Lecture #1

I. Brain Function: Historical perspective 1-1

'Lesion' Evidence: P. Gage - Frontal Lobes
H.M. - Hippocampus
Strokes - cortical

II. Studying the Nervous System 1-4
1-5

Goal of Neurobiology: Understand N.S. Function → Behavior

- General Questions (Cell Bio, Devel., Function)
- Comparative approach: Why?
  1. 'Favorable prep' - specialized
  2. Diversity of solutions to a problem
  3. General Principles
- Levels of Organization
  Diversity of techniques

Lecture #2: Cellular & Molecular Neuro

I. Neurons

•Structure	soma, dendrites, axons	2A, 2-1, 2-2
•Types	Mono, Bi, Multipolar	T2-1
	Interneuron vs. Projection neuron	
	Many types, based on Morphology	
•Synapses	Presynaptic vs. Postsynaptic	2-3
	Chemical vs. Electrical	2-4

II. Membrane Structure

-Phospholipid Bilayer ~ 4nM 2-8

-Proteins T2-3

1. Transport — Ion channels, pumps — 2-10
2. Signaling — Receptors, G proteins, nZ's
3. Binding

Lecture #2 cont.

Ion Channels

Features 2-10

-Ion selectivity 2-12

-Voltage gating (conformational vs. occlusion)

-Ligand gating

-Stretch sens. (mechano receptors)

Pumps

Active transport of ions. E from hydrolysis of ATP T2-4

Signaling

Receptors:

Types: 1) Ionotropic 2-13

2) Metabotropic--

Associated with and act via '*G*' proteins (guanine nucl. Binding)

-Ligand & Receptor → Activate G protein

↓

Activates other memb-bound nZ

eg (adenylate cyclase)

Lecture #3: Structure of Nervous Systems (Neuroanatomy)

I. Parts of the Nervous System:

1. General organization, terminology
   - -Peripheral vs. Central — 3-1
   - -Ganglia, Nerves
   - -Somatic vs. Autonomic
2. Invertebrate Nervous Systems
   - -Diversity: Nerve nets, Ganglia and connectives — 3-2, 3-4
     Fused ganglia, Brain
   - -Neuropil (interior of ganglion) = Integrating Region — 3-B
     No synapses on somas
3. Vertebrate Central Nervous System
   - -Spinal Cord — 3-6
     Gray vs. white matter (tracts)
   - -Brain
     Gray matter organized into "Nuclei"
     Cortex and other laminated structures

Lecture #3 cont.

Brain Structure 3-8

1. General Vertebrate organization

   Homologous structures

   Phylogenetically old vs. new 3-10

Lower Brain (Stem) 3-13, Anim.

1. Medulla and Pons 3-14, T3-3
   - Nuclei-control vital functions
   - Origin of Cranial Nerves V-XII
   - Many tracts 3-15
   - Reticular Formation (arousal, sleep, pain sensation)
2. Cerebellum 3-17

   'motor planning and memory'

   calibration of motor responses
3. Midbrain

   Tectum-Superior Colliculi 3-18

   Torus-Inferior colliculi

   Red Nucleus

   Substantia Nigra

Lecture #3 cont.

4. Diencephalon
   - -Thalamus
     - Lateral Geniculate N.
     - Medial Geniculate N.
   - -Hypothalamus
     - Maintaining Homeostasis
     - Component of 'Limbic system'
5. Telencephalon 3-19
   - -Cerebrum: highly dev. in mammals 3-20,21
   - -Basal Ganglia: Extrapyramidal motor system
     - caudate N., Putamen & Globus pallidus
   - -Limbic System 3-22,3-23
     - Functionally related, interconnected structures

Cingulate Gyrus
Parahippoc. Gyrus
uncus
Fornix

Internal Compon.

Hippocampal Form.
Amygdala
Septal N.
Mammillary Bodies

Lecture #4: Electrical Potential of a Resting Neuron

I. Factors influencing ion movement across a cell membrane:

1. Concentration Gradient 4-1
2. Electrical Potential
3. Ion Pumps 4-2
4. Channels

II. Ionic Basis of the 'Resting Potential'

1. Factors Responsible: 4-3
   - -Selective Permeability
   - -Unequal Distributions of Ions
   - -Ion Pumps

2. Generation of the R. Pot.
   - -R. Pot. If only permeable to K^+ (hypothet. Case) 4-3
   - -Real Neuron: perm. $K^+ \cong 25 *$ perm. Na^+ 4-4

     (g $K^+ \cong 25$ g Na^+)

Lecture #4 cont.

A. Equilibrium potentials for Na^+, K^+, Cl^-

4-5

Equil. Potential (ion) = Transmembrane voltage where elect force is equal & opposite to chemical force.

Nearnst Equation: $E(ion) = \frac{RT}{FZ} \ln \frac{[ion]\ out}{[ion]\ in}$ T 4-2

$$= 25 * 2.3 * \log \frac{[ion]\ out}{[ion]\ in}$$

$$= 57 \log \frac{[ion]\ out}{[ion]\ in}$$

E_K = -75 mV

E_{Na} = +54 mV

4-6

Lecture #4 cont.

B. Calculating the Membrane Potential

1) Factors: -Equil. Potential, each. Ion type 4-7

(short term) -Permiability, each Ion type 4B (a, b, c)

Goldman Equation:

$$E_m = \frac{RT}{F} \ln \frac{P_K [K^+]_o + P_{Na} [Na^+]_o + P_{cl} [cl^-]_i}{P_K [K^+]_i + P_{Na} [Na^+]_i + P_{cl} [cl^-]_o}$$

Or

$$= \frac{RT}{F} \ln \frac{[K^+]_o + P_{Na}/P_K [Na^+]_o + P_{cl}/P_K [cl^-]_i}{[K^+]_i + P_{Na}/P_K [Na^+]_i + P_{cl}/P_K [cl^-]_o}$$

Lecture #5: Action Potential Gen. (spike)

I. Characteristics of Action Potentials

- -Measuring & Viewing Action Potentials — 5-A, 5-B, 5-C, 5-1
- -Depolarization, repolarization hyperpolarization phases — 5-3
- -Triggered (all or none) by depol. — 5-2
  Time & Voltage-depend. Conduct (g)
  g = 1/resist.

II. Ionic Basis of the Action Potential

(in Squid Giant Axon)

A. Ion Substitution Exps:

↑ $[Na^+]_o$ ↑'s A. Pot. Height
↑ $[K^+]_o$ ↓'s A. Pot. Height (makes resting potential less negative)

5-4

Lecture #5 cont.

B. Voltage - Clamp Exps.

1. How a V-Clamp works:
   - 'clamp' (hold) membrane pot. @ desired value by delivering (injecting) current into cell to compensate for flow of ions through channels.
   -Record time course and magnitude of current flow @ various clamp values ('Holding Potentials').

2. Measuring Ion Flow and Channel Properties 5-5
   -'Isolate' g's to particular ions.
   -Block other channel types
   -or substitute Ion (e.g. choline Na^+) 5-6
   -or change concentration & clamp @ E Ion (reversal pot.)

Lecture #5 cont.

Na^+ conductance:

R. Pot. = -70mV

Measuring Single Channel Properties (conductances) 5-E

-'Patch' pipettes & voltage clamp 5-7

measure magnitude & time course of conductance T5-1

Diversity of channel types

Lecture #6: Synaptic Transmission

I. Overview of Synaptic Transmission: T6-1

-Electrical

-Chemical: 1) Classical 6-1

Excitatory (EPSPs) 6-3

Inhibitory (IPSPs)

2) Neuromodulatory

II. Specific types of Chemical Synaptic Transmission

1) Characteristics of receptors

-Ligand gated

-Ligand specificity

-Ion channel assoc. with receptor (Postsynaptic response determined by ionic specificity)

2) Excitatory Transmission: 6-5

EPSPs (Excitatory Postsynaptic Potentials)

-Reversal Potential: 6-6

@ Neuromuscular Junction

gNa^+, En_a

gK^+, E_{K+}

Rev. Pot. ~ OmV

(gNa > g K)

-10mV if gNa = gK

Lecture #6 cont.

-time course of Epsps:

- Duration of transmitter @ receptor
- Receptor Desensitization
- Resist. & Capacitance of Neuron Membrane

*In some Neurons, voltage-depend. G's influence Epsp shape & Amplitude.

-Spike initiation zone: TTX Blocks Spike Initiation 6-7

High density of Voltage gated Na^+ channels (TTX sensitive)

3) Inhibitory Transmission

a) Postsynaptic Inhibition: 6-8

IPSPs (Inhibitory Postsynaptic Potentials)

IPSPs = hyperpolarizations (usually) 6-9

due to K^+ or Cl^- conductance ↑

special case: synaptic Rev. Potential = Memb. Pot.
or slightly less negative (-62 vs -65 V)

Lecture #6 cont.

b) Presynaptic Inhibition: 6-10

Function: Selective inhibition (specific to particular terminal)

Mech. : Reduces Ca^{+2} influx $\rightarrow$ less transmitter released

by: A) Decrease Voltage sens of Ca^{+2} channels

B) Increased Cl^- g ; decreases

Depol. Of terminal (short circuit shunt)

***Gaba: can produce both types of Presynaptic inhibition & Postsynaptic inhibition**

4) Neuromodulatory Transmission T6-2

A) Comparison w/ classical transmission

Single neurotransmitter type can have both classical & neuromodulatory roles 6-11

B) Role of 'G' Proteins: 6-12

-open an ion channel or activate nZ's to produce mostly "2nd messengers" T6-3

*Many types of G proteins; each specific for receptor and 2nd messenger system

-Sequence of events - G-protein mediated transmission

Transmitter Binds receptor →changes in charge distribution of receptor attract G protein

$\propto$ GTP ← $\propto$ subunit ↵ GTP replace GDP

β splits from β

↓

Activate nZ's to produce "2nd messengers"

eg Adenylate cyclase
Guanylate cyclase
Phospholipase C (Phosphodiesterase (PDE)

↓

2nd messenger stimulate Protein kinases to phosphorylate proteins (such as ion channels)

Functional consequences:

-Long lasting action: (Activation of nZ's & phosphorylation persist)
-Amplification
-Action is primarily on altering effects of other inputs.

Lecture #6 cont.

5) Inactivation:

Diffusion

nZ degradation

Reuptake

Lecture #7: Neurotransmitters & their Release

1) The release Process:

a) Role of Ca^{+2} & Depol.

Reducing Ca^{+2} , or increasing Mg^{+2}

Reducing depolarization decreases trans. Release

Exps @ squid Giant Axon synapse: 7-1

-Block A.P. w/TTX, depol. Pre.

-Epsp Amplitude depends on depol. 7A

-Transmission depends on Ca^{+2} @ terminal (iontophoresis exps.)

b) Quantal Release: Vesicular hypothesis

-MEPPs, synaptic vesicles

(spont.) 7-2

-Evoked release (EPP's) in high Mg^{+2} are also quantal in amplitude

-Vesicles - Readily releasable pool 7-3

- storage pool

Lecture #7 cont.

-Release of "docked" vesicles - [Ca^{+2}] depend. Fura - 2 analysis

2) Neurotransmitters:

a) Criteria

1. Synthesized & stored in neuron
2. Released when the Neuron depolarized
3. Causes approp. Action (response) when iontophoresed onto postsynaptic cell.

b) Main Neurotransmitters:

1. Amino Acid Transmitters T7-2

Glutamate - Excit. Transmitter

Aspartate - Excit. Transmitter

Glycine - Inhibitory

GABA (amino butyric acid)

[formed from Glutamic Acid]

MAIN Inhibitory transmitter

Lecture #7 cont.

2) AMINE Transmitters (Biogenic amines)

-Histamine

-Octopamine

-Serotonin (5HT)

-Dopamine

-Epinephrine

-Norepinephrine

3) Peptides (many)

Often co-localized w/conventional transmitters - mostly modulatory

4) Other Neurotransmitters

-*Acetylcholine (Ach)

-ATP

Not clear if - NO, CO (soluble gasses-not stored in or released from vesicles)

Really transmitters

T7-3

Terminology

Lecture #7 cont.

3) **Synthetic Pathways:**

_____-Amino Acids: Acquired of synthesized 7-9

Glutamic Acid → GABA 7-10

(Decarboxylation) 7-11

-Catecholamines: synthesized (from Tyrosine)

*L Dopa

-Serotonin, Ach: Synthesized

Lecture #8: Integration of Synaptic Action

I. Electrical Circuits:

a) General

$V = IR$

$I = V/R$

$Q = CV$

$dV/dt = i/C$

V= voltage

I= Current (amps)

R= Resistance (ohms)Ω

Q= Charge (coulombs)

C= Capacitance (Farad)

b) Cell

1. Factors governing ion (current) Flow.

Membrane Potential (voltage)

Membrane Resistance (Rm)

Membrane Capacitance

Internal Resistance (Ri)

Lecture #8 cont.

Lecture #8 cont.

b) Time Constant

$T = rm \cdot Cm$ 8-A

= time for Voltage to rise to 63% of its final value 8-3

$V(t) = V_{max}(1-e^{-t/T})$

when $t = T$, e^{-1}

$(1- 1/e)$

$1-.37 = .63$

II Integration 8-4

1) Summation 8-5

a) Spatial

b) Temporal 8-6

Lecture #8 cont.

2) Integration of Excitatory & inhibitory Potentials

net effect depends on timing of excite & inhibitory inputs, spatial summ.

3) Plasticity: Activity-depend. Changes in synaptic transmission

a) Facilitation 8-7

1) Homosynaptic - Facil. @ active synapse Ca^{+2} dependent 'residual Ca^{+2} hypoth.'

2) Heterosynaptic- Facil. @ synapse other than the active one. 8-8, 8-9

e.g. aplysia 5HT $\rightarrow$ closure of K^+ channels

Lecture #8 cont.

Potentiation: Long-lasting facilitation

-Post tetanic Potentiation (PTP) 8-10

Epsp Amplitude (response to test pulse) remains larger for minutes after a high-frequency stimulation of inputs.

-Long term Potentiation (LTP)

Potentiation of Epsps lasting hours or more.

1) Homosynaptic LTP 8-11

2) Heterosynaptic LTP: simultaneous input @ two synapses leads to potentiation of transmission through single synapse later. AMPA & NMDA receptors for Glutamate can mediate this 'associative LTP'

Increase conductance Of AMPA receptors ← Stim Ca^{+2}/calmodulin Kinases; (PKC) ← Depol thru AMPA receptors releases Mg^{+2} Block of NMDA receptor & Ca^{+2} enters neuron.

Lecture #9: Properties of Sensory systems

I. **Performance:**

Sensitivity - eg. Vision: 10-15 photons

audition: 10nm movement of eardrum

Dynamic Range - auditory : 10^{12} (120 dB)

Discrimination/Recognition- eg. Face recognition/Discrimination

II. **Sensory Specificity:**

"Law of specific Nerve Energies"

(muller's doctrine)

Sensory experience/perception is dictated by the neurons that are active-not the sensory stimulus e.g. mech. Stim of retina

Implications for correct connectivity

Lecture #9 cont.

If sensory pathways are incorrectly routed (inapprop. Connections), perceptual errors would occur.

e.g. 1) Synesthesia: Sensory perception is not, in some cases, matched specifically to the sensory stimulus.

2) Adapt. / Fatigue of Detectors in Brain (cogitate……cogitate)

III. Sensory Receptors T9-1

1) Types

Chemoreceptors (smell, taste)

Mechanoreceptors (touch, hearing, balance)

Photoreceptors (vision)

Electroreceptors

Thermoreceptors

Magnetoreceptors

2) Specificity (tuning)

Lecture #9 cont.

3) General Functional Properties:

a) Transduction

Stimulus→ Receptor Potential (change in memb. pot. of receptor)

; channels are non specific. 'Generator Potential' if A.P. s are produced.

b) Encoding Stimulus Strength 9-4

stimulus ampl. Is coded by amplitude of receptor potential & Spike (A.P.) rate of the primary sensory neurons.

9-5, 9-6

Pacinian corpuscle example: log. Relation 9-7

between stim. Strength and Generator Potential

Saturation @ high stimulus strengths

c) Temporal Variation of Responses 9-8

1) Tonic (e.g. Proprioceptors)

2) Phasic (Adaptation) 9-9

3) Many Receptor Potentials have phasic & tonic components

phasic = detect rate of change in stimulus ampl. 9-10, 9-11

Lecture #9 cont.

IV. Common Features of Sensory Systems

1. Receptive fields of Sensory Neurons 9-12

center-surround organization: lateral inhibition gives contrast enhancement 9-13

2. Range Fractionation

Individual receptors respond only over part of the range in stimulus property that the entire system is sensitive to. 9-14, 9-15

e.g. color (wavelength) selectivity of cones 9-2

Combinatorial processes $\rightarrow$ Perception of many categories

Lecture #9 cont.

V. Principles of Organization of Sensory regions-Brain

1) Topographic Organization

a) Mapping of sensory surface 9-16

somatotopic maps

Cochleatopic (tonotopic) maps

Retinotopic maps

b) Computational Maps

a computed variable (info.) is mapped.

2) Columnar Organization

(functional) 9-17

Neurons in a 'column' are functionally similar

computational map "nested" w/I a topographical map of the peripheral receptor array.

Lecture #10: Coding & Control of Sensory Information

I. Coding: How is information coded using A.P.'s? Morse code analogy

1) Coding stimulus strength

10-1

- Stronger stimuli cause larger receptor/generator potentials
- Dynamic range: Spont. To 100-300 spikes/s
- Firing Rate $\propto$ log stimulus strength
- Adaptation 'resets' operating range

(perception $\therefore$ is subjective)

Lecture #10 cont.

2) Coding stimulus 'quality'

Identity

a) Labeled line code/concept

: Elaboration of 'specific nerve energies' concept

- Individual Neurons convey info. About a specific aspect of a stimulus.

10-2

Examples: 1) Chemoreceptors, blowfly

2) Somatosensory system- 'phantom limb' sensation

b) Population coding:

Stimulus is coded in the pattern of activation of a population of neurons. 10-3, 10-4

e.g. Encoding of 'tilt' in statocyst organ-Lobster

****These two coding strategies ARE NOT mutually exclusive!!!**

Lecture 10 cont.

- Precise determ. of body angle: Pattern of activity w/i the array must be decoded.

c) Coding info in the temporal pattern of activity

1) Temporal code- Ex.: Neuromasts in Lat. Line 10-5
   - modulation of spike rate of Afferents codes water movements relative to fish

   ∴ Flow direction & rate is coded.

2) Calls of Frogs-Coding call identity in temporal pattern of activity; how is this info. Decoded?

Lecture 10 cont.

III. Efferent Control of sense Organs & their output

: output of receptors is modulated by the central nervous system

1) Functions of Efferent Control

a) 'smoothing' of motor responses 10-7,10-8,10-9

e.g. muscle spindle - stretch reflex

b) Compensation for <u>Reafference</u>

Exafferent	vs.	Reafferent
↓		↓
External stimulus causes receptor response		Due to own motor activity

10-10

e.g. Lateral line-swimming

1) inhibition of receptors
2) Cancellation of expected Reafference

<u>Efference Copy</u>

Lecture 10 cont.

c) Protection

e.g. Hair cells in Ear (cochlea)

-damage by loud sounds is minimized by contraction of middle ear muscle

Lecture #11: The Visual System

I. Performance - vert. Eyes

A) Resolution: ~ 1 min of ARC (1/60 degree)

B) Positional •Hyperacuity : 2-5 secs. of ARC

1) Vernier Acuity

2) Spatial modulation

-Foveal Receptors separated by 25 secs ARC

II. Vertebrate Visual System

1) Eye & Photoreceptors 11-1

a) Cone vs. Rod receptors & vision 11-2

11-4

-Cones= concentrated in Fovea, less sens. to light, mediate color vision-3 types 11-3

-Rods= very sensitive, not color. Nocturnal animals have mostly Rod receptors

Lecture #11 cont.

2) Transduction

a) Photopigments = Rhodopsin (Retinal & opsin)

Blue, Red, Green Cones differ in type of Opsin

b) Biochemistry of phototransduction

Isomerization (by light) of Rhodopsin 11-6

↓

Closure of "Na^+" channels

-hyperpolarization

c) Adaptation (adjusting sens. of photoreceptor)

Dark - channels are open Na^+ & Ca^{+2} Flowing into

↓ receptor-depol.

Ca^{+2} 'Brake' on cGMP synthesis Removed

Light - closure of channels - saturation ; reduced Ca^{+2} ,

↓ now cGMP levels rise & some channels open

Additional light - Closure of some open channels

Lecture #11 cont.

3) Anatomy & Physiology of the Retina

a) Cell types 11-7

b) Response to light T11-1

- Center-surround receptive fields

  Bipolar 11-8, 10

- 'on-center' vs. 'off-center' types 11-9
- Ganglion cells; on-center off-center (from cnxs w/ bipolars) 11-11

4) Central Visual system: Anatomy & Physiology 11-12

a) LGN (Lat. Geniculate N.) 11-13

- Laminar segregation of m (motion) vs. P (position) input

- Like ganglion cells: center-surround

  ON-center

  OFF-center

Lecture #11 cont.

*LGN receives 'descending' feedback from cortex
search-light hypothesis

b) Visual Cortex 11-14

1) Simple, Complex Cells 11-15

sensitive to orientation of an edge 11-16

simple cells- position & orientation 11-17

complex cells- orientation & movement

2) Hierarchical, Serial Processing 11-18

Additional features are extracted @ each successive level.

3) Mapping of Computations

(topography of Function)

a) orientation columns 11-20

b) ocular dominance columns 11-19

Lecture #11 cont.

4) High-order visual processing:

a) MT - motion of visual images

b) Temporal Cortex - complex form

e.g. Face recognition. Neurons respond to particular faces.

III. Invertebrate Visual Systems

1) Eyes - 1^{o} = spatial resolution

a) Molluscan eye 11-22

b) Insect eye: 11-23

compound eye- 11-24

many ommatidia.

Each facet = cornea of ommatidium photoreceotors. Depolarize when light strikes them.

11-26

Rhabdom: From the rhabdomeres of the visual cells (this is the light-sensing structure)

Lecture #12: Hearing: The Auditory System

I. Sound: Sound 'waves'

a) Production

alternation of compression
& rare faction of air molecules

b) Propagation In air, sound wave propagation @ 330 m/s

c) Frequency $\therefore \quad \frac{\text{velocity}}{\text{wave length}} = \text{Frequency}$

e.g. $\frac{330 \text{ m/s}}{1 \text{m/cycle}} = 330 \text{ cycles/s}$

330 Hz

Lecture #12 cont.

(one class of sounds)

II. Communication Signals

1) Differentiation of Comm. Signals

Frequency structure

Temporal Structure

(e.g. how frequency & or Amplitude changes over time)

2) Coding & Decoding of Signals

How does the auditory system discriminate & recognize so many different sounds?

III. Vertebrate Auditory System 12-1

1) Overview 12-2

2) Cochlea - Transduction 12-3

a) Mechanics (Basilar & Tectorial membs.) 12-4

b) Hair cells & Receptor potential 12-5

@ threshold, stereocilia move about .3 nM @ tip!

Lecture #12 cont.

Bending stereocilia toward tallest ones--opens channels
Bending stereocilia toward shortest ones--closes (ion) channels

opening channels -- Depolarization
closing channels -- Hyperpol.

$[K^+]$

K^+ carries most of current

C) Tuning: auditory neurons respond best to particular frequencies 12-6

1) Passive tuning- mechanics of Basilar membrane
2) Active tuning
   a) Electrical : Resist., Cap. & Voltage Dependent g's (K^+, Ca^{+2} channels)
   b) Biomechanical : outer H. C. 's actively lengthen & shorten

Amplifier

Lecture #12 cont.

3) Response properties of auditory 1° Afferents (Neurons)

1. Frequency tuning 12-7
2. Temporal coding (pattern of A.P. 's produced over time)

e.g. Amplitude modulations

IV. Interpreting Sound Stimuli-

****How are unique spatio temporal patterns of activity in 1° Afferent array READ?**

1) Pattern Recognition (analyzing/identifying sounds) 12-8

a) Frog calls: 1) Peripheral specializations (Freq.)
2) Combination-sensitive neurons
3) Temporal tuning of Neurons

Lecture #12 cont.

Combin. Sensitivity
(frequency)

Temporal tuning-
For rate of pulses

2) Locating Sound

Interaural Amplitude & timing differences-

sound arrives first & is loudest @ ear, closest to sound source

12-9

12-10

-Map of sound location ('space map') Computational Map

Lecture #12 cont.

3) Other Computational Maps

-Biosonar, Bats

a) Target Relative Velocity

CF/CF map (use Doppler shift info.)

b) Target Range

FM/FM map (use delay info.)

4) Hearing in Insects:

a) organs 12-13

b) Functional aspects 12-14

Lecture #13: The Chemical Senses

I. Vertebrate Chemosensory Systems

A. Anatomy

1. Gustatory System (taste) 13-1

-clusters of receptors = 'taste buds' 13-2

-pathway (Primate)

Tongue → VII Facial → CNS
IX Glossopharyngeal
Throat → X Vagus

2. Olfactory System (Smell)

-receptors send axons → Olfactory Bulb 13-3

↓

Other cortical areas

B. Transduction

Sensitivity: Single molecules (of odorant) elicit responses in receptor cells

Lecture #13: The Chemical Senses

1. Gustatory Transduction 13-5

a) "Sour", salt receptors

(acids) Compounds have direct action @ ion channels

b) "Sweet"

Act via 2nd messenger pathways

Sucrose - Receptor

↓

G protein Activation

↓ *Protein kinase A

adenylate cyclase cAMP ↓

closure of K^+ channels

c) "Bitter"

Diversity of Actions - Direct action on channels 13-6

2nd messengers

These primary 'tastes' are mapped in CNS: N. solitary tract

Thalamus (VPM)

*Pontine taste N. (parabrachial)

Lecture #13 cont.

2. Olfactory transduction 13-7

a) **Stage 1**: Binding of odorant to Proteins (mucosal)

↓

Binding to receptors (membrane)

> 1000 Receptor types ?

b) **Stage 2**: Transduction 13-8

2 pathways

G. Adenylate cylase → Produce cAMP → open ion channels

Adapt.

G. Phospholipase C (PLC) → IP_3 → open ion channels 13-9

3. Central Nervous System (Brain)

-Coding of olfactory information Animation 13-10

a) sensory performance: thousands of odors can be discriminated

b) Neural coding: convergence

13-11

5,000-10,000 single "glomerulus"

1° olfactory Neurons

Lecture #13 cont.

Glomerular Function: Olfactory Neurons of similar 'tuning' project to (Receptors)

13-11

Same Glomerulus ; about 2000 glomeruli

$\therefore$ 2,000 odors represented

II. Chemoreception - Invertebrates 13-13

a) Transduction: G-protein based

Some use cAMP, IP_3 2nd mess. System 13-15

b) Central Processing

Insects - Convergent Evolution w/ regard to glomerulus

**Both verts. & inverts. show glomerular organization @ 1st-order central station

1000-2000 receptors converge on each glomerulus

Issue of
Brain space
& Biol. Relevance

Macroglomeruli - Respond to sex pheromone

Lecture #14: Somatic & other Senses

I. Vertebrate Somatosensory System

A. Pathways

14-1

Lemniscal : "Touch Pathway" - Fast

Spinothalamic: "Pain Pathway" - Slow

B. Receptors

1. Temperature & pain receptors

-thermoreceptors

-Nociceptors

'Receptors' are Free Nerve Endings

2. Skin Mechanoreceptors

14-2

Time course Of adaption		
		a. Light touch: Hair follicle receptors Some free nerve endings
Fast	←	b. Vibration: Pacinian Corpuscle
Slow	←	c. Pressure: Ruffini's end organ Merkel's Nerve complex

T14-2

Lecture #14 cont.

3. Internal (DEEP) Mechanoreceptors (Proprioceptors)

Joints & Muscles	Force
a. Ruffini Endings	Steady state
b. Pacinian Corpuscles	Changes in force
c. Golgi Tendon Organs	Muscle 14-3
d. Muscle spindle organs	Stretch
	(Actual vs. intended changes in muscle length)

C. Transduction

Stretch-Activated Channels

Nociceptors : Chemicals from damaged tissue activate receptors

Adaptation - Mechanical Basis (Pacinian Corp.) 14-4

Lecture #14 cont.

D. Central Processing of Somatosensory Information

1. Touch Discrimination 14-6

Fast adapting receptors encode velocity of mechanosensory stimulus.

2. Pain Sensitivity

Suppression of transmission by Endorphins released by Neurons in Brainstem

3. Somatotopic maps in cortex 14-7

Significance of multiple maps - not well understood.

II. Vertebrate Vestibular System

Mechanoreceptors mediate the sense of balance 14-8

Lecture #14 cont.

1) General Functions: Detection of:

-Position relative to gravity

-linear acceleration

-angular acceleration

Determined by structure of the sense organ

2) Vestibular organs:

a) Otolith organs 14-9

-Gravity sensors 14-14

-Linear acceleration sensors

b) Semicircular Canals 14-10,11

'Angular' Acceleration — Accel. Assoc. with turning head causes rel. movement of fluid & walls of canals

*Each unique rotational movement - unique pattern of activity within the population of canal afferents

Lecture #14 cont.

III. Electric Sense- Only vertebrates have electroreceptors

1) Passive vs. Active Electric Sense 14-15

2) Electroreceptors 14-16

a) Ampullary - tuned to low frequencies

b) Tuberous - tuned to higher frequencies that the fish generate

3) Transduction

Both receptor types depolarize in response to an electric field; Ca^{+2} currents are responsible for this depol.

IV. Magnetic Sense

1) Sharks and Rays

2) Other verts. - mechanism is unknown

Behaviorally demonstrated

Lecture # 15 & 16: Muscles, Reflexes & Pattern Generation

I. Functional Control of Skeletal Muscle

1) Anatomy 15-5

'Motor Unit' = motor neuron & muscle fibers it innervates

Verts. - Each. muscle fiber gets input from a signal neuron (motor units don't overlap)

Inverts. - overlap is common

2) Neural control 15-7

a) Control of muscle tension - Force

Recruitment of motor units - size Principle (smaller Fire First)*

Frequency control

Faster spike rate →more force

*Smaller motor neurons have higher input resist. V= IR; greater depol. (EPSP)

b) Matching of innervation w/ muscle type: 15-8

Fast, phonic → Fast-twitch muscle

Neural

Slow, tonic → Slow twitch muscle fibers

Lecture #16: Reflexes & Pattern Generation

I. Reflexes

1) Simple

16-1

e.g. stretch reflex

Direct cnxn. Or via inter neuron

2) Complex

16-2

-Coordinated Activation (Excitation) of some motor neurons & inhibition of others

-Reciprocal inhibition - usually between functionally antagonistic units

Lecture #16 cont.

II. Pattern Generation

1) Types

← Range →

Rhythmic behaviors (walking, digestion, calls (certain types))

Complex Sequence of motor commands (throwing an object, playing a piano, etc)

2)Mechanisms of Rhythmic Pattern Generation

a) Central pattern Generators

-not just a sequence of reflexes-

Deafferentation Exps: Rhythm persists despite lack of sensory (Reafferent) feedback

Models: Network vs. cellular properties 16-3

-Reciprocal inhibition model (network) 16-4

-Endogenous oscillator neurons (cellular) 16-5

Lecture #16 cont.

Experimental Evidence:

Lobster Stomatogastric Nervous System 16-6

1) Anatomy - General

2) Circuits & Rhythms 16-7

Cardiac Sac, Pyloric, Gastric Mill

a) Pyloric Rhythm

Laser ablation Experiments

-AB-PD = Pacemaker ; Endogenous Bursters

-Rhythm initiated by activity in 'command' inputs; once started, rhythm persists without further input

-Isolated ganglion can generate a rhythm (once initiated)

-Reciprocal inhibition does not generate the rhythm; controls the relative phase @ which neurons "burst"

Lecture #16 cont.

**Motor Pattern results from the combination of intrinsic 'cellular' properties (e.g. Voltage-dependent conductances) & connections between particular Neuron types

-Most cells are Endogenous Bursters

-Inhibitory Cnxs predominate

Post-inhibitory rebound

3) Neuromodulation of Pattern Generators - Remodeling of 'Functional circuits' 16-10

a) Classical view

'Hard-wired' - Fixed connections (Functional)

Circuits are immutable

b) Contemporary

Cnxs are plastic ; can be strengthened or weakened.
Neuromodulators determine the Functional circuit

Neurons can participate in multiple rhythms & behaviors

'PS' Example - Pyloric network switches to 'swallowing' Rhythm

Lecture #17: Sensory influence on Motor output

I. Compensatory Control

1. Stabilization, smoothing:

"closed loop" Behavior

a) Muscle Spindle System 17-1

coactivation

deviations from expected movement are detected by stretch receptors & compensatory ↑ or ↓ in motor neuron activity is produced.

b) Insect Flight 17-2

Deviations from flight path due to unexpected turbulence/wind gusts are detected by sensory system

-wind - sens. Hairs

-visual information

The sensory input (exafferent) provides compensatory signals to motor system.

Lecture #17 cont.

Pitch & Yaw: abdomen bends in opposite direction to correct course; wing adjustments to change lift

Roll: wing movements compensate (more or less lift on one side)

2) The Coordinating Effects of Sensory Feedback

a) Coordinating the relative timing (phase) of activity in multiple pattern generators 17-3

-Dog fish: Deafferent Tail, immobilize → 'Fictive swimming'

3-5 sec. Rhythm

* This Rhythm can be changed by moving tail @ different frequency

Lecture #17 cont.

Sensory feedback is required to appropriately set relative timing of oscillatory networks @ each segment for various swimming frequencies.

Locus Flight: stretch receptor set rhythm in this system too -General principle. The magnitude of change in rhythm due to sensory feedback varies.

17-5

Lecture #17 cont.

II. Other sensory motor interactions

1) Reflex Gating

17-6

Certain reflexes are only triggered when in particular behavioral context.

Reflex is Gated ∴ by behavioral state

e.g. Locus flight: sensory stimulation causes movements of wings & thorax only during flight (legs must not be touching ground)

2) Reflex Modulation

Effects of a stimulus (magnitude of reflex) changes as a function of the phase in the oscillatory cycle at which it occurs.

17-7

Lecture #18: Motor Output cont.-Beyond the CPG

1) General: Motor Hierarchy

Decisions

Motor Commands

Pattern generation, coordination of sequence

Reflex

Motor Neurons

2) Motor control in lower Vertebrates & Invertebrates

a) 'Command Neuron' concept

1) History

Invertebrates: Large, identifiable Neurons

Stimulation of individual Neuron

↓

Behavior organized motor pattern is output

Lecture #18 cont.

Examples: **Crayfish**: Lateral & Medial Giant Interneurons 18-2
(Escape behavior) **Fish**: Mauthner cells 18-B

2) Definitions - In order to be a "command neuron", must be Necessary & Sufficient

* Necessary: Behavior cannot be elicited if this Neuron is removed
* Sufficient: Stimulation of the Neuron elicits the complete expression of the Behavior

3) Evidence-

Stimulate: Medial Giant Interneuron $\rightarrow$ Backward swimming
Lateral Giant Interneuron $\rightarrow$ Upward swimming

Sufficient (Activation organizes complete escape sequence)
BUT NOT Necessary (Other Neurons also can trigger the Behavior with longer latency.)

Lecture #18 cont.

Mauthner Neurons: same - Sufficient, not Necessary

Remove Neuron, Escape can still be triggered but @ longer latency

B) Command "Networks"

(small population of Neurons for controlling behavior)

Leech swimming: Parallel & Hierarchial organization 18-3

Parallel - Swimming can be activated via several parallel paths

Lecture #18 cont.

3. Motor Control in Vertebrates

a) Brainstem motor control 18-5

-Vestibular & Reticular Nuclei:

mediate postural control

(spinal animal = not able to stand)

medial vestibular N. → controls eye movement VOR 18-6

-Mesencephalic locomotor Region:

Triggers walking (cats)

Triggers swimming in lower verts (fish)

SPEED of locomotion strength of stimulation

*If brainstem severed between diencephalon & midbrain, cats can still maintain posture and walk if on a treadmill. Can not make voluntary movements

Lecture #18 cont.

B) Motor cortex 18-4

18-7

1) Primary motor corex

Anatomy: Pyramidal system: Direct projection to motor Neurons (parallel to input to control of brainstem Nuclei)

-Controls Distal musculature (fingers, hands, feet….)

Physiology: Four main classes of Neurons 18-8

Code 1) 'Static' - Force: fire tonically to force maintained

2) Dynamic - Respond only when changes in force are made

3) Intermediate between 1 & 2

4) Directional - Respond best for particular direction of movement

Discuss further using Saccodic eye movement example

**Broadly tuned, 'Range Fractionation' 'movement fields'

Lecture #18 cont.

C) Superior colliculus: (s.c.)

A 'Motor Map' (for eye movements)

saccades = rapid eye movements

* Saccade metrics (direction & magnitude) are mapped in the superior colliculus

Lecture #18 cont.

1) Individual S.C. Neurons have broad 'movement fields'

(tuning -motor-)

2) Consequently, for any particular movement, many Neurons in the MAP are active.

3) This is a Computational Map

Saccade direction & magnitude must be computed; desired eye position -current eye position

"A to B to C exper."

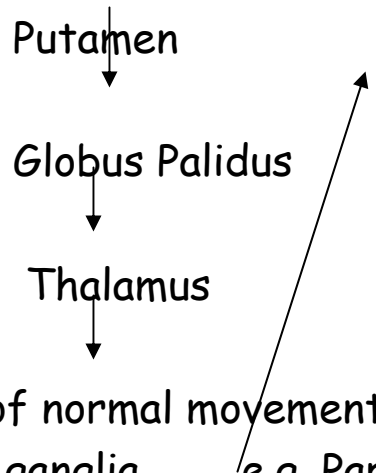
Lecture #18 cont.

D) Premotor & Supplementary Motor Cortex 18-7

-Function to plan (orchestrate) complex movements & postural adjustments, (Details of how they do this is unknown). Also, planning adjustments in motor output based on anticipated loads.

E) Roles of the Basal Ganglia 18-19

1) Anatomy: MI, MII, Premotor Cx 18-10



2) Function: Planning of normal movements cannot be executed w/out intact based ganglia e.g. Parkinson's, Huntington's Diseases

*Details of Function of basal ganglia in motor performance aren't clear.

Lecture #18 cont.

F) The Cerebellum:

1) Divisions: Cerebrocerebellum 18-12
Vestibular "
Spino "

2) Circuits (Anatomy) 3-17
-Sensory input via mossy fibers 18-13
-Parallel fiber system = difuse
-Climbing Fibers = specific (local)
(inferior Olive)

3) General Function: Calibration
VOR Example: adjustment of, gain of eye movements in response to vestibular stimulation.

Plan/coordinate complex, multi-joint movements

Lecture #19: Mechanisms of escape behavior

How are sensory & motor systems integrated to produce behaviors?

I. Neuroethology:

Neural Basis of 'natural' Behavior (Behaviors that animals exhibit in nature, and are important in their survival)

-Robust Behaviors are studied

-Behavioral analyses set up hypotheses concerning neural processing

-Biologically important stimuli are used in Neurobiological Expers.

II. Neural Basis of Escape Behavior

1) Startle response of fish

Lecture #19 cont.

A. General Features of startle (escape) responses

-Fast - Latency of (only) < 10ms

-Directed - sensory info. is integrated to determine the correct direction of escape.

-Controlled by a set of 'command-like' Neurons;

Mauthner Neurons is largest (pair) 18-B

∴ Redundancy of Neural control

Fish still perform escape responses when Mauthner cells are removed, but latency is greater. 19-8

Coordination of Neural commands for escape w/ those of CPG's 19-9 controlling Rhythmic activity (swimming)

[Cordination of Escape w/other motor patterns]

B. Sequence of Activity in the 'Escape Circuit'

Lecture #19 cont.

Coordination: If triggering stimulus occurs @ time when body muscles are contracting on the 'stimulus side', the ongoing motor pattern must be suppressed before the escape Response (control contractions) can be initiated

Lecture #20: Analysis of simple Behavior

1) **Servomechanisms**: Feedback loops 20-1

-Thermostat Example; hypothalmic control of temperature

-Muscle Spindle: sensor of muscle stretch other than that expected

∴ comparator 20-2

Motor Neuron = integrator

Sign of Feedback: Positive (Excitatory)

Negative (Inhibitory)

2) **'Open Loop' systems**: Circuits that lack feedback control of ongoing output; **Feed forward sometimes present.** 20-4

a) Vestibular-Ocular Reflex (VOR) 20-5

Vestibular sensory info about head turn is sent to the oculomotor system

Visual info. used to Evaluate error

Feed forward signal (vestibular info.) is sent to cerebellum for calibration of the reflex gain

Lecture #20 cont.

3) Sensory computations & the control of Behavior:

Case study: The Jamming Avoidance Response (JAR)

a) Behavior: change in frequency of Electric Organ Discharge (EOD) 20-7

EOD frequency set by pacemaker (CPG)

b) Properties of the sensory signals 20-8,9

c) Behavioral analyses of computations that underlie the decision to change the EOD freq up or down

*Model system for studying the Neural basis of Decision making (Discrimination of sensory stimuli).

Freq Jamming signal < Fish's own EOD freq

Clockwise (adv w/ ampl. ↑)

(delay w/ ampl. ↓)

Counterclockwise (adv w/ Ampl ↓)

(delay w/ Ampl. ↑)

Freq, jamming signal > Freq. Of own EODs

∴ Analysis of temporal patterns of phase modulations & amplitude modulations "tells" fish which way to "go"

Lecture #20 cont.

*Proof: Presenting fish with amplitude modulations (changing the amplitude of the signal that the fish senses) alone or phase modulations alone, → does not enable the animal to decide which way to change its pacemaker (EDD) Frequency.

D) Neural control of the JAR — 20-10

1) Peripheral coding of Amplitude & phase info. — 20-11

2) Computation of ampl. Changes (modulations) — 20-12

parallel processing Of these Two types of info.

ampl. ↑ vs. ampl. ↓ — 20-10

3) Computing <u>phase difference</u> — 20-13, 20-10

Adv vs Delay

4) Combination sens. Neurons — T20-1

"sign selectivity"

5) Resolving Ambiguity: sign-selectivity regardless of orientation (spatial) of jamming signal Field. — 20-14

Lecture #20 cont.

Pre Pacemaker Nucleus: "Grandmother" cells for discriminating the "sign" of the Frequency difference (DF). (Jamming Freq - Fish's own EOD Freq)

The activity of Prepacemaker Neurons, unambiguously codes the sign of DF

The decision to ↑ or ↓ the EOD freq. Is unambiguously represented in the firing of Pre Pacemaker Neurons.

∴ Amplitude & phase Difference info. Is coded in <u>spatio temporal</u> activity of populations of Neurons @ lower levels of this Hierarchy.

This spatio temporal pattern is read by Neurons that integrate ampl. & phase difference info. To respond selectively when <u>combinations</u> are present.

The Decision:	**Torus**	**PPn**
	Is evident in the Activity of a population	Evident in the Activity of individual Neurons

Lecture #21: Neural Basis of complex Behavior

I. Neural Activity & Complex Behavior

1) Spatial Analysis: Hippocampus

"place cells" - Activity is correlated with the animal's position within arena. 21-7

Place fields are BROAD ∴ many Neurons are active when the rat is @ any particular location.

Ambiguity Issue: The activity of individual Neurons does not code place unambiguously.

The rat's position can only be determined from the collective firing of the population; for each spot in the arena, a unique constellation of activity in the population of hippo. cells exists.

∴ Activity of particular Neurons does not reliably indicate 'place'

Lecture #21 cont.

2) Functional Analysis of human brains 21-1A

a) Techniques: non invasive measures of "Activity"

PET - Positron Emission Tomography: Radioactive subst. (^{15}O) is given.

Decay ⟶ Positrons collide w/electrons ⟶ gamma rays

fMRI - functional Magnetic Resonance Imaging. High frequency radio signal is adjusted to resonant freq. Of Protons.

In a high strength magnetic field, measure release of electromagnetic radiation when radio signal is turned OFF.

[Proton] = high in H_2O → Measures water content of brain regions - Δ's in water content reflect activity changes (because blood flow is ↑ed)

Changes in Oxygenation → alters magnetic properties of hemoglobin

Lecture #21 cont.

b) Localization of Function in Cerebral Cortex

1) Language

Classical:	Broca's Area	Wernicke's Area
	↓	↓
	Production	Analysis
	(Generating Speech)	(Deciphering & understanding speech)

*Noninvasive functional mapping confirms that the two regions have different roles in language; classically, determined from stroke patients

**Functional mapping provides a more detailed picture of regional differentiation of Function

e.g. saying verb approp. for particular noun.

Lecture #21 cont.

2) Lateralization - Role of Corpuse Callosum 'Split Brain' patients 21-9

The two cerbral hemispheres (left vs right) receive different info and control, in part, different functions

-sensory info. From right → left hemishphere

-motor cx controls muscles on opposite side

-language = primarily left hemisphere

** ∴ a split brain patient can only describe vis. images shown in right visual field

Visual images shown in right visual field → left vis cx 21-10

-only right hand can correctly choose the appropriate object!

Left hemisphere visual info about object can't be transmitted to right hemisphere motor cx.

Lecture #21 cont.

Lateralization continued

Language is highly lateralized - but most functions are NOT

: Most functions are carried out by regions of BOTH hemispheres, although the contributions of each are not identical.

Generalization: Right = 'Holistic' , parallel Left = Analytical, serial

Lecture #23: Developmental Plasticity

I. Background: Intrinsic Factors

Crude topographic projections A → B → C
are made independent of activity

II. Roles of activity in shaping connectivity & function

1) Visual System

-Behavior : Blind from Birth Remove Cataracts

Individual does **not** achieve functional vision.

"Critical period" is prior to 12 weeks age

Lecture #23 cont.

-Neurobiology; visual development

A) LGN

-Segregation of eye - specific

inputs to LGN is activity dependent;

TTX blocks formation of normal cnxs.

•Intially, there is substantial overlap

•Synapses that are active synchronously w/ the greatest # of the other active synapses are strengthened, others are eliminated.

•Spontaneous waves of electrical activity in retina are sufficient to organize cnxs. 23-2

B) Cortex

-Oculardominance 23-3

(Extent cells are driven by stim. of one eye vs other)

-**Ocular dominance columns**: regions of cx where cells are primarily excited by stim. of one eye

Lecture #23 cont.

1) Role of activity in development of ocular dominance/Binocularity

"Frosted" Lens gives Same result

Monocular Deprivation (close one eye-open after 3 month age)

*cx cells now excited only by eye that remained open 23-4

[Retina & LGN are normal] 23-5

Further orientation is disrupted

Binocular Deprivation - then open both after 3 months

**Now, cortical cells can be driven by one or the other eye. Strong ocular dominance organization but very few 'Binocular cells' 23-6

Closing an eye after 2-3 months has no effect.

∴ A 'critical period' exists during which competition for establishment of synapses on cortical cells takes place - Activity - dependent stabilization of synapses.

Lecture #23 cont.

2) Activity Dependent formation of the auditory space map - owls

a) Background

Interaural Intensity diff: Elevation (vert.) 12-9

Interaural Time diff: Azmuith (horizontal)

b) Plasticity:

1) Earplug Exps.

-plug before/during critical period

*Adjustment is made in auditory system

*Visual & auditory spatial maps are aligned (receptive fields of tectal neurons are same for vis. Or aud. Stimuli)

-plug as adult, NO adjustment - permanent mis-alignment

2) Visual Prisms Exps: if owl prism goggles during critical period, auditory map realigns to match visual one!

Lecture #23 cont.

"Eye instructs the Ear"

∴ Visual & auditory receptive fields of Tectal Neurons regain alignment as a result of plasticity within the auditory system--Even the visual info is incorrect (owl makes errors when it strikes @ targets).

III. Molecular Mechanisms of Development Plasticity

1) Neurotrophic factors: NGF, Neurotrophins, BDNF

Blocking these factors → prolongs the critical period

Adding (infusion into cx) → blocks the effects of differential activity

2) NMDA-type Glutamate Receptors: (mediate LTP); 8-11

NMDA receptors are most abundant during critical period.

Visual cx

Blocking NMDA receptors (infusion of APV):

-Blocks formation of orientation selectivity

-Blocks effects of monocular occlusion

Owl MLD

'New Connections' (mediating realignment in prism exps) are primarily of the NMDA type

Lecture #23 cont.

After critical period, new cnxs change to 'combined' AMPA/NMDA pharmacology.

III. Plasticity in the adult brain

1)Somatosensory system: 23-8

If innervation of particular regions is eliminated, cortical neurons that normally represent that skin surface become responsive to stimulation of intact, neighboring regions of skin. Neural basis of 'phantom digit' sensation

2) Rich vs. impoverished Environ. Experience

"complex" "simple"

Rats in complex environments have more 'developed' brains

-more elaborate dendrites & synaptic density

-solve maze problems more easily

Lecture #24: Behavioral Plasticity Learning

(Plasticity in adults)

I. Simple forms of Experience- dependent plasticity:

1. Modifiable Efference Copy

Electric fish; cancel expected reafference from:

-Electric organ discharge (effects on ampullary receptors)

-Ventilation

Plasticity: Efference copy (Negative image of expected reafference) must be calibrated.

Lecture #24 cont.

2) Habituation : Decline in Response with repeated stimulation

ex. Gill withdrawal reflex of Aplysia 24-1
24-2

Mechanism: synaptic Depression

-Depletion of readily releasable vesicles

-Inactivation of Ca^{+2} channels

3) Dishabituation/sensitization 24-3

-Dishabituation - Recovery from habituation due to Novel stimulus

-Sensitization - Strengthening of a reflex, due to stimulus that does not elicit "alerting" the reflex

Mech. = Presynaptic, heterosynaptic facilitation 24-3

'5HT' : G-Protein mediated closure K^+ channels, $\uparrow Ca^{+2}$

" " "$\uparrow$ readily releasable pool of vesicles

Lecture #24 cont.

4) Associative Conditioning (learning)

a) Behavior

U.S. "unconditioned" stimulus (eg. Food)

C.S. "conditioned" stimulus (eg. Bell)

Pairing Rule: CS must precede US

Aplysia 24-4

U.S. = shock to tail

C.S. = Gentle touch of mantle

Pairing CS, US → assoc. condition. Now touching mantle causes strong withdrawal of Gill

* Not just sensitization, because response to siphon stimulation still small.

Lecture #24 cont.

Associative Conditioning

B) Mechanism : Aplysia

-Effects of C.S. & U.S. converge in activating Adenylyl cyclase

-Enhanced release is specific to the presynaptic terminals that are active during pairing

-"Memory" is in the PKA - mediated phosphorylation & closure of K^+ channels

: Reverse Pairing- US, CS does not give assoc. conditioning & does not cause enhancement of Adenylyl cyclase activity. Why Not??

C) LTP - heterosynaptic

May mediate assoc. conditioning

Phosphorylation ↑ 's sensitivity of AMPA R

Lecture #24 cont.

II. Types of Complex Memories

1) Declarative Memory:

Recalling experiences; Facts, Events and their relationships(particularly temporal order)

"Recall" = bring to consciousness

2) Procedural Memory (non Declarative)

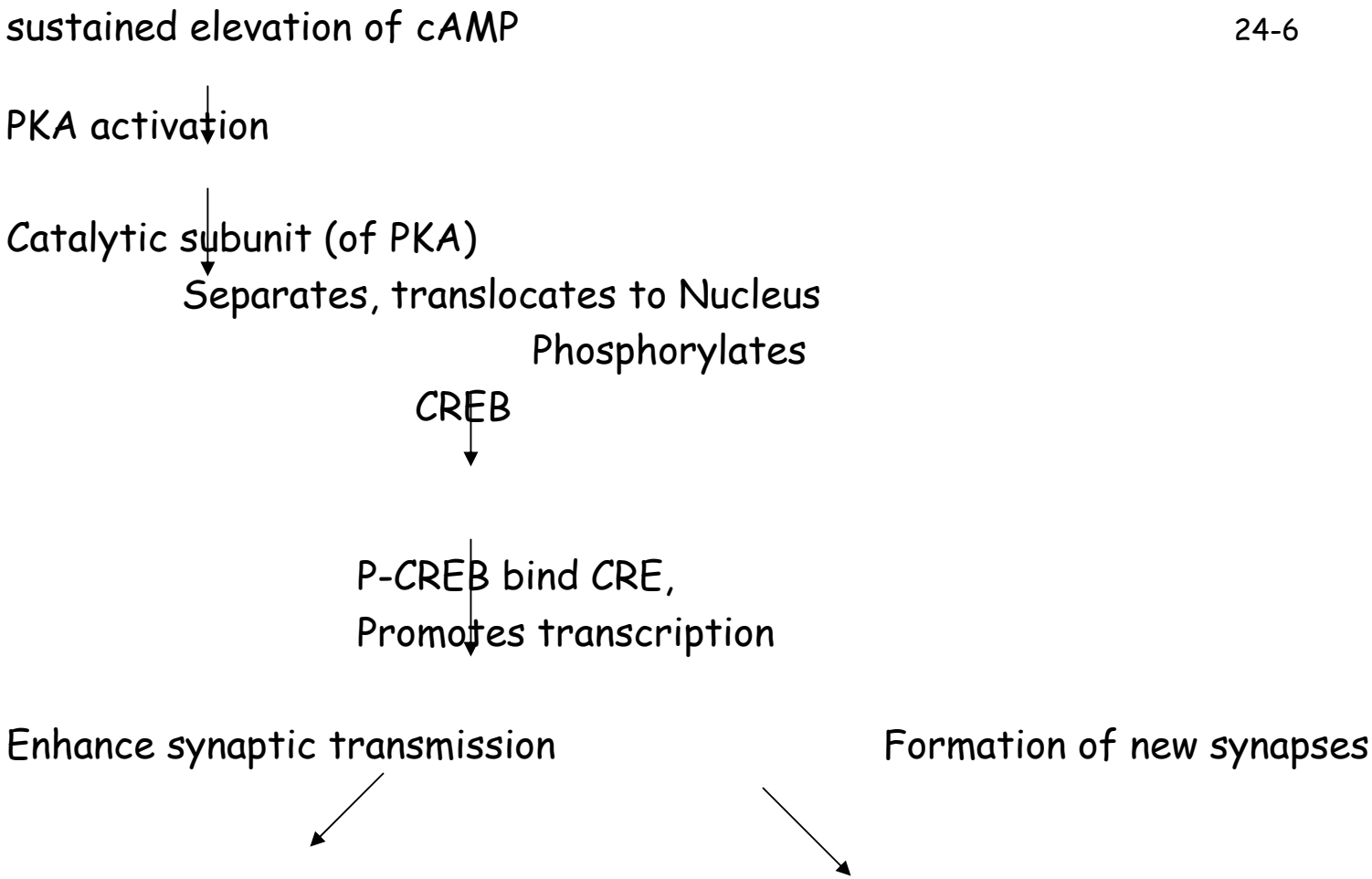
-"motor learning"

Simple forms of learning (habituation, sensitization) also are "Nondeclarative"

Short-term vs. Long-term Memory

Lecture #24 cont.

III. Long-term Memory Formation



Lecture #24 cont.

IV. Memory Storage

1) How localized are memories?

Lashley's experiments

-Rats, maze learning

-Distributed representation

? Inconsistent with synapse-specific learning in Aplysia?

NO -Complexity of info. used by rats in maze learning

-VOR, conditioned eye blink show localized synaptic changes

2) Hippocampus - mammals, required for consolidation of long-term memories

-but memories do not reside there.

Lecture #25: Hormones and the nervous system

I. The Neuroendocrine System:

Nervous system ⟷ Endocrine system

Traditionally viewed as separate systems, now single.

II. Examples of effects of hormones on nervous system:

1. Insect metamorphosis: 25-1

Ecdysone ('molting hormone', steroid) → Eclosion hormone then triggers molting 25-3

↓ Initiates developmental changes required for molt

eg. Stimulates new cuticle formation

Released by endo. Gland, stimulates growth of ipsilateral dendrites of MN-1 (motor neuron). Ensures that MN-1 responds when sensory input arises from either side 25-4

Function: Change in morphology mediates change in behavior, Larval (lateral flexion vs. Adult (D-V flexion)

Drop in Ecdysone levels → Trigger for programmed cell death

Lecture #25 cont.

III. Action of Steroid Hormones on Vertebrate Brain:

Sexually dimorphic behavior and brain structures

General: Brain starts out female and must be masculinized by action of Hormones, e.g testosterone

A. Mammalian Reproductive behavior: Rats

1. Developmental effects of hormones: 25-7

___ Sex. Dimorph. N. of Preoptic area (hypothalamus):
- twice as large in males. Controls mounting behavior.

Anteroventral periventricular N. of Preoptic area
- Larger in females. Secrete Oxytocin ⟶ stimulates maternal behavior.

SDN-POA size: Due to early exposure to Testosterone.

Lecture #25 cont.

2. Control of sexual behavior, in adults, by particular brain areas, and hormones:

Medial preoptic area: Lesion, almost completely eliminates copulatory behavior in males, but not motivation to access receptive females (press bar equally frequently to access females)

25-8

Lordosis behavior (females): High levels of estrogen and progesterone are required for making female receptive act on ventromedial, & other hypothalamic areas. 25-9

B. Songbirds: Seasonal-hormonal regulation of behavior and nervous system

Vocal control nuclei: HVC (high vocal center) & RA (robust n. of archistriatum), largest in males 25-10

Seasonal plasticity: HVC and RA increase, in response to testosterone increase in Spring (trig. By day length). 25-11

Neurogenesis & increase in cell size and dendritic branching

HVC