SOMATOSENSORY SYSTEMS: Pain and Temperature
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Sensory systems are “afferent,” meaning that they are carrying information from the periphery TOWARD the central nervous system. The somatosensory systems transmit information about the tactile world and the body’s position in that world to consciousness. This information includes the submodalities of touch, pressure, vibration, proprioception, kinesthesia, stereognosis, pain, and temperature.

**Proprioception** – sense of static and dynamic position of limbs and body.

**Kinesthesia** – ability to feel movements of the limbs and body.

**Stereognosis** – ability to recognize objects based on touch alone.

The pathway information is used to associate a patient’s symptoms with the location and structures that may be damaged. After studying the material of these lectures, the student should be able to identify the location of a lesion when given a description of symptoms and to identify the symptoms associated with a particular lesion.

**LEARNING PATHWAYS:** The key to learning the pathways will be repetition, much of which you will need to do on your own. There are two aspects of the pathways to learn. The first is the details of the pathway, that is, in what structures are the cell bodies located, where are the synapses made, and at what level of the pathway do axons cross the midline. You will get this information from the lectures. The second aspect is to learn the location of nuclei and tracts within stained brain sections. This aspect will be covered in the ‘lab’ which is a viewing of a video that takes you through the atlas.

**Ipsilateral** – a relative term indicating the same side of the body, so we refer to something as being ipsilateral to something else, your left arm is ipsilateral to your left leg.

**Contralateral** – a relative term indicating the opposite side of the body.

**Bilateral** – a relative term indicating both sides of the body.

The pathways for the somatosensory system can be grouped into 4 main categories: (1) **Lateral Spinothalamic Tract** transmits information about pain and temperature from the body to consciousness (cortex). So sticking a pin into a finger on your right hand will cause neurons in your left cortex to fire action potentials. (2) The **Dorsal Column – Medial Lemniscus** pathway transmits information about fine discrimination touch (refers to a high level of spatial resolution), vibration, pressure, kinesthesia, stereognosis, and conscious proprioception from the body to consciousness (cortex). Throughout these
notes and in lecture I will refer to all of these submodalities as “fine touch” or “proprioception”, so that when you hear these terms, we are referring to all of these submodalities together. This information ends up in the cortical hemisphere contralateral to the side of the body where the information started. So touching your left leg will cause neurons in your right cortex to fire action potentials. (3) The Trigeminal System conveys somatosensory information of all submodalities (pain, temp, touch, proprioception, etc) from the head and face to consciousness, which means to the neocortex. This information ends up in the cortical hemisphere opposite from the side of the body where the information started (contralateral). So touching your left cheek will cause neurons in your right cortex to fire action potentials (4) Spinocerebellar Tracts that carry non-conscious proprioceptive information from muscles and tendons on one side of the body to the cerebellum on the same side (ipsilateral). (Information from muscles of the right arm, for instance, will be transmitted to the right half of the cerebellum).

Begin learning these pathways by associating the modality with the pathway name.

**The Basic Plan for Somatosensory Information to Consciousness**

The systems that transmit somatosensory information to the level of consciousness follow a basic plan. (see Figure 1) Adequate stimuli evoke generator potentials in peripheral receptors or end organs. **Adequate Stimulus** – The stimulus modality to which a sense organ responds optimally. **Generator Potentials** – depolarizations in receptors that are graded relative to the intensity and form of the stimulus. The generator potential then initiates action potentials in first-order fibers whose **first-order neurons** lie outside the CNS in the dorsal root ganglion for information from the body or in the trigeminal ganglion for information from the head and face. The first-order fibers synapse on **second-order neurons** in the spinal cord OR in the brainstem (depending on the pathway). The second-order neurons give rise to second-order fibers that cross the midline and ascend to terminate in the opposite side of the brain (contralaterally) upon **third-order neurons** in the thalamus. From the cells of the thalamus arise third-order fibers that pass through the thalamic radiation and posterior limb of the internal capsule to the ipsilateral cerebral cortex. Layer IV of the cerebral cortex contains the **fourth-order neurons**. For somatosensory pathways, the fourth order neuron is specifically within primary somatosensory cortex, located in the postcentral gyrus. Brodman identified distinct regions of the cortex based on cell size and packing density (called cytoarchitecture). Brodman’s areas 3, 1, and 2 make up the primary somatosensory cortex.
If you learn some of the rules common to all somatosensory pathways to consciousness, then it will be easier to learn the individual pathways.

**Generalizations:**

1. Cell bodies of the primary afferents are located outside of the central nervous system. (**Except for those in the Mesencephalic Trigeminal Nucleus.**)

2. Cell bodies of the second order neurons are located either in the spinal cord or in the brainstem.

3. The axon of the second order neuron crosses the midline (at the level of the second order neuronal cell body).

4. Cell bodies of the third order neurons are located in the thalamus, within the Ventral Posterior Lateral (VPL) nucleus for the information from the body, and within the Ventral Posterior Medial (VPM) nucleus for information from the head and face.

5. The thalamic neurons ascend ipsilaterally to the cortex.

6. The fourth order neurons are located in Primary Somatosensory Cortex, Brodman’s 3, 1, and 2.

7. If you lesion a pathway before it crosses the midline, there will be a loss of sensation ipsilateral to the lesion.

8. If you lesion a pathway after it crosses the midline, you create contralateral deficits (loss of sensation contralateral to the lesion).

9. If you lesion a pathway as it is crossing you create bilateral deficits.

**Figure 1:** The basic plan for somatosensory information to consciousness involves 4 neurons and 3 synapses. The cell bodies of first order neurons are located outside the CNS in the dorsal root ganglion for information from the body and in the trigeminal ganglion for information from the head. The synapse between the primary and secondary neurons occurs in the spinal cord or brainstem, depending on the pathway. The axon of the second order neuron crosses the midline. Synapse
between the second and third order neurons happens in the Ventral Posterior Lateral Nucleus of the thalamus for information from the body and in the Ventral Posterior Medial Nucleus of the thalamus for information from the head. Third order neurons from the thalamus project ipsilaterally to the primary somatosensory cortex (Brodman’s areas 3,1,2). The body representation is head medial in the thalamus and head lateral in the cortex. Stimuli that affect the left side of the body are perceived by cortical neurons in the contralateral (right) hemisphere.

**Somatosensory Systems: PAIN and TEMPERATURE**

**Pain and Temperature from the Body to Consciousness (Lateral Spinothalamic Tract)**

Pain and temperature are carried in the lateral spinothalamic tract, which is one component of the anterior lateral system (ALS).

A. **Receptors.** Free nerve endings.

B. **First-Order Neurons.** Pseudounipolar neurons in the dorsal root ganglion, with their central axon forming the dorsolateral fasciculus (Lissauer’s tract). In Lissauer’s tract the incoming fibers divide into ascending and descending branches. Most branches are ascending. All branches ultimately synapse on second-order neurons in the dorsal horn. The axon of these neurons are small diameter, thinly myelinated (Aδ fibers) and unmyelinated (C fibers), and are thus slowly conducting. **Dermatome** – area of skin innervated by the sensory portion of a single sensory or cranial nerve. So primary afferent fibers associated with free nerve endings in the T4 dermatome will enter the spinal cord at T4 then ascend to T2 before synapsing in the dorsal horn.

C. **Second-Order Neurons.** Multipolar neurons located in the dorsal horn of the spinal cord. Axons cross the midline in the anterior white commissure and then ascend contralaterally in the lateral funiculus as the lateral spinothalamic tract. This tract ascends through the spinal cord, medulla, pons, and midbrain to the thalamus.

D. **Third-Order Neurons.** Most of the spinothalamic tract fibers terminate upon third-order neurons in the ventral posterolateral (VPL) nucleus of the thalamus. Some of the fibers branch off and synapse in the reticular formation (see Collateral Pathways below). The axons of neurons in VPL project through the posterior limb of the internal capsule to terminate in the dorsal and medial parts of the postcentral gyrus of the cerebral cortex, which is primary somatosensory cortex.

E. **Fourth-Order Neurons.** Layer IV Neocortical neurons of Primary Somatosensory Cortex (Bordmann’s areas 3, 1, and 2).
Key Questions:

a) Where are the cell bodies of origin for the lateral spinothalamic tract? This means where are the cell bodies that are connected to the axons that make up the tract.

Answer: Contralateral dorsal horn of the spinal cord.

b) Where does the lateral spinothalamic tract project or terminate (means where does it synapse)? Answer: Ipsilateral Ventral Posterior Lateral Nucleus of the Thalamus.

Figure 2: Lateral Spinothalamic Pathway, subserving Pain and Temperature sensations. This is a slower pathway, utilizing the slowly conducting primary afferent fibers. Note this pathway crosses the midline in the spinal cord! So if there is a lesion of this pathway within the medulla, there will be a loss of pain and temperature sensation on the contralateral (opposite) side of the body. Figure from Fix, JD, 2000, High-Yield Neuroanatomy, Philadelphia, Lippincott Williams & Wilkins.
**Somatotopy** – body ordered map. The nervous system creates a representation of the body by having, for instance, the cell that code for hand stimuli lie adjacent to those that code for arm stimuli. In upper levels of the spinal cord the axons from the lower spinal cord segments are already present in the tract. The axons of the second order neurons at the upper level segments will cross the midline in the ventral white commissure and add to the ventral portion of the lateral spinothalamic tract. So sacral spinal cord segments will be represented most dorsally. Ventrally adjacent to them will be the axons from the lumbar segments, then ventrally adjacent will be the axons from the thoracic segments, and finally most ventrally will be the axons from cervical segments. This type of body map is maintained at all levels of the CNS. Within the thalamus, the lower body information is represented laterally, and upper body medially within the VPL, and most medially is the head representation in the VPM nucleus. Pain and temperature from the head is transmitted by the Trigeminal pathways, discussed below. Within the primary somatosensory cortex, the lower body is represented medially and the upper body information is located laterally.

**Collateral Pathways**

Chronic pain is very difficult to treat, in part because of multiple representations throughout the nervous system. One way this information gets distributed to additional structures is through collaterals of the lateral spinothalamic tract. These are axonal branches that come from the main axonal branch that is ascending towards thalamus. These axonal branches are given off throughout the brainstem and midbrain and synapse in the reticular formation in these structures, as well as in the superior colliculus. These collateral pathways are referred to as the spinoreticular tract (collaterals to medullary reticular formation), the spinomesencephalic tract (collaterals to the mesencephalic reticular formation), and the spinotectal tract (collaterals to the superior colliculus within the tectum). You can see that the names of tracts tell you where the tract originated and where it terminates, example spinal cord to thalamus = spinothalamic tract.

**Coarse Touch from the Body to Consciousness (Anterior Spinothalamic Tract)**

The second component of the anterior lateral system is the anterior spinothalamic tract, which carries a coarse or crude form of touch, sometimes also called light touch. This means that there is a more crude resolution or ability to localize touch stimuli, as compared to the pathway that transmits “fine touch” (dorsal column-medial Lemniscus pathway). Using the fine touch pathway, you can more
accurately determine the location of stimulus on the body (high degree of spatial resolution). The anterior spinothalamic tract is located just anterior to the lateral spinothalamic tract within the spinal cord and medulla. Other than this slightly more lateral position, the anterior spinothalamic tract follows the same path as the lateral spinothalamic tract. It begins with receptors in the skin, that are associated with small diameter, thinly myelinated and unmyelinated axons, that have their cell body in the dorsal root ganglion. The central portion of the axon enters the spinal cord just above the gray matter of the dorsal horn, and synapses on dorsal horn neurons. These second order neurons send their axon across the midline in the ventral white commissure, and then travel to the lateral funiculus, just anterior to the lateral spinothalamic tract, and ascend as the anterior spinothalamic tract to the VPL of the thalamus, where a synapse with the third order neuron is made. The third order, VPL neuron sends its axon to the ipsilateral primary somatosensory cortex, (Brodman's 3, 1, 2).

**Trigeminal Pathways – fine discrimination touch, deep touch (pressure), and vibration sensitivity, pain and temperature, nonconscious proprioception from the head and face.**

A. **Receptors.** Free nerve endings, Merkel’s discs, hair receptors and receptors with encapsulated endings.

B. **First-Order Neurons.** Pseudounipolar cell bodies in the trigeminal ganglion, located outside the CNS, similar to dorsal root ganglion neurons (**Except for some proprioceptive information from the head, where the first order cell bodies are located in the Mesencephalic Trigeminal Nucleus). Peripheral processes (component of axon that extends from the sensory receptor to the ganglion) come from 3 branches of the trigeminal nerve, the Ophthalmic, Maxillary, and Mandibular. These nerve branches are named for the dermatome they subserve. The Ophthalmic branch innervates the superior part of the face, the Mandibular branch innervates the lower jaw region and the Maxillary branch innervates the area in between. Central processes (component of axon that extends from the ganglion into the CNS) pass through the lateral part of the pons at the base of the middle cerebellar peduncle and enter the tegmentum. At this point the fibers distribute according to sensory modality. The three major divisions are the (1) Mesencephalic, the (2) Principal or Main, and the (3) Spinal Trigeminal Nucleus.

1. **Ascending fibers** project to Mesencephalic Trigeminal Nucleus; and subserve non-conscious proprioception. These fibers do not have their cell body in the trigeminal ganglion, but rather have it within the Mesencephalic Trigeminal Nucleus. This is the ONLY place within the CNS that contains primary afferent cell bodies. These neurons
ultimately project to the Cerebellum and Thalamus, where their second order neurons are located.

2. *Fibers* project directly to the Principal (also called the Main or Chief) Trigeminal Nucleus; and subserve fine discrimination touch (includes pressure, vibration sense, conscious proprioception, kinesthesia, and stereognosis).

3. *Descending fibers* project to the spinal trigeminal nucleus. This component can be further subdivided into pars oralis, interpolaris, and caudalis (from rostral to caudal, respectively). It is specifically the pars caudalis that subserves pain and temperature. This pathway consisting of primary afferents projecting to the caudal portion of the spinal trigeminal nucleus is called the Spinotrigeminal Tract. Adding axons to this tract are the fibers from Cranial Nerve Ganglia VII, IX, and X.

C. **Second Order Neurons.** Second order neurons are located in the Trigeminal Nucleus (Main and Spinal components). Please note that on the first day of Somatosensory Pathways, we will focus on the spinal component, since that is the one carrying pain. Here the complete Trigeminal Pathways are presented. The Principal Sensory Nucleus of V will be mentioned, but its pathways will be more fully discussed on the second day of lecture on Somatosensory Pathways.

1. **Principal Sensory Nucleus of V** (also called the Main or Chief Trigeminal Nucleus) located mid pons. This nucleus and subsequent pathway is similar to the dorsal column system. This nucleus transmits information about fine discrimination touch, similar to the Dorsal Column-Medial Lemniscus Pathway both receive that information from primary afferents that are large, fast-conducting axons. The axons of the second order neurons project to the thalamus through 2 paths. Most axons from the Main Sensory Nucleus of V cross the midline and then ascend as the Ventral Trigeminothalamic tract (axons) to ultimately synapse in the VPM nucleus of the Thalamus. Some axons project ipsilaterally as the Dorsal Trigeminothalamic Tract, ultimately synapsing in the ventral posterior medial (VPM) nucleus of the ipsilateral Thalamus.
2. The caudal-most region of the Trigeminal Nucleus is the **Spinal Trigeminal Nucleus**. This is further divided into 3 components: Oralis, Interpolaris, and Caudalis. It is in the caudalis component of the spinal trigeminal nucleus that information on pain and temperature from the face is transmitted. This component is similar to the lateral spinothalamic tract. It receives information from slowly conducting Aδ and C fibers. The second order fibers from the Spinal Trigeminal Nucleus CROSS THE MIDLINE in the reticular formation and ascend as the Ventral Trigeminal Thalamic Tract. These axons will synapse in the VPM nucleus of the thalamus. Pars Oralis and Interpolaris are associated with coarse (also called ‘light’) touch, similar to the Anterior Spinothalamic Tract.

NOTE: At levels above the pons, the ventral trigeminal thalamic tract contains information from the contralateral side of the face about BOTH fine discrimination touch, as well as pain and temperature.

***For neurons within the Mesencephalic Nucleus of V, the second order neurons are located in the ipsilateral Cerebellar Hemispheres and the ipsilateral VPM of the thalamus, delivering proprioceptive information to these locations.
D. **Third-Order Neurons.** The dorsal and ventral Trigeminothalamic tracts terminate on neurons in the ventral posteromedial (VPM) nucleus of the thalamus. The axons of neurons in VPM project through the posterior limb of the internal capsule to terminate in the ventrolateral portion of the postcentral gyrus of the cerebral cortex, which is primary somatosensory cortex, and can be identified as Brodmann’s areas 3, l, and 2.

E. **Fourth-Order Neurons.** Layer IV Neocortical neurons of Primary Somatosensory Cortex (Bordmann’s areas 3, 1, and 2).

**Key Questions:**

a) Where are the cell bodies of origin for the Spinotrigeminal tract?
   **Answer:** Ipsilateral cranial nerve ganglia of V, VII, IX, and X.

b) Where does the Spinotrigeminal tract terminate?
   **Answer:** Ipsilateral Spinotrigeminal Nucleus.

c) What symptoms would result from lesion of the Spinotrigeminal tract?
   **Answer:** Ipsilateral loss of pain and temperature in the head and face.

d) Where are the cell bodies of origin for the Ventral Trigeminothalamic tract?
   **Answer:** Contralateral Trigeminal Nucleus (Main and Spinal Components).

e) Where does the Ventral Trigeminothalamic tract terminate?
   **Answer:** Ipsilateral Ventral Posterior Medial Nucleus of the Thalamus.

f) What symptoms would result from lesion of the Ventral Trigeminothalamic tract?
   **Answer:** Loss of pain, temperature and touch senses in the contralateral face and head.
Clinical Syndromes

1. **Syringomyelia** – Gliosis and cavitation of the midline of the spinal cord. This can occur as a result of malformed brain tissue, or as a result of trauma, or as a result of tumor. Anything that compresses the cerebrospinal fluid (CSF) at one point will cause an expansion at another point, since it is a closed system. The expansion of CSF into the spinal cord lesions the surrounding tissue. Just below the central canal, which contains the CSF in the spinal cord, is the ventral white commissure. This commissure contains the pain and temperature fibers that are crossing the midline (before forming the lateral spinothalamic tract). Remember that if you lesion a pathway as it is crossing, you create bilateral deficits. Thus the result of this lesion is Bilateral loss of pain and temperature at ~ the level of the lesions (and 2 dermatomes below, due to lissauer’s fasciculus).

2. **Wallenberg’s Syndrome** (also called Lateral Medullary Syndrome) – Lesion of the lateral structures of the medulla. This can occur as a result of occlusion of the Posterior Inferior Cerebellar Artery. This artery wraps around the medulla and supplies oxygen to the lateral structures. Thus an occlusion will deprive these structures of oxygen, resulting in their lesion
(see structures lesioned in Fig. 5). This lesion results in symptoms of loss of pain and temperature on the ipsilateral face, loss of pain and temperature on the contralateral side of the body, and ataxia. The Spinal Trigeminal Tract consists of first order axons from cranial nerve nuclei V, VII, IX, and X, carrying information about pain and temperature from the ipsilateral side of the face. These fibers are about to synapse in the Spinal Trigeminal Nucleus which is located just medial to the tract. This structure contains the second order cell bodies, so also contains pain and temperature information from the ipsilateral face. The Lateral Spinothalamic tract contains second order axons that crossed the midline back in the spinal cord. The Lateral Spinothalamic tract carries pain and temperature information from the contralateral body. The dorsal spinocerebellar tract carries proprioceptive information to the cerebellum from the ipsilateral lower body. The ventral spinocerebellar tract carries proprioceptive information to the cerebellum from the contralateral lower body. Lesion of the two spinocerebellar tracts results in ataxia (difficulty in walking).

Figure 5: Fiber-stained section of the Medulla, showing the structures damaged in Wallenberg’s Syndrome.