A sketch of the central nervous system and its origins

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Part 6: A brief look at motor systems

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 controlled the three types of body movement, 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) **Approach and Avoidance**
   - Locomotor control, directional
   - Explore/forage/seek: basic for all drives

2) Orienting of head and body: important for accomplishing the goals of the above

3) Grasping: with mouth; with limbs (reaching and the control of distal muscles); important for consummation
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

- **Olfaction**: 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

- **Vision**: The other modality that strongly shaped the evolution of forebrain
  - Evolution of several links to locomotor controls (via subthalamus, pretectum, tectum)

- **Gustatory** inputs played an important role in learning which sights and smells to approach and to avoid.

- **Somatosensory** inputs from head: Entering through the hindbrain, they probably had less, or at least a different, influence on early evolution of forebrain.
  - This is probably true also for **audition**.
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

- Central Pattern Initiators
- Central Pattern Generators
- Motoneuron Pools
- Behavior

Figure by MIT OCW.
Hierarchic control of locomotor behavior

Other inputs
Neothalamus
Neocortex
Corpus Striatum
Paleo Thalamus (old)

Olfaction

Locomotor pattern controller (Hypothalamic locomotor region)
"Drives"
Locomotor pattern initiator (Midbrain locomotor region)

Locomotor pattern generator (Spinal cord)

Somatomotor neuron pools (Spinal cord)

* + Hindbrain
Forebrain additions added

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)
- 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 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
Brainstem Nuclei: secondary sensory and motor neuron columns

Figure by MIT OCW.
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

Corpus cerebelli

Flocculonodular lobe

Flocculus

Nodulus

Intermediate zone

Hemisphere

Anterior lobe

Vermis

Primary fissure

Posterior lobe (Vermis)

Anterior lobe (Vermis)

Primary fissure

Nodulus

"Vestibulocerebellum"

"Spinocerebellum"

"Cerebrocerebellum"

Figure by MIT OCW.
Vestibular nerve to cerebellum:

"Vestibulocerebellum"

- Vestibular Nuclei
- Vestibular Nerve
- Vestibulospinal Tract
- Extraocular Muscle Nuclei

Figure by MIT OCW.
Altman & Bayer

Figure removed due to copyright reasons.
Three major types of body movement, prior to refinements made possible by neocortex

1) Approach and Avoidance
   - Locomotor control, directional
   - Explore/forage/seek: basic for all drives

2) **Orienting of head and body**: important for accomplishing the goals of the above

3) Grasping: with mouth; with limbs (reaching and the control of distal muscles); important for consummation
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
    - 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
  - 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

Carnivore

Monkey

Ape

Man

Dentate nucleus

Red nucleus

Figure by MIT OCW.
Evolution of mammalian rubrospinal projections: parcellation increases topographic organization

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

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

• Somatic motor neuronal pools: locations
Arrangement of motor neurons in the three motor systems

- **Somatic**: Synaptic
- **Autonomic**: Paracrine
- **Neuroendocrine**: Endocrine

Figure by MIT OCW.
The three motor systems

*(Where are the central pattern generator networks that coordinate the three systems?)*
Distribution of somatic motor neurons

Where are these neurons located in frontal sections of CNS?

Figure by MIT OCW.
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.*

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

(Lawrence & Kuypers, 1968)

Figure removed due to copyright reasons.
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
Selected References


