Medical Neuroscience | Tutorial Notes

Upper Motor Neuronal Control—Overview & Primary Motor Cortex

Map to Neuroscience Core Concepts[1]

NCC1. The brain is the body's most complex organ.

NCC3. Genetically determined circuits are the foundation of the nervous system.

NCC4. Life experiences change the nervous system.

Learning Objectives

After study of the assigned learning materials, the student will:

1. Discuss the neural centers that give rise to lateral and medial descending projections to lower motor neurons.
2. Discuss the organization of the motor cortex and its contributions to the control of volitional movement.
3. Characterize the representation of the body in the motor cortex and compare it to the representation of the body in the primary somatic sensory cortex.
4. Discuss population coding in the motor cortex.

Tutorial Outline

I. Introduction

- A. General features of upper motor neuronal control
  1. **mosaic of motor control areas** in the posterior frontal lobe that organize and initiate the activities of lower motor circuits in the brainstem and spinal cord
  2. governs the expression of **specific motor behaviors** that we choose to perform (e.g., writing, sports, musical performance, speaking)
  3. some areas govern specific motor behaviors over which we have less control (e.g., emotional nuances in speech, "fight or flight" responses)
  4. there are additional brainstem circuits that operate "behind the scenes" to implement **adjustments of posture and gain**
  5. there are lateral (skilled movements) and medial (supporting movements) **parallel pathways** to lower motor neuronal pools

[1] Visit **BrainFacts.org** for *Neuroscience Core Concepts* (©2012 Society for Neuroscience) that offer fundamental principles about the brain and nervous system, the most complex living structure known in the universe.

B. for voluntary movement, there is a **volitional** or **somatic motor system** (this is sometimes called the "pyramidal motor system", named for the pyramidal tract, the major subcortical outflow of the motor cortex) (see **Figure 17.1**[2])

1. lateral component: governs the independent ("fractionated") movements of the lower face and distal extremities, conveyed via the **corticobulbar** and **corticospinal tracts**

   See tutorial on "Upper Motor Neuronal Control of Facial Expressions"

2. medial component: governs postural control and orienting movements of head and neck conveyed via projections from brainstem nuclei (note: although these functions are, strictly speaking, non-volitional, we include them here to emphasize their service of other, more specific volitional movements)

3. this lateral/medial division of labor is a reflection of the organization of motor neurons in the ventral horn of the spinal cord

C. for the expression of movements that are less volitional, often in the context of emotional experience, there are additional pathways from the cortex and brainstem that mediate emotional motor behavior; these neural centers and pathways comprise an "**emotional motor system**" (see **Figure 29.2**)

1. lateral component: governs the expression of specific somatic and visceral motor behaviors via diffuse projections that are not part of the pyramidal tract

2. medial component: modulates the gain of brainstem and segmental/intersegmental spinal reflexes

II. Motor Control Centers in the Cerebral Cortex: lateral projections for volitional motor control

A. **"Motor cortex"** refers to the mosaic of cortical areas in the posterior frontal lobe that are mainly concerned with the planning and execution of volitional movements; these include the **primary motor cortex** and the **premotor cortex** (see **Figure 17.2**)

B. each of these divisions of the motor cortex gives rise to descending projections to lower motor neuronal circuits in the brainstem and spinal cord

C. collectively, the motor cortex receives input from the motor nuclei of the thalamus (**ventral anterior/ventral lateral complex**) and somatic sensory and visual input from somatic sensory and visual cortical areas ("where" pathway) in the parietal lobe

D. primary motor cortex (Brodmann's **Area 4**)

1. located in the anterior bank of the precentral gyrus

   a. the origin of a large fraction of the corticospinal (pyramidal) tract

   b. most descending projections (which arise from layer 5) terminate on the dendrites of interneurons in local-circuit neuronal pools of the brainstem and spinal cord

   c. some output neurons (including the exceptionally large Betz cells) make monosynaptic excitatory connection onto α motor neurons

[2] Figure references to Purves et al., *Neuroscience, 5th Ed.*, Sinauer Assoc., Inc., 2012. [click here]

2. this area is "primary" because it has the lowest threshold for the elicitation of movements with electrical stimulation of any area in the cerebral cortex

3. the primary motor cortex governs the execution of volitional movements, particularly those that involve the distal extremities in central personal space

4. somatotopy in the primary motor cortex

    a. along the length of the central sulcus, there is a crude topographic representation of the body's musculature (see **Figure 17.5**)

        (i) although similar to the somatotopic map in the primary somatic sensory cortex, the topographic map in the primary motor cortex is less columnar and, therefore, much less precise

        (ii) e.g., rather than a systematic mapping of each digit in sequence (such as exists in S1), there is a general hand region that cannot be subdivided into representations of individual digits

        (iii) neurons that are connected to lower motor neurons that govern the movements of different digits are interspersed and highly interconnected within this hand region

        (iv) this arrangement allows for the dynamic assembly of **functional ensembles of neurons** that orchestrate the coordinated movements of the digits

        (v) dynamic assembly of functional networks is subject to experience-dependent modification

    b. what is represented in the primary motor cortex? (an ongoing debate; see **Box 17B**)

        (i) *movements!* (not muscles) … and maybe even the *intentions* (goals) of movements

        (ii) encodes movements that engage the hand, lower face (mouth), and the coordinated activity of hand and mouth

        (iii) skilled manual behaviors in central personal space

            - individuals with selective lesions of the primary motor cortex can reach to grab small objects, but have difficulties picking them up with their fingers

            - some residual digit function may reflect preservation of synergistic projections from other parts of the motor cortex (and maybe the red nucleus)

    c. how is movement coding implemented?

        (i) "tuning properties" of any corticospinal neuron are broad, even though movements may be highly specialized and specific

        (ii) movements are encoded by the concurrent discharges of large populations of neurons in the motor cortex; this is an example of a "**population code**" in neural processing (see **Figure 17.8**)

STUDY QUESTION

What features best differentiates the body map in the precentral gyrus (primary motor cortex) from the post central gyrus (primary somatic sensory cortex)?

A. The central segment of the precentral gyrus represents the contralateral foot, while the central segment of the postcentral gyrus represents the contralateral face.
B. The inferior segment of the precentral gyrus represents the contralateral face, while the central segment of the postcentral gyrus represents the contralateral hand.
C. The medial portion of the precentral gyrus (in the paracentral lobule) represents the contralateral hand, while the medial portion of the postcentral gyrus represents the contralateral face.
D. The body map in the precentral gyrus faithfully represents the detailed structure of the contralateral body, especially with respect to the digits of the hand, while the body map in the postcentral gyrus lacks such detail.
E. The body map in the precentral gyrus is actually not a map of the body and its parts per se, as it is in the postcentral gyrus, but a map of movement intention.