During normal foraging activity, the tentacles are constantly being used to feel the mole's surroundings, moving so rapidly that they appear as a blur of motion, touching as many as 12 objects per second. Using these supersensitive organs, identification of prey can be made in under half a second.
GENERAL ORGANIZATION OF THE SOMATOSENSORY SYSTEM

Dorsal root ganglion cell
Cerebral cortex
Thalamus
Brain stem
Anterolateral system
Spinal cord
Receptor ending
Primary afferent fiber
Medial lemniscus
Dorsal column

Cerebral cortex
Thalamus
Brain stem
Anterolateral system
Spinal cord
Receptor ending
Primary afferent fiber
Medial lemniscus
Dorsal column
« Take Home Message » (Fig. 87)

- A chain of three neurons carry the somatosensory information from the periphery (e.g. skin) up to the primary somatosensory cortex (S1)
- The projection from periphery to S1 is crossed
- The cell body of the primary somatosensory neurons is in the spinal ganglia, close to the spinal cord (or close to the brainstem)
- There are two separate ascending pathways: the dorsal column system (precise touch; proprioception) and the anterolateral system (temperature; pain)
- The two separate ascending pathways cross the midline at different levels
TYPES OF CUTANEOUS RECEPTORS

- Bare nerve ending
- Merkel’s disk receptor
- Meissner’s corpuscle
- Pacinian corpuscle
- Hair receptor

Pain / Temperature

Touch
- Detect gentle touch and determine position
- Detect vibration and determine frequency and amplitude
- Texture perception (e.g., Braille reading)
- Detect Objects grasped with hand
CUTANEOUS RECEPTORS

(greater touch sensitivity)
There are specialized receptors for the sense of touch: Pacini, Meissner, Rufini, Merkel, hair follicle

Free nerve endings are receptors for temperature and pain

These receptor zones are located at various depth of the skin and correspond to the extremity of the “dendrite” of the primary somatosensory neurons

The density of receptors varies across different regions of the skin (e.g. hand versus back for instance)
TRANSUDCTION MECHANISMS IN A MECHANOSENSOR

Amplifier to oscilloscope

Action potentials
Combined response
Receptor potentials
Stimulus

(c) Time (msec)

Compression

Vm (c) Time (msec)

| Time when pressure is applied |

| Action potential |

| Generator potential |

Spike generation region
Conduction region

Pacinian corpuscle in posterior (nerve ending)

Cell body in posterior root ganglion (Spinal cord)

First node of Ranvier

Interiors of nerve ending

Receptor region
The transduction by mechanoreceptors (sense of touch) involves “stretch-sensitive” ion (sodium) channels on the membrane of the touch receptors.

A mechanical deformation of the skin opens the channels and sodium enters into the « nerve » terminal, inducing a depolarization, corresponding to a receptor potential.

The receptor potential is then propagated, till the first node of Ranvier. The receptor potential opens “voltage sensitive” ion (sodium) channels, creating a generator potential.

If the generator potential reaches threshold, then an action potential is generated.

Receptor and generator potentials are graded, whereas an action potential follows the “all or none” principle.
SOMATOSENSORY RECEPTIVE FIELD

A Slowly adapting mechanoreceptors

Merkel disk receptors

B Rapidly adapting mechanoreceptors

Meissner’s corpuscles

C Receptive field architecture

10-20 receptors per DRG cell

Supraficial layers

Deep layers

Ruffini endings

Pacinian corpuscles
Superficial layers (Merkel/Meissner): 10-20 receptors per DRG cell

Deep layers (Ruffini/Pacinii): 1 receptor per DRG cell
The « receptive field » is defined, for a primary somatosensory neuron, as the skin area on which the presentation of an adequate stimulus provokes a response of that neuron. The same definition applies to single neuron in the thalamus or S1 (see further).

The size of the receptive fields may vary across the different types of receptors.

The receptive fields of two neighboring receptors may partially overlap.

The receptor field has usually a central zone with maximal sensitivity, surrounded by a less sensitive peripheral zone.
SIZE OF RECEPTIVE FIELDS AND ADAPTATION

<table>
<thead>
<tr>
<th>Receptor (Fiber)</th>
<th>How Fiber Responds</th>
<th>Frequency Response</th>
<th>Perceptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merkel (SA1)</td>
<td>Continuous (slow adapting)</td>
<td>0.3–3 Hz</td>
<td>Fine details</td>
</tr>
<tr>
<td>Meissner (RA1)</td>
<td>Responds to change (rapid adapting)</td>
<td>3–40 Hz</td>
<td>&quot;Flutter&quot;</td>
</tr>
<tr>
<td>Ruffini (SA2)</td>
<td>Continuous (slow adapting)</td>
<td>1.5–400 Hz</td>
<td>Stretching (grasped object shape)</td>
</tr>
<tr>
<td>Pacinian (RA2)</td>
<td>Responds to change (rapid adapting)</td>
<td>10–500 Hz</td>
<td>Vibration</td>
</tr>
</tbody>
</table>
The "receptive fields" are usually smaller for receptors located near the surface of the skin.

Slow adaptation is observed in receptors showing a generally stable response to a prolonged stimulus, lasting as long as the stimulus.

Rapid adaptation is observed in receptors showing a rapidly changing response to a prolonged stimulus, often limited to the onset and/or the offset of the stimulus.
TWO POINTS DISCRIMINATION
(receptor density dependent)

HUMAN DETECTION LIMITS
The ability to finely discriminate two distinct points of touch varies dramatically across skin territories.

Two points tactile discrimination is maximal at the level of the fingers and the face.

This variation of two points tactile discrimination is mainly correlated with the density of touch receptors, being maximal at the level of fingers and the face.

The limit of human perception is determined by the most sensitive somatosensory receptor.
Intensity function

- Neuron 1
- Neuron 2

Discharge frequency (spikes/sec) vs. Stimulus intensity
« Take Home Message »

- A primary somatosensory neuron is characterized by a spontaneous discharge rate, in absence of stimulus or in presence of a sub-threshold stimulus.
- Above threshold, the discharge rate progressively increases as a function of growing stimulus intensities.
- At a certain intensity, the response reaches its maximal discharge level (plateau), above which an increase of stimulus intensity does not provoke an increase of the number of action potentials (phenomenon of saturation).
- Different primary somatosensory neurons have different thresholds.
PROPrioception

Limb position I
Limb position II
Limb position III

(a) ACTION POTENTIALS FROM STATIC PROPrioCEPTORS

(b) ACTION POTENTIALS FROM DYNAMIC PROPrioCEPTORS

Intramuscular muscle fibers
Capsule
Sensory endings
Afferent axons

Ion channel
Extracellular

Cytoskeletal strands
Stretch-sensitive channels in sensory nerves
Take Home Message

- Receptors in the joints give proprioceptive information based on stretch sensitive ion channels
- Both dynamic and static proprioceptive information is encoded
THERMORECEPTORS

STATIC TEMPERATURE

DYNAMIC TEMPERATURE
« Take Home Message »

• The thermoreceptors carry static information, namely the absolute value of the constant temperature in a stable environment

• The thermoreceptors carry also dynamic information, namely the direction and the amplitude of a sudden variation of temperature

• The temperature information is carried by two types of receptors: cold receptors and warm receptors. The cold and warm receptors have opposite response to a change of temperature

• The temperature information coming from the skin is used in particular in the function of thermoregulation
NERVE FIBERS CARRYING SOMATOSENSORY INFORMATION

<table>
<thead>
<tr>
<th>Sensory Axons</th>
<th>Aα</th>
<th>Aβ</th>
<th>Aδ</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>II</td>
<td>III</td>
<td>IV</td>
<td></td>
</tr>
<tr>
<td>Diameter (μm)</td>
<td>13-20</td>
<td>6-12</td>
<td>1-5</td>
<td>0.2-1.5</td>
</tr>
<tr>
<td>Speed (m/s)</td>
<td>80-120</td>
<td>35-75</td>
<td>5-30</td>
<td>0.5-2</td>
</tr>
<tr>
<td>Receptors</td>
<td>Proprioception</td>
<td>Skin Touch receptors</td>
<td>Pain Temperature</td>
<td>Pain, Itching Temperature</td>
</tr>
</tbody>
</table>
CONSEQUENCES OF SPINAL CORD HEMISECTION

1. Loss of all sensation on right side in dermatone T₁₀
2. Loss of pain and temperature sense
3. Loss of touch and vibration sense
4. No loss of sensation
The various ascending and descending tracts occupy different locations in the spinal cord white matter. As a consequence, incomplete spinal lesion may affect different functions.

Due to the midline crossing of the dorsal column and anterolateral systems at different levels, a spinal cord lesion may lead to a segregation of lost modalities (touch, temperature, pain, motor control).

In the classical Brown-Sequard syndrome (e.g. hemi-section at T10 level), voluntary motor control and precise touch are lost on the ipsilesional leg, whereas pain and temperature sensations are lost on the contralesional leg.
TYPES OF PAIN

• Nociceptive: normal response to a noxious stimulus (protective function)

• Inflammatory: e.g. post-operative (repair/healing), arthritis

• Neuropathic: PNS or CNS lesion
Distribution on the skin of pain sensitive points
Nociceptive fibers terminate in dorsal horn of the spinal cord
On the skin, points sensitive to pain are more numerous than points sensitive to touch.

Pain is carried by A-delta and C fibers making synapse in the dorsal horn with the secondary nociceptive neurons.

The two types of pain fibers (A-delta and C) are correlated with the “fast” and “slow” pain sensations, corresponding to precise and diffuse pain sensations, respectively.
Chemical mediators on peripheral endings of nociceptors
• The mechanisms of pain transduction are not precisely known. However, several neuromodulatory molecules are known to play a role.

• Bradykinin is the most potent molecule producing pain when put in contact with pain receptors in the skin.

• Other molecules play also a role: extracellular potassium, histamin, prostaglandins, serotonin, substance P, etc…

• Presumably, these molecules interact with ion channels on the pain receptor, thus producing receptor potentials which, in turn, induce generator potentials, followed by action potentials if the threshold is reached.
Pain originating in a visceral structure is felt as if it came from muscle or skin.
Descending pathways for pain control
The origin of the pain does not always correspond to the localization of the sensation by the patient (referred pain).

There are descending pathways which may control pain in a feedback manner.

When activated, the descending pathways lead to release of neurotransmitters acting on opiate receptors.

Opiates are molecules which can decrease pain sensation. Some of them (such as enkephalin, endorphins, etc) are produced naturally. Other opiates (morphin) are used in medicine to treat chronic pain. Opiates receptors are present on primary and secondary nociceptive neurons.