The light bulb indicates topics that you are required to understand more thoroughly – that is, understand the implications, not just the mechanisms.

Basics I – Neurons:

• **Special** – designed for transmitting signals
  - Form & Size (name different components)
  - Requirements & Life Span
  - Function: fast & point-to-point transmission
  - Need glia cells (different types of glia)

• **Within: Bio-electrical**
  - Chemical processes at the cell membrane in general
  - Resting potential
  - Generator potential (electrotonic transmission) & action potential

• **Between: Bio-chemical**
  - Synapse: the point of contact
  - Neurotransmitter
  - Pre-synaptic / post-synaptic processes
  - Connectivity
Basics II – Structure:

• **Principles:**
  - Input – integration (temporal / spatial) – output
  - Convergence / divergence
  - Feed-forward / feed-back

• **3 systems for communication**
  - Immune system
  - Endocrine system
  - Nervous system

• **Specialisation:**
  - Endocrine system: slow / global
  - Nervous system: fast / local

Basics II – Structure:

• **Basic structures of the NS**
  - CNS vs. PNS

![Diagram of the nervous system structure and functions]

- Forebrain
  -Telencephalon
  -Diencephalon
- Midbrain
- Hindbrain
  -Spinal Cord

<table>
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<th>Structure &amp; functions of the CNS:</th>
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</tbody>
</table>
Basics II – Structure:

• **Input:**
  - Signals send via medulla & pons to midbrain and cerebellum
  - Further to thalamus: central relay station, sending signals to their respective primary sensory areas, receives input from cortex to modulate signal transmission

• **Output:**
  - Secondary motor areas (PMC and SMA) in frontal lobe => action planning
  - M1: final execution stage
  - Form complex control circuits with BG – motor initiation and inhibition of competing motor responses (e.g., PD)

**BUT: everything is interconnected with everything else!**

Vision 1

Eye:
Resembles automatic, digital camera
Focussing:
  - cornea (main),
  - lens (fine tuning – autofocus via accommodative reflex)

Retina:
Photoreceptors
  - Rods:
    - high sensitivity to light, scotopic (“night”) vision,
    - one type => no colour
  - Cones:
    - less sensitive, photopic (daytime) vision,
    - three types (R, G, B) => colour
Retina (continued):

**Macula**: small region of high acuity, mainly cone receptors

**Fovea**: very small central region of macula, highest acuity, cone density high, no rods

**Peripheral retina**: everything outside the macula, rods density high, cones density very low

**Blind spot**: region with no photoreceptors

**Layers**:
- **Nuclear**: contain cell bodies (of photoreceptors, amacrine, bipolar, horizontal and ganglion cells)
- **Plexiform**: contain axons/dendrites

**Ganglion cells**: output from retina to brain along ganglion cell axons (for the optic nerve)

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Ganglion cells (several types; two important ones)

(1) *parvo* (midget/small) cells, carry colour information
(2) *magno* (large) cells, don’t carry colour information.

**Receptive field (RF)**: region of retinal surface where stimulation affects ganglion cell response (roughly circular in shape)

**Centre-surround** RF structure: stimulation at centre of RF has one effect on ganglion cell (excitatory/inhibitory), stimulation outside the centre has the opposite effect.

**Two types of RF**:
- (1) on-centre (excitatory), off-surround (inhibitory);
- (2) off-centre (inhibitory), on-surround (excitatory).

**Perceptual effects** of centre-surround structure:
- Size of RF determines visual acuity.
- Mach bands: due to imbalance of illumination of centre and surround parts of RFs
Vision 2

Beyond the Retina:

Ganglion cell axons form the optic nerve.

Two pathways:

1. **Geniculostriate (GS) pathway** (conscious vision):
   
   retina $\rightarrow$
   lateral geniculate nucleus of the thalamus (LGN) $\rightarrow$
   striate cortex (or visual area 1, V1)

2. **Retinotectal (RT) pathway** (pupillary reflexes, reflexive eye-movements):

   retina $\rightarrow$
   superior colliculus (midbrain)

Vision 2

GS pathway:

Axons from left and right half of each retina (hemiretina) travel separately.

Images from **left** visual field
   project to the two **right** hemiretinæ;
   axons from these project along the **right** optic tract to the **right**
   LGN
   neurons in **right** LGN project to the **right** half of V1.

Images from **right** visual field
   project to the two **left** hemiretinæ
   axons from these project along the **left** optic tract to the **left** LGN
   neurons in **left** LGN project to the **left** half of V1.
Vision 2

Visual area 1 (striate cortex)

Retinotopic organization (nearby parts of retina represented in nearby parts of V1).

Cortical magnification:
Equal areas of retina not represented by equal areas of cortex
Fovea < 1% of retina, represented by > 20% of V1!

Cells in V1 have retinal RFs (areas of retina which when stimulated affect the cortical cell).

Example: simple cells
centre-surround type organization, but RFs elongated (not circular)
respond best to bar and edge shaped images (not spots of light)

Vision 2

Higher visual areas

Visual areas 2, 3, 4 and 5
Specialized for particular types of information (e.g., V5 for motion information, V4 for colour information)

Damage to V1 leads to blindness – cannot see those parts of the retinal image that project to the damaged region(s).

Damage to higher areas leads to specific visual deficits, but not blindness (e.g., cannot see movement if V5 is damaged; akinotopsia or “motion blindness”).

Embryonic Development

• **Background I: Genetics**
  - What are genes
  - Mammals: Autosomes and sex chromosomes
  - Chromosomal sex: XX vs. XY
  - Gametes are haploid – only one sex chromosome
  - Fertilisation combines male and female genes
  - Sperm determines sex of offspring

• **Background II: Steroid hormones**
  - Fat-like, can easily enter a cell
  - Produced by gonads (testes / ovaries) and adrenal gland
  - Types: Estrogens/progesterons, androgens (testosterone), corticosteroids (cortisol)
  - All produced by males and females, but in different ratios
  - Act by modifying gene expression within target cells

Embryonic Development

• **Sex determination in mammals**
  - Sex determined genetically: TDF gene on Y chromosome triggers male development
  - Discovery of TDF: translocation & incomplete chromosomes

• **Sexual development**
  - Embryos initially sexually undifferentiated
    - Separate precursor organs for male and female internal reproductive system (Müllerian duct, Wolffian duct)
    - One common precursor organ for external genitalia (urogenital groove)
  - Developing gonads ‘switch on’ TDF (if present)
    - Without TDF, all tissues develop into female organs, following their own intrinsic program (female development as ‘default’)
    - TDF triggers cascade of hormonally controlled processes, resulting in development of male body
Embryonic Development

• Problems with sexual development

  - Chromosomal disorders:
    - One sex chromosome only (X0: Turner syndrome; Y0)
    - Too many sex chromosomes (e.g., Klinefelter syndrome)

  - Hormonal disorders:
    - Congenital adrenal hyperplasia
    - Persistent Müllerian duct syndrome

  - Receptor disorder: Androgen insensitivity syndrome

  - Enzyme disorder: 5-α-reductase-deficiency syndrome

• WHAT DO THESE DISORDERS TEACH US??

Embryonic Development

• Brain development

  - Female-typical pattern is the default

  - Aromatisation:
    - (In rodents), hormones triggering male-typical form (e.g., SDN-POA) are estrogens, not androgens
    - Why don’t have all rodents male brains? Estrogens can’t enter the brain. Why have male rodents male brains?
    - Aromatase transforms androgens (which can enter the brain) into estrogens

  - In humans, mechanisms are as yet not known
    - Evidence against aromatisation theory: androgen insensitive XY females
    - Evidence for aromatisation theory: XX females who have been exposed to synthetic estrogens during embryonic development
Development & Learning

- **Sexual maturation in humans**
  - No (complete) sexual behaviour until puberty
  - Puberty: Hypothalamus secretes GnRH, which trigger a hormonal cascade resulting in maturation of reproductive system and development of secondary sexual characteristics
  - Event triggering puberty not known – possibly body mass?

- **Environmental influences on organisational effects of hormones**
  - Environmental factors can influence hormone levels => organisational effects => behaviour
  - Animal examples:
    - Uterine contiguity effect
    - Maternal stress effect
    - Gender-specific maternal behaviour
  - Effects for humans unknown – no sufficiently precise definition of gender-typical behaviour possible!

Development & Learning

- **Environmental influences on development of sexual behaviour**

  - Evidence for ‘sexual learning’ in rodents (raised in single-sex vs. mixed-sex groups)
  - For humans only anecdotal evidence – seems to indicate that learning is not important
    - 5-a-reductase-deficiency syndrome: ‘Girls’ seem to turn into ‘boys’ without apparent behavioural problem
    - Girls with CAH syndrome often described as ‘boyish’
    - Children raised by homosexual couples are not more likely to become homosexual
  - **BUT**: relevant learning might be indirect rather than resulting from direct teaching
## Development & Learning

**Biological basis of learning**
- Learning = rapid, intra-individual adaptation of one’s behaviour to the environment
- Memory = lasting effects of learning.
- Law of mass action (Lashley)
- Cell assemblies (Hebb)

**Basis:**
- Increased activity results in short-term molecular changes
- Which can result in long-term structural changes

**LTP / LTD:**
- Systematic strong input increases, systematic weak input decreases neuronal connectivity
- Role of NMDA receptors

## Development & Learning

**Fundamental Postulates:**
- Adaptation through evolution at macroscopic level
- Adaptation through learning at cellular level
- Relationship between behaviour, brain processes and brain structures
- Relationship between brain structures, genes, hormones, and environment
Development & Learning

• Brain structures involved in learning
  - Hippocampus – ‘gateway’ for learning new information
    - Evidence from patients; animal lesion studies; genetically modified animals
    - Memory pill??
  - Amygdala – involved in learning biologically significant stimuli
    - Evidence from lesioned animals and electrical stimulation experiments
  - Diencephalon (Korsakoff’s syndrome)
  - Cerebellum and basal ganglia (involved in motor learning and implicit learning?)

Development & Learning

• Hormones and neurotransmitters involved in learning
  - Adrenalin and noradrenalin: sympathetic arousal – ‘fight or flight’
    - Secreted in emotionally arousing situations
    - Experimental evidence for a role in memory: Picture & Story experiment
  - Acetylcholine: activates and facilitates learning (AD)

• Is human sexual behaviour learned?
  - Conceptual, methodological, ethical problems
Lecture 7 – Hormonal Control: Activational Level

- **Hormones and neurotransmitters involved in learning**
  - **Acetylcholine**
    - Activates and facilitates learning (AD)
  - **Adrenalin and noradrenalin**
    - Sympathetic arousal – ‘fight or flight’
    - Secreted in emotionally arousing situations
    - Promote memory (experimental evidence: “Picture & Story” study)
    - Promote “social bonding” (perhaps by promoting memory?)
  - **Oxytocin**
    - Released by the hypothalamus
    - Associated with emotionally charged situations
    - Possibly a ‘reward’ molecule?
Lecture 7 – Hormonal Control: Activational Level

- **Structures involved in (social) learning**
  - **Adrenal gland**
    - Cortex: hormonal control; secretes cortico-steroids
    - Medulla: neural control; secretes adrenalin
  - **Hypothalamus (!!!)**
    - Controls hormone secretion & ANS
  - **Cortex**
    - Analyses input
  - **Amygdala**
    - Evaluates input

- **A functional model of social learning**
  - Structures and hormones in action / negative feedback loops
  - Social bonding and sexual maturation: Oxytocin levels rise dramatically in puberty

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Lecture 7 – Hormonal Control: Activational Level

- **Sexual maturation in humans**
  - No sexual behaviour until puberty
  - Puberty: Hypothalamus secretes GnRH, which
  - trigger a hormonal cascade resulting in maturation of reproductive system and development of secondary sexual characteristics
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Lecture 7 – Hormonal Control: Activational Level

- **Sexually dimorphic behaviour:**
  - Reflects different priorities resulting from
  - different ‘costs’ of reproduction, expressed in
  - differences in hormonal control
    - **Males:** Presence, but not precise level, of sex hormones determines presence of sexual behaviour
    - **Female (non-primate) animals:** Level of sex hormones determines presence of sexual behaviour
    - **Female higher primates (including humans):** “emancipation” of sexual behaviour from hormone levels

- **Varieties of sexual behaviour (non-human animals):**
  - Different types of social/sexual relationship
  - Example: social suppression of reproduction
  - In humans: almost complete dissociation of sexual behaviour & reproduction

Lecture 8 – Structures

- **IF** sexually dimorphic behaviour exists, **THEN** there are bound to be sexually dimorphic structures.

- **Animal examples for sexually dimorphic brain structures:**
  - HVC of songbirds
  - SDN-mPOA in rats
  - Anatomically different structures correspond to different (sexual) behaviours (there’s experimental evidence for this relationship!)
  - Problems of finding similar differences in humans

- **“Sexually dimorphic” task performance in humans:**
  - Visuo-spatial, mathematical, motor skills, verbal fluency
  - All differences very small and not always reliable

- **Galaburda-Geschwind model:**
  - Men have less ‘symmetrical’ hemispheres than women
  - This is because of differences in prenatal androgen exposure
Lecture 8 – Structures

- Hemispheres are ‘functionally lateralised’
  - e.g., language processing mainly LH
- Areas of specialisation correspond (to some extend) with areas that show gender-specificity

- Evidence for hemisphere specialisation:
  - Invasive methods:
    - Wada test, electrical stimulation & lesion studies
    - Split-brain surgery
  - Non-invasive methods:
    - Patient studies (behavioural and imaging)
    - Visual hemifield presentation tasks
    - Dichotic listening tasks
- Results:
  - Women generally show less (behavioural, imaging) asymmetry

- Are male and female brains anatomically different?

Lecture 9 – Homeostasis (Eating)

- Homeostatic processes
  - Actively maintain the body’s internal states within a critical range
  - Are based on negative feedback loops (producing oscillating behaviour)

- Eating as a homeostatic process
  - Dietary requirements (nutrition & energy generation)
  - Food intake needs regulation (short-term & long-term control)
  - Why “feeling hungry” and “feeling full” can’t be the whole story
Lecture 9 – Homeostasis (Eating)

- **Organs & chemicals involved in**
  - Energy storage
    - Liver & muscles: short-term, in form of **glycogen**
    - Fat cells: long-term, in form of **fat**
  - Energy utilization:
    - Neurons – in contrast to all other body cells! – use glucose *directly*
    - All others: Free fatty acids directly; glucose only with the aid of **insulin**
  - Energy conversion:
    - Protein hormones **insulin** (2nd function!) & **glucagon**

Lecture 9 – Homeostasis (Eating)

- **Biochemical signals**
  - Insulin levels
    - Controlled by 3 different organ systems
    - Experimental evidence for & against control function
  - Glucose levels
    - Evidence for & against control function
  - Glucose utilisation
    - Evidence for & against control function
  - Other biochemical signals
  - Conclusion: there can’t be a single signal controlling it all…
Lecture 9 – Homeostasis (Eating)

- Signal integration & control: Hypothalamus
  - Special features of hypothalamus neurons
  - Input- & output-connections
  - Dual-centre theory of eating control:
    - VMH (satiety) – LH (hunger)
    - Experimental evidence in favour of this (electrical stimulation / lesion)
    - Experimental evidence against (e.g., rats defend their new weight)
  - ‘Higher’ brain areas participate in control – hierarchic control network

Lecture 9 – Homeostasis (Eating)

- Learning
  - Mealtimes, meal-associated cues, anticipation & sensory-specific satiety
  - Evidence: Anecdotal (humans) & experimental (rats)

- Mood
  - Increased meal size when feeling ‘blue’
  - Experimental evidence: subliminal presentation of mood-inducing words

- Fat tissue
  - Amount is actively controlled
  - Fat cells produce hormone leptin
  - Leptin is involved in control of eating behaviour:
    - Experimental evidence: genetically modified mice
    - A model of leptin control
    - No clear evidence for humans!
Biological rhythms: regular changes in behaviour & internal states
- Different length: infradian, circadian, ultradian rhythms
- Controlled by:
  - Endogenous generators (‘biological clocks’)
  - Exogenous cues (‘zeitgebers’)

Characteristics of sleep-wake cycle
- Co-varies with other biological rhythms
- Shows typical internal structure (e.g., cyclical sleep stages)
  - Sleep stages occur in roughly 90 min. cycles
  - Characterised by typical patterns of brain & muscle activity
  - Both overall structure and internal structure change over life time

Forebrain structures involved in sleep-wake cycle control
- SCN (‘master pacemaker’)
  - Nucleus in the hypothalamus (!)
  - Directly sensitive to light
  - Actively produces circadian firing rhythms
  - Lesion results in disturbed sleep-wake cycles
- Basal forebrain
  - Actively generates SWS

Brainstem structures involved in sleep-wake cycle control
- Reticular formation: ‘Wakes up’ the forebrain
- Locus coeruleus (adrenalin): Promotes wakefulness
- Raphe nuclei (serotonin): Promote sleep
- Pontine nuclei (acetylcholine): Trigger REM sleep
Lecture 10 – Biological Rhythms (Sleep)

- **Sleep deprivation**
  - Results in cognitive & motor impairment
  - Potentially fatal in animals
  - In humans (of course) this has not been tested

- **Evolutionary perspective**
  - Being asleep is dangerous
  - But virtually all animals do it
  - Therefore, it has to have some advantage – but we don’t know yet what it is…