9.14 - Brain Structure and its Origins
Spring 2005
Massachusetts Institute of Technology
Instructor: Professor Gerald Schneider

A sketch of the central nervous system and its origins

G. E. Schneider 2005

Part 6: A brief look at motor systems

MIT 9.14 Class 14

Overview of motor system structure

Three major types of movement:
a functional starting point for studying structures

- **Locomotor Approach or Avoidance**
  - Directional locomotor control
  - Explore/forage/seek, locomotor aspects
    - Basic for all drives
- **Orienting** of head and body: important for accomplishing the goals of the above
- **Grasping**: important for consummation
  - With mouth
  - With limbs (reaching and the control of distal muscles)

These are "general purpose movements", as they are used in many different action patterns.

REVIEW: Outputs of midbrain for motor control

- Origins of the
  1) Locomotor commands from the MLA
  2) Tectospinal tract, from deep tectal layers
  3) Rubrospinal tract, from red nucleus
- By these means, the midbrain controls body movements critical for survival:
  1) Locomotion:
     - Approach & avoidance;
     - Exploring/ foraging/ seeking behavior
  2) Orienting
  3) Limb movements for exploring, reaching and grasping.

The midbrain was the connecting link between the primitive forebrain and motor systems

- It <u>controlled the three types of body movement</u>, prior to the refinements made possible by neocortex.
  - *Via* its projections to the hindbrain & cord
- It also controlled the visceral nervous system and associated motivational states (*via* limbic midbrain areas)
  - With inputs from below & above, and outputs to ANS, as well as modulatory projections to many structures
- The midbrain also influenced control and differentiation of special purpose movement sequences for specific functions (specific Fixed Action Patterns)
  - Additions to the repertoire of hindbrain & spinal cord
  - E.g., predatory attack, defensive aggression … … …

Three major types of body movement, existing prior to refinements made possible by neocortex

1) **<u>Approach and Avoidance</u>**
   - Locomotor control, directional
   - Explore/forage/seek: basic for all drives
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Approach & Avoidance: Fundamental throughout evolution

- Basic functions of both surface and distance receptors are the elicitation of approach and escape/ avoidance movements.
- Head receptors evolved with these functions as crucial roles: This has shaped the chordate neural tube.

Head receptors and approach/avoidance functions

- **<u>Olfaction</u>**: Smells that incite fear or entice approach required links to locomotor control
  - *Via* striatum to caudal midbrain (locomotor mechanisms)
  - *Via* medial pallium (which evolved into hippocampal formation), which projected to ventral striatum as well as to hypothalamus & "limbic" parts of the midbrain
- **<u>Vision</u>**: The other modality that strongly shaped the evolution of forebrain
  - Evolution of several links to locomotor controls (via subthalamus, pretectum, tectum)
- <u>Gustatory</u> inputs played an important role in learning which sights and smells to approach and to avoid.
- <u>Somatosensory</u> inputs from head: Entering through the hindbrain, they probably had less, or at least a different, influence on <u>early</u> evolution of forebrain.
  - This is probably true also for <u>audition</u>.

Locomotion is initiated not only by sensory input from outside. It can be started by an internal motivational state — a drive.

Foraging activity initiated from limbic midbrain or hypothalamus

- Foraging drives act by initiating and modulating locomotion.
  - Hypothalamic cell groups control cyclic behaviors, e.g., feeding, a preparation for which is the initiation of locomotion for foraging.
- "Spontaneous" activity in drive mechanisms results in endogenous buildup of the level of neuronal activity.
  - Such activity represents a motivational state, and corresponds to the "action specific potential" of ethologist Konrad Lorenz)
  - When it rises to a threshold, it triggers movement.
- **Next: Larry Swanson's conceptualization of this within a motor system hierarchy.**

The Motor System Hierarchy

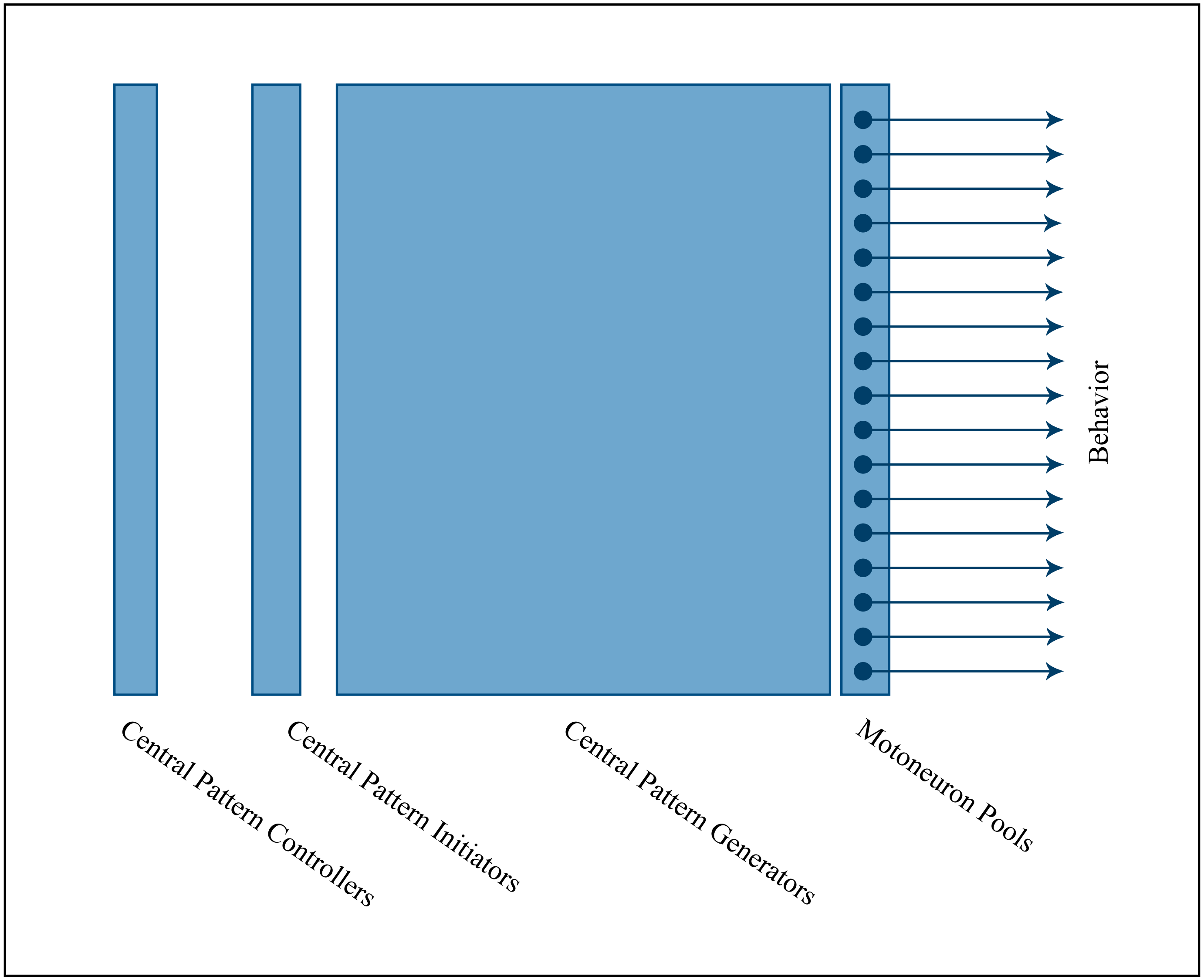


Figure by MIT OCW.

Hierarchic control of locomotor behavior

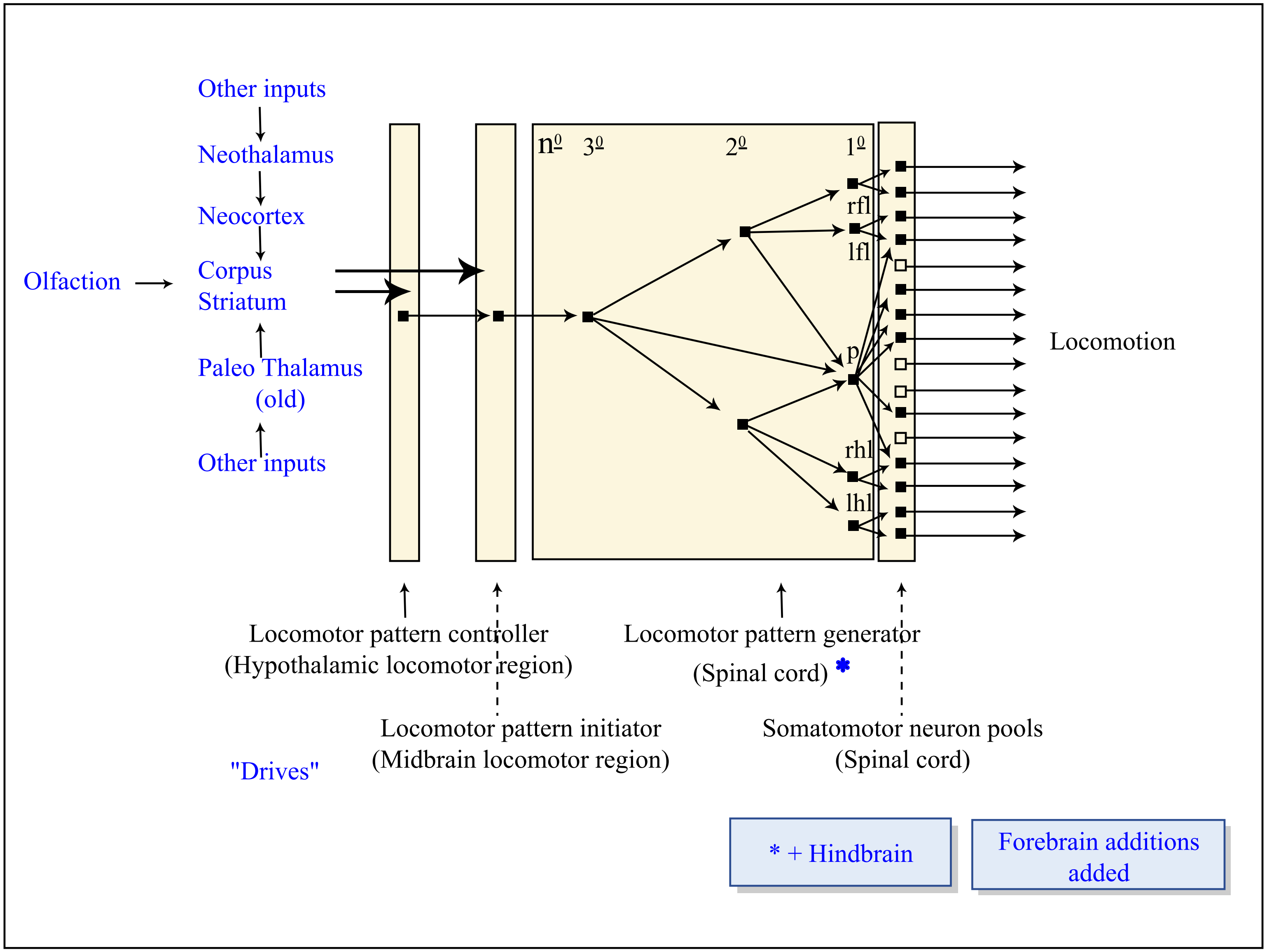


Figure by MIT OCW.

Brain locations of locomotion pattern controllers and initiators

- Caudal Hypothalamic and/or subthalamic locomotion controller
  - Inputs from ventral striatum, which receives olfactory inputs
  - Some olfactory system projections bypass striatum
- Midbrain locomotor area, which is a controller of the more caudal locomotor pattern generators
  - Location: Caudal tectum, below inferior colliculus
  - Inputs from more rostral locomotion controllers (subthal/hypothal) and from striatum more directly
  - Some inputs from visual system may bypass striatum: *via* anterior (deep) pretectal nucleus (*R. Thompson*)

Locomotor pattern generation

- Locomotion is a general purpose Fixed Action Pattern
- It depends on the spinal cord's propriospinal system (illustrated earlier) Location of pattern generators
- Its execution is strongly influenced by activity in hindbrain structures.
  - Vestibular nuclei
  - Cerebellum, part of which is closely connected to the vestibular nuclei
- Its execution is modulated by reflex inputs coming in to cord through the dorsal roots, especially from the feet.

Vestibular Nuclei and Vestibular Nerve – part of the 8th cranial nerve

- **Location in the alar plate**
- **The large cells of Deiter's Nucleus (lateral vestibular nucleus), with direct projections descending to the spinal cord (vestibulospinal tract)**
- **The Medial Longitudinal Fasciculus (mlf) of the brainstem: interconnecting the vestibular nuclei and the oculomotor nuclei**

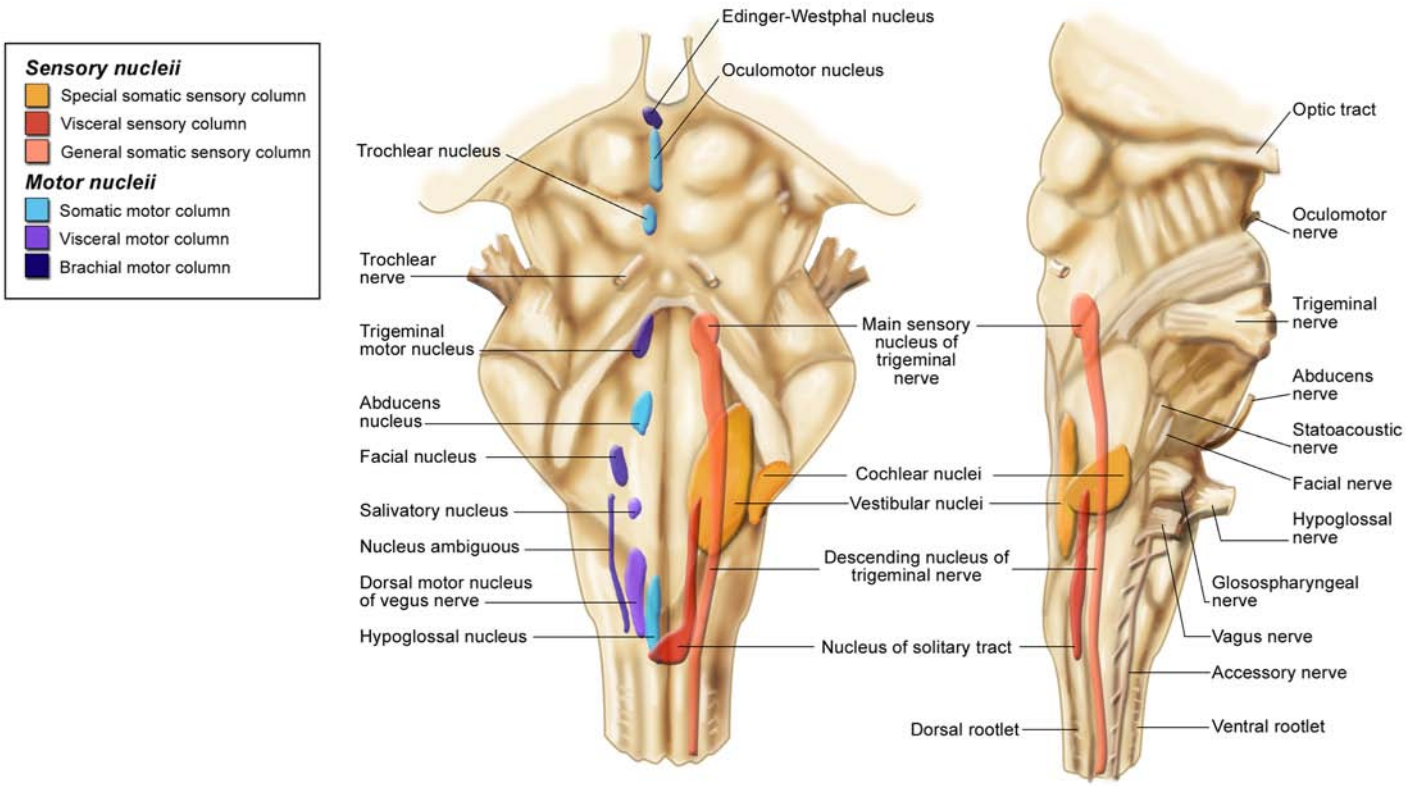


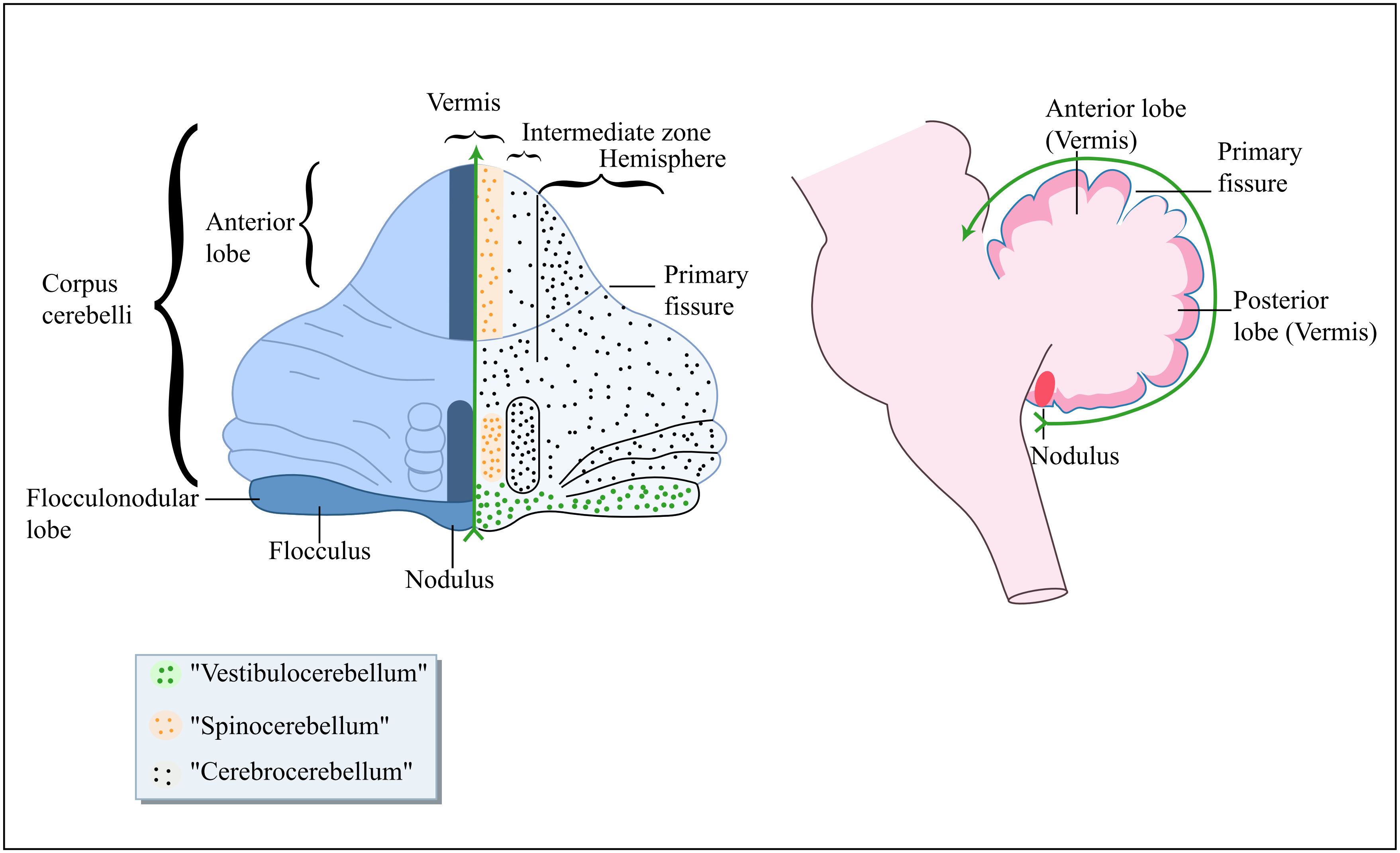
Figure by MIT OCW.

Brainstem Nuclei: secondary sensory and motor neuron columns

The Vestibulo-cerebellum

- **ILLUSTRATIONS**
  - **The flocculus and nodulus, with direct input from vestibular nerve**
  - **Fastigial nucleus, the medial-most of the three deep nuclei of the cerebellum, with direct projections to the spinal cord (fastigiospinal tract)**

Main cerebellar subdivisions



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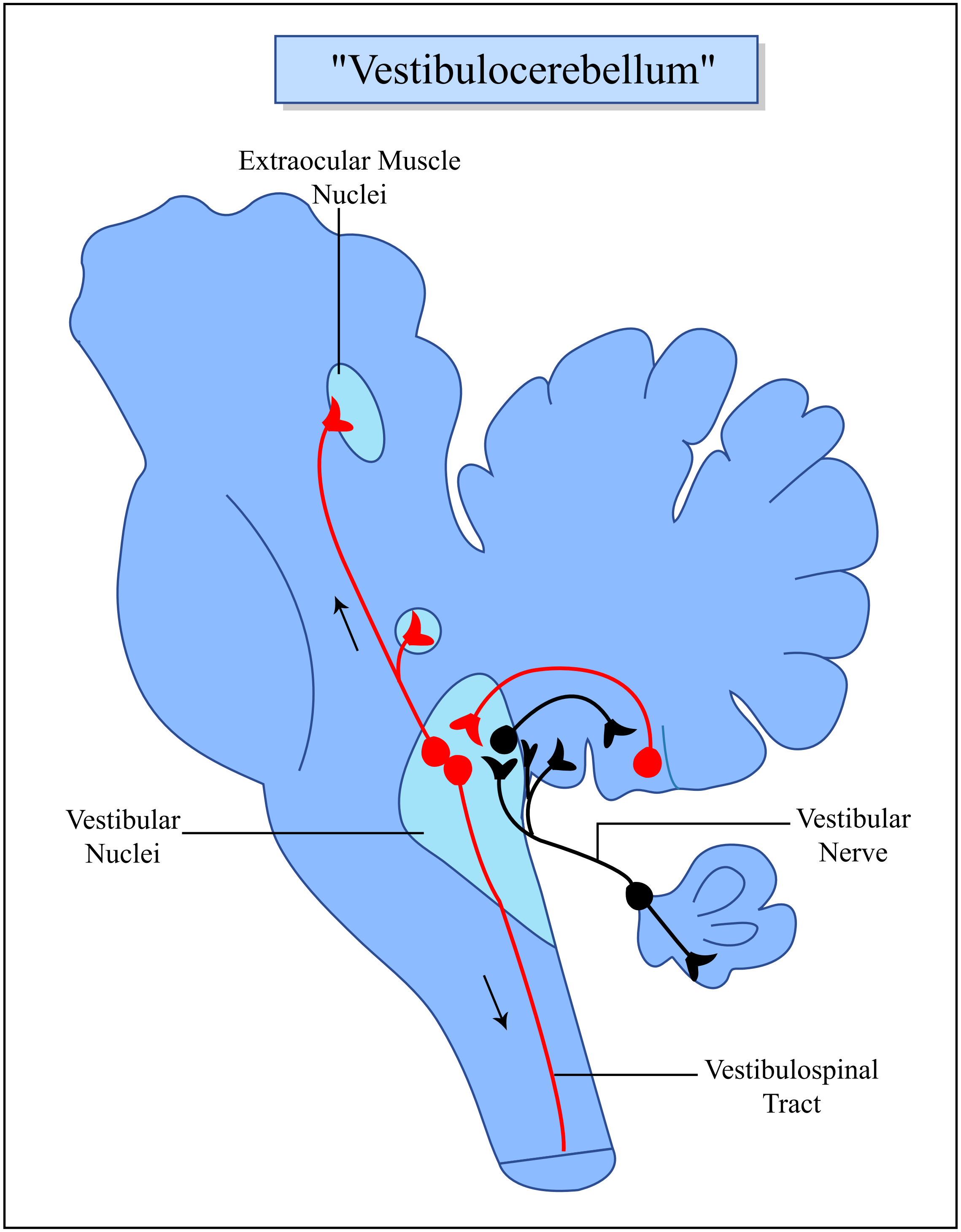
Vestibular nerve to cerebellum:



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Altman & Bayer

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Three major types of body movement,
prior to refinements made possible by neocortex

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Orienting of head and body:

Important for accomplishing the goals of approach and escape/avoidance

- Somatosensory, visual, auditory triggers
  - Early controls: simple reflexive orienting for approach and escape
    - Visual: Early control of turning movements **may** have been *via* subthalamus and pretectum; projections to brainstem and spinal cord

retinal inputs to

  - Evolution of topographic maps of the world around the head in the midbrain tectal correlation center
    - Visual, auditory, somatosensory maps that correspond
    - Control of precise turning toward objects
- There are distinct tectal outputs for escape movements and for turning towards a novel or desired object

Tectum & Pretectum

- Pretectum:
  - Large in non-mammals
  - Role in protective responses: pupil constriction, escape from rapidly approaching objects, avoidance of barriers during locomotion
  - Role in orienting (likely, but not well studied)
- Tectum:
  - The “visual grasp reflex” and the map of the retina
  - Underlying auditory, somatosensory maps that match the visual map
  - Tectal stimulation and lesion data: the **dual outputs**
    - Orienting: crossed “tectospinal tract”
    - Escape: uncrossed descending pathway

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Grasping: with mouth; with limbs

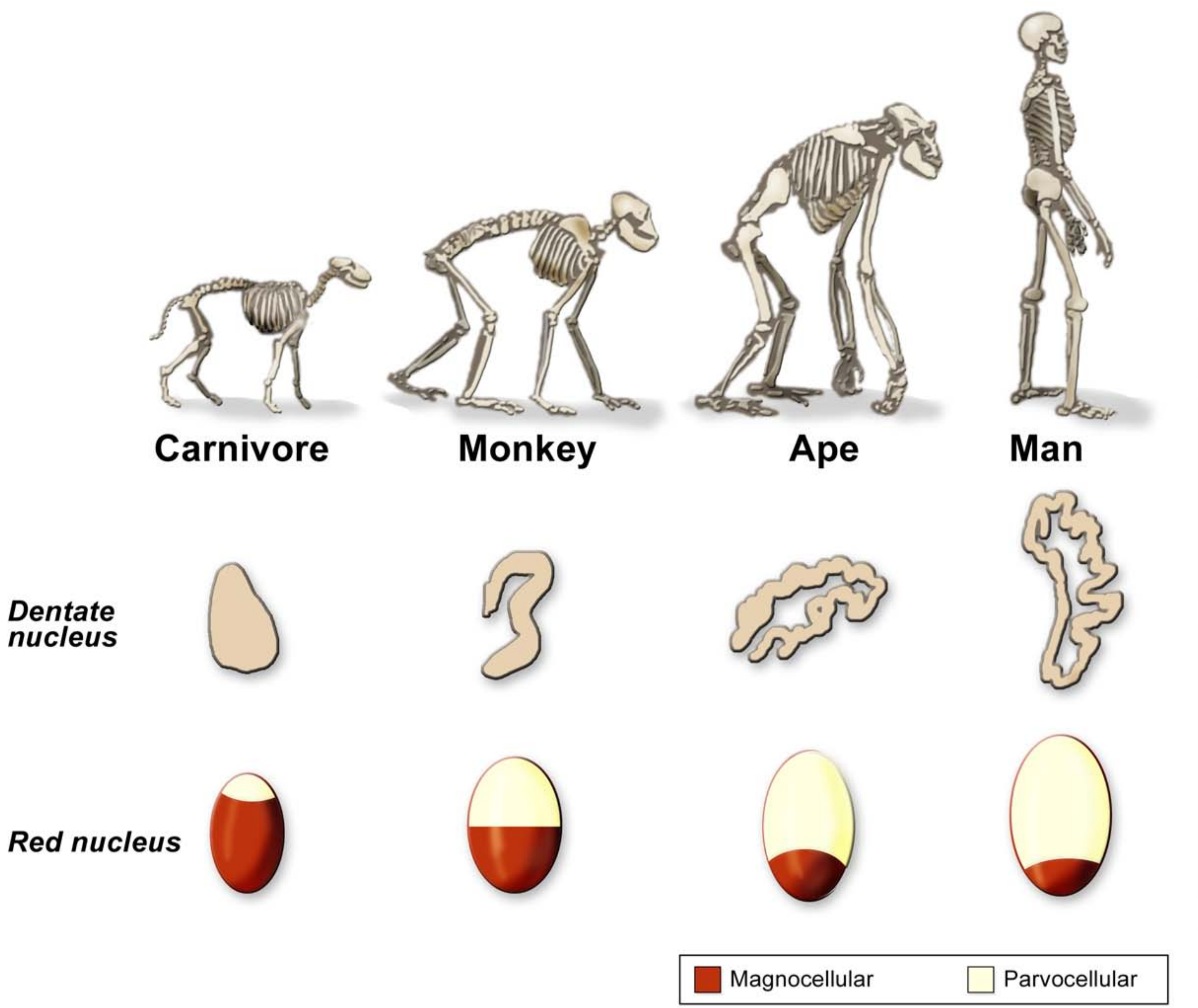
(reaching and the control of distal muscles)

- Goal-directed behavior: 2 types of grasping with midbrain control
  - Tectal/pretectal orienting followed by oral grasping
  - Red nucleus and limb control; grasping with hands
    - Inputs to red nuc. from striatum/subthalamus and from cerebellum (and, later in evolution, the somatosensory and motor neocortex)
- Reflex levels of control: the background that remains even after neocortical expansion
  - Spinal mechanisms with higher controls
- Evolution of forebrain controls that became dominant, the subject of traditional neurology [a following topic]

Red nucleus in phylogeny

- Absent in hagfishes and lampreys (primitive, jawless vertebrates)
- Present in frogs,
  - with input from striatum and cerebellum.
  - Striatal inputs tend to end mainly in pre-rubral field of the ventral thalamus
- Prominent in reptiles, birds and mammals

Dentate nucleus & red nucleus, comparative anatomy



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Evolution of mammalian rubrospinal projections: parcellation increases topographic organization

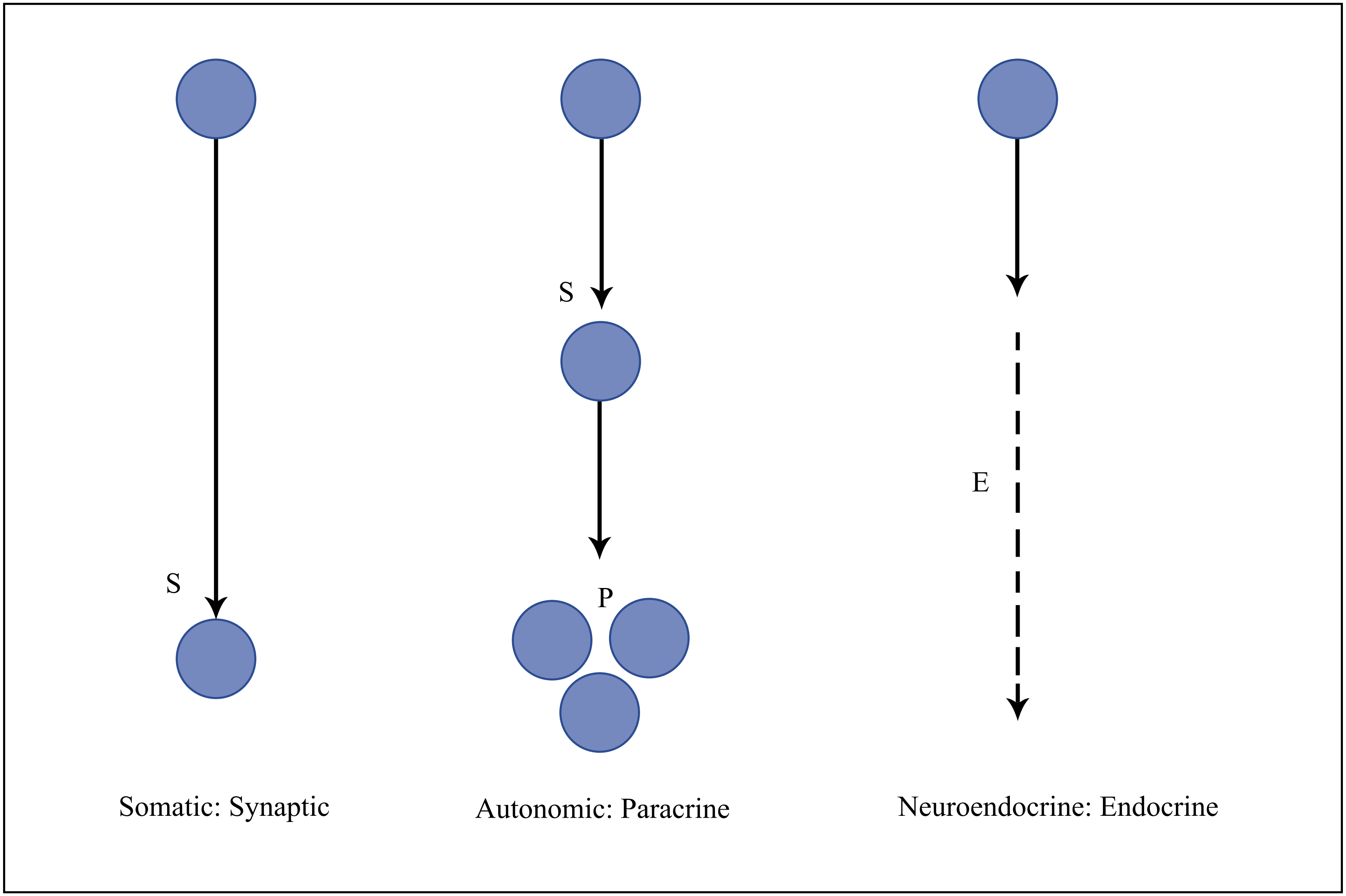
- *See Striedter (2005) text, p. 234 figure, illustrating results of a retrograde tracing study of projections in opossum, rat and cat.*

A structural approach to understanding motor control: Begin with the motor neurons

- Three types of effector contact in three major motor systems REVIEW
  1) Somatic motor neurons: synaptic control
  2) Autonomic: pre- and postganglionic motor neurons; paracrine control
  3) Neuroendocrine: hormonal control
- Somatic motor neuronal pools: locations

Review:

Arrangement of motor neurons in the three motor systems



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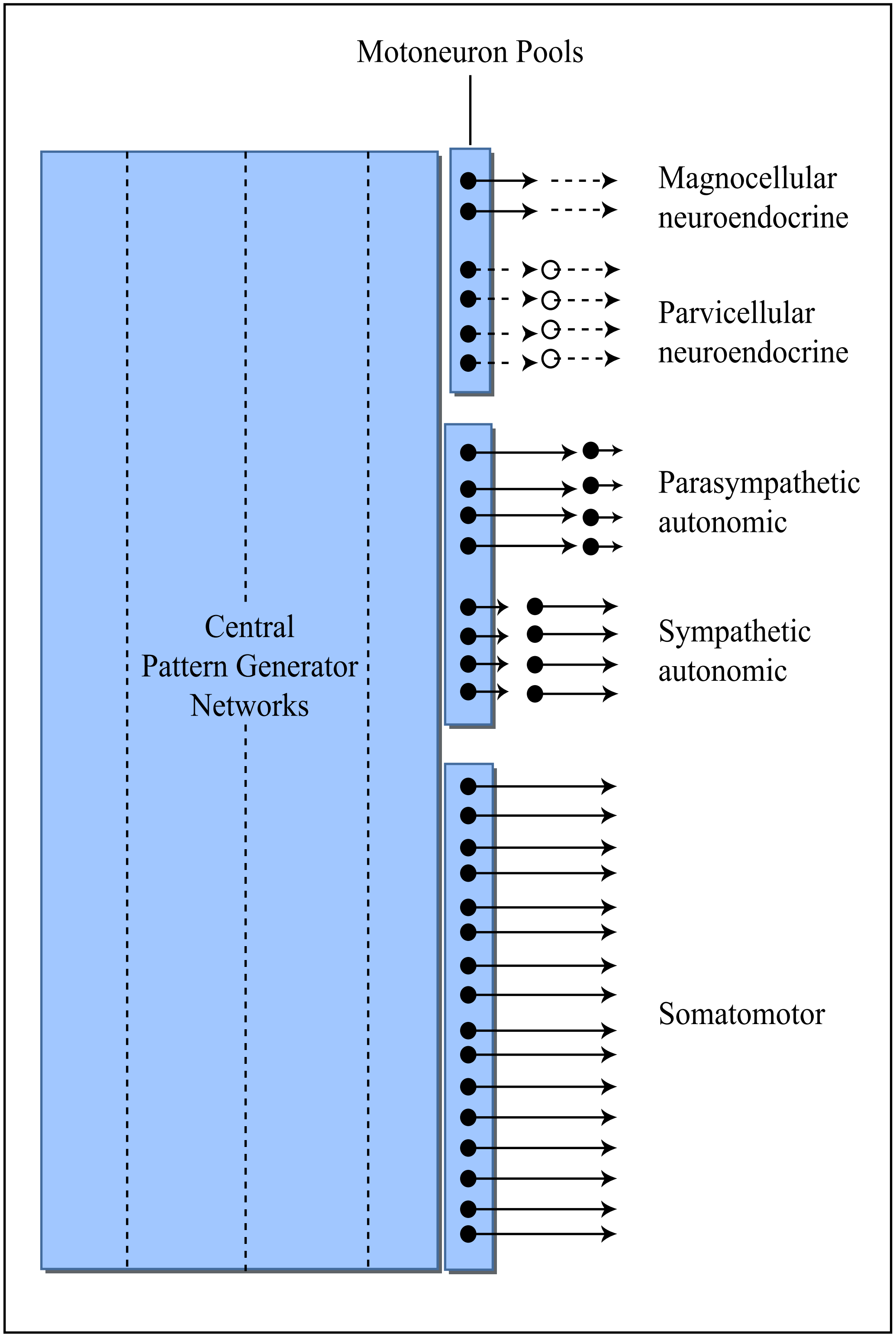

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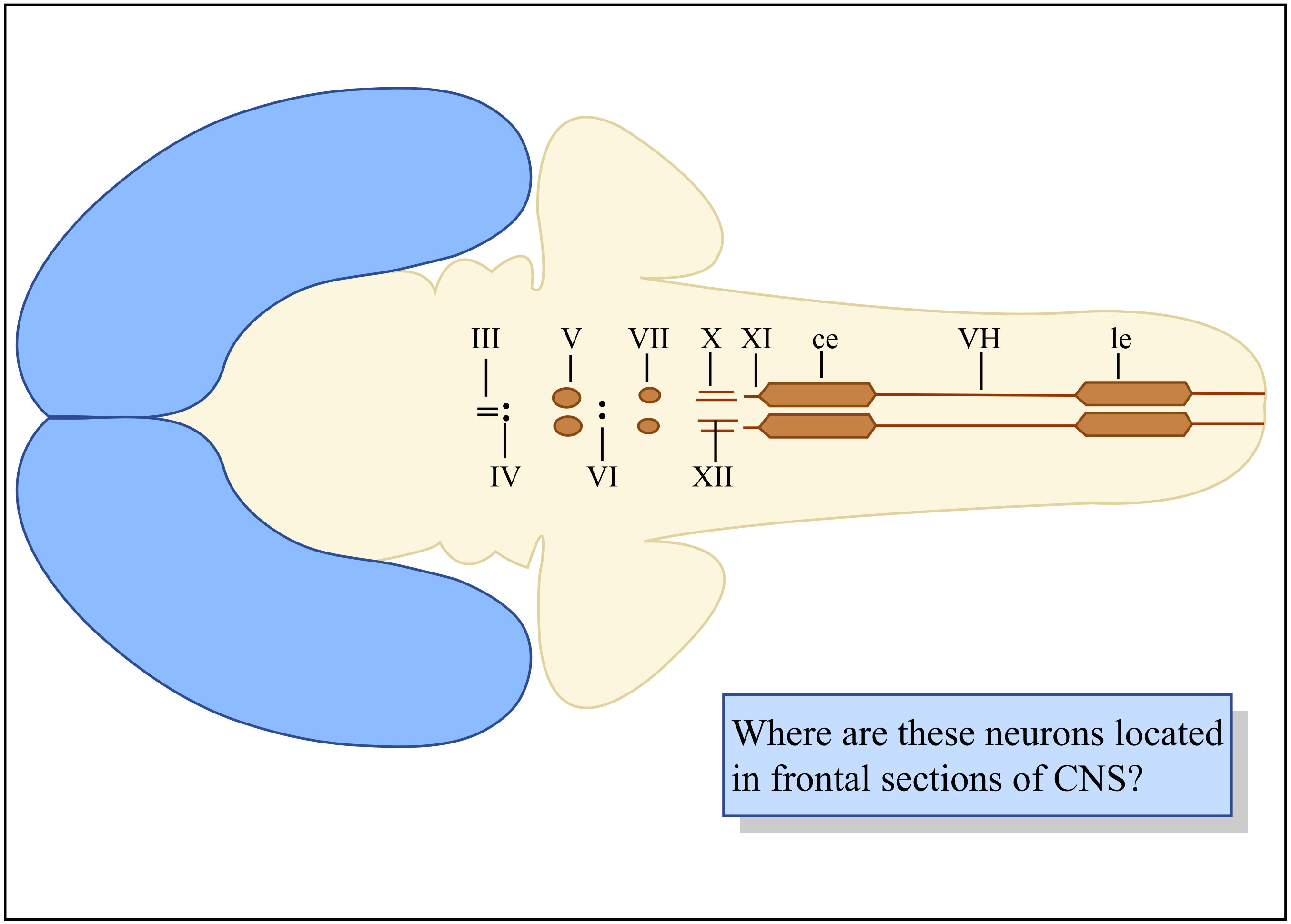
The three motor systems

(Where are the central pattern generator networks that coordinate the three systems?)

Distribution of somatic motor neurons



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End session 14.

The spatial arrangements of motor neurons: illustrated for monkey

- Spinal cord at one of the enlargements
- Radial projections of interneurons
- Descending connections in the cord

- (see figures)

Topographic distribution of somatic motor neurons, human spinal cord

Figure removed due to copyright reasons.

Please see Figure 6.3 in

Swanson, Larry W. *Brain Architecture, Understanding the Basic Plan.*

Oxford, New York, NY: Oxford University Press, 2003, p. 105. ISBN: 0195105052.

Terminal distribution pattern of descending cortical and subcortical pathways, spinal cord, rhesus monkey

(Lawrence & Kuypers, 1968)

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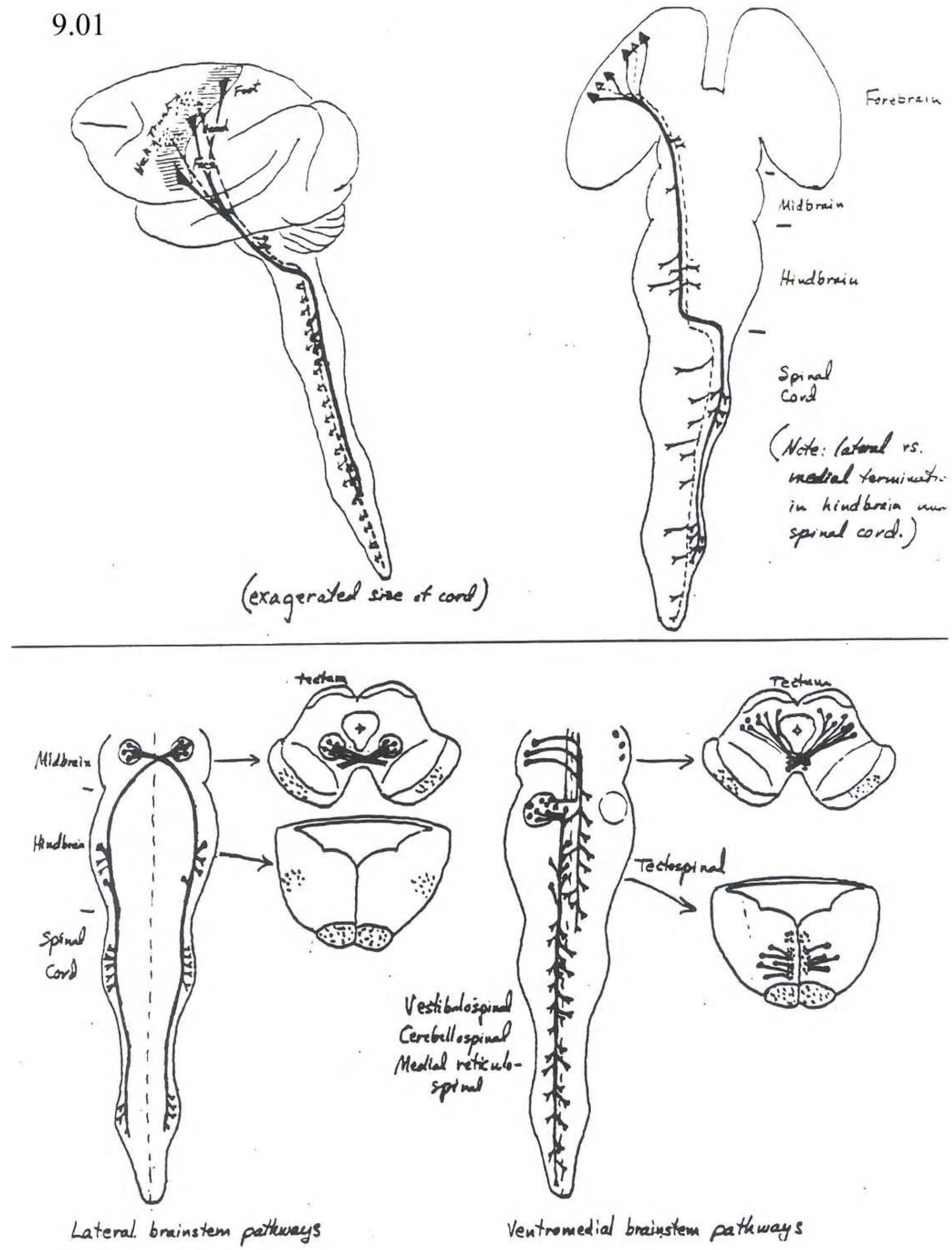
Three Descending Motor Pathways:

Separated course of axons influencing axial and distal muscle control

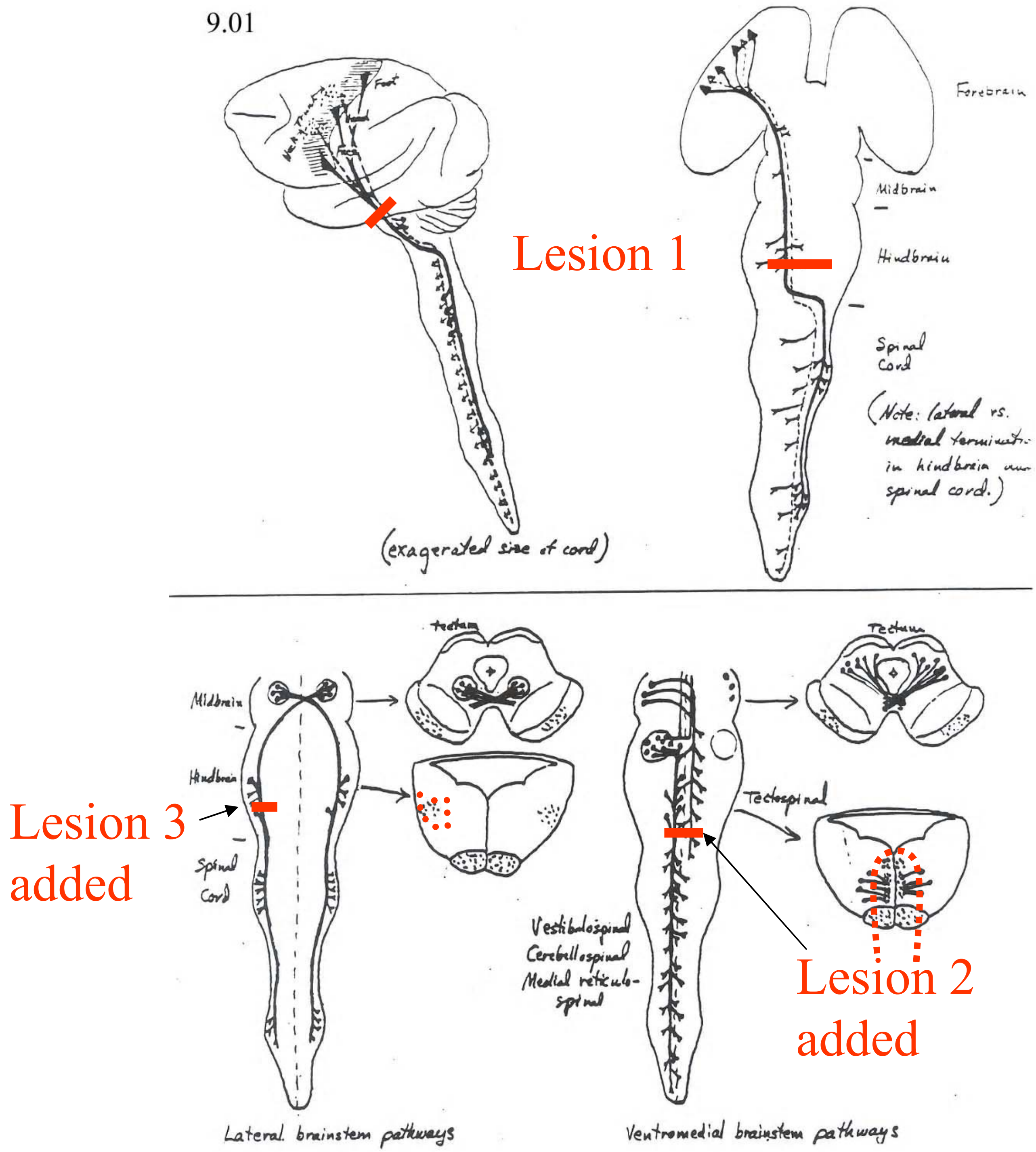


Effects of lesions:

- The logic of Lawrence & Kuypers, 1968 paper in *Brain*

- Begin with elimination of the corticospinal projections; wait for recovery from diaschisis effects
- Then, ablate either the medial or the lateral pathways descending from the hindbrain and midbrain

Selective lesions of the descending motor pathways



Lawrence & Kuypers, 1968:

- **Lesion #1: pyramidotomy**
  - Loss of control of digits used one at a time
  - Loss of speed and strength
- **Lesion #2: medial brainstem pathways** (added to pyramidotomy)
  - Defective axial control:
    - Righting: only after 10-40 days
    - Falling: failure to elicit the usual corrective movements
    - Walking: only one monkey could take many steps; he veered from course, bumped into obstacles
- **Lesion #3: lateral brainstem pathways** (added to pyramidotomy)
  - Defective limb control: hand flexion done only with total arm movements
  - Good axial control: hand used better in running & climbing (total body movements)

The brain disconnected from the motor output:
Motor cortical activity in human tetraplegics

- Thought without the ability to act: Activation of specific parts of the motor cortex
- Question: Can the long pathways be reconnected in people or animals with such injuries?

Motor-cortical activity in tetraplegics

Figures removed due to copyright reasons.
Please see Figure 1 in
Shoham, S., E. Halgren, E. M. Maynard, and R. A. Normann. "Motor-cortical activity in tetraplegics." *Nature* 413, no. 6858 (October 25, 2001): 793.

Selected References

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