NBL 356 Module 1 Review Q&A

1. *The two general types of motor systems are the somatic and autonomic motor system. What does each control? How are they similar and different?*

The somatic motor system controls the voluntary and involuntary contraction of skeletal muscles. The autonomic motor system controls the involuntary contraction of smooth muscles, cardiac muscles and release from glands.

Note that both skeletal and heart muscle are types of striated muscle. The heart beats on its own (through the function of cardiac pacemaker cells), does not require innervation to beat, but is controlled by only the autonomic nervous system. The diaphragm is classified as a skeletal muscle and is under both voluntary and involuntary (automatic-reflex) control by the somatic motor system. The esophagus contains both smooth and striated muscle and is controlled by both the autonomic (smooth muscle) and somatic (striated muscle) nervous systems.

To review: the autonomic nervous system is involved in the involuntary/unconscious control of smooth muscles, cardiac muscles and glands. The somatic nervous system innervates skeletal muscle (and a few other striated muscles-but not heart) for the voluntary/conscious control of movement, and the involuntary/unconscious control of several automatic reflexes such as breathing and muscle contractions involved balance, posture and rhythmic motor patterns such as walking.

The autonomic and somatic motor systems are similar in that they both include cholinergic motor neurons located in either the spinal cord or brainstem, that extend their axons out of those regions. In the somatic system, those axons directly innervate the target skeletal muscle where they produce muscle contraction. In the autonomic system, those axons innervate the post-ganglionic neurons (PGNs) found in autonomic ganglia, which then extend their axons and innervate the target tissues. PGNs use different neurotransmitters (acetylcholine, norepinephrine or dopamine) depending on whether they are sympathetic or parasympathetic and the tissue they control. In addition, most organs and glands are usually coordinated by both the sympathetic and parasympathetic systems, and so can be activated or inhibited by autonomic neurons.

1. *How is movement produced? What are three main types of movement?*

Movement allows us to maintain posture and balance, move our body, limbs, hands, eyes and tongue, and communicate through speech. Movement is produced by the contraction and relaxation of skeletal muscles. The three types of movement are reflex responses (e.g. breathing, cough, knee jerk, withdrawal), voluntary movements (e.g. playing a musical instrument, peeling an orange, hitting a tennis ball and typing), and rhythmic motor patterns (e.g. walking, running and chewing).

1. *What are the two descending systems involved in the control of movement, and what is the function of each?*

The two types of descending systems/pathways (also called the upper motor systems) are the pyramidal tracts (which control conscious/voluntary movements) and is also called the direct system; and the extrapyramidal tracts, most of which control unconscious/involuntary movements, (with the exception of the rubrospinal tract, which controls voluntary muscles). The extrapyramidal tracts are also called the indirect system.

1. *Voluntary movements are controlled by the two pyramidal tracts. a) What are the two pyramidal tracts? b) What parts of the head/body do they control? c) Where do they originate?*

The two pyramidal tracts are the corticobulbar and corticospinal tracts. The cell bodies of the upper motor neurons of both tracts are located in the motor cortex (in the primary motor cortex, premotor cortex and supplementary motor area (SMA)). The corticospinal tracts controls muscles below the neck-the limbs and trunk. The corticobulbar tract controls muscles in the head, face and neck. The axons of both tracts originate in the motor cortex and initially travel together.

1. *What are the functions of the frontal lobe?*

From Wikipedia (with editing) “The frontal lobe is part of the brain that controls voluntary movement and many cognitive skills in humans, such as executive functions (including decision making, problem solving, reasoning, and planning), working memory, language (speech production), judgment, emotional expression, and sexual behavior. It is a major ‘control panel’ of our personality and ability to communicate.” The motor cortex also provides input to involuntary/unconscious movements as well.

1. *Voluntary movements are controlled by the two pyramidal tracts, the corticobulbar and corticospinal tracts. Where do they originate? (What main main areas of the brain do their upper motor neurons originate?)*

The cell bodies of the great majority of upper motor neurons of both pyramidal tracts are located in the motor cortex (in the primary motor cortex, premotor cortex and supplementary motor area-SMA). Surprisingly it has been shown that there are a few upper motor neurons also located in the nearby primary somatosensory cortex and in the posterior parietal cortex. (See Module 1: Lecture 3 slide 13)

1. *Briefly describe the motor cortex. Where is it, what does it contain, how is it organized and what does it do? What does it mean that the motor cortex is “topographically mapped?” How is the motor cortex map arranged (which region of the primary motor cortex is the origin of the corticobulbar tract that controls the face, head and neck; which region of the primary motor cortex is the origin of the corticospinal tract that controls the body?*

The motor cortex is located in the frontal lobe immediately anterior to (in front of) the central sulcus. The motor cortex is composed of the primary motor cortex, the premotor cortex and supplementary motor area (SMA). The primary motor cortex is located in the pre-central gyrus and anterior wall of the central sulcus. Similar to other neocortex it contains 6 cortical layers. Layer 5 contains many of the upper motor neurons of the pyramidal tracts, which include Betz and non-Betz motor neurons, which are projection/principal neurons (all glutamatergic – excitatory). The primary motor cortex is organized topographically, with specific cortical regions controlling particular groups of voluntary muscles. Neurons are organized corresponding to the muscles they control, forming a “map” of distinguishable regions, with the neurons controlling the head, face, mouth and tongue located more laterally in the motor cortex, and those controlling the body found more medially. That said, there is not an absolute one to one correspondence between upper motor neurons and the muscles they control, but rather there is overlap. In summary, the primary motor cortex contains upper motor neurons that project to the brainstem and spinal cord to control voluntary movement. The motor cortex receives input from the prefrontal cortex, somatosensory cortex, posterior parietal cortex, and the thalamus (which provides indirect input from the basal ganglia/nuclei and cerebellum) to regulate motor function.

1. *What are Betz and non-Betz cells and where are they located? Where are the premotor cortex and supplementary motor area and what do they do?*

Betz and non-Betz cells are the upper motor neurons located in layer 5 that have been characterized in the primary motor cortex. However, similar cells are likely to be present in premotor cortex, SMA, primary somatosensory and possibly the posterior parietal cortex.

Premotor cortex: an area of motor cortex within the frontal lobe of the brain just anterior to the primary motor cortex, part of Brodmann area 6. It plays a role in the direct control of some voluntary movements, with a relative emphasis on the trunk muscles of the body. It also plays a key role in spatial planning of movement, spatial and sensory guidance of movement, understanding others’ actions, and performing specific tasks that require abstract rules.

The supplementary motor area (SMA) is located anterior to the primary motor cortex and dorsal to the premotor cortex, and likely plays a role in stabilizing body posture, coordinating both sides of the body, controlling internally generated movements, and controlling movement sequences. Many researchers suggest that the premotor cortex and SMA have some similar functions and should be considered the “motor association area.”

1. *In addition to the two pyramidal tracts, to what other brain regions does the motor cortex send axons/output and information (either directly or indirectly) and what is the function of that communication?*

To the basal ganglia/nuclei, to the cerebellum (via the large corticopontine tract), to the thalamus (corticothalamic tract) and to brainstem nuclei in the extrapyramidal tracts. The function is to control movement.

1. *The motor cortex receives input information, either directly or indirectly, from the prefrontal cortex, parietal association cortex, somatosensory cortex, cerebellum, and basal ganglia. What is the role of each in controlling motor output? What is the role of the thalamus in motor systems?*

The parietal association cortex (or posterior parietal cortex) plays a role in planning of motor movements, providing sensory information for the guidance of movements and some motor commands. (From Wikipedia: “The posterior parietal cortex receives input from the three sensory systems that play roles in the localization of the body and external objects in space: the visual system, the auditory system, and the somatosensory system. In turn, much of the output of the posterior parietal cortex goes to areas of frontal cortex: the dorsolateral prefrontal cortex, various areas of the association motor cortex (premotor cortex and SMA), and the frontal eye fields. The PAC is thought to be responsible for transforming multisensory information into motor commands, and to be responsible for some aspects of motor planning.”

The somatosensory cortex: The primary somatosensory cortex, especially the part called area 3a, which lies directly next to the primary motor cortex, is sometimes considered to be functionally part of the motor control circuitry. It may actually contain some upper motor neurons, and/or it sends connects directly to the motor cortex for sensory inputs to the planning/guidance/initiation/feedback of movements.

The cerebellum contributes to coordination, precision, and accurate timing of movements. The cerebellum receives inputs not only from the motor cortex (via the corticopontine tract) but also from sensory modalities and the spinal cord, and integrates that information for feedback to the motor cortex (via the thalamus).

The basal ganglia/nuclei is involved in control and initiation of voluntary motor movements, procedural learning, routine behaviors or habits, eye movements, cognition, and emotion. The basal ganglia/nuclei may be involved in motivation based actions. From Wikipedia, “Popular theories implicate the basal ganglia/nuclei primarily in action selection – in helping to decide which of several possible behaviors to execute at any given time. In more specific terms, the basal ganglia's primary function is likely to control and regulate activities of the motor and premotor cortical areas so that voluntary movements can be performed smoothly.”

The thalamus is considered the gateway to the cerebral cortex because the vast majority of input to the cortex from subcortical brain areas occurs from the thalamus. Importantly for the motor cortex, the thalamus relays information from the basal ganglia/nuclei and cerebellum.

1. *In addition to the motor cortex, what are two other motor areas of the frontal lobe, and what is the function of each?*

Frontal eye fields are responsible for saccadic eye movements for the purpose of visual field perception and awareness, as well as for voluntary eye movement. Broca’s area: language production.

12. *According to Dr. Daniel Wolpert, what is the real reason for brains?*

To produce adaptable and complex movements. According to Dr. Wolpert, “the key idea to Bayesian inference is you have two sources of information from which to make your inference. You have data, and data in neuroscience is sensory input. So I have sensory input, which I can take in to make beliefs. But there's another source of information, and that's effectively prior knowledge. You accumulate knowledge throughout your life in memories. And the point about Bayesian decision theory is it gives you the mathematics of the optimal way to combine your prior knowledge with your sensory evidence inputs (evidence) to generate new beliefs.” Beliefs here refer to the brain’s strategies for control of movement.

*13. Voluntary movements are controlled by the two pyramidal tracts, the corticobulbar tract (CBT) and corticospinal tract (CST). a) Where do they originate? (What main areas of the brain do their upper motor neurons originate?) b) What part of the brain (white matter regions) do their axons travel through, c) Where do the axons decussate/cross? d) Where do their axons terminate? e) What types of neurons do they synapse on?*

a) The cell bodies of the upper motor neurons of both pyramidal tracts are located in the motor cortex (in the primary motor cortex, premotor cortex and supplementary motor area-SMA). b) The axons of the CST and CBT leave the motor cortex and form part of the corona radiata, then merge and travel through the internal capsule and then through the cerebral peduncles of the midbrain. c-e) For the CST, about 85-90% of the axons cross/decussate at the pyramids of the medulla. The axons in the CST terminate in the spinal cord where they synapse on spinal interneurons and lower motor neurons in the ventral/anterior horn of the spinal cord. The CST controls skeletal muscles below the neck in the limbs and trunk. For the CBT, some of the axons of the CBT decussate in the brainstem. The axons of the CBT terminate in the brainstem where they synapse on local circuit neurons and lower motor neurons in the cranial nerve motor nuclei in the brainstem. The CBT controls muscles in the head, face and neck. e) Axons in both tracts synapse on local interneurons and lower motor neurons.

*14. In addition to the two pyramidal tracts, to what other brain regions does the motor cortex send axons/output and information (either directly or indirectly) and what is the function of that communication?*

To the basal ganglia, to the cerebellum (via the large corticopontine tract), to the thalamus (corticothalamic tract) and to brainstem nuclei in the extrapyramidal tracts. The function is to control movement.

*15. What specific types of movements do the corticobulbar tracts control? Which cranial nerves have somatic motor components, and where are the motor cranial nerve nuclei located? Should the corticobulbar tracts really be considered pyramidal tracts?*

Voluntary movements of the head, neck, face, mouth and tongue are controlled by the corticobulbar tract (CBT). In the CBT, upper motor neurons in the motor cortex make synapses on lower motor neurons and local circuit neurons located in the brainstem motor nuclei (motor nuclei of cranial nerves including: III (oculomotor), IV (trochlear), V (trigeminal), VI (abducens), VII (facial), IX (glossopharyngeal), X (vagus), XI (spinal accessory) and XII (hypoglossal). The exam or quiz will not ask which cranial nerve nuclei are involved in the corticobulbar tract.

*16. What three brain white matter regions/areas does the corticospinal (CST) tract travel though as it descends to the spinal cord? Where does the CST tract decussate, and what are the two types? (This is redundant with questions above).*

The CST and CBTs first travel through (and form part of) the corona radiata. Then the tracts come together and travel through (and form part of) the internal capsule, an important white matter area, on their way to the brainstem. Then they both travel through the midbrain cerebral peduncles. The CBT axons end and synapse on their specific brainstem motor nuclei. The motor neurons in those nuclei send their axons out to form the motor components of many cranial nerves.

The CST splits at the pyramids of the medulla. About 85-90% of axons decussate (cross over) at the pyramids and form the lateral CST, while the other 10-15%, which don’t cross, form the anterior CST. The two tracts descend in the spinal cord as separate tracts. Axons in the lateral CST emerge out of the tract and into the ventral/anterior horns of the spinal cord. The lateral CST controls fine movement of the ipsilateral limbs (since the axons had already crossed at the pyramids, so the right motor cortex controls the left limbs and vice versa). The anterior CST (which does not cross at the medulla) branches and one branch crosses to the contralateral ventral/anterior horn of the spinal cord right before synapsing, and controls mainly the movements of axial muscles in the trunk.

1. *What is the extrapyramidal (indirect) system? Briefly describe the four extrapyramidal tracts (EPTs), where they originate, where they travel and what their functions are. Which EPTs are involved in involuntary/unconscious movements and which are involved in voluntary/conscious movements.*

The extrapyramidal tracts originate in specific nuclei in the brain stem and travel to the spinal cord (and a few travel to other regions of the brain stem). The rubrospinal tract is the only extrapyramidal tract involved in control of voluntary movements. All the rest of the extrapyramidal tracts function predominantly in the unconscious control of balance, posture, coordination, locomotion and reflexes. These tracts include the reticulospinal tract, the vestibulospinal tract, and the tectospinal tract, which are all involved in the unconscious control of posture, balance, locomotion, reflexes and coordination of the head and body movements. From Wikipedia: “These tracts are in turn modulated by various parts of the CNS, including the motor cortex, nigrostriatal pathway, the basal ganglia/nuclei, the cerebellum, the vestibular nuclei, and different sensory areas of the cerebral cortex.

Reticulospinal Tract Origin: Reticular formation (located in the midbrain, pons and medulla). Responsible primarily for locomotion and postural control.

Vestibulospinal Tract Origin: vestibular nuclei in pons and medulla. From Wiki “The function of [this tract] is to alter muscle tone, extend, and change the position of the limbs and head with the goal of supporting posture and maintaining balance of the body and head.”

Tectospinal Tract Origin: tectum (superior colliculus) in midbrain. Involved in postural movements of the head in response to visual cues.

Rubrospinal Tract Origin: magnocellar red nucleus in midbrain. Involved in voluntary muscle control of limbs.

For the EPTs upper motor neurons are located in nuclei in the brainstem, and they extend axons, form tracts in the spinal cord and synapse on spinal interneurons and lower motor neurons in the spinal cord ventral horns. A few axons of the EPT extend to other regions of the brainstem where they synapse on local circuit neurons and lower motor neurons in motor brainstem nuclei.

1. *In the pyramidal systems, in addition to originating in the motor cortex, a limited number of upper motor neurons are also proposed to lie/originate where?*

The great majority of upper motor neurons in the pyramidal tracts (corticospinal and corticobulbar tracts) originate in the motor cortex (including the primary motor cortex, premotor cortex, and supplemental motor cortex.) However, there is also evidence that a small number of upper motor neurons (for the CST and CBT) are also found in the primary somatosensory cortex and possibly in the posterior parietal cortex.

1. *In some texts, the two main motor systems are divided into the lateral system and the ventromedial system based on the location of the tracts in the spinal cord white matter. What tracts do the lateral and ventromedial systems contain?*

The two lateral spinal cord systems are the corticospinal tract and rubrospinal tract. They synapse on motor neurons located more laterally in the ventral gray matter and control the voluntary movement of distal muscles in the arms-hands and legs-feet.

The four ventromedial spinal cord tracts include three extrapyramidal tracts (reticulospinal, tectospinal, and vestibulospinal) and one corticospinal tract (anterior corticospinal tract). (Apologies about the anatomy names. Ventral = Anterior. For some reason the anterior CST is usually called anterior instead of ventral. And the group of ventromedial systems are called ventromedial instead of anterior-medial.) These axons synapse on motor neurons located more medially in the ventral gray matter and control axial (trunk) and proximal limb muscles.