The representation of texture statistics in visual cortical networks of the mouse

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Hierarchical processing of visual information

Hubel and Wiesel 1962, 1968, Schrimpf et. al., 2020, Yamins and DiCarlo 2016
CNNs mimic hierarchical representation of the brain

Yamins and DiCarlo 2016, Zhuang et. al., 2021, Lindsay 2020
The computations occurring in mid-level areas remain unknown.
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Textures are everywhere!

Portilla & Simoncelli 2000, Freeman & Ziemba et. al., 2013, Okazawa et. al., 2015, 2017, Jagadeesh & Gardner 2022
Addressing these questions in the mouse animal model

Synthesis algorithm using VGG16
Synthesized texture and scramble pairs

Textures
- Scales
- Rocks
- Honeycombs
- Plants

Scrambles
- Scales
- Rocks
- Honeycombs
- Plants
Matching power spectrum and orientation content
Can mice see textures?

? 

Textures
- Scales
- Rocks
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Scrambles
High-throughput behavioral system

Aoki et. al., 2017
Go no-go behavioral tasks

1. Texture/scramble detection task: Main goal is to distinguish textures from scrambles.
2. Texture/texture discrimination task: Main goal is to distinguish between two families of textures.
Texture/scramble go/no-go task

\[ d' = z(\text{hits}) - z(\text{false alarms}) \]

Where \( z \) is the inverse cumulative density function of a normal distribution.
Video of expert mouse doing the task (3X speed)
Texture/texture go/no-go task

\[ \Theta = [0^\circ - 180^\circ] \]

- HIT
- MISS
- CR
- FA

ITI: 4-6s, RW: 2s, Feedback: 1s or 10s, ITI: 4-6s

Texture-texture discrimination

- n=6
- n=7
- n=9
- n=5
- n=5
- n=5

Rocks/scales, Honeycomb/scales, Honeycomb/rocks, Scales/plants, Rocks/plants, Honeycomb/plants
What is the neural substrate underlying the encoding of texture statistics in the mouse visual cortex?
Widefield experimental setup
Mean response to textures and scrambles in V1/LM
Texture modulation across higher visual areas

Significance map

\[ d'_{tex} = \frac{\mu_{tex} - \mu_{sc}}{\sqrt{\frac{1}{2} (\sigma_{tex}^2 + \sigma_{sc}^2)}} \]

\[ p = 3 \times 10^{-6} \]
What is the single-cell and population level substrate underlying this differential selectivity?
2-photon imaging setup

ITI 750ms  stim 250ms  ITI 750ms  ...

Textures
Scrambles
Example responses of four single neurons
Texture selectivity across all cells higher in LM

\[ d'_{tex} = \frac{\mu_{tex} - \mu_{sc}}{\sqrt{\frac{1}{2}(\sigma^2_{tex} + \sigma^2_{sc})}} \]

\[ d' \]

Scales
p=7\times10^{-5}

Rocks
p=6\times10^{-4}

Honeycomb
p=2\times10^{-2}

Plants
p=4\times10^{-3}

V1 LM V1 LM
Relating population activity to behavior

![Diagram](image-url)
Linking neural representations and behavioral output

- Trained a binary logistic regression classifier on the neural data to discriminate textures from scrambles just like the mouse behavior.

- Rocks was the worst performing family in both the classifier ($p < 0.035$) and mouse behavior ($p < 0.03$).
Is the worse neural and behavioral discriminability of the “Rocks” family related to the statistical properties of these images?
Computing intercluster distances in PS space

- Calculated the intercluster distances for all the four PS statistics groups.
  \[ d_{\text{norm}} = \frac{d_{\text{tex,sc}}}{\frac{1}{2}(r_{\text{tex}} + r_{\text{sc}})} \]

- Of all the image statistics only the energy statistics showed a correspondence with the neural and behavioral discriminability.

- These statistics were also the most complex
Energy statistics aligned with behavioral and neural performance
Geometrical changes between layers

Cohen & Chung et. al., 2020, Chung & Abbott, 2021