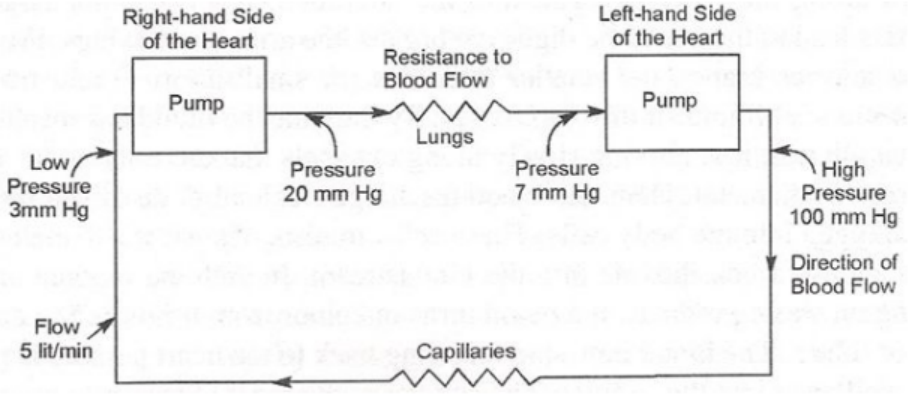
Sources of Biopotentials - The Heart and Nervous System

Cardiovascular System (Electrocardiogram)

- Heart consists of two pumps in series
- Smaller right-hand pump forces blood through lungs
- Larger more powerful left-hand pump force blood through rest of body



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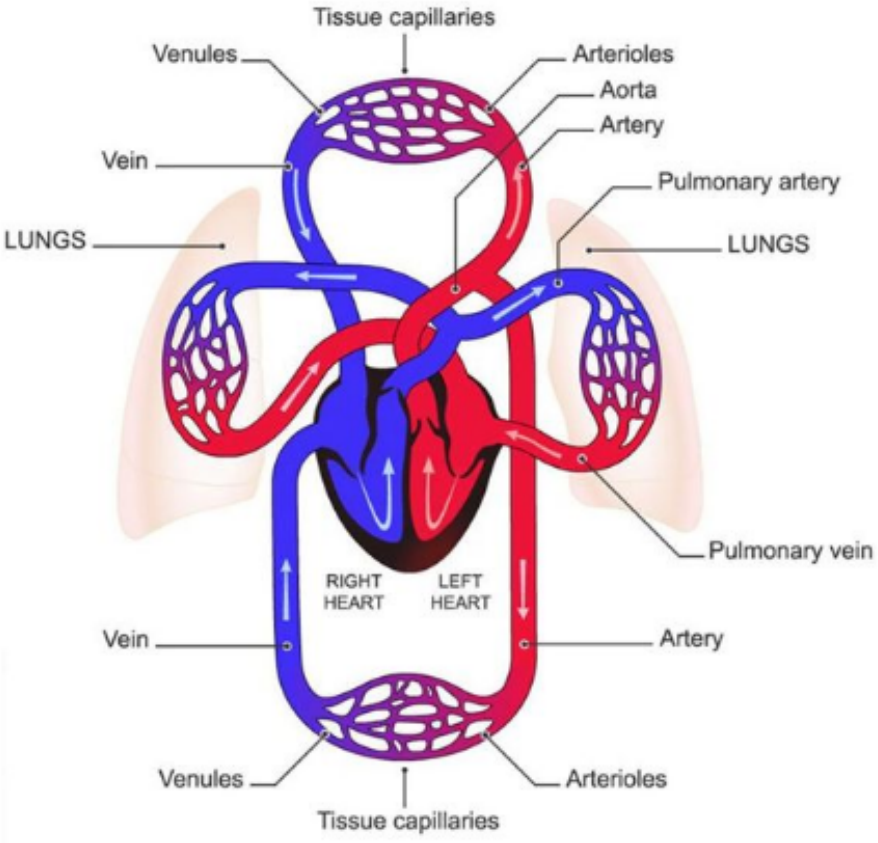
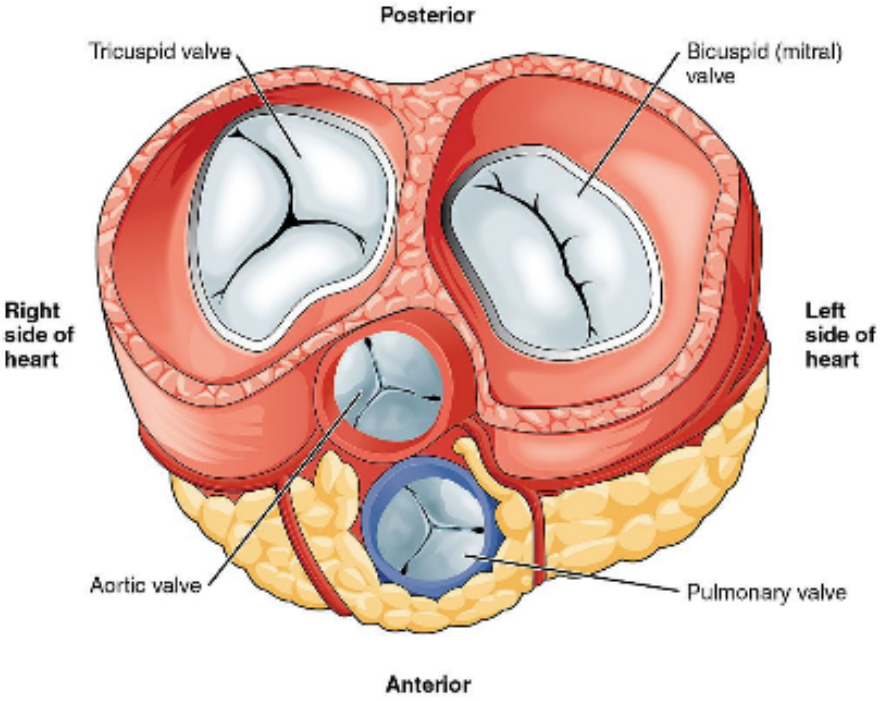


[H]

- Blood flows from heart to aorta
- Large arteries to head, digestive organs, limbs
- Arteries branch to smaller arterioles
- Arterioles to tiny capillaries ($10\mu m$)
- discharges load of dissolved food, oxygen into body cells
- Cells deposit waste materials (eg CO2) into bloodstream
- Blood turns from bright red to dull red/blue
- Blood flows back to heart
- From capillaries to venules
- Venules to larger veins
- End in Vena Cava, delivers to right atrium
- From here pumped to right ventricle
- Ventricle to tricuspid valve
- Out through pulmonary artery, opening pulmonary valve to lungs
- After oxygenation
- Blood passes from lungs to left atrium
- Pumped to left ventricle
- Through mitral/bicuspid valve

- Passes out via aorta
- Opens aortic valve to restart circulation process
- As part of systemic circulation
- Waste in blood removed by kidneys, liver
- Avg male blood capactiy of 5l completely circulated once a minute
- Pericardium
- Covering of heart
- Consists of two layers of fibrous tissue separated by small space filled with thin film of pericardial fluid
- Left, right sides of heart separated by septum - dividing wall of tissue
- Walls of heart made entirely of muscle surrounding four hollow chambers



[H]

- Heart contracts 70 times per minute to squeeze blood around circulatory system
- Diastole
- Period between contractions
- Heart assumes max. size, fills with O2 blood from lungs, venous blood returning to body
- Systole
- Contraction
- Initiated by contraction of muscles surrounding atria which propel additional blood into ventricles
- Ventricles begin to contract causing rise in pressure

- Shuts artrioventricular valves (tri/bicuspid)
- With further contraction pressure continues to rise
- Ventricular ejection
- Begins when pressures of systemic, pulmonary circulation exceeded
- Aortic valve forced open
- Blood squeezed into aorta, onward to systemic circulation
- Peak pressure of blood flow 120 mm Hg
- Systolic Pressure
- Min. pressure of blood flow 80 mm Hg
- Diastolic Pressure
- Slight back pressure build up, mitral valve closes
- Shows up as Dicrotic Notch in blood pressure waveform
- After ventricular contents partially ejected
- Muscles surrounding ventricles relax
- Ventricular pressures fall
- As soon as pressure falls below pressure sustained by circulatory system
- Aortic and pulmonary valve close
- Indicates onset of diastole

Electric Potentials generated within the heart - The ECG Waveform

- Sinoatrial (SA) node
- Bundle of nerves in right atrium
- Function: start heart beat, assess rhythm
- Pulses generated stimulate contraction of atrial muscles
- Atrioventricular (AV) node
- Pulses from SA travel along conducting fibers in atrium
- AV in lower part of heart wall between two atria on the septum
- Acts as delay line
- Provides appropriate timing between action of atria and ventricles
- Stimulation vauses impulses to be sent to myocardium muscles of ventricles
- Thus atria, ventricles functionally linked only by AV node and conduction system
- Delay required so atrial contraction can complete ventricular filling before ventricular contraction
  - When ventricle depoolarising, atria repolarising
- Depolarization, repolarization generate external bioelectric potentials
- Can be recorded at surface of body

ECG Waveform

- External representation of sequence of electrical activity of heart
- **Atrial Depolarisation** - P wave (0.25mV, 110ms)

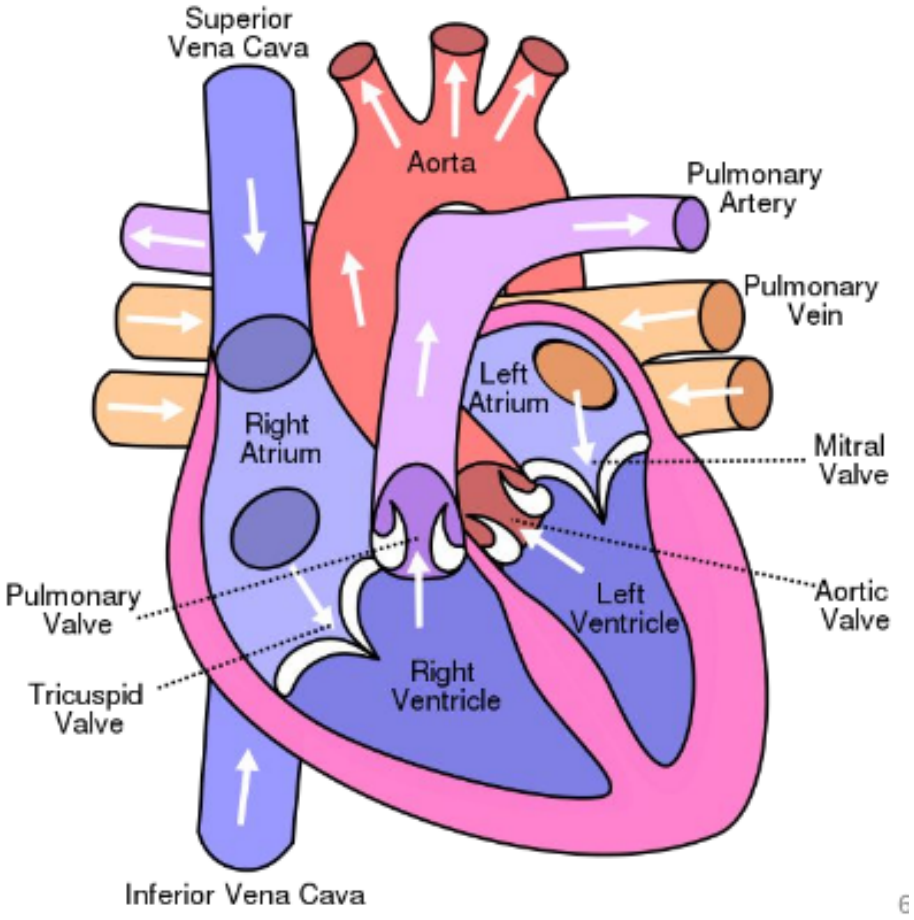

Superior
Vena Cava
Aorta
Pulmonary
Artery
Pulmonary
Vein
Left
Atrium
Right
Atrium
Mitral
Valve
Pulmonary
Valve
Aortic
Valve
Left
Ventricle
Tricuspid
Valve
Right
Ventricle
Inferior Vena Cava

Figure 1:

- **Atrial Repolarisation** - TA wave (not always observed)
- **Ventricular Depolarisation** - QRS complex
- **R-wave** - 1.6mV
- **Q-wave** - 25% of R-Wave
- **Atriocentricular Conduction Time** - PR interval (120-220ms)
- **QT Interval** - (350-440ms)
- **ST segment** - (50-150ms)
- **Ventricular Repolarisation** - T-Wave (100-50ms)
- **U-Wave** may be after-potentials of ventricular muscle or repolarization of Purkinje fibres

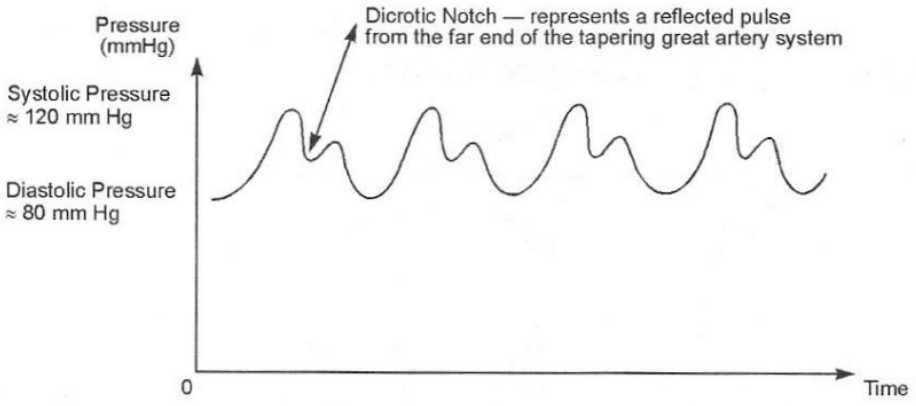


Figure 2:

- Useful Terms:
- **Brachycardia** - Abnormally slow heartbeat
- **Tachycardia** - Abnormally fast heartbear
- **Arrythmia** - Uneven spacing of heartbeats

The Central Nervous System - The Neuron

- Neuron
- Basic unit of nervous system
- Single cell
- Soma
- Cell Body
- Dendrites
- One or more input fibres
- Axon
- Long transmitting fibre
- Branches near end to Terminals
- Axon Hillock

- Part of Axon adjacent Soma
- Point where Action Potentials generated

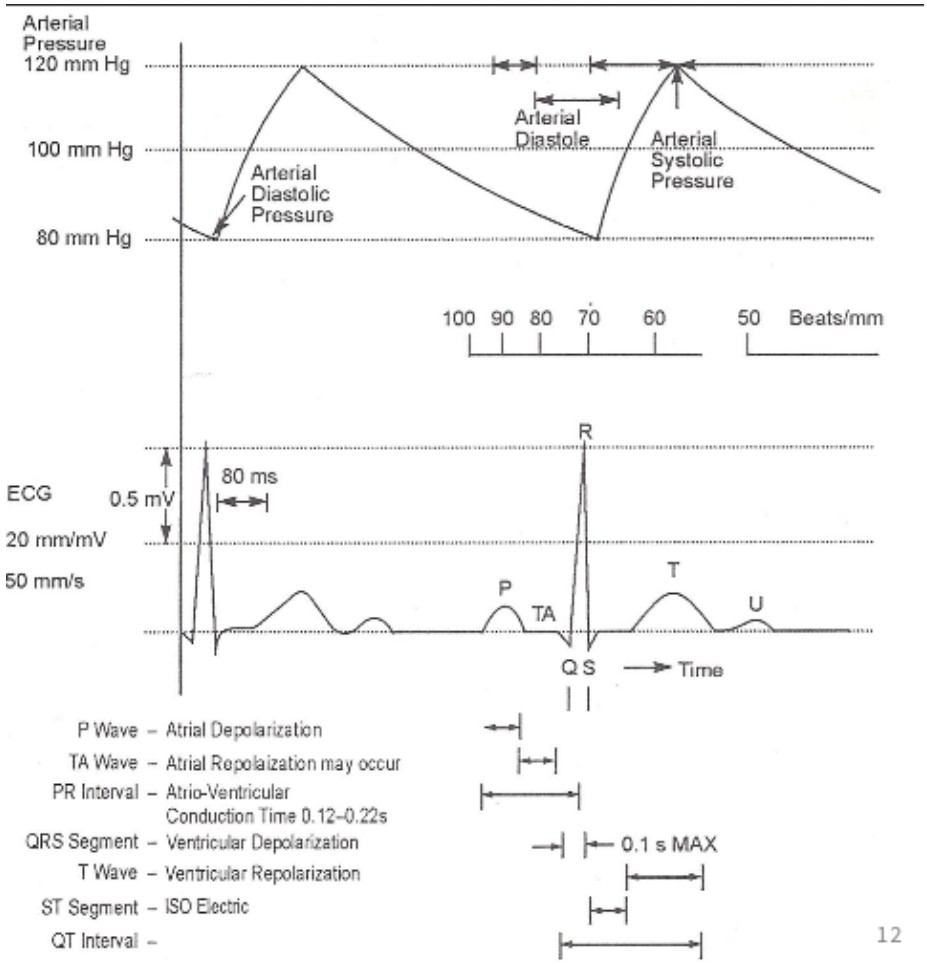


Figure 3:

- Myelin
- Fatty Insulating substance coating axons and dendrites of some neurons
- Often interrupted at regular intervals by Nodes of Ranvier
- Speeds up pulse transmission
- Neurilemma
- Insulating layer surrounding myelin sheath outside central nervous system
- Consists of thin cells, Schwann Cells
- When stimulus detected by dendrite, impulse generated in Soma, sent along Axon
- Neurons not directly connected

- Impulses transmiit from one to the other via Synapses between axon terminals of one neuron and dendrites of a succeeding one
- Sensory Neurons
- Transmit stimuli to central nervous system
- Motor Neurons
- Transmit impulses to muscle tissue

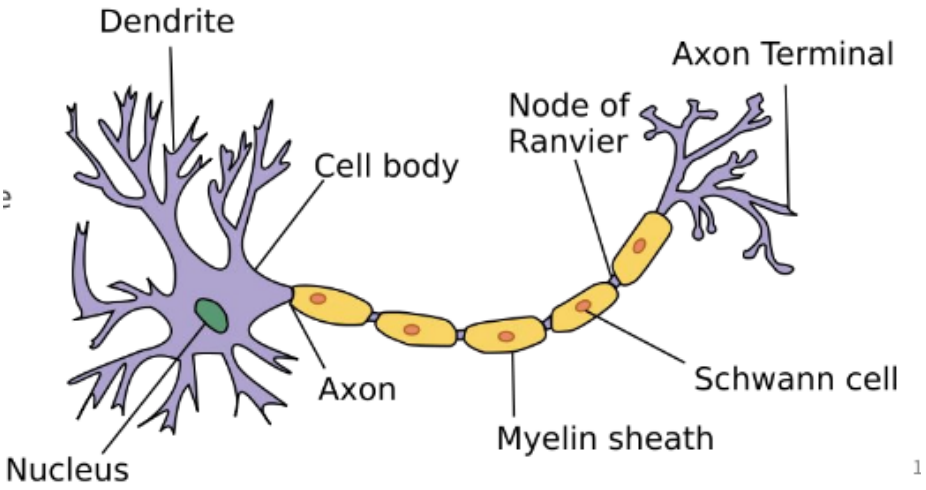


Figure 4:

- Single axon can have multiple branches, making synaptic connections with many postsynaptic cells
- Single neuron can receive thousands of synaptic inputs from many presynaptic neurons

The Nervous System - The Synapse

- Axon terminal of sending cell contains synaptic vesicles
- Membrane-bound spheres filled with neurotransmitter molecules
- Synaptic Cleft
- Small gap between axon terminal of presynaptic neuron and membrane of postsynaptic cell
- Nerve impulse (action potential) arrives at axon terminal
- Activates voltage-gated calcium channels in cell membrane
- Caˆ2+ in much higher concentration outside neuron than inside
- Rushes into cell
- Caˆ2+ allows synaptic vesicles fuse with axon terminal membrane
- Release neurotransmitter into synaptic cleft
- Neurotransmitter diffuse across synaptic cleft

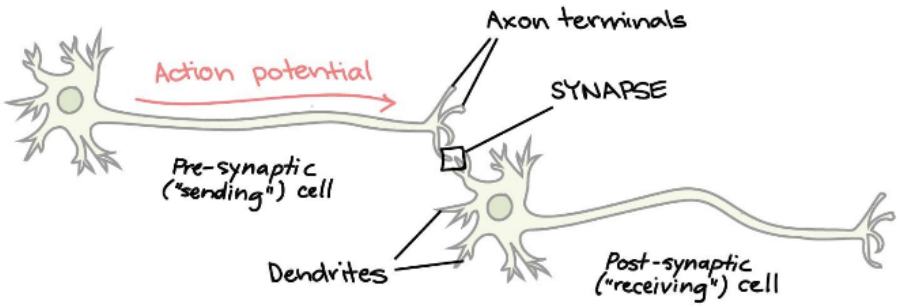


Figure 5:

- Bind to receptor proteins on postsynaptic cell
- Activation of postsynaptic receptors lead to open/close ion channels in cell membrane
- Depending on ions involved:
- Depolarizing (excitatory)
- Hyperpolarizing (inhibitory)
- Postsynaptic neurons add together/integrates all inputs received
- Triggers action potential at axon hillock if summation above threshold
- Spatial Summation
- Integration of postsynaptic potentials from different dendrites that occur about the same time
- Temporal Summation
- Integration of postsynaptic potentials occur at same place, at slightly different times
- E.g: presynaptic neuron fires quickly multiple times, driving membrane potential above threshold

- Must be some way to "turn off" signal once sent (clear synaptic cleft of neurotransmitter for synapse to function effectively
- Let postsynaptic cell return to normal resting potential, ready for new signals
- Neurotransmitter may
- Diffuse away
- Broken down by enzyme
- Sucked bacak into presynaptic neuron
- 'Mopped up' by nearby glial cells
- Anything (drugs, incesticides, toxins) interfere with proces that terminate synaptic signal can have significant physiological effects
- Action potential all-or-none response
- Synaptic signalling more flexible
- Changes can strengthen/weaken communication at particular synapse
- Sending neuron can "dial-up"/"dial-down" amount of neurotransmitter

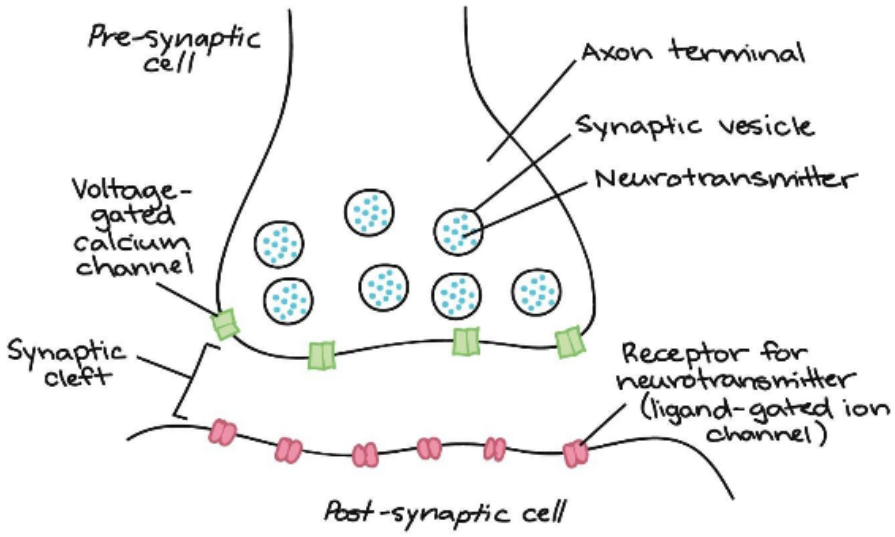


Figure 6:

released in reponse to arrival of action potential
- Receiveving cell can alter
- Number of receptors it puts on its membrane
- How readily it reponds to activation of receptors
- Plasticity makes synapse key site for altering neural circuit strength
- Plays role in learning, memory, addiction
- Different presynaptic, postsynaptic cells produce different neurotransmitters and neurotransmitter receptors
- Different interactions, effects on postsynaptic cell

The Nervous System - The Electrical Synapse

- Electrical Synapses
- Direct physical connection between pre/postsynaptic neuron in form of channel called gap junction
- Allows current (ions) flow directly from one cell to another
- Transmit signals more rapidly than chemical
- Allow for synchronized activity of group of cells
- Carry current in both directions
- Depolarization of posstsynaptic neuron can lead to depolarization of presynaptic neuron
- Cannot turn excitatory signal in one neuron into inhibitory signal in another (unlike chemical synapse)

- Lack versatility, flexibility and capacity for signal modulation seen in chemical synapses

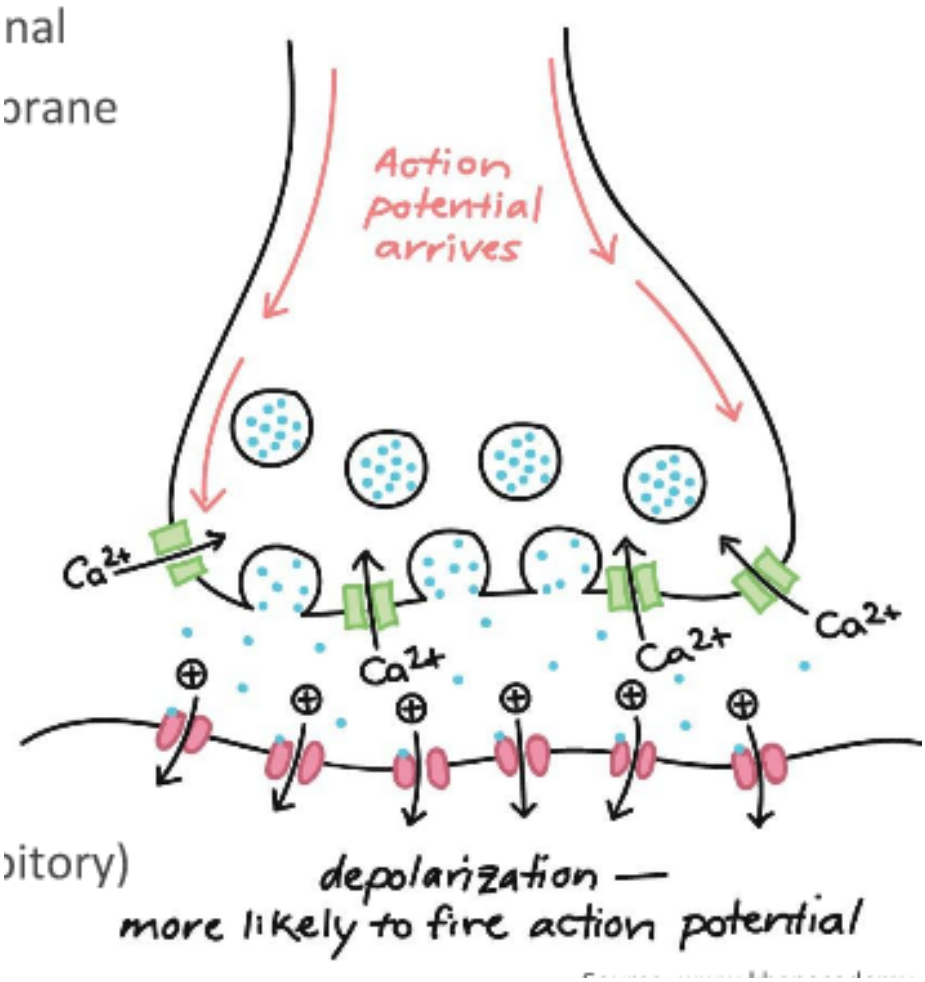


Figure 7:

The Nervous System - Operation and Function

- Operation fundamentally based on
- Action potentials/impulses in neurons
- Synapses of one neuron to another
- Summation of neural inputs in dendrite tree of neuron
- How neural inputs affect generation or not of its own action potential
- Main function of nervous system

- Control of bodily activity, configuration through sensing and motor signals flowing on neurons
- Some of the acivities
- Available to concious control
- Subconcious, auto controlled - e.g. heart rate, digestion
- Unconcious, relflexive
- Spinal cord responsible for reflexive actions becauseee response can be much faster than if stimuli had to travel to brain for processing

The Nervous System - Structure and Function

- More complex responses require more sophisticated processing capabilities of brain, consists of three main parts

1. Cerebrun (including cerebral cortex)

- Large amouts of info can be stored, analysed, used for immediate/future reference
- Approx. 9 of 12 billion neurons in brain
- Responsible for
- Sensing activities; seeing, hearing, touching
- Memory of past events and sensations
- Conciousness, Awareness, Thinking processes
- 2 Hemispheres joined by corpus callosum, each divided into four lobes
  - Frontal:
  - Emotion, personality, consciousness, awareness, thinking processes
  - Parietal:
  - Part of cortex responsible for sensing, motor actions
  - Occipital:
  - Vision
  - Temporal:
  - Part of cortex responsible for hearing, storage of long-term memories of past events and sensations

2. Cerebellum (major feature of hindbrain of vertebrates

- Responsible for:
- Balance
- Low-level motor control processes in operation of muscles
- Loearning to adjust to changes in sensorimotor relationships
- May be involved in cognitive functions such as
- Attention
- Language
- Regulating fear/pleasure responses

3. Medulle (in brainstem, connects higher levels of brain to spinal cord)

- Responsible for:

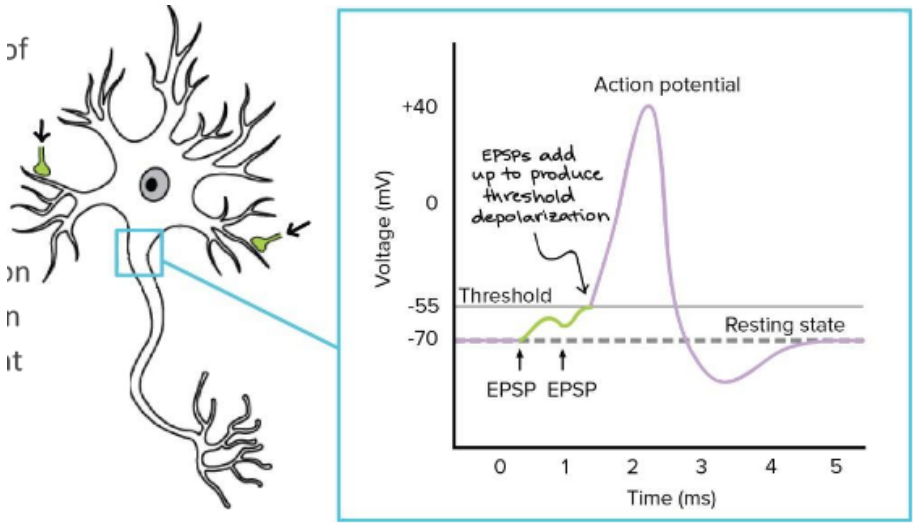


Figure 8:

- Autonomic (involuntary) functions ranging from:
  - Vomiting to sneezing
  - Basic functions:
  - Breathing, heart rate, kidney functions, blood pressure
- May contain timing mechanisms as part of these processes

The Nervous System - Electroencephalogram (EEG)

- Recording of gross electrical activity of brain, taken frm electrodes placed at strategic points aroud head
- Result of biopotentials in brain
- Not possible to isolate/distinguish firing of individual neurons except by invasive procedures
- Varies in form amplitude, frequency
- Generally consists of rhythmically slow, sinusoidal-like waveforms 10-100microN in amplitude
- Basic frequency of aroud 10Hz markedly reduces in amplitude with increase in mental activity called alpha rhythm

The Nervous System - Muscle action and the electromyogram EMG

- Motor Unit

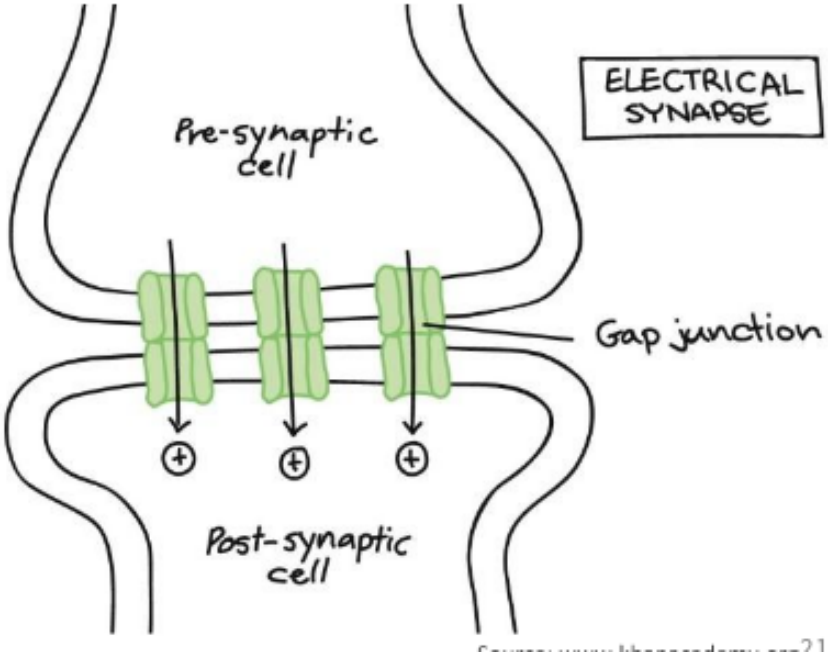


Figure 9:

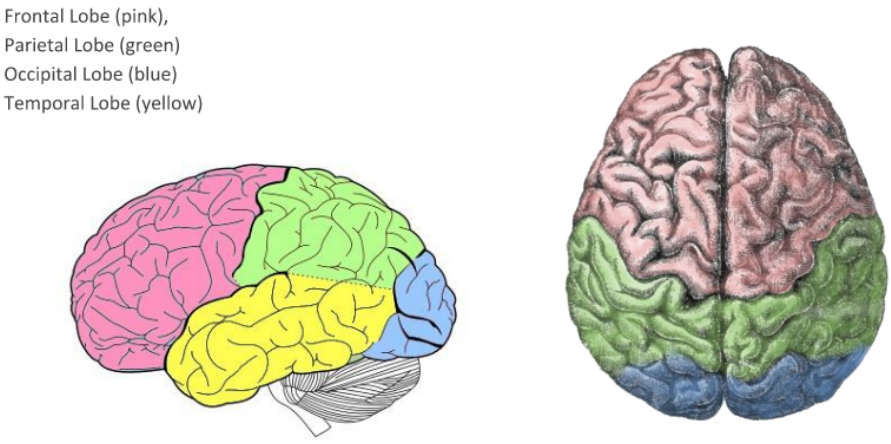


Figure 10:

- Biological unit of muscle function
- Consists of motor nerve arising from motor neurons in brainstem/spinal cord, branching into various motor end plates
- Motor End Plates
- Connected to individual muscle fibres
- Stimulation causes contraction of single muscle fibre attached to it
- Generally larger muscle, more motor units found
- Size of motor unit (no. of fibres activated by same nerve fibre) may vary in human from 25 to 2000 muscle fibres
- Muscle fibres not clumped together in one part of muscle
- Fibres of different units interlaced

Figure 11:

- Individual neuron can only exist in polarised/depolarised state:
- Only transmits one/other of these potential levels to motor end plates
- Causing binary on/off action of muscle fibres
- Individual muscle fibres of one motor unit can only exist as relaxed/tensed
- Normal muscle activity (in terms of movement, steadiness, precision)
- due to combined effect of large no. of motor units comprising any one muscle
- More motor units recruited into action as greater effort required of muscle
- Additional smoothness movement obtained by modulating no. muscle fibre contractions per unit time (similar to pulse width modulation)
- Muscular effort controlled by no. of motor units activateed, rate of activation
- Skeletal Muscles
- Generally considered under control of the brain
- Reflex action
- Control loop through brain short-circuited by local loop through spinal cord
- Oftern response to large sensory neuron signal - high repitition impulse

rate

- Bioelectric potentials associated with muscle activity measured in EMG
- Measured at surface of body, near muscle of interest, directly from muscle by penetrating skin with needle electrodes
- Most measurements intended to obtain indication of amount of activity of a given muscle/group of muscles rather than individual muscle fibre
- Pattern usually summation of individual action potentials from fibre constituting muscles being measured
- Amplitude of measured EMG waveform instantaneous sum of all action potentials generated at given time
- Action potentials sometimes add, sometimes cancel
- EMG waveform appears like random noise waveform with energy of signal being function of amount of muscle activity and electrode placement