Somatosensory System, Limbic System, and Reticular Formation

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Objectives:

1. Describe the basic organization of the somatosensory system.
2. Describe the concepts of receptor coding and receptive fields.
3. Describe the organization of the dorsal column and spinothalamic pathways.
4. Describe the organization and function of the limbic system.
5. Describe the organization and function of the reticular formation.
Sensory Information

Sensory information flows from PNS to CNS via:
  • Cranial nerves (Head)
  • Spinal nerves (Body)

CNS receives info. from a variety of receptors (transduce signals into action potentials):
  • Retina: vision
  • Inner ear: hearing and balance
  • Nose: smell (olfaction)
  • Tongue: taste

  • Skin: pain, temp., discriminative touch, pressure, vibration, itch
  • Joints & muscles: proprioception (i.e., position, movement, stretch/tension)
Somatosensation: CN V & Spinal Nerves

- Trigeminal n. has 3 branches: supply forehead, maxilla (upper jaw), and mandible (lower jaw)
- Body supplied by 31 pairs of spinal nerves (8 cervical, 12 thoracic, 5 lumbar, 5 sacral and 1 coccygeal)
- **Dermatome**: area of skin innervated by the sensory fibres of a spinal nerve; accounts for the segmental innervation of the body
- Injury to 1 spinal nerve rarely causes the loss of sensitivity in a dermatome (much overlap between dermatomes)
Trigeminal N (CN V)

**Dermatome Landmarks**
- CV – face
- C2 – back of head
- C5 – shoulder
- C6 – lateral arm, first 2 digits
- C7 – middle digit
- T4 – nipple
- T10 – umbilicus
- L4 – antero-medial shin
- L5 - antero-lateral shin, dorsum of foot
- S1 – small toe
- S2, S3, S4 – saddle-like area, perineum
Spinal Cord Video #1

Spinal Cord Video #2

Somatosensory System

• Sensation is dependent on the type of receptor on the nerve ending
• The ability to discriminate the quality and type of stimulus is dependent on the specificity of the receptor
• Skin & muscle contain a number of receptor types activated by mechanical stimuli (touch, vibration, muscle length, muscle tension)
• Also contain receptors that detect temperature, chemical irritation, ‘painful’ stimuli
Somatosensory System (cont.)

Initiation of the sensation depends on the stimulus being converted into action potentials.
Transmission of the signal travels from the
i. *Receptors*, which are at the end of the
ii. *Peripheral nerves*, which are continuous with the
iii. *Spinal nerves*, which enter the
iv. *Spinal cord* containing the
v. *Ascending sensory tracts*, that are relayed to the
vi. *Thalamus*. Thalamic neurons project to
vii. *Sensory regions* of the brain (i.e., 10 sensory cortex)
Somatosensory System (cont.)

Somatosensation involves:
1. Sensory info.
   - Nerve impulses generated by the original stimuli
2. Sensation
   - Awareness of stimuli by the senses
3. Perception
   - Interpretation of the sensation into meaningful forms
   - Interaction between brain & environment
   - e.g., perceive a stimulus as ‘painful’ and respond to decrease the pain

• What regions of the CNS do these functions occur in?
Sensory Coding: Place & Pattern

1. **Place**: stimulus is only detected if the place where the receptor specific to a certain stimuli is found, is stimulated.

2. **Pattern**: perceived sensations result from the activation of more than 1 receptor type in more than 1 place, with the relay of info to the brain occurring along more than 1 pathway.
Rate of Coding & Receptor Adaptation

**Rate coding**: stimulus intensity increases (beyond threshold for initiation of an AP) and this is coded as an increased rate of firing of the afferent fiber; i.e. receptors detect stimulus & intensity

**Receptor Adaptation**: Receptors are able to adapt to a maintained stimulus (e.g. presence of clothing).

1. **Slowly adapting** (tonic) – continue firing for a prolonged period during the maintained stimulus
2. **Rapidly adapting** (phasic) – receptors cease firing soon after stimulus is applied.
Sensory Receptor Classification

Divide receptors on the basis of the stimulus to which they are most sensitive (‘adequate stimulus’)

1. **Chemoreceptors**: smell, taste, and internal stimuli like pH, O₂, CO₂, metabolites
2. **Photoreceptors**: light (retina)
3. **Thermoreceptors**: temperature & temp. changes
4. **Mechanoreceptors**: many types including auditory and vestibular receptors, touch, muscle tension
5. **Nociceptors**: ‘pain’ receptors (mechanical & chemical)
Sensory Receptors: Receptive Fields

- Receptors differ in their receptive field, which is the area where adequate stimulus produces activation; tested by 2-point discrimination,
- Also depends on anatomical arrangement
Sensory Receptors: Receptive Fields

- Area of skin specific to each individual receptor
- Sensitivity relies on # of sensory endings
- 2-pt. discrimination depends on anatomical arrangement
Afferent Nerve Characteristics

For somatosensation, there are different fibres types; a 100x range in axon diameter and conduction velocity (Note that larger fibres = faster conduction; myelinated > unmyelinated):

1. **Touch, Vibration and Proprioception**: larger myelinated fibres (conduction velocity in the 90 - 120 m/sec range)

2. **Pain and Temperature**: small myelinated fibres and unmyelinated fibres (conduction velocity in the 0.5 – 5 m/sec range)
Axon Diameter and Conduction

1. Large myelinated fibres
   - Muscles, tendons and joints

2. Medium:
   - Joint capsules, Muscle spindles, Cutaneous touch & stretch, Pressure

3. Small
   - Pain, crude touch / itch, temperature
Somatosensation: Proprioception

• Provides info on position of joints, tension on tendons, stretch on muscles (can be static or dynamic).
• Self regulation of posture & movement
Muscles Spindles

- Stretch receptors contained within muscle and may be stretched passively (reflex) or actively
- Intrafusal fibres innervated by large (Ia) fibres
- Surrounded by extrafusal fibres (‘ordinary’ muscle fibres)
Golgi Tendon

- Innervated by large (Ib) afferent fibres
- Intertwine with tendon fibre bundles and are sensitive to tension
- Inhibit muscle activation (-ve feedback)
- Protective for muscle

Joint Receptors

Ligament Receptors (Ib):
• sensitive to tension

Ruffini Endings:
• Sensitive to changes in range of motion

Paciniform Corpuscles:
• Activated by extremes in range of motion and vibration

Free Nerve Endings (Aδ & C):
• responsive to inflammation
Somatosensation:

Skin Receptors - Encapsulated Endings

Consists of nerve ending within a connective tissue capsule:

1. **Meissner’s corpuscles** – light touch; textured surfaces (5 μm elevation is detectable!). Located at dermis epidermis interface they have a small receptive field (rapidly adapting)

2. **Ruffini corpuscles** – sensitive to stretch of skin, with a large receptive field; deeper in the dermis (slowly adapting)

3. **Pacinian corpuscles** – sensitive to vibration (& touch), with a large receptive field; deep within dermis (rapidly adapting)
Skin Receptors: Nerve Endings

Consists of nerve ending without a connective tissue capsule:

1. **Follicular Nerve Ending** – nerve endings closely associated with hair follicles. Sensitive to bending of hair. Have a small receptive field (rapidly adapting).

2. **Merkel cells** – sensitive to sustained pressure on skin, with a small receptive field; Nerve ending closely associated with a Merkel cell in base of epidermis. (slowly adapting)

3. **Free Nerve endings** – some are thermoreceptors (sensitive to warm or cold); some are nociceptors, sensitive to pain a large receptive field; also deep in dermis. Also sense mechanical deformation and chemical irritants
Skin showing free nerve endings (B), Merkel cells (C), and Follicular endings (D)
Skin showing Meissner’s corpuscle (C), Ruffini endings (D), and Pacinian endings (E)
Anatomical Organization of Somatosensory System
Somatosensory System

• Conscious somatosensation uses a relay of 3 neurons from periphery to the 1^0 somatosensory cortex in the parietal lobe (conscious perception)
• Uses specific pathways/tracts to get to cortex

3 major pathways:
1. Dorsal Column: touch, vibration & conscious proprioception
2. Spinothalamic Tract: pain and temp.
3. Trigeminal System: somatosensation from the face
1. Dorsal Column / Medial lemniscus

• The 1st order neuron is in the dorsal root ganglion. It extends axon out to periphery and ends in receptor.

• Also extends axon into spinal cord where it ascends in the dorsal part of the spinal cord to the medulla (fasciculus gracilis [leg] & fasciculus cuneatus [arm])

• Synapses onto 2nd order neuron in medulla that projects to contralateral thalamus as the medial lemniscus. 3rd order neuron from thalamus to cortex
Dorsal Column / Medial Lemniscus System

3rd order neuron

2nd order neuron

1st order neuron
2. Spinothalamic Pathway

- The 1\textsuperscript{st} order neuron is in the dorsal root ganglion. It extends axon out to periphery and ends in receptor.
- Also extends axon into spinal cord where it synapses onto 2\textsuperscript{nd} order neuron in the gray matter of spinal cord
- 2\textsuperscript{nd} order neuron in cord sends axon across the midline and projects to contralateral thalamus. 
  3\textsuperscript{rd} order neuron from thalamus to cortex
Spinothalamic / Anterolateral System

1st order neuron

2nd order neuron

3rd order neuron
3. Trigeminal System

- The 1\textsuperscript{st} order neuron is in the trigeminal ganglion. It extends axon out to periphery and ends in receptor.
- Also extends axon into brainstem where it synapses onto 2\textsuperscript{nd} order neuron
- 2\textsuperscript{nd} order neuron in brainstem nucleus sends axon across the midline and projects to contralateral thalamus. 3\textsuperscript{rd} order neuron from thalamus to cortex
Key Features

• The cell body of 1\textsuperscript{st} order neuron is in a dorsal root ganglion or trigeminal ganglion.
• 2\textsuperscript{nd} order neuron is in the CNS and its axon crosses the midline to project to the thalamus.
• 3\textsuperscript{rd} order neuron is in the thalamus and its axon projects (via internal capsule) to the 1\textsuperscript{st} somatosensory cortex in the parietal lobe in a topographic manner (somatosensory homunculus).
Cerebral Cortex

- The cortex has been mapped out according to microscopic features by Brodmann in 1909
- Each colour represents an area and is numbered 1-52.
Cortical Somatotopy (Maps of the body on the cortex)

- Wilder Penfield (McGill/MNI) neurosurgeon
- Stimulated the cortex of awake patients and developed the motor and sensory homunculi
Primary Sensory Cortex

- In addition to somatosensory cortex, also have $1^0$ auditory cortex (temporal lobe), $1^0$ visual cortex (occipital lobe), and $1^0$ olfactory cortex (temporal lobe).
- $1^0$ cortex discriminates intensities & qualities of the sensory information.
- $1^0$ auditory ctx discriminates loudness and pitch.
- $1^0$ visual ctx discriminates shapes, sizes, location.
- $1^0$ somatosensory ctx discriminates, texture, shape and size.
1. Primary Sensory Cortex
Sensory Association Cortex

- Association cortex carries out higher order interpretation, analysis and processing of sensory information
- Receives input from 1^{st} sensory cortex
- Auditory association ctx important for understanding and producing language
- Visual association ctx interprets visual images, recognition of faces etc.
- Somatosensory association ctx recognition and identification of objects by touch
2. Sensory Association Areas

- Supplementary motor area (SMA)
- Premotor cortex
- Prefrontal association cortex
- Broca’s area
- Limbic cortex
- Primary auditory cortex (in Sylvian fissure)
- Auditory association cortex
- Primary motor cortex
- Central sulcus
- Primary somatosensory cortex
- Somatosensory association cortex
- Secondary somatosensory cortex (in parietal operculum)
- Wernicke’s area
- Primary visual cortex
- Visual association cortex

Legend:
- Primary motor or sensory cortex
- Heteromodal association cortex
- Unimodal association cortex
- Limbic cortex

Association Cortex

- Areas of cortex not involved with sensation or movement (heteromodal association cortex)
- Houses very complex abilities.
  - Personality and goal oriented behaviour
  - Integration & interpretation of sensations
  - Processing of memory
  - Generations of emotions
  - Connects to many different areas of cortex
Limbic System

• Provides the basis for giving subjective properties (feelings/emotions) to a wide variety of stimuli (e.g., music, photographs, effect of colors on emotions)
• Aspects of memory (emotional & declarative)
• Transmits signals via somatic, reticular, hormonal & autonomic pathways.
• The limbic system is the source of emotions and instincts (organizes inputs into complex behavior)
• Regulates feeding, drinking, defensive, reproductive behaviors, fear, aggression, as well as visceral & hormonal functions
Limbic System

What does it do? A number of things:

Market Researcher: “..approximately 80% of all decision making is done at the level of the limbic system -- our...emotional level.”

• Is intimately tied to decision making
• Regulates emotional behavior and visceral responses to emotion (think “road rage”)
• Sometimes referred to as the ‘emotional brain’
Limbic System: Components

• Several evolutionarily older cortical and sub-cortical structures

Includes:
• Hippocampus
• Cingulate gyrus
• Olfactory system
• And others

Connects to hypothalamus (controls Autonomic NS and Endocrine System)
Location of Limbic System
Limbic System

• Provides the feelings of love, generosity, altruism….and hate, greed, resentment, & rage; also involved in motivation and drug addiction

• A number of psychiatric diseases (e.g., depression, anxiety, PTSD, & other affective disorders) may involve the Limbic System

• Alzheimer’s disease affects the hippocampus

• Drug addiction involves limbic system
Limbic System: Stress Response

- Emotions influence function of all organs because of a bi-directional connection between nervous & immune systems
- Reaction to experiences may trigger a stress response, which disrupts the body’s homeostasis
  - Increase in muscle tension (somatic system)
  - Increase blood flow to muscles, decrease blood flow to organs (autonomic)
  - Increase in HR and BP (hormone release - epinephrine)
  - Mediated by Autonomic NS and Endocrine system
Short Term Response to Emotional Stress
Long Term Response to Emotional Stress

Chronic psychological stress →
- Pituitary hormonal activation of adrenal glands →
  - Release cortisol → Increase plasma triglyceride levels
- Sympathetic nerve endings in the adrenal glands →
  - Release epinephrine → Inhibit lymphocyte and cytokine production
- Sympathetic nerve endings in thymus, lymph nodes, spleen, bone marrow →
  - Release norepinephrine and peptides → Suppress natural killer cells and proliferation of lymphocytes; increased number of white blood cells
- Blood platelets secrete more adenosine triphosphate (ATP) →
  - Blood vessel changes → May lead to heart attacks and strokes
Reticular Formation (RF)

• Complex network of connected nuclei located in the brainstem

Its functions include regulation of:
  o Consciousness and sleep
  o Attention and arousal
  o Pain
  o Movement
  o Cardiovascular activity
  o Respiratory activity
Basic Organization of RF

The nuclei are arranged in 3 zones:

1) **Median/Midline Zone**: these are aka the raphe nuclei and have serotonin as the neurotransmitter

2) **Medial Zone** (aka paramedian zone): contains the nuclei that have dopamine, noradrenaline, and adrenaline as their neurotransmitter

3) **Lateral Zone**: receive sensory information and are largely involved in visceral function
Reticular Nuclei

Serotonin

Serotonergic Neurons: Functions

- Activity of the neurons that project to the forebrain fluctuates with sleep and wakefulness
- These neurons are thought to determine the overall level of arousal and receive input from numerous sensory systems
- Enhancing serotonin: treatment of depression
- Neurons that project to the brainstem (PAG) and spinal cord (dorsal horn) decrease pain transmission
Noradrenaline

Plane of Figure 24.4
Locus ceruleus
To spinal cord
Noradrenergic Neurons: Functions

• Changes in activity of the neurons is associated changes in sleep and wakefulness
• Are largely silent during REM sleep, lightly active during non-REM sleep, and increase in activity during wakefulness
• These neurons are thought to be especially important in promoting attention and vigilance
Dopamine

Dopaminergic Neurons: Functions

- Nigrostriatal projections are important in initiating motor activity
- DA projections are considered to be important in cognition and motivation
- Many drugs of abuse are thought to target the DA system which increases the sensation of pleasure (‘reward circuit’)
- Imbalance in DA transmission may underly some forms of mental illness (schizophrenia)
Acetylcholine
Cholinergic Neurons: Functions

- Activation of cholinergic neurons that project to cortex are involved in heightened arousal
- Modulate the sleep-wakefulness cycle; REM sleep is associated with the activation of the pontine cholinergic neurons (decreased activity of the Noradrenergic neurons)
- May be involved in learning and memory
- Alzheimer’s disease is associated with loss of cholinergic neurons in the basal forebrain