NBL 356-656 Module 4 Review Q&A

*1. Of the five classical senses, which senses are considered general senses and which are considered special senses? What are the other important somatic (body) senses in humans?*

The five classical senses are sight/vision, touch/somatosensation, hearing/audition, taste/gustation, and smell/olfaction. In addition to touch, other human somatic senses include pain/nociception, temperature/thermoreception, proprioception, itch/pruriception, chemical detection/chemoreception, equilibrium/equilibrioception. General senses are mediated by sensory neurons located in skin/muscles/tendons/joints and include: touch/ mechanoreception, pain/nociception, temperature/thermoreception, itch/pruriception, chemical detection/chemoreception, and proprioception. Special senses are mediated by sensory neurons located in specific sense organs and include vision, hearing, smell, taste and vestibular/equilibrium. (Some distinctions get very blurred since taste and smell involve chemoreception, and pain can involve painful pressure/mechanoreception, painful chemicals/ chemoreception or painful temperatures/thermoreception.

*2. What are the main components of a sensory system and briefly what does each component do?*

A sensory system is a part of the nervous system responsible for detecting, transmitting and processing sensory information. A sensory system refers to the pathway and nervous system regions that transduce a stimulus input into electrical signal that is ultimately received and interpreted in the brain. The stimulus is the energy source or chemical signal, it can be external or internal. Cellular sensory receptors are specialized cells or cellular process that detect and monitor specific conditions and/or changes. There are three formal types: interoceptors detect signals from viscera/organs and internal tissues, exteroceptors detect signals in skin and proprioceptors detect signals in muscles, tendons and joints. (Most neuroscientists describe exteroreceptors by their specific category of mechanoreceptors, thermoreceptors, nociceptors or pruriceptors. In addition, sensory receptors are present in special sense organs, which are structures specialized to respond to stimuli. The molecular receptors and transducers respond to the stimulus energy or chemical and convert that into synaptic signals to other neurons that are eventually transduced into action potentials.

Sensory Pathways Conduction. This includes the axons (afferent pathways) and neurons involved in relaying sensory information and transmitting it to the brain. Nerve impulses (which are action potentials) are transmitted to the CNS. For 5/7 senses, information is relayed through the thalamus.

Processing and Integration. Sensory information is relayed/transmitted from the thalamus to the primary sensory cortex for each modality. Then, the sensory information is integrated and processed by the sensory association cortex for each modality and eventually combined with other sensory information. The sensory information that is detected and arrives at the primary sensory cortex is a sensation. Awareness of a sensation is perception – reality

In summary, sensory receptor cells detect specific stimuli, neural pathways including axons in nerves and tracts deliver the action potentials to the thalamus, which relays the information to the primary sensory cortices, and the association cortices process and integrate that information to produce perception.

*3. What are the main sensory modalities? What is a sub-modality? What four types of information (sensory coding) about each stimulus does every sensory system provide?*

The main modalities include: electromagnetic waves (light), taste/tastants, odorants, sound waves, chemicals, temperature and pressure. A sub-modality is a quality or category of a modality that is distinguishable on its own. A submodality includes specific aspects of the stimulus, including wavelength of light or pitch of sound. Types of information transmitted about each stimulus include modality, location, timing, and intensity.

*4. Which region of the brain is involved in transmitting/relaying the majority of sensory information to the sensory cortices?*

The thalamus transmits the majority of sensory information including somatosensation (including touch, temperature, pressure, pain, itch and conscious proprioception), vision/sight, audition/hearing, gustation/taste, and position-balance from the vestibular system.

The two sensory systems in which the thalamus does not relay information is unconscious proprioception (which is transmitted to the cerebellum) and olfaction, which is transmitted to the olfactory bulb.

*5. In every sensory system, what does the stimulus modality eventually get transduced into? Why is that important?*

The stimulus modality is eventually transduced into an action potential (AP). The AP is the language of communication used by neurons in the CNS. The AP is used for synaptic transmission by neurons in the CNS.

*6. What is sensation and what is perception? How does sensation contribute to perception; what additional components contribute to perception? What are the three phases/components of perception, and what does each involve? From Wiki:*

Sensation is the body's detection of external or internal stimulation (e.g., eyes detecting light waves, ears detecting sound waves), and transmission of that information, in most cases through the thalamus, to the primary sensory cortex.

Perception is the organization, identification, and interpretation of sensory information in order to represent and understand the presented information, or the environment. Perception utilizes the brain to make sense of the stimulation (e.g., seeing a chair, hearing a guitar). Perception involves integration of multiple sub-modalities and/or modalities, as well as information recalled from memory.

The three phases/components of perception are: selection, organization, and interpretation. Selection involves attention, and attending to a stimulus. In organization, we mentally arrange stimuli into meaningful and comprehensible patterns. The outcome is the construction of a mental representation of the stimulus (or combined stimuli), called a percept. The final stage of perception is interpretation, which is the subjective process through which we interpret sensory information in a way that makes sense, using our existing information about the world, and allows us to represent and understand stimuli.

*7. The two types of information processing are called top-down and bottom-up. What do these terms mean and what does each involve?*

Though initially argued as two distinct mechanisms/theories of information processing, most neuroscientists today would probably agree that top-down processing involves, and in most cases requires, bottom-up processing.

In bottom-up processing, sensation is the main component. Sensation occurs when the sensory organs transmit information to the brain. In bottom-up processing, information about the incoming stimulus works upwards to the simplest representation of the object that is formed in our minds. This component of the perceptual experience is based on the sensory stimuli that we piece together using only data that is available from our senses. It is said to be data driven, does not involve prior knowledge, and takes place as it happens.

Top-down processing refers to how our brains make use of information that has already been brought into the brain by one or more of the sensory systems, through sensation. Top-down processing refers to perception that is driven by cognition. It integrates past experience and prior knowledge related to a stimulus, as well as our emotional and mental status, context, level of attention, expectations and motivations, to help us make sense out of and understand the sensory information. Top-down processing is also known as conceptually-driven processing, since out perceptions are influenced by expectations, existing beliefs, understanding and feelings.

*8. In what ways is somatic sensation different from special senses? What are the five modalities of somatic sensation? What are the five main types of primary somatosensory receptor cells? Which of these is polymodal?*

Somatosensory neurons are located in many tissues in the body, while special senses neurons are located in special sense organs. Each special sense involves only a single modality while somatosensation has five different modalities. The five modalities of somatosensation are tactile (touch, pressure, and vibration), proprioceptive stimuli, innocuous temperatures, painful stimuli (noxious pressure, temperatures and chemicals) and pruriceptive chemical stimuli (itch). The five types of primary somatosensory receptor cells are mechanoreceptors, proprioceptors, thermoreceptors, nociceptors and pruriceptors.

*9. Provide a brief and general overview of the somatosensory pathway.*

The cell bodies of primary somatosensory neurons that form spinal nerves are located in the dorsal root ganglia. Their axons project to skin, muscles, tendons or joints in the body and neck. Their other axon projects into the dorsal horn of the spinal cord, and/or it extends to the medulla. The cell bodies of primary somatosensory neurons that form cranial nerves are located in the cranial ganglia, which are located outside but next to the brainstem. Their axons project to skin, muscles, tendons or joints in the head/neck/face. The other axon projects to the cranial nerve nuclei in the brainstem. Note that some cranial nerves contain axons from somatosensory neurons, while some cranial nerves contain axons from special sense neurons for vision, hearing, taste, olfaction or balance (vestibular).

*10. Describe the basic structure of a primary somatosensory (dorsal root or cranial ganglion) neuron and the two morphological types (complex-encapsulated and simple-free endings). Which cranial ganglion contains somatosensory neurons that innervate the majority of the face and head?*

For all primary somatosensory neurons, their cell body is located in either the dorsal root ganglia or the cranial ganglia. Each neuron has two axons, one which extends to the tissue it innervates, and the other that extends to the spinal cord or brain stem. Simple somatosensory neurons can have free nerve endings (thermoreceptors, nociceptors and pruriceptors), and their axons are either unmyelinated or lightly myelinated. Complex somatosensory neurons have encapsulated/ensheathed nerve endings that are surrounded by connective tissue or specialized epithelial cells (in the case of Merkel disks). The axons these mechanoreceptors are myelinated. The trigeminal ganglion (aka the Gasserian ganglion) contains the primary somatosensory neurons for most of the somatosensation of the face and head.

Another classification of somatosensory neurons (that I didn’t provide in my lectures, but it is covered in the YouTube video review 2) is the following: Protopathic neurons are involved in crude touch (nondiscriminative touch), temperature and pain and send information by the spinothalamic pathway. Epicritic neurons are involved in fine touch (discriminative touch), vibration and proprioception, and send information by way of the DCML pathway (see below.)

*11. What are the four types of mechanoreceptor cells found in glabrous skin? In general where are they located? What are the sub-modalities of touch? (What types of tactile information do the mechanoreceptors transmit?) What is an additional mechanoreceptor found in hairy skin?*

Meissner’s corpuscles respond to light/sensitive touch, flutter and stroking movements; Merkel’s disks respond to sustained pressure, texture and skin motion; Ruffini’s corpuscles respond to cutaneous tension and skin stretch; Pacinian corpuscles respond to deep pressure and vibration. In the skin additional somatosensory receptors include free nerve endings (nociceptors/thermoreceptors/pruriceptors), and the root hair plexus, which form a plexus around the hair follicle in hairy skin. The hair follicles are also mechanoreceptors conveying touch sensation (including crude touch and pain) about the movement of the hair.

*12. Describe the proposed transduction mechanism of mechanosensitive channels. What does activation of these channels produce first in the receptor region and then in the axon? How is sensory information thought to be encoded by the somatosensory system? What is adaptation and what are the two types (for mechanoreceptors)? What are the proposed purposes of adaptation in sensory systems?*

When pressure or touch is applied to a mechanoreceptor cell, the plasma membrane becomes deformed or moved, which leads to the opening of stretch or stress-gated mechanosensitive ion channels in the plasma membrane. Many of these are nonselective cation channels which, when activated, allow Na+ to flow down its electrochemical gradient, flowing into the neuron. The influx of Na+ depolarizes the membrane potential, which produces a receptor potential at the end of the axon. (Sometimes the receptor potential is called a ‘generator potential’ for mechanoreceptor responses). If this receptor potential is a large enough depolarization to reach threshold (-55 mV) it will produce an action potential (AP) in the axon, since the axon has VG Na+ and VG K+ channels in the regions next to the ends. The AP will then be conducted along that axon, past the cell body (in the DRG or cranial ganglion) and then along the other axon branch into the spinal cord or brain stem. Since it’s a graded potential, the magnitude and duration of the receptor potential depends on the intensity and timing of the stimulus. Therefore the frequency and duration of APs will be proportional to the intensity and duration of the stimulus. When the APs arrive at the presynaptic terminus, they will be converted into neurotransmitter release onto the secondary sensory neuron in the spinal cord or brainstem. Mechanoreceptors undergo adaptation. All somatosensory receptor cells are glutamatergic neurons.

Most mechanoreceptors undergo adaptation, which is when the response (AP’s being generated) decreases, even in the continued presence of the stimulus. There are slowly adapting and rapidly adapting mechanoreceptors. Meissner and Pacinian corpuscles are rapidly adapting, while Merkel disks and Ruffini corpuscles are slowly adapting. Thermoreceptors and nociceptors do not adapt. Adaptation is thought to increase the dynamic range of the response, meaning that an accurate response can be produced over a greater range of the stimulus. Adaptation may also decrease the “noise” of the system and allow the body to disregard irrelevant small or persistent stimuli.

*13. What type of neurons are mechanoreceptors (and all other primary somatosensory neuron as well? What happens when the action potentials that are conducted along the sensory afferents arrive at the synapse on the secondary sensory neurons?*

Mechanoreceptors and other somatosensory neurons are glutamatergic neurons. When action potentials arrive at their presynaptic terminus, they release glutamate into the synapse where the secondary sensory neurons are located (in either the dorsal horn or the medulla.) In addition to releasing glutamate, some nociceptors also release neuropeptides such as NPY, CGRP, or substance P. Remember that neuropeptides are neuromodulatory in their function (they work through metabotropic receptors) so they likely modify the responses of the secondary sensory neurons.

*14. In general, what is the receptive field? What are dermatomes. What does the size of the receptive field and # of inputs determine?*

The receptive field is the region of the body or the world (e.g. visual space) that is represented by that primary sensory receptor cell. The receptive field in the somatosensory system is that region of skin (or muscle/tendon/joint) in which a stimulus will cause a response (AP firing) in the sensory receptor cell that innervates that tissue. A dermatome is an area of tissue that is innervated by a single spinal nerve. The density of receptors varies in different areas of the body and in different sensory systems. For spatial resolution of the receptive field, the smaller the receptive field, the higher the spatial resolution, and the higher the density of innervation, the higher the spatial resolution.

*15. What is proprioception and why is it important? Where (three regions) are the (also proprioceptors found that mediate proprioception? Why do you think it’s necessary that proprioceptors are mechanoreceptors that have encapsulated endings? Proprioception can be conscious or unconscious. Where are these two types of proprioceptive information transmitted to in the CNS? Why do you think two types are necessary?*

From Wikipedia, “Proprioception is the sense of the relative position of one's own parts of the body (especially the position of limbs in space) and strength of effort being employed in movement (to sense movement within joints and limbs).” It is important for balance, posture, locomotion, and for many motor skills and coordinated tasks. Proprioceptors are located in skin, muscles, joints and tendons. Proprioceptors are mechanoreceptors that sense movement and position, which involves mechanical movement (stretch of muscles, depression of skin, compression of tendons and movement of joints). Unconscious proprioception is transmitted from the spinal cord to the cerebellum. Conscious proprioception is transmitted from the primary somatosensory neurons to the medulla, which is then transmitted to the thalamus. Note that though only muscles, tendons and joints are shown in the PowerPoint, proprioceptors are also located in skin. In addition to type Ia and type II neurons in the muscle spindle, Pacinian corpuscles and Ruffini endings are also types of mechanoreceptors thought to be involved in proprioception, and these are located in both joints and skin.

*16. What is nociception and why is it important? Describe the structure of cellular nociceptors. What areas (tissues) do they innervate? What are the three types of nociceptors (which submodality does each transduce)? What is meant by polymodal? What chemicals are released by tissue damage or immune responses?*

From Wikipedia: “Nociception is the sensory nervous system's response to certain harmful or potentially harmful stimuli. In nociception, intense chemical (e.g., chili powder in the eyes), mechanical (e.g., cutting, crushing), or thermal (noxious heat and cold) stimulation of sensory nerve cells called nociceptors produces a signal that is transmitted via the spinal cord (or brainstem) to the brain.” Nociception is important because it protects our tissues from injury and damage. Cellular nociceptors have free nerve endings. Nociceptor cells respond to noxious stimuli (noxious heat, pressure and chemicals) and mediate pain sensation and perception. They innervate skin, muscles, tendons and joints. Three types: mechanosensitive, thermosensitive, and chemosensitive nociceptors. Some are polymodal, meaning they can respond to more than one type of painful stimulus, such as heat and chemicals. Tissue damage can lead to the release of bradykinin, prostaglandins, K+, and substance P from damaged cells, and histamine from immune cells.

*17. What is meant by noxious and innocuous? Where (what tissues) are thermoreceptors found? What type of temperature information do thermoreceptors sense and transduce? What type of information do thermosensitive nociceptors transduce? What is proposed as the thermosensitive channel? Are they polymodal? If so, provide an example.*

Noxious means painful, while innocuous means non-painful. Thermoreceptors are found predominantly in the skin and transmit innocuous warm and cool temperature information. (As described above, thermosensitive nociceptors are also located in skin, muscles and joints, and transduce noxious hot and cold temperatures.) The thermosensitive channel is the Trp channel, and is polymodal. An example is the TrpV1 channel is activated/opened by both temperatures between 50-55 degrees C, and also by the chemical capsacin from chili peppers. Different Trp channel proteins (encoded by different but conserved Trp genes) are activated by different temperatures. Trp channels are thought to be involved in both thermoreception and nociception.

*18. What are the four main types of primary somatosensory afferents and how are they different? What modalities does each type transmit?*

The four types of afferents/axons from the skin are called Aα, Aβ, Aδ, and C fibers. The four types of afferent from muscles/tendons/joints are called Group I, Group II, Group III, and Group IV. The afferents differ in their diameter and myelination. They transmit all somatic sensory information about touch, proprioception, temperature, nociception and pruriception. In general, Aα and group I transmit proprioception, Aβ and group II transmit tactile/touch information, and Aδ and C (and group III and IV) transmit pain, temperature, and itch. (Some Aβ afferents also transmit proprioception.)

*19. What are “Rexed laminae?” How could stimulating one modality type of somatosensory receptor affect the sensation produced by of anther modality type of receptor? (How and where can transmission be integrated before reaching the brain?)*

From Wikipedia,”the Rexed laminae\* comprise a system of ten layers of grey matter (I-X), identified in the early 1950s by Bror Rexed to label portions of the grey columns of the spinal cord. Similar to Brodmann areas, they are defined by their cellular structure rather than by their location.”

When the sensory afferents enter the spinal cord, they branch. For the nociceptor, one axonal branch synapses on a secondary sensory neuron (called projection neuron in the slide) located in the dorsal horn and the other branch synapses on an inhibitory spinal interneuron (also called a local circuit neuron in the slide.) For the mechanoreceptor, one axon branch extends in the dorsal column to the medulla where it synapses on its secondary sensory neuron, and the other branch synapses on the inhibitory spinal interneuron. Thus the spinal interneurons can receive inputs from different axons (one from the nociceptor and one from the mechanoreceptor). And those spinal interneurons can synapse on and provide information to the secondary sensory neurons (projection neurons). In this way, information from the mechanoreceptors can modulate the information being transmitted through the nociceptor pathway. If the interneuron is inhibitory as shown in the figure, and the mechanoreceptor input synapse is excitatory as shown, this will lead to more inhibitory input to the secondary sensory neuron (projection neuron) and reduce the nociception transmission. (In the figure on the left, the mechanoreceptor can also make an excitatory synapse on the secondary sensory neuron (for nociception) in the spinal cord. This adds another level of complexity and is one way that touch can increase pain transmission)

\* I wanted you to be introduced to the term Rexed Laminae for future courses, or in case you have heard of some of these spinal cord anatomical terms. Cells mean neurons.

*20. What is discriminative touch? Describe the basic pathway (connections and tracts) for discriminative touch, pressure, vibration and conscious proprioception. What happens when primary somatosensory axons (for these modalities) enter the spinal cord?*

Discriminative touch or fine touch is a sensory modality that allows a subject to sense and localize touch. The dorsal column medial lemniscus (DCML) pathway transmits discriminative touch, pressure, vibration and conscious proprioception. The primary sensory axons that sense and transmit these modalities branch when they enter the spinal cord. One axonal branch synapses on a spinal interneuron in the dorsal horn. The other branch ascends ipsilaterally within the DCML to the medulla oblongata, where it synapses on a secondary (also called second order) sensory neuron in either the gracile nucleus or cuneate nucleus. Those neurons then project their axons, which immediately decussate and then travels within the lemniscus (a ribbon-like white matter tract within the length of the brainstem) up to the thalamus where it synapses on a tertiary (third order) neuron in the ventral posterior nucleus (VPN) in the thalamus. Those thalamic neurons send their axons to and synapse on neurons in the primary somatosensory cortex.

*21. Where is the DCML tract in the spinal cord, and what are the two areas (fasciculi) of the dorsal column. What information does each fasciculus transmit, and to which nucleus in the medulla? What and where is the medial lemniscus?*

The two DCML tracts are located in spinal cord, in the dorsal (posterior) column. The two tracts are called the gracile fasciculus and the cuneate fasciculus. (A fasciculus is a bundle of myelinated axons in the CNS-a tract.) The axons that form the gracile fasciculus terminate and synapse with neurons in the gracile nucleus in the medulla. Information from the middle thoracic and lower limbs of the body travels via the gracile fasciculus to the gracile nucleus. The axons that form the cuneate fasciculus terminate and synapse on neurons in the cuneate nucleus. Information from the arms and hands travel via the cuneate fasciculus to the cuneate nucleus. The lemniscus is a ribbon-like white matter tract located in the brainstem from the medulla to the midbrain. The medial lemniscus is the part of the lemniscus in the medulla where the axons from the gracile and cuneate nuclei decussate.

*22. Describe the basic pathway (connections and tracts) for pain, temperature, itch and crude touch. What happens when primary somatosensory axons (for these modalities) enter the spinal cord? Where are the spinothalamic tracts located in the spinal cord? How are these tracts mapped?*

The spinothalamic tracts transmit pain, crude touch, temperature and itch, from the limbs, trunk, neck, and posterior head to the thalamus. The primary somatosensory neurons extend their axon into the spinal cord and synapse on secondary (second order) sensory neurons in the dorsal horn. The secondary sensory neurons are a type of projection neuron. Their axons immediately decussate (cross the midline) and ascend in the contralateral spinal cord, forming the spinothalamic tracts (also called the anterolateral column) that eventually end at and synapse on neurons in the VPN of the thalamus. The neurons in the thalamus send their axons to the primary somatosensory cortex. The lateral spinothalamic tract transmits pain and temperature. The anterior spinothalamic tract transmits crude touch and firm pressure. The axons that transmit pain can also branch before terminating in the thalamus and hence pain information is also transmitted to several specific brainstem nuclei. These include one nucleus called the periaqueductal gray (PAG) in the midbrain, another nucleus in the pons called the parabrachial (PB) nucleus (or parabrachial complex since it’s actually a group of three small nuclei), and the rostroventromedial medulla (RVM). These nuclei are also involved in the descending pain pathways.

*23. Describe the basic pathways (connections and tracts) for unconscious proprioception. Where are the spinocerebellar tracts in the spinal cord? Where is the cuneocerebellar tract and what does it transmit? Where does the cerebellum send information?*

The spinocerebellar tracts transmit unconscious proprioception from the body to the cerebellum. The primary somatosensory neurons send axons to the spinal cord where they synapse on secondary sensory neurons. The axons of the secondary sensory neurons form the spinocerebellar tract and travel in the ipsilateral spinal cord to the cerebellum. Hence this is one sensory system where the brain (left and right cerebellum) receives sensory information from the same side of the body. The posterior spinocerebellar tracts contain information from muscle spindles (MS) and Golgi tendon organs (GTO) in the trunk; the anterior spinocerebellar tract- transmits information from the GTO in trunk. A third tract called the cuneocerebellar (CC) tract transmits information from the MS and GTO in arms and hands. The CC tract actually travels with the axons in the DCML, before splitting off to go to the cerebellum. The cerebellum sends information to the four nuclei in the brainstem that form the extrapyramidal tracts, the rubrospinal, tectospinal, vestibulospinal and reticulospinal tracts. The cerebellum also sends information to the thalamus (as discussed in the motor systems), which is then relayed from the thalamus to the motor cortex.

*24. Describe the trigeminothalamic pathway. From where and what information does it convey.*

From Wikipedia: “The trigeminal nerve (the fifth cranial nerve, or simply CN V) is a nerve responsible for sensation in the face and motor functions such as biting and chewing; it is the largest of the cranial nerves. Its name ("trigeminal" = tri-, or three, and - geminus, or twin: thrice-twinned) derives from the fact that each of the two nerves (one on each side of the pons) has three major branches: the ophthalmic nerve (V1), the maxillary nerve (V2), and the mandibular nerve (V3). The ophthalmic and maxillary nerves are purely sensory, whereas the mandibular nerve supplies motor as well as sensory functions.” The cell bodies of the primary somatosensory neurons form the trigeminal ganglion and their axons form the majority of the trigeminal nerve (though there are a few motor axons in V3). From the trigeminal ganglion a single, large sensory root enters the brainstem at the level of the pons. Immediately adjacent to the sensory root, a smaller motor root emerges from the pons at the same level. All three types of somatosensory neurons (for touch, proprioception, pain and temperature) are found in the trigeminal ganglion/nerve. The sensory axons synapse on neurons in the trigeminal nucleus. (The trigeminal nucleus extends from the midbrain to the medulla). Axons from neurons in these nuclei convey information for most somatic sensations from the face, scalp, nasal cavity, oral cavity and teeth to the VPN of the thalamus (specifically to the VPM).