Conversion from an _____________ signal to a ________________ signal
- electrical signal is the _______________________
- chemical signal is the _______________________

Presynaptic - refers to ________________ that sends/receives the signal

Postsynaptic - refers to ________________ that sends/receives the signal

________________________(PSP)
the membrane potential on the dendrite that is affected by activity in the synapse
Directed and non-directed synapses
- depends on proximity between neurotransmitter and receptor

Neurotransmitter

The unit of communication between neurons

______________ neurotransmitters
- cause the post-synaptic neuron to depolarize/hyperpolarize, more/less likely to fire
- Excitatory Postsynaptic Potential (EPSP)

______________ neurotransmitters
- cause the post-synaptic neuron to depolarize/hyperpolarize, more/less likely to fire
- Inhibitory Postsynaptic Potential (IPSP)

Neurotransmitters will only influence the cells that have a receptor for it

Lifecycle of neurotransmitter

Synthesized in cell

Packed into ______________

______________ - released into synapse
- arriving action potential causes influx of Ca++ ions, which trigger exocytosis

Interact with ______________
- a molecule in the post synaptic membrane that reacts to neurotransmitter
- sometimes there are presynaptic receptors (autoreceptor)

Removed from synapse
- reuptake transport
Receptors

Ionotropic

Permits the flow of ions
Ligand-gated, as opposed to voltage-gated channels in action potential
Neurotransmitter can cause channel to open or close
For example:
  - if Na+ channels are opened, cause EPSP/IPSP
  - if K+ channels are opened, cause EPSP/IPSP
Fast/short acting

Metabotropic

G-protein-coupled receptor
Subsequently can effect
  - ion channels
  - 2nd messenger
2nd messenger can alter DNA expression, having effects on cell functioning
Slow/long acting
Integration

A depolarization at one synapse is typically not enough to trigger an action potential
Each neuron can receive signals from 1000s of synapses
Integration - combining many different signals to determine if an action potential occurs

Temporal Integration
  depolarizations that _________________ may combine to cause an action potential

Spatial Integration
  depolarizations that _________________ may combine...

Types of neurotransmitters

More than 100 identified neurotransmitter substances

_________________ (small NT)
  Molecules that make up proteins, found in our diet
  Most common neurotransmitters for fast acting, directed synapses

_________________ - main excitatory transmitter, sensory & learning systems

_________________ - main inhibitory transmitter

_________________ (small NT)
  Not a typical synapse NT
  Release NT broadly throughout brain
  Produced by cells in the brain stem
  More likely to modify "global" function/state of the brain

_________________ - motor function and reward
___________ - (adrenaline, adrenergic)

___________ - (nor-adrenaline, nor-adrenergic) - brain arousal, mood, hunger, sleep

___________ - mood, temperature, aggression, sleep

___________ (small NT)
Neurons are called cholinergic
Location
  Neuromuscular junction
  Throughout autonomic system (parts of our nervous system NOT under voluntary control)
  In parts of central nervous system - cortical arousal, memory

___________ (large NT)
Full proteins made up of many amino acids
>100 neuropeptides
Many have role as both neurotransmitter and hormone
Typically act at metabotropic receptors
Examples: endorphins, enkephalin (another opioid), Neuropeptide Y (food intake)
Long lasting effects

Drug action

Antagonist - decrease the effect of a neurotransmitter
Agonist - increase the effect of a neurotransmitter

Receptor agonists
  Nicotine - stimulates acetylcholine receptors
Receptor blockers
  Botox - nicotinic receptor antagonist

Reuptake blockers
  Cocaine, amphetamines - impairs dopamine transporter

Source: http://www-scf.usc.edu/~uscience/adderall_abuse.html

Gap Junctions
A direct connection between the cytosol (internal fluid) of two cells
Faster than a chemical synapse
Doesn’t require neurotransmitters
Not common in the brain, but extensive in heart muscle and retina

Synaptic Plasticity

Changes in connections between neurons can produce changes in behavior

"Neurons that fire together, wire together"*
- paraphrasing Donald Hebb’s 1949 theory of memory

Long Term Potentiation (LTP)

Typically studied in hippocampus

Process

1. Put a STIMULATING electrode in the upstream (presynaptic) neuron
2. Put a RECORDING electrode in the downstream (post-synaptic) neuron
3. Record the reaction of the downstream neuron to a single upstream stimulation
4. Provide high-frequency, high-intensity stimulation to upstream neuron (no measurement)
5. Record the reaction of the downstream neuron to a single upstream stimulation

Increased response in downstream neuron
Can be measured months later
Requires pre- and post- synaptic neurons to both have action potentials

Induction

Source: http://employees.csbsju.edu/ltennison/PSYC340/learning.htm

LTP Requires ___________ receptors
  NMDA receptors allow Ca++ to enter
    Ca++ causes changes in cell functioning, such as creating new receptors

  NMDA receptors are excited by _______________
    and require post-synaptic neuron to already be partially _______________

  NMDA are able to detect the co-occurrence of

    ______________________ and ______________________ depolarization
Maintenance/Expression

The post-synaptic neuron does not strengthen connections with all pre-synaptic neurons, only across synapses that were depolarized

LTP requires protein synthesis

Neuron is making new ___________ to “build” or strengthen the synapse

Relation to behavior

LTP is a model for memory, and memory is probably "like" LTP, but LTP is an artificial technique done in a laboratory setting

Rats learning a maze task fail to learn if NMDA receptors are blocked (Morris et al 1986)

Rats learning an avoidance task produce new AMPA receptors, the same receptors produced by LTP. Also, in vitro synapse that were potentiated during training could not be further induced by LTP. (Whitlock et al, 2006)

Animals undergoing fear conditioning show evidence of LTP-like processes (Rogan et al, 1997)

Learning in a Sea Slug

Aplysia
A sea slug with 200 neurons studied by Eric Kandel

Has a gill which it will withdraw if its siphon is touched

These are two examples of synaptic changes that explain an animal’s behavior

**Habituation**

Source: [http://michaeldmann.net/mann18.html](http://michaeldmann.net/mann18.html)

If the siphon is repeatedly touched, the gill withdrawal reflex disappears

With repeated activation, the neurons contain less dopamine and release less dopamine each time
Eventually gill withdrawal stops

A "short term" change in synaptic activity that does NOT require building new proteins

**Sensitization**

If the tail is shocked at the same time the siphon is touched:
- Gill is more vigorously withdrawn to a siphon touch
- Siphon has become "more sensitive"

Facilitating interneuron releases serotonin onto sensory neuron
- Causes the sensory neuron to release more neurotransmitter when the siphon is stimulated
- Causes motor neuron to react more vigorously

A "short term" change in synaptic activity that does NOT require building new proteins
(can be made "long term" with more training)

Source: [http://michaeldmann.net/mann18.html](http://michaeldmann.net/mann18.html)

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