Intro to Cognitive Neuroscience

Organization of the brain
Some neurotransmitters
Some anatomical terms

- Dorsal
- Ventral
- Anterior
- Posterior
- Medial
- Lateral
Brain organization labels derive from development

- Neural tube forms three distinct bumps
- Forebrain - most anterior of these
- Hindbrain - most posterior of these
- Midbrain - in-between
- In fully-developed human brain, these distinctions are much harder to see
Forebrain

- Divided into cerebral hemispheres (end-brain) and “between-brain” structures

- Cerebral hemispheres (telencephalon)
  - Cerebral cortex and connecting white matter
  - Subcortical: basal ganglia (motor), limbic system (emotion, learning)
Forebrain

- Divided into cerebral hemispheres (endbrain) and “between-brain” structures

- Between-brain (diencephalon)
  - Thalamus - processes and distributes sensory and motor information
  - Hypothalamus - maintains homeostasis; controls endocrine system; involved in emotional response.
Midbrain

- Tectum - nuclei involved in visual and auditory systems.

- Substantia nigra and ventral tegmental area have large concentrations of dopaminergic cells.
Hindbrain

- Divided into cerebellum, pons, and medulla

- Cerebellum - motor coordination, maintenance of posture

- Pons - alertness, attention, aggression, emotion

- Medulla - vital functions (heart rate, breathing, digestion, blood pressure, etc)
Neurotransmitters

- Criteria for a substance being a neurotransmitter:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Exists in presynaptic axon terminals</td>
</tr>
<tr>
<td>2.</td>
<td>Presynaptic cell contains enzymes for synthesizing substance</td>
</tr>
<tr>
<td>3.</td>
<td>Substance is released in significant quantities when nerve impulses reach terminals</td>
</tr>
<tr>
<td>4.</td>
<td>Receptors specific to substance on post-synaptic membrane</td>
</tr>
<tr>
<td>5.</td>
<td>Application of the substance causes post-synaptic potentials</td>
</tr>
<tr>
<td>6.</td>
<td>Blocking release of substance prevents pre-synaptic impulses from affecting post-synaptic potentials</td>
</tr>
</tbody>
</table>
Acetylcholine (ACh)

- First NT to be discovered, by Otto Loewi in 1921.
- Experiment design came to him in a dream.
- Showed that nerve stimulation => release of chemical, which affects other cells.
- Loewi called it “Vagusstoff” (vagus-stuff).

![Acetylcholine molecule](image)

Image courtesy of Taiwan-awei
Acetylcholine

- NT at neuromuscular junction

- In brain, basal forebrain cholinergic system (BFCS) innervates cortex, hippocampus, limbic system.

- Blocking ACh in BCFS interferes with learning tasks.
Acetylcholine - nicotinic receptors

• ACh has two types of receptors

• Nicotinic receptors are ionotropic. Channel for Na\(^+\) and Ca\(^{2+}\), so excitatory.

• Receptor at neuromuscular junction; also some in CNS.

• Also enhance release of NT when located on terminals.
Acetylcholine - muscarinic receptors

• Muscarinic receptors are metabotropic.

• (Metabotropic receptors cause long-lasting changes in the post-synaptic cell, usually by activating a second-messenger system.)
Acetylcholine - muscarinic receptors

• Muscarinic receptors are metabotropic.

• (Metabotropic receptors cause long-lasting changes in the post-synaptic cell, usually by activating a second-messenger system.)

• Cortex, hippocampus, thalamus, striatum, and basal forebrain all have lots of muscarinic receptors.

• Muscarinic receptors are involved in cognitive and motor functions of ACh.
Norepinephrine (NE)  
(British: Noradrenaline (NA))

- Noradrenergic cells primarily located in pons and medulla.

- Cells from locus coeruleus in pons project to cortex, limbic system, thalamus, hypothalamus.

- Locus coeruleus cells involved in vigilance - alertness to stimuli.

- NE also acts as a hormone.
Norepinephrine

• Norepinephrine receptors are metabotropic.

• Found in cortex, thalamus, hypothalamus, cerebellum, hippocampus, and amygdala.

• Four types of NE receptors. All activate second-messenger systems to cause changes w/ in the post-synaptic neuron.
Dopamine (DA)

• Dopaminergic cells primarily located in midbrain; two pathways.

  • Nigrostriatal path: cells in substantia nigra project to striatum

  • Mesolimbocortical path: cells in ventral tegmental area project to cortex and to limbic structures.

• Nigrostriatal path involved in motor control

• Mesolimbocortical path involved in reward and addiction

Image courtesy of the National Institutes of Health
Dopamine

• DA receptors are metabotropic

• Five types of DA receptors, classified as D$_1$-like and D$_2$-like

• D$_1$-like cause an increase in cAMP, D$_2$-like cause a decrease in cAMP

• DA and NE are very chemically similar; both are reuptaken from the synapse by similar transporter proteins.

\[
\begin{align*}
\text{HO} & \quad \text{NH}_2 \\
\text{HO} & \quad \text{HO}
\end{align*}
\]
Serotonin (5-HT)

- Serotonergic cells concentrated in raphe nuclei in brainstem
- Project to cortex, hippocampus, basal ganglia, limbic system
- 5-HT implicated in sleep, mood, anxiety

Image courtesy of the National Institutes of Health.
Serotonin

- 5-HT is reuptaken by the 5-HT transporter
  - SSRI antidepressants (like Prozac) block this transporter
- >15 types of 5-HT receptors
- Most are metabotropic (but 5-HT3 receptors are ionotropic and excitatory)
Glutamate

• The transmitter for fast excitatory transmission

• Ionotropic receptor types include AMPA and NMDA

• Metabotropic receptors work by a variety of pathways - inhibit cAMP formation, activate phosphinositide system, inhibit glutamate release.
Glutamate

• High levels of glutamate can be toxic to cells.

• So, uptake of extracellular glutamate is important!

• Astrocytes as well as neurons have proteins for glutamate uptake.

A blood vessel covered by astrocytes (in green).  
*Image courtesy of Zerd.*
GABA (γ-aminobutyric acid)

- Workhorse inhibitory transmitter in the brain.

- 10%-40% of nerve terminals in cortex, hippocampus and substantia nigra are GABAergic.

- In cortex and hippocampus, lots of local GABAergic interneurons.

- GABAergic neurons from striatum to substantia nigra are projection neurons.
GABA

• $\text{GABA}_A$ receptors are ionotropic; allow $\text{Cl}^-$ to flow into cell.

• $\text{GABA}_B$ receptors are metabotropic inhibit formation of cAMP, stimulate $K^+$ channels opening.