



▲ **FIGURE 12.24**
Symptoms of a neglect syndrome.
A patient who had had a stroke in the right posterior parietal cortex was asked to copy the model drawing but was unable to reproduce many of the features on the left side of the model. (Source: Springer and Deutsch, 1989, p. 193.)

Damage to posterior parietal areas

The **posterior parietal cortex** seems to be essential for the perception and interpretation of spatial relationships, accurate body image, and the learning of tasks involving coordination of the body in space.

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neglect syndrome是什么疾病？主要是什么脑区的问题？



Neglect syndrome (忽视综合征) 是一种神经心理障碍，患者在意识上忽视一侧的视觉、听觉或触觉刺激，通常是身体一侧（通常是右侧或左侧）所对应的环境或身体部分。这种状态并不是由于感觉缺失，而是由于对该侧信息的意识缺失。

主要脑区

Neglect syndrome 主要与以下脑区的损伤有关：

1. 右侧顶叶 (Right Parietal Lobe) :

- 右侧顶叶损伤通常与左侧忽视有关。这一区域对于空间感知和注意力的分配至关重要。右侧顶叶的损伤会导致患者在感知和反应左侧信息时出现明显的缺失。

2. 额叶 (Frontal Lobe) :

- 额叶特别是前额叶部分在注意力控制和执行功能中发挥重要作用。额叶的损伤可能影响患者的注意力分配和意识。

3. 颞叶 (Temporal Lobe) :

- 尽管颞叶主要与听觉和记忆相关，但其某些区域也与空间感知和视觉注意力有关，可能在忽视综合征中起到辅助作用。

总结

”

Neglect syndrome 主要与右侧顶叶的损伤有关，影响患者对左侧刺激的感知和注意。这种综合征通常与中风、脑外伤或其他神经系统疾病相关，影响患者的日常生活和功能。

Embodied Intelligence 具身智能

什么是具身智能？



具身智能（Embodied Intelligence）是指智能系统（无论是人类、动物还是人工智能）在其身体和环境交互过程中展现出的智能能力。这个概念强调了身体在认知和感知过程中的重要性，认为认知不仅仅是大脑内部的运算，而是与身体状态和与环境的互动紧密相关。

主要特点

1. 身体与认知的关系：

- 具身智能强调身体的存在和运动如何影响认知过程。身体状态、感官输入和运动反馈共同作用，形成对环境的理解。

2. 环境互动：

- 具身智能体能够在环境中自我调节，通过感知和行动的循环与外界互动。这种动态的交互促进了学习和适应。

3. 多模态感知：

- 具身智能通常依赖于多种感官输入（如视觉、听觉、触觉等），通过整合不同类型的信息来理解和反应环境。

4. 自主性与适应性：

- 具身智能体通常具备自主决策能力，能够根据实时感知信息调整行为，以适应不断变化的环境。

触觉是人类感知的重要组成部分。而传统的人工智能系统往往缺乏真实的触觉感知。

SENSORS

Haptic perception using optoelectronic robotic flesh for embodied artificially intelligent agents

Jose A. Barreiros¹, Artemis Xu², Sofya Pugach², Narahari Iyengar², Graeme Troxell¹, Alexander Cornwell², Samantha Hong³, Bart Selman⁴, Robert F. Shepherd^{2*}

Flesh encodes a variety of haptic information including deformation, temperature, vibration, and damage stimuli using a multisensory array of mechanoreceptors distributed on the surface of the human body. Currently, soft sensors are capable of detecting some haptic stimuli, but whole-body multimodal perception at scales similar to a human adult (surface area ~17,000 square centimeters) is still a challenge in artificially intelligent agents due to the lack of encoding. This encoding is needed to reduce the wiring required to send the vast amount of information transmitted to the processor. We created a robotic flesh that could be further developed for use in these agents. This engineered flesh is an optical, elastomeric matrix “innervated” with stretchable lightguides that encodes haptic stimuli into light: temperature into wavelength due to thermochromic dyes and forces into intensity due to mechanical deformation. By exploiting the optical properties of the constitutive materials and using machine learning, we infer spatiotemporal, haptic information from light that is read by an image sensor. We demonstrate the capabilities of our system in various assemblies to estimate temperature, contact location, normal and shear force, gestures, and damage from temporal snapshots of light coming from the entire haptic sensor with errors <5%.

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请总结这篇论文: Haptic perception using optoelectronic robotic flesh for embodied artificially intelligent agents

这篇论文探讨了使用光电机器人皮肤 (optoelectronic robotic flesh) 来增强具身人工智能代理的触觉感知能力。以下是论文的主要内容和结论:

主要内容

1. 研究背景:

- 具身智能强调身体在认知和感知中的重要性，触觉是人类感知的重要组成部分。传统的人工智能系统往往缺乏真实的触觉感知。

2. 光电机器人皮肤的设计:

- 论文介绍了一种新型的机器人皮肤，它结合了光电传感器和机械结构，能够模拟人类的触觉感知。
- 这种皮肤可以感知压力、温度和纹理等多种触觉信息。

3. 触觉感知机制:

- 研究了如何将光电传感器与机器学习算法结合，以实现对复杂触觉输入的有效处理。
- 采用深度学习模型分析来自机器人皮肤的触觉数据，提高感知的准确性和响应能力。

4. 实验与结果:

- 进行了多项实验，验证了光电机器人皮肤在不同触觉任务中的表现，包括识别不同材料和判断物体形状。
- 实验结果显示，该系统在触觉感知上具有较高的准确性，能够有效地识别和分类物体。

5. 应用前景:

- 讨论了这种技术在医疗、机器人、虚拟现实等领域的潜在应用，强调了具身智能系统如何通过增强触觉感知改善人机交互。

结论

论文总结认为，光电机器人皮肤为具身人工智能代理提供了一种有效的触觉感知解决方案，展示了结合生物启发设计和先进传感技术的潜力。通过提高触觉感知能力，这种系统能够更好地理解和适应环境，为未来的智能代理开发提供了新的思路。

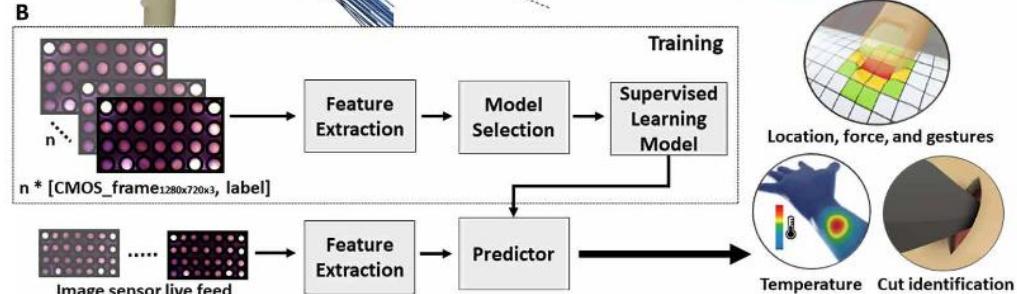
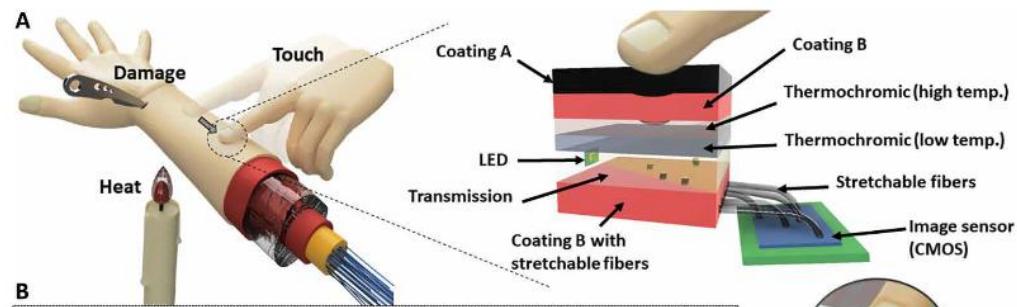


Fig. 1. Overview of the elastomeric, optoelectronic, robotic flesh. (A) Schematic showing the functional layers and components. (B) Flowchart of the machine learning pipeline.

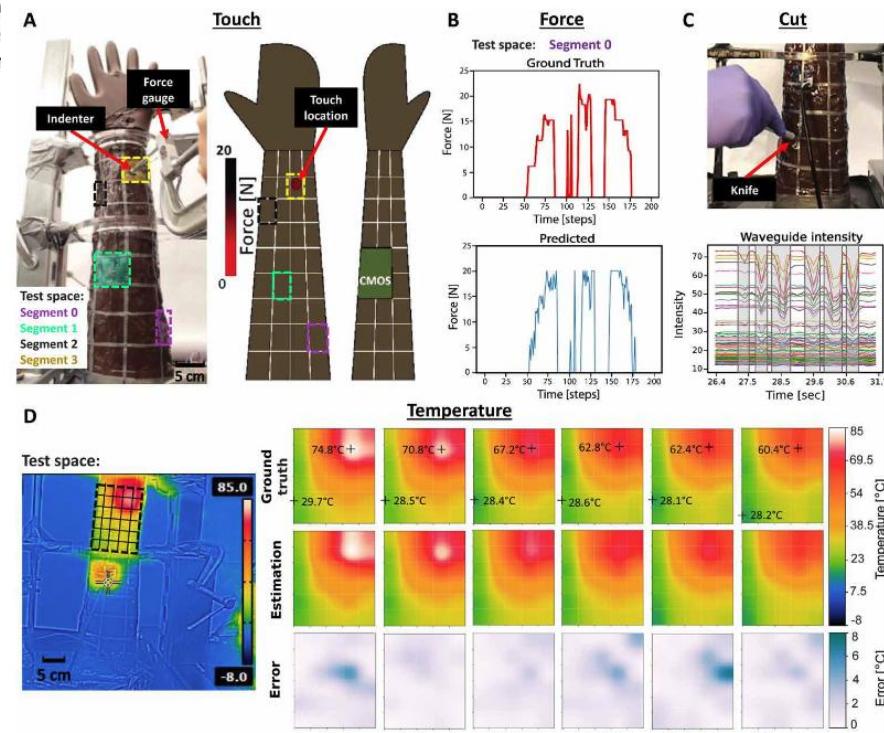


Fig. 4. Demonstration of the proposed robotic flesh in a human-scale forearm. Images showing the test space

Electronic skin

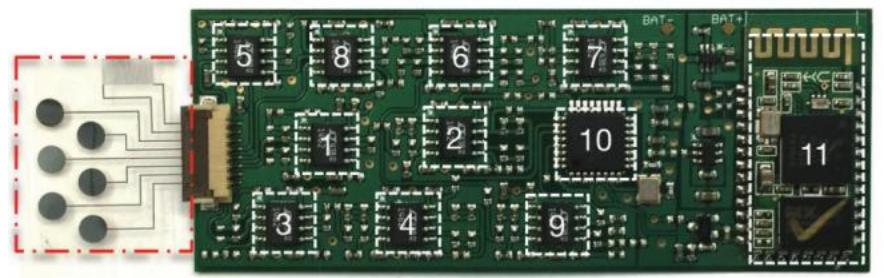
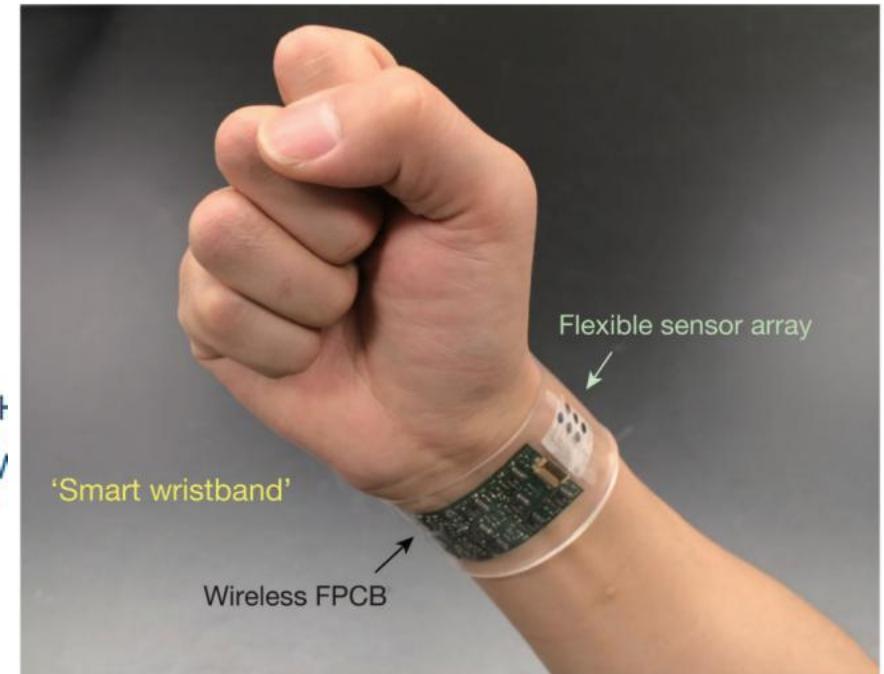
Published: 27 January 2016

Fully integrated wearable sensor arrays for multiplexed *in situ* perspiration analysis

Wei Gao, Sam Emaminejad, Hnin Yin Yin Nyein, Samyuktha Challa, Kevin Chen, Austin Peck, Fahad, Hiroki Ota, Hiroshi Shiraki, Daisuke Kiriya, Der-Hsien Lien, George A. Brooks, Ronald V Ali Javey 

Nature 529, 509–514(2016) | Cite this article

38k Accesses | 1652 Citations | 1042 Altmetric | Metrics



A wearable electrochemical biosensor for the monitoring of metabolites and nutrients

Minqiang Wang, Yiran Yang, Jihong Min, Yu Song, Jiaobing Tu, Daniel Mukasa, Cui Ye, Changhao Xu, Nicole Heflin, Jeannine S. McCune, Tzung K. Hsiao, Zhaoping Li & Wei Gao✉

Nature Biomedical Engineering (2022) | [Cite this article](#)

Schematics of the wearable biosensor ‘NutriTrek’.

a, Circulating nutrients such as AAs are associated with various physiological and metabolic conditions.

b, Schematic of the wearable ‘NutriTrek’ that enables metabolic monitoring through a synergistic fusion of LEG, RARs and artificial antibodies.

c,d, Schematic (c) and layer assembly (d) of the microfluidic ‘NutriTrek’ patch for sweat induction, sampling and biosensing. T, temperature.

e,f, Images of a flexible sensor patch (e) and a skin-interfaced wearable system (f). Scale bars, 5 mm (e) and 2 cm (f).

g, Block diagram of electronic system of ‘NutriTrek’. The modules outlined in red dashes are included in the smartwatch version. h, Custom mobile application for real-time metabolic and nutritional tracking.

i, ‘NutriTrek’ smartwatch with a disposable sensor patch and an electrophoretic display. Scale bars, 1 cm (top) and 5 cm (bottom).



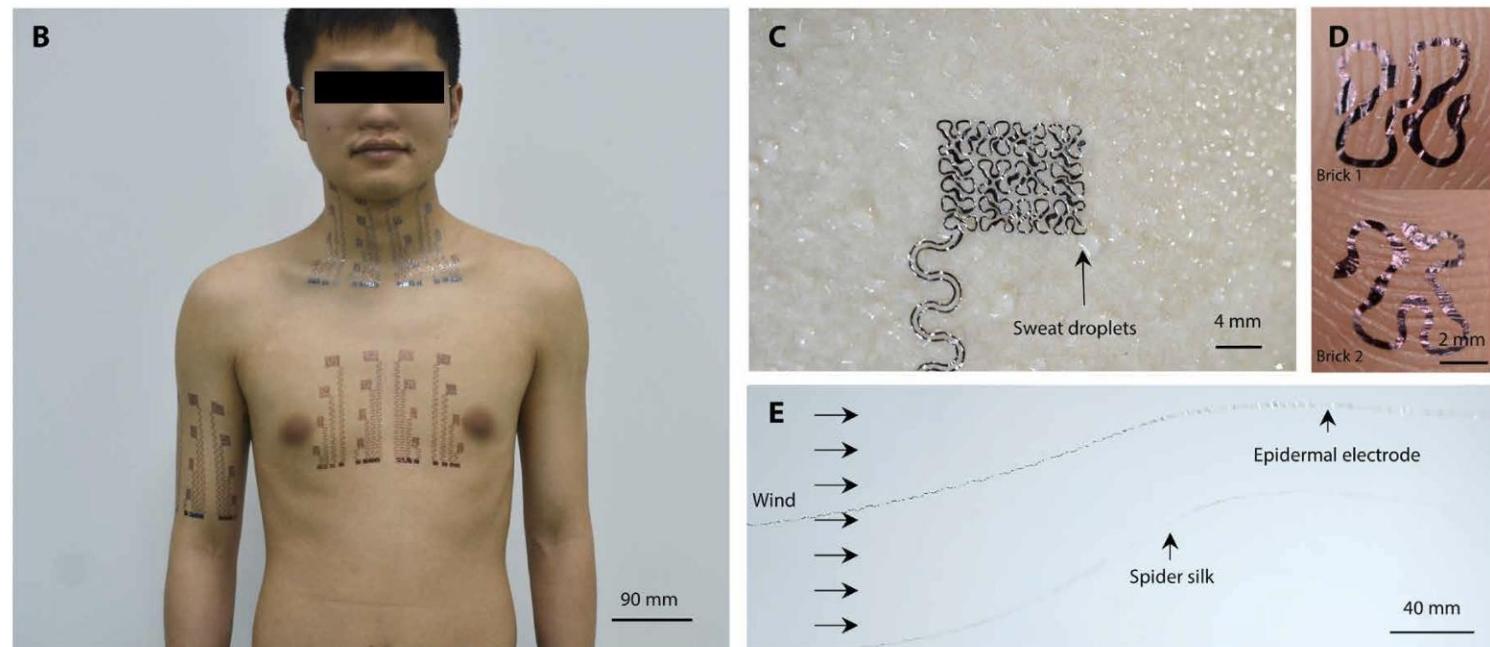
Electronic skin

SCIENCE ADVANCES | RESEARCH ARTICLE

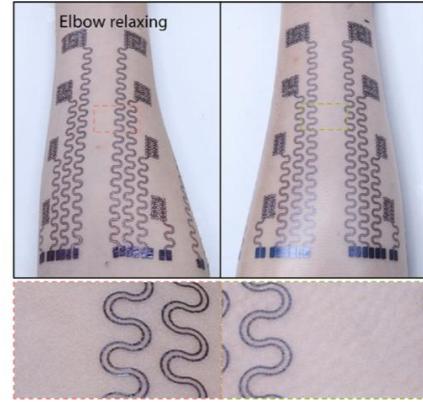
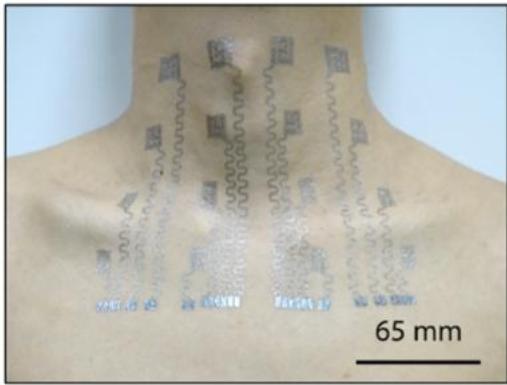
APPLIED SCIENCES AND ENGINEERING

Electrically compensated, tattoo-like electrodes for epidermal electrophysiology at scale

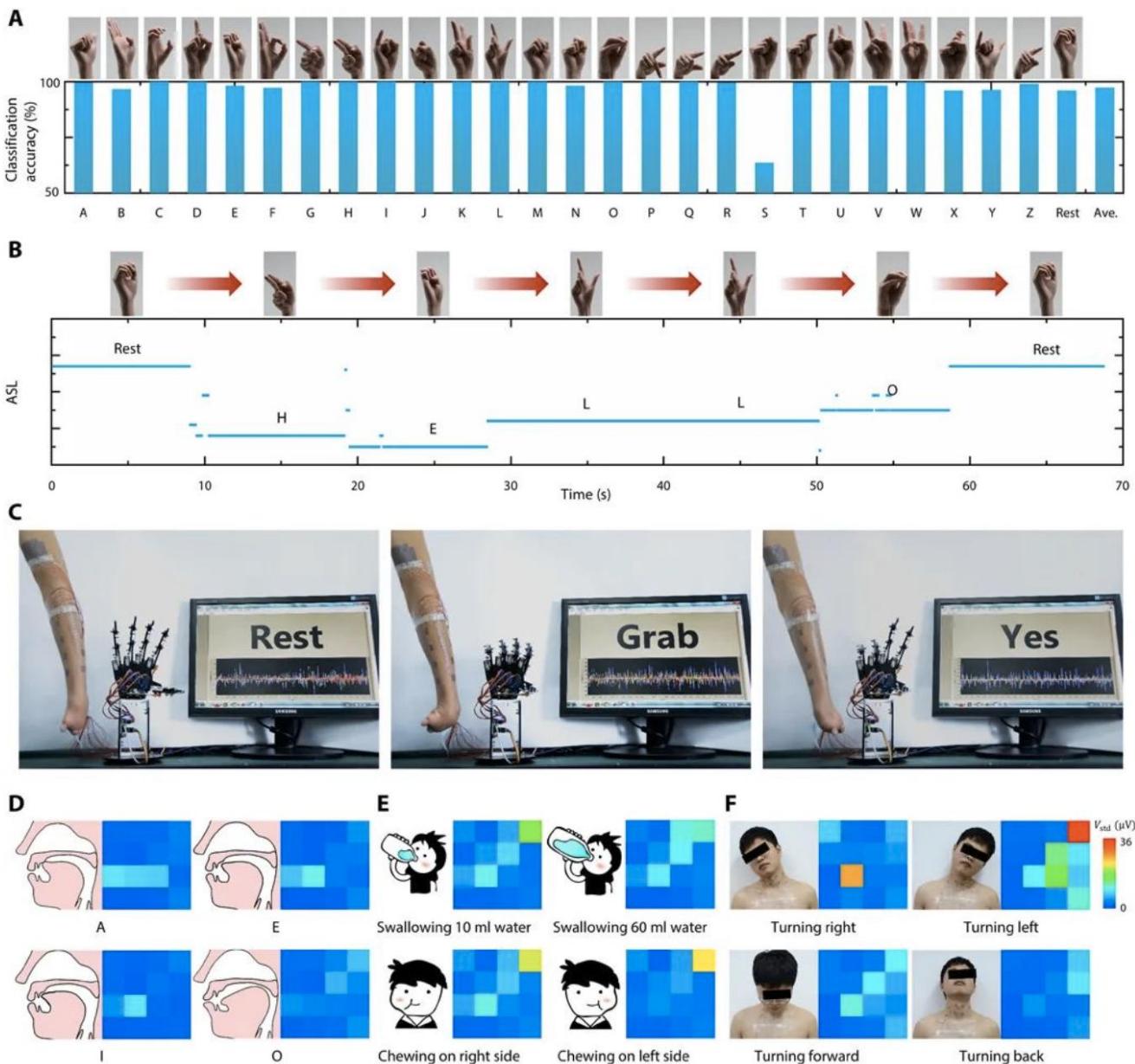
Youhua Wang^{1,2}, Lang Yin^{1,2}, Yunzhao E¹, Chao Hou^{1,2}, Zhaoyu Yang^{1,2}, Hao Wu^{1,2}, Shuchang Zhang^{1,2}, Tangjian Duan^{1,2}, Zhen Nanshu Lu^{3,5,6*}, YongAn Huang^{1,2*}



Electronic skin



Various applications



Wang et al (2020) *Science Advances*

图 | 大面积电子纹身的应用实例——手语识别、假肢控制、颈部肌电云图

Electronic skin

Science Advances

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RESEARCH ARTICLE | ENGINEERING



Heterogeneous integration of rigid, soft, and liquid materials for self-healable reconfigurable wearable e



Chuanqian Shi^{1,2,*}, Zhanan Zou^{2,*}, Zepeng Lei³, Peng Li¹

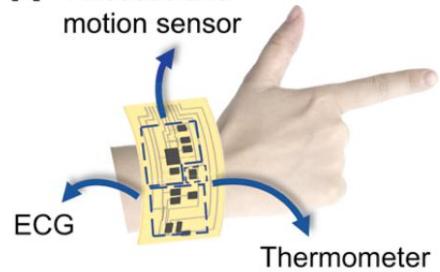
+ See all authors and affiliations

Science Advances 06 Nov 2020:
Vol. 6, no. 45, eabd0202
DOI: 10.1126/sciadv.abd0202



Electronic skin

A Acoustic and motion sensor



C Crumpled



Bended

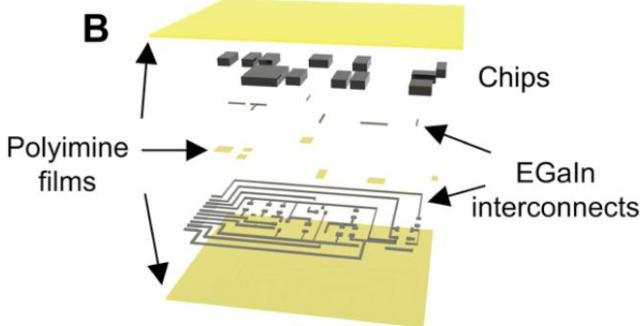


Twisted



Stretched

B



E Crumpled



Bended

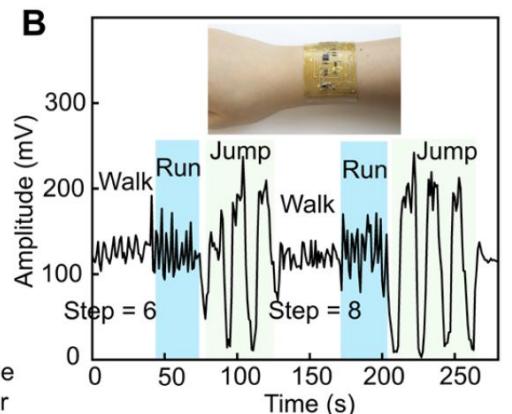
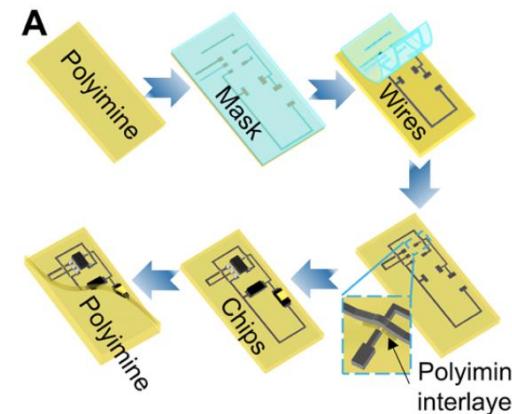
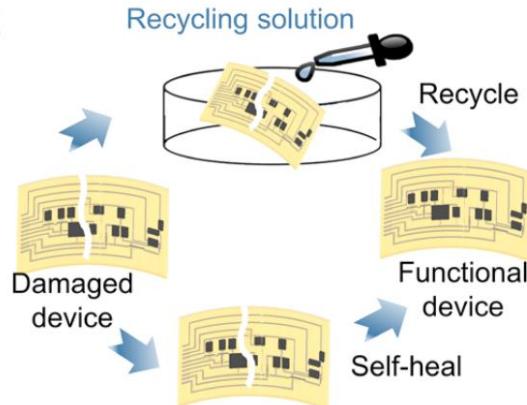


Twisted

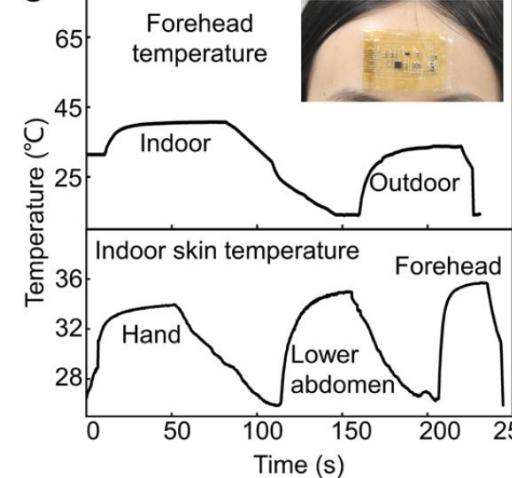


Stretched

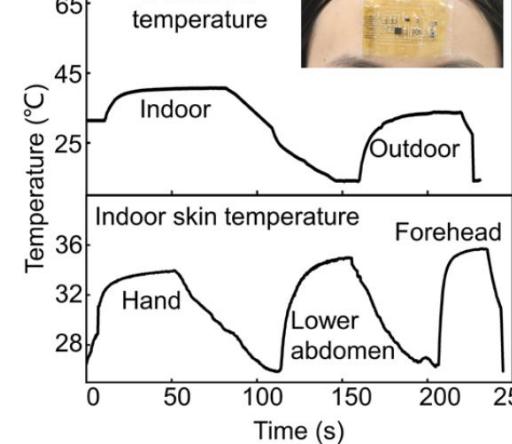
E



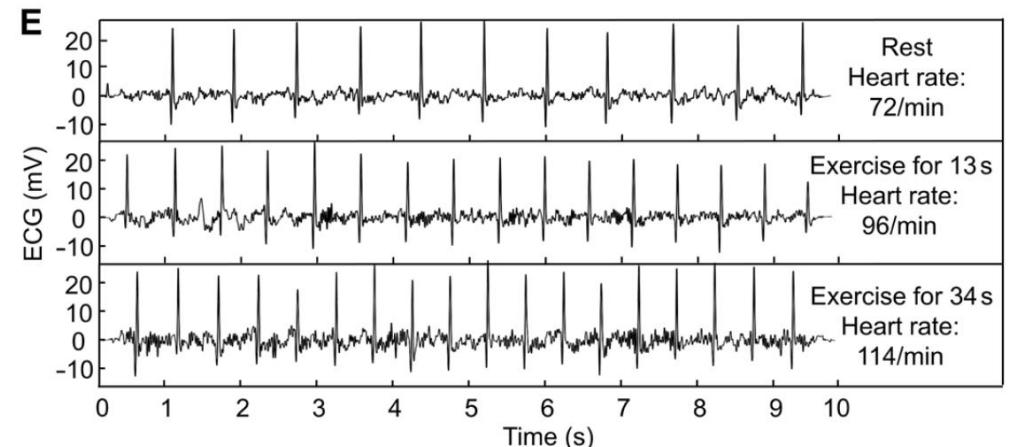
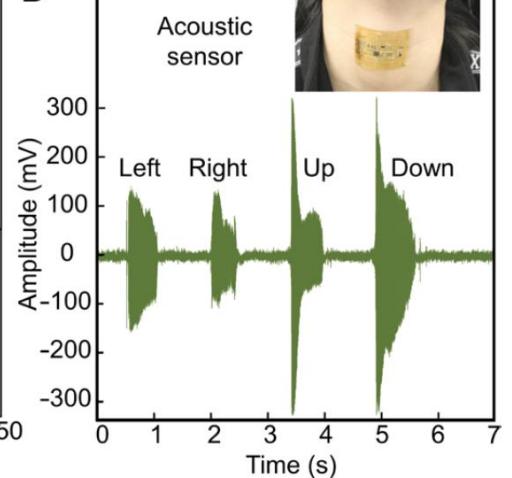
C Forehead temperature



Indoor skin temperature



D Acoustic sensor



ChatGPT 4o mini

我是个计算神经科学家，我想用AI来研究感知觉系统。有哪些尚未解决的前沿科学问题？

在计算神经科学和感知觉系统的研究中，使用AI技术探索前沿科学问题具有很大的潜力。以下是一些尚未解决的前沿科学问题，可能值得深入研究：

1. 感知与意识的关系

- 如何将神经活动与主观感知体验联系起来？AI模型能否帮助我们理解哪些神经机制与意识状态相关？

2. 跨感官整合

- 不同感官信息如何在大脑中整合？使用深度学习分析多模态数据（如视觉、听觉和触觉）可能揭示整合机制。

3. 动态感知处理

- 感知是如何随着时间变化的？AI能否模拟大脑如何实时处理不断变化的环境信息，以改进对动态场景的理解？

4. 个体差异与适应性

- 不同个体在感知上的差异是如何产生的？利用机器学习分析遗传、环境和经验对感知的影响，可能帮助我们理解个体差异。

5. 感知失调与神经机制

- 在感知失调（如幻肢痛或感知障碍）中，神经机制如何运作？AI可以帮助分析神经影像和行为数据，以揭示潜在机制。

6. 大脑中的编码策略

- 大脑如何高效编码感官信息？使用深度学习模型来分析神经元放电模式，可能发现新的编码策略和规律。

7. 模型与真实生物系统的比较

- AI模型的感知机制如何与真实生物系统中的机制相匹配？探索模型与生物神经网络之间的相似性和差异性，有助于理解自然感知系统。

8. 长期记忆与感知的交互

- 感知与记忆如何交互影响？AI可以用于分析感知过程中如何调用和更新记忆信息，特别是在复杂任务中。

9. 机器人感知的生物启发

- 如何将生物感知系统的原理应用于机器人技术？AI可用于设计仿生感知系统，提高机器人在复杂环境中的适应性。

10. 感知在社会交互中的作用

- 在社交环境中，感知如何影响人际交往和情感交流？研究AI如何分析社交互动中的感知信息，可以帮助理解人类行为。

这些问题都涉及复杂的神经机制和感知过程，利用AI的强大数据分析能力和模型构建能力，可以推动这些领域的前沿研究。

感知觉与具身智能研究方向，有哪些进展？



感知觉与具身智能的研究近年来取得了一系列重要进展，涵盖了多个领域。以下是一些关键方向和进展：

1. 具身认知理论

- 理论基础：具身认知理论强调身体在认知过程中的重要性，研究者开始更加关注身体状态如何影响感知、思维和行为。
- 实验证据：通过行为实验和神经影像技术，研究人员发现身体动作和感知之间的关系，进一步支持具身认知的理论。

2. 机器人与仿生系统

- 具身智能机器人：开发了能根据环境变化自我调整的机器人，这些机器人使用感知信息来指导运动和决策。
- 仿生感知：利用生物启发的方法设计感知系统，使机器人在复杂环境中能够更好地适应和导航。

3. 感知与运动的整合

- 跨感官整合：研究如何通过身体运动来增强感知能力，探索不同感官信息如何协调工作以优化任务表现。
- 运动学习：结合深度学习和运动控制，研究如何通过反复的运动实践来改善感知能力和技能。

4. 虚拟现实与增强现实

- 沉浸式体验：利用虚拟现实（VR）和增强现实（AR）技术，研究如何在具身环境中模拟感知体验，帮助用户更好地理解和学习。
- 反馈机制：探索感知反馈在VR和AR环境中的应用，改进用户体验和互动。

Summary 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**

Quiz 1:

你现在拿到了**10亿投资**，
要在**3年内**研发出一个拥有**具身智能的超级机器人**。

- 1、画一个机器人的**最终形态图**，及功能说明。
- 2、详细画一个**技术路线图**，阐述各个功能如何实现。
- 3、你会打造一个怎样的**研发团队**，请写出技术实现的**time table**。

Reading materials

- *Neuroscience: Exploring the brain* (3rd ed), **Chapter 12 – The Somatic Sensory System**, pp415-437
- *From Neuron to Brain* (5th ed), **Chapter 21 – Touch, Pain, and Texture Sensation**, pp434-452
- 【杜克大学】Medical Neuroscience 4. 感觉系统：总则及躯体感觉
<https://www.bilibili.com/video/BV1uE41137tA?p=4>