Test4: Wednesday on:

week4 material – CH5 CH6 & NIA 😊

CAPE Evaluations – please do them for me!!

...ask questions  ...discuss  ...listen  ...learn.
now on to affection
The Chemical Senses: Olfaction
Brain mechanisms of smell:

1. Odor molecule representation: Odor images – basis for smell perception
2. Retronasal smell: Basis for flavor perception
3. Brain systems for emotions and cravings
<table>
<thead>
<tr>
<th>Operations</th>
<th>Orthonasal olfaction</th>
<th>Retronasal olfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stimulation route</td>
<td>Through the external nares</td>
<td>From the back of the mouth through the nasopharynx</td>
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<tr>
<td>Stimuli</td>
<td>Floral scents</td>
<td>Food volatiles</td>
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<td></td>
<td>Perfumes</td>
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<td>Smoke</td>
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<td></td>
<td>Food aromas</td>
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<td>Prey/predator smells</td>
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<td>Social odors</td>
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<td></td>
<td>Pheromones</td>
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<td>MHC molecules</td>
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<tr>
<td>Processed by</td>
<td>Olfactory pathway</td>
<td>Olfactory pathway combined with pathways for taste, touch, sound and active sensing by proprioception form a ‘flavour system’</td>
</tr>
<tr>
<td></td>
<td>influenced by the visual pathway</td>
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</tbody>
</table>

Note the interesting contrast, that orthonasal olfactory perception involves a wide range of types of odors processed through only the olfactory pathway, in comparison with retronasal olfactory perception which involves only food volatiles but processed in combination with many brain pathways.
Brain systems involved in smell perception during orthonasal olfaction (sniffing in).

Brain systems involved in smell perception during retronasal olfaction (breathing out), with food in the oral cavity.

Air flows indicated by dashed and dotted lines; dotted lines indicate air carrying odor molecules. ACC, accumbens; AM, amygdala; AVI, anterior ventral insular cortex; DI, dorsal insular cortex; LH, lateral hypothalamus; LOFC, lateral orbitofrontal cortex; MOFC, medial orbitofrontal cortex; NST, nucleus of the solitary tract; OB, olfactory bulb; OC, olfactory cortex; OE, olfactory epithelium; PPC, posterior parietal cortex; SOM, somatosensory cortex; V, VII, IX, X, cranial nerves; VC, primary visual cortex; VPM, ventral posteromedial thalamic nucleus.

The hows…

- Animals depend on the chemical senses to identify nourishment, poison, potential mate
- Chemical sensation
  - Oldest and most common sensory system
- Chemical senses
  - Gustation
  - Olfaction
  - Chemoreceptors
The organs of Smell – it’s *not your nose* it is a thin sheet of cells high up in the nasal cavity!
Bipolar olfactory neurons are in the olfactory epithelium!

Dendrites form olfactory cilia.

Axons form CNI.

CNI

Axons (unmyelinated)

Cilia

Nasal cavity
Olfactory epithelium

- **Olfactory receptor cells**
- **Supporting cells**
- **Basal cells**

**The site of transduction**
- ORC are the site of transduction – unlike taste receptor cells, olfactory receptors are genuine neurons with axons of their own that penetrate into the CNS.

**Source of new receptor cells**
- These are similar to glia – help produce mucus too!

**Note to self: Olfactory receptor cells are neurons!**
Mucus-flows constantly & replaced every 10 minutes

Water based with dissolved mucopolysaccharides

Proteins, antibodies, enzymes, salts

Odorant binding proteins – concentrate odorants in mucus

Inhaled air

Odorants

Bacteria or virus

Olfactory bulb

Cribriform plate

Olfactory epithelium

Inhaled air
- Odorants: Activate transduction processes in neurons
- Olfactory axons constitute olfactory nerve
- Cribriform plate: A thin sheet of bone through which small clusters of axons penetrate, coursing to the olfactory bulb
- Anosmia: Inability to smell
- Humans: Weak ‘smellers’
  - Due to small surface area of olfactory epithelium
    Humans – 10cm² vs. Dogs – 170cm²
Olfactory Receptor Neurons

ORNs are bipolar neurons that have a single thin dendrite.

Dendrite has a knob that ends at the surface of the epithelium in the mucus.

Long thin cilia extend from the end of the dendrite.

Axon is thin and unmyelinated.

Cranial Nerve I – olfactory nerve.
olfactory transduction

odor molecules → detected by odorant receptors (in olfactory cilia)
Transduction (cont.)

G protein coupled receptors

\[ \rightarrow \text{cAMP} \text{ 2nd messenger} \]
\[ \rightarrow \text{opens ion channel (+)} \]
\[ \rightarrow \text{graded potential} \]
Olfactory transduction

- Odorants → bind to odorant receptor proteins
- G-protein ($G_{olf}$) stimulation
- Activation of adenylyl cyclase
- Formation of cAMP
- Open CA$^{++}$/Na$^{+}$ channels
- Ca$^{++}$-activated Cl$^{-}$ channels
- Membrane depolarization (receptor potential)
cyclic-nucleotide-gated ion channel

This is a cation selective cAMP-gated ion channel.
intracellular cation triggers Cl- channels to open.

I_cl- amplifies the signal
Recordings from an olfactory receptor cell

Odorants generate a slow receptor potential in the cilia

The receptor potential propagates down the dendrite and triggers a series of AP within the soma

Finally, the AP’s propagate continuously down the olfactory nerve axon
Receptor proteins have odorant binding sites on the extracellular surface in humans, more than 350 receptor protein genes.
The olfactory epithelium is organized into a few large zones,

Each zone contains receptor cells that express a different subset of receptor genes.

Within each zone, individual receptor types are scattered randomly.
Broad tuning of olfactory receptor cells

Each receptor cell expresses a single olfactory receptor protein.

Receptor cells are randomly scattered within a region of the epithelium.

Recordings from three different cells show that each one responds to many different odors.

The response has different preferences.

By measuring responses from all three cells, each of the four odors can be clearly distinguished.

Three different groups of genes are mapped – notice the nonoverlapping zone of distribution.

Population coding!
Remember:

Each olfactory sensory neuron expresses just a single species odor receptor protein and...
Each odorant receptor binds to a range of related molecules.
Central olfactory pathways

Olfactory receptor neurons \( \rightarrow \) olfactory blubs

Each olfactory axon synapses upon second order neurons within glomerulus.

Second order neurons send axons through the olfactory tract.
Odor stimuli produce spatial patterns of activity in the glomerular layer that are overlapping but that vary for different odors.

Axons of sensory neurons in the olfactory epithelium project to the olfactory bulb – they then converge onto modules known as glomeruli.

Specific mapping of olfactory receptor neurons onto glomeruli

Each glomerulus receives input from the same type of receptor cell
The convergence of olfactory neuron axons onto the olfactory bulb. Olfactory receptor neurons expressing a particular receptor gene all send their axons to the same glomeruli. (a) In a mouse, receptor neurons expressing the P2 receptor gene were labeled blue, and every neuron sent its axon to the same glomeruli in the olfactory bulbs. In this image, only a single glomerulus with P2 axons is visible. (b) When the two bulbs were cut in cross section, it was possible to see that the P2-containing receptor axons project to symmetrically placed glomeruli in each bulb. (Source: Adapted from Mombaerts et al., 1996, p. 680.)
Odor “images”

fMRI images of the different but overlapping activity patterns seen in the glomerular layer of the olfactory bulb of a mouse exposed to members of the straight-chain aldehyde series, varying from four to six carbon atoms.

Axons of the olfactory tract: Branch and enter the forebrain

Neocortex: Reached by a pathway that synapses in the medial dorsal nucleus
Thalamus: Medial Dorsal Nuc.
Amygdala

emotions
Spatial and Temporal Representations

- Individual receptors are broadly tuned to their stimuli
- Each cell is sensitive to a wide variety of chemicals
- How then does one get maintain odorant percept sensitivity?

Olfactory Population Coding

- Each odor is represented by the activity of a large population of neurons to encode a specific stimulus.
- By looking at the combination of responses from all three cells, the brain can unambiguously distinguish the different odorants
- 1000 receptors → recognize 10,000 odors.
Spatial and Temporal Representations

- **Sensory Maps**
  - Neurons responsive to particular odors may be organized into spatial maps.
  - A sensory map is an orderly arrangement of neurons that correlates with certain features of the environment.

  Recall, axons of each receptor cell type synapses on a specific glomeruli in the olfactory bulb.

  Neurons in a specific place in the bulb respond to particular odors.
  - Neurons' position form a specific and reproducible spatial pattern.
  - Smell of a particular chemical is converted into a specific map.
  - Nature and concentration of odorant is map dependent.

  Voltage sensitive dyes: the colors of the maps represent differing levels of neural activity. Hotter colors imply more activity.
Temporal Representations of Odors in an Olfactory Network

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The responses of projection neurons in the antennal lobe of the locust brain (the functional analog of mitral–tufted cells in the vertebrate olfactory bulb) to natural blends and simple odors were studied with multiple intra- and extracellular recordings in vivo. Individual odors evoked complex temporal response patterns in many neurons. These patterns differed across odors for a given neuron and across neurons for a given odor, but were stable for each neuron over repeated presentations (separated by seconds to minutes) of the same odor. The response of individual neurons to an odor was superimposed on an odor-specific coherent oscillatory population activity. Each neuron usually participated in the coherent oscillations during one or more specific epochs of the ensemble activity. These epochs of phase locking were reliable for each neuron over tens of repeated presentations of one odor. The timing of these epochs of synchronization differed across neurons and odors. Correlated activity of specific pairs of neurons, hence, generally occurred transiently during the population response, at times that were specific to these pairs and to the odor smelled. The field potential oscillations, therefore, fail to reveal a progressive transformation of the synchronized ensemble as the response to the odor unfolds. We propose that (1) odors are represented by spatially and temporally distributed ensembles of coherently firing neurons, and (2) the field potential oscillations that characterize odor responses in the olfactory system occur, at least in this animal, in parallel with a slower dynamic odor representation.

Key words: locust; olfaction; coding; cross-correlation; synchronization; oscillation
Range of temporal patterns of response to a single odor across neurons. Temporal response patterns of nine different antennal lobe PNs in response to the odor apple. The recordings (all intracellular) were performed sequentially in the same animal over a 3.5 hr period. Traces have been aligned on the odor pulse. (Action potentials clipped.)

Note the distribution of response patterns, from short and brisk (trace 1), to prolonged (2,3), delayed firing (4, 5), multiphasic (6–8), and purely inhibitory (9).

Note also the subthreshold membrane potential oscillations underlying the periodicity of firing (most noticeable in traces 3–5). These response patterns were consistent for each neuron over tens of responses (see Fig. 2).

Not all neurons that responded to this odor, therefore, were active at the same time. Rather, the ensemble response was distributed in time.
Concluding Remarks

- Transduction mechanisms
  - Gustation and olfaction
- Similar to the signaling systems used in every cell of the body
- Common sensory principles - broadly tuned cells
  - Population coding
  - Sensory maps in brain
- Timing of action potentials
  - May represent sensory information in ways not yet understood