Overview of Lecture: Sensory, Perceptual Mechanisms

see the schedule for reading and watching assignments

THE FOLLOWING PREVIEW HAS BEEN APPROVED FOR ALL AUDIENCES

Bullet Points:
• the CNS - Brains
• cortical maps & fMRI
• the hungry brain
• the social brain hypothesis
• sensation & perception
• cortical “top-down” control – expectations
• perception – “the brain’s best guess”
• placebo effect
• vision – allocating attention
• split-brains: consciousness
• the story we tell ourselves
Learning Goals:

1. Be able to explain how fMRI works and describe how it can be used to develop topographical maps of brain activity and function. Give a very general description of how sensory and motor “body surfaces” are mapped onto the human brain, including the left-right mapping pattern.

2. Be able to briefly describe “the social brain hypothesis.”

3. Be able to explain how eye-tracking studies illustrate (1) the distinction between sensations and perceptions (2) how attention is typically allocated to informative locations, and (3) how is it atypically allocated on children with autism.

4. Be able to describe the placebo effect and explain how it relates to cortical activity (ACC), limbic dopamine cells, impulsivity and variation in the magnitude of the placebo effect.

5. Be able to describe the Necker cube illusion-phenomenon and explain how it illustrates the mind testing alternative hypotheses for consistency with the data.

6. Be able to provide a superficial overview of the “split-brain studies” and explain what they suggest about the lateralization of verbal and non-verbal information processing and of the localization of consciousness.
The Brain Research through Advancing Innovative Neurotechnologies® (BRAIN) Initiative is aimed at revolutionizing our understanding of the human brain.

What is the BRAIN Initiative?

The Brain Research through Advancing Innovative Neurotechnologies® (BRAIN) Initiative is aimed at revolutionizing our understanding of the human brain. By accelerating the development and application of innovative technologies, researchers will be able to produce a revolutionary new dynamic picture of the brain that, for the first time, shows how individual cells and complex neural circuits interact in both time and space. Long desired by researchers seeking new ways to treat, cure, and even prevent brain disorders, this picture will fill major gaps in our current knowledge and provide unprecedented opportunities for exploring exactly how the brain enables the human body to record, process, utilize, store, and retrieve vast quantities of information, all at the speed of thought.
A human brain consists of ~200 billion neurons each connected to as many as 10,000 other neurons. The brain of a three-year-old child has about $10^{15}$ synapses (1 quadrillion). This number declines with age, stabilizing by adulthood at $10^{14}$ synapses.
Motor and sensory body surfaces are topographically mapped onto the cerebral cortex with 'association areas' nearby. These mappings are variable across people, and 'plastic' within people (some reorganization after injury).
... **functional magnetic resonance imaging**, fMRI:
provides high resolution, noninvasive reports of neural activity detected by
Because of its large size, the human brain has unusually high energy costs, which are particularly elevated compared with the body’s metabolic budget early in the life cycle.

The human brain is a very costly machine to run, even during sleep, and so it has to pay huge fitness returns to pay off those metabolic costs.
What makes humans unique as an *species* and as *individuals*? Our uniqueness stems from language, tool use, reasoning, and other cognitive abilities that are largely mediated by specialized regions of the cerebral cortex. These regions of higher cognitive function have expanded disproportionately during human evolution (compared with nonhuman primates) and during postnatal maturation, when cortical surface area expands threefold between infancy and adulthood. Our uniqueness as individuals reflects countless differences in brain structure, function, and connectivity. One basic anatomical difference between similarly aged individuals is a more than 1.5-fold variation in total brain size (and total cortical volume).

On page 1222 of this issue, Reardon et al. bring this aspect of individual variability under the umbrella of “differential scaling” by showing that human brains of different sizes do not scale uniformly across regions.
Just as the computational load of an integrative algorithm can increase supralinearly with the size of its inputs, larger cortices may need to disproportionally expand the anatomical substrates for integrative computation in association cortex.

[computational complexity scales \( \sim \) exponentially with increasing complexity of the problems being solved.]

Consider “the social brain hypothesis.”
The Social Brain Hypothesis and Human Evolution

Primates have unusually large brains for body size compared to all other vertebrates. The conventional explanation for this is known as the "social brain hypothesis," which argues that primates need large brains because their form of sociality is much more complex than that of other species.

What is Social Network Analysis?
https://www.youtube.com/watch?v=xT3EpF2EsbQ
Sensations & perceptions
begin with the detection of a stimulus by sensory receptors. ... specialized neurons or epithelial cells.

In vertebrates, sensory signals generally go first to the thalamus (lateral geniculate nucleus), the gateway to the cerebral cortex.

This gateway is influenced by instructions coming back from the cortex. {there is active ‘top down’ control of sensory input} The information is then sent on to the many parts of the brain that contribute to forming our perceptions.
“Perception can be described as a process of inference, integrating bottom-up sensory inputs and top-down expectations.”

Where is the front face, closest to you?
When the 3D world is projected onto the 2D retina, the image is ‘underdetermined:’ different hypothetical ‘real 3D worlds’ could have created the same 2D image.

From phylogeny and ontogeny,

the mind has expectations (constraint assumptions) about how the real world works,

things like: every mark is in only one place at a time
a dot on one retina corresponds to only one dot on the other,
matter is smooth and cohesive, etc {“folk physics”}

We are constantly testing alternative hypotheses against sensory data in “the mind’s eye.”
{am I above-right looking down or below-left looking up?}

Necker cube


"Whilst part of what we perceive comes through our senses from the object before us, another part (and it may be the larger part) always comes out of our own mind."

William James

The account of perception that’s starting to emerge is what we might call the “brain’s best guess” theory of perception ...

The mind integrates {information} from a variety of sensory channels, past experiences, and hard-wired processes, and produces ... meaning.
(from an article in the New Yorker... by Atul Gawande).
The account of perception that’s starting to emerge is what we might call the brain’s best guess theory of perception ...

The mind integrates information from a variety of sensory channels, past experiences, and hard-wired processes, and produces meaning.

(from an article in the New Yorker... by Atul Gawande).

Kanizsa’s triangle
What’s most remarkable is not that our fantasies contain so much reality; it is that our reality contains so much fantasy.

Most of us understand that our perceptual systems, far from passively reflecting the world around us, actively sort, select, distort, ignore, and alter a huge amount of information in order to construct reality as we experience it. …
http://www.pnas.org/content/114/39/10473.abstract.html?etoc

Perception can be described as a process of inference, integrating bottom-up sensory inputs and top-down expectations. It has been proposed that expectations lead to prestimulus baseline increases in sensory neurons tuned to the expected stimulus, which affect the processing of subsequent stimuli. ...

We used magnetoencephalography (MEG) [and math models] to probe the representational content of neural signals ...

Participants were exposed to auditory cues that predicted the likely orientation of an upcoming visual grating stimulus. The question that we wanted to answer was whether the expectations induced by these auditory cues would evoke templates of the visual stimuli [in visual cortex] before the presentation of the gratings.

Invalidly expected gratings [miscues – the rare 25% opposite orientation] had to “overcome” a prestimulus activation of the opposite orientation, while validly expected gratings were facilitated by a compatible prestimulus activation [and the match between expectation and experience improved discrimination accuracy].
Placebo and opioid analgesia - Imaging a shared neuronal network.
Petrovic Pet al. SCIENCE 295 (5560): 1737-1740 MAR 1 2002

We compared the analgesic effects of a placebo treatment (PPL) and a rapidly acting opioid (POP) ... in a standard pain-stimulus paradigm.

- **Covariation between rACC and the brainstem**
  - [a pin prick in the leg]
  - Red: correlated changes in blood flow
  - rACC (rostral Anterior Cingulate Cortex)
    - Implicated in empathy, impulse control, emotion ...

The larger the anticipated benefit from a drug or a procedure, the greater is
Revealed: **how the mind processes placebo effect**

Expecting a big reward helps the reward to come true.

People who experience a stronger dose of pleasure **at the thought of an upcoming reward** [measured by activity of *limbic dopamine cells*] are more susceptible to the placebo effect.

Greater activity in this brain region, called the nucleus accumbens, ["reward center" in forebrain] is linked to a stronger placebo effect ...

[via dopamine cells from amygdala (MFB)]

1. Rays of light (blue) reflected off of an image \{3D\} are focused through the lens onto the back of the eye, forming an upside-down image \{2D\} on each retina.

2. … we can think of the image as a \{2D\} pixellate map of activated and nonactivated photocells on the retina.

3. \{After much processing in retina by horizontal, amacrine & bipolar cells\} A nerve from each \{ganglion cell\} connects to a particular location in the visual cortex of the brain. \{via lateral geniculate nucleus of thalamus\}

4. **The brain** … reconstructs the pixellate map.

5. then **interprets** \{or misinterprets\} the \{2D\} maps as an \{3D\} image \{made up of “sensible” objects\}.
In the human retina, **rods** are absent from the **fovea**. You cannot see a dim star at night by looking at it directly with the fovea – too dim; you can see it at an angle by focusing the starlight onto the periphery & rods, which aggregate light over a large angle with low resolution. You achieve your sharpest daylight vision by looking straight at the object of interest because **cones** are most dense at the **fovea**.

We unconsciously allocate visual attention by sequentially fixing the fovea very briefly on "interesting", informative locations in the visual field; then the mind constructs a coherent, high resolution color perception from the sequence of thumbnail-sized foveal snapshots.

*one eye dominates perception!*
How much one identical twin looked at the eyes of people on screen matched the other identical twin 91 percent of the time.
For fraternal twins, the match dropped to 35 percent.
For unrelated children, when measured as pairs of the same age and sex, the match was 16 percent.

How we look at other people’s faces is strongly influenced by our genes, scientists have found in new research that may be especially important for understanding autism …

The study, in the journal Nature, suggests that genetics underlie how children seek out formative social experiences like making eye contact or observing facial expressions.

https://www.nature.com/articles/nature22999

How much one identical twin looked at the eyes of people on screen matched the other identical twin 91 percent of the time.
For fraternal twins, the match dropped to 35 percent.
For unrelated children, when measured as pairs of the same age and sex, the match was 16 percent.
The split brain: A tale of two halves

... Severing the corpus callosum [connects the left and right sides of the cerebrum] was first used as a treatment for severe epilepsy in the 1940s, on a group of 26 people in Rochester, New York. The aim was to limit the electrical storm of the seizure to one side of the brain. ... Although the procedure never became a favoured treatment strategy — it's invasive, risky, and drugs can ease symptoms in many people — it nevertheless became a technique of last resort for treating intractable epilepsy. To Roger Sperry and Michael Gazzaniga, split-brain patients presented a unique opportunity to explore the lateralized nature of the human brain.
The body-surface to cortical-surface mapping crosses over, and back, unless ...

By using a tachistoscope, which displays visual stimuli for very brief intervals of time on each half of the screen in front of the patient, information presented on the left is exclusively perceived by the right hemisphere, and vice versa. If we ask the patient to identify what is seen, the right hand (controlled by the left hemisphere) will point toward a chicken...

... whereas the left hand (operated by the right hemisphere) will choose a shovel (needed to remove snow in the scene).

Figure 1. Lateralized presentation of information in a split-brain patient

Gazzaniga’s ‘left-brain interpreter’ (from Massimo Pigliucci) if asked to explain ... the left hemisphere acted as an interpreter ... and fabricated a just-so story to fit all the available data! {is consciousness just a post hoc interpretation – story? more later}
The Blind Decision-Maker: **What is the relation between intention, choice, and introspection?**

http://www.sciencemag.org/cgi/content/short/310/5745/116

Johansson *et al.* used a card trick in a simple decision task …

Participants were given a choice to make in the attractiveness of two female faces shown on two cards, and then asked to justify their choice as they examined the card with the alternative they had allegedly chosen.

In some trials, the experimenters covertly switched the cards. In the majority of such trials, participants **failed to recognize the switch, and proceeded to justify their choice of the card they were handed**, although it was not the one they had selected.

... participants **produce confabulatory reports when asked to describe the reasons behind their choices.**

*post hoc rationalization = story to self why the one “chosen” is more attractive*

Our consciousness may be primarily the continuous story we tell ourselves, from moment to moment, about what we did and why we did it. It is a thin, often inaccurate **veneer rationalizing a mountain of unconscious processing**.

Outlandish’ competition seeks the brain’s source of consciousness
By Sara Reardon  Oct. 16, 2019 , 1:30 PM
Brain scientists can watch neurons fire and communicate. They can map how brain regions light up during sensation, decision-making, and speech. What they can't explain is how all this activity gives rise to consciousness. … the $20 million contest will compare two theories of consciousness by scanning the brains of participants during cleverly designed tests.