Lesson 6.
encoding, decoding, perception, decision making
neuronal activity
quantified sensory input
sensory coding
psychophysics
percept, behavior
decoding, decision making
neuronal activity
Neuronal basis for perception of whisker vibrations
Ehsan Arabzadeh

Schematic model for texture discrimination: the kinematic “signature” of whisker vibrations is encoded by neurons. In this scheme, vibrations take the simplest possible form, sinusoidal waveforms.
stimulus set for measuring cortical encoding of vibration
Onset response
barrel cortex encoding of vibration velocity at stimulus onset
Coding of vibration frequency $f$ and amplitude $A$ ... ... and the resulting ambiguity
For a sinusoidal function characterized by amplitude $A$ and frequency $f$, mean speed (abs velocity) across an integer number of cycles is proportional to the product $Af$.

Barrel cortex firing proportional to $Af$
decoding barrel cortex activity to mean whisker speed
No sign of temporal code
decoding barrel cortex activity to mean (across cycles) whisker speed
But is it really the mean speed \((Af)\) of a vibration that the rat feels???

Adibi, Diamond, Arabzadeh, 2012
Nose-poke → Stimulus presentation → Choice and Reward
The set of experiments just reviewed claims that the signal that gives rise to the percept resides in primary somatosensory cortex:

- When primary somatosensory cortex contains a signal that does not distinguish between two stimuli, likewise the whole rat will not be able to distinguish.

The next set of experiments will show (in another species) that when primary somatosensory cortex provides an ambiguous signal, it is the activity late in sensory processing pathways that determines the percept.

In particular, when the incoming sensory signal is uncertain, firing late in the pathway is better correlated with choice than is firing early in the pathway. (late refers to the number of processing stages and late in time.)
High-frequency vibration

Pressure

Pressure, stretch

Temperature, noxious stimuli

Touch, low-frequency vibration
map

Ventroposterior lateral nucleus of the thalamus

Medial lemniscus

Dorsal column nuclei

Medulla

Spinal cord

From arm

From leg
(A) Owl monkey brain

Somatic sensory cortex

Hand representation
Ranulfo Romo
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Neural correlate of subjective sensory experience gradually builds up across cortical areas
De Lafuente & Romo
PNAS, 2006

• “When a sensory stimulus is presented, many cortical areas are activated, but how does the representation of a sensory stimulus evolve in time and across cortical areas during a perceptual judgment?

• We investigated this question by analyzing the responses from single neurons, recorded in several cortical areas of parietal and frontal lobes, while trained monkeys reported the presence or absence of a mechanical vibration of varying amplitude applied to the skin of one fingertip."
In other words…

Where in the brain, and how, is a sensory receptor input converted to a subjective experience?

The “criterion” or “decision threshold” must have a neuronal basis… how is it implemented by the brain?
Push buttons

Stimulus probe

Key
Detection task.

- Probe down
- Hold key
- Pre-stim (1.5-3.5 s)
- Stimulus present (0.5 s)
- Stimulus absent
- Delay (3 s)
- Probe up
- Response movement
Mean firing rate in stimulus-present trials across the recorded cortical areas

(a) Each row plots mean firing rates to a suprathreshold stimulus in a given cortical area, and each column groups the neuronal responses with similar dynamics across cortical areas (n= number of neurons). Neurons from each cortical area were sorted into three possible categories (ordered into three columns).

(Left) Neurons with transient responses to the stimulus (sensory neurons). Continuous line indicates rapidly adapting responses (area 3b and area 1 panels). Dashed lines indicate slowly adapting responses (area 3b and area 1 panels). Solid red lines in the remaining panels show neurons that transiently decreased their firing rate in response to the stimulus. Red dashed line in the area M1 panel shows mean activity of neurons that responded only during movement time.

(Center) Activity of neurons that responded during the stimulus period and continued during the delay period (delay neurons).

(Right) Mean activity of neurons with ramping changes in firing rate during the delay period.
Mean firing rate in stimulus-present trials across the recorded cortical areas

Cortical region

3b
1
2
5
S2
VPC
DPc
MPc
M1

Temporal relation with stimulus
Firing during stimulus (M1: response, red: decreased)

(b) Mean normalized firing rates as a function of stimulus amplitude. Colored lines are linear fits to the firing rate as a function of the logarithm of the amplitude.

Recorded areas:

Area 1/3b
Area 2
Area 5
S2
VPC
DPc
MPc
M1

“stimulus coding” most prominent in posterior (sensory) cortex, least prominent in anterior cortex.

Now let us distinguish “stimulus coding” from “choice coding.”
Examine neuronal firing on all trials where very weak, near-threshold stimulus applied at near-threshold amplitudes (12.6, 9.0, and 6.4 μm).

**Neuronal firing**

- **NEURON 1**
  - Stimulus judged as NOT present
  - Stimulus judged as present

- **NEURON 2**
  - Stimulus judged as NOT present
  - Stimulus judged as present

**Neuron 1 shows LOW choice probability**

**Neuron 2 shows HIGH choice probability**

This analysis not limited to trials with stimuli!

Why not consider trials with NO STIMULUS present and ask how neuronal firing differs between “correct rejection” trials and “false alarm” trials.
Proportion of behavioral responses that were predicted from the neuronal activity.

Mean choice-probability indices across all neuronal types as a function of time for each of the recorded cortical areas
- stimulus-present trials (Left) and
- stimulus-absent trials (Right).

Note how choice-probability values increase from the primary sensory areas to the premotor areas (black lines, mean value; red area, SEM). Black lines at the top of each panel mark the times where choice-probability values significantly depart from 0.5 (t test, p < 0.01).
Timing and strength of perceptual decision signals across cortical areas.

(a) Choice probability indices for individual neurons (mean value: hits vs. misses and correct rejections vs. false alarms) plotted as a function of the response latency for each cortical area (colors are as in Fig. 1d). Neurons from each area were fitted with two-dimensional Gaussians. Color markings at the abscissa indicate the mean response latency for each cortical area.

(b) Mean choice-probability index for each area plotted as a function of the mean response latency. A linear fit shows how the choice-probability index increasingly grows as a function of latency (M1 neurons were excluded from the fit; red dot and dotted circle).

(c) Recorded areas grouped into five processing stages by analysis of variance of response latencies. Each rectangle groups the areas with latencies that were statistically indistinguishable from each other.
• They showed that the strength of the covariations between neuronal activity and perceptual judgments progressively increases across cortical areas as the activity is transmitted from the primary somatosensory cortex to the premotor areas of the frontal lobe.

• This finding suggests that the neuronal correlates of subjective sensory experience gradually build up across somatosensory areas of the parietal lobe and premotor cortices of the frontal lobe.

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Populations of neurons in prefrontal cortex

$n = 132$