Rapid adaptation impacts the encoding of natural stimuli

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Background

Adaptation alters visual processing in response to input history

- Suppression of neural response to repeated or prolonged presentation of stimuli
- Causes neuronal tuning to be biased away from that of frequently encountered adapter stimuli
- Proposed to reduce redundancy in population activities and increase coding efficiency in terms of energy use

Adaptation is amplified in ventral visual pathway of rat and macaque, which might facilitate the encoding of object identity in its downstream

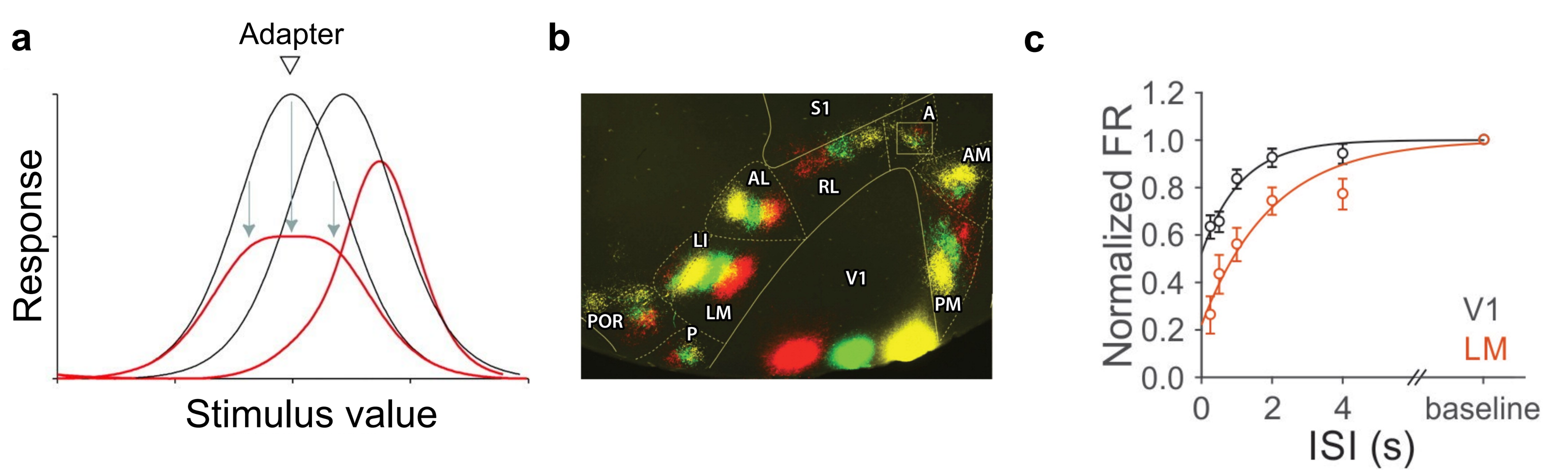


Fig 1. Neural response is reduced and biased following adaptation to brief stimulus presentation.

a. Adaptation in V1 generates repulsive bias of neuronal tuning, which flattens tuning curves of neurons that prefer the adapter and repels tuning curves of neurons that prefer stimuli neighboring the adapter.

b. Image of the mouse visual cortex after three colored anterograde tracers were injected into distinct retinotopic positions in V1, marking the connectivity between V1 and the higher visual areas (HVAs). Note the mouse ventral pathway: V1 → lateromedial area LM → laterointermediate area LI.

c. Stimulus-evoked firing rate of neurons in V1 and LM for test stimulus normalized to response to adapter stimulus, showing that adaptation increases along the cortical hierarchy.

? Question: How does visual adaptation transform the encoding of stimulus identity in a realistic setting - at rapid timescales, with naturalistic visual input, and across stages of visual processing?

Methods

- Present to mice stationary gratings or natural images
- Two-photon calcium imaging recording from V1, LM, and LI
- Leverage Allen Institute visual behavior open source dataset

Results

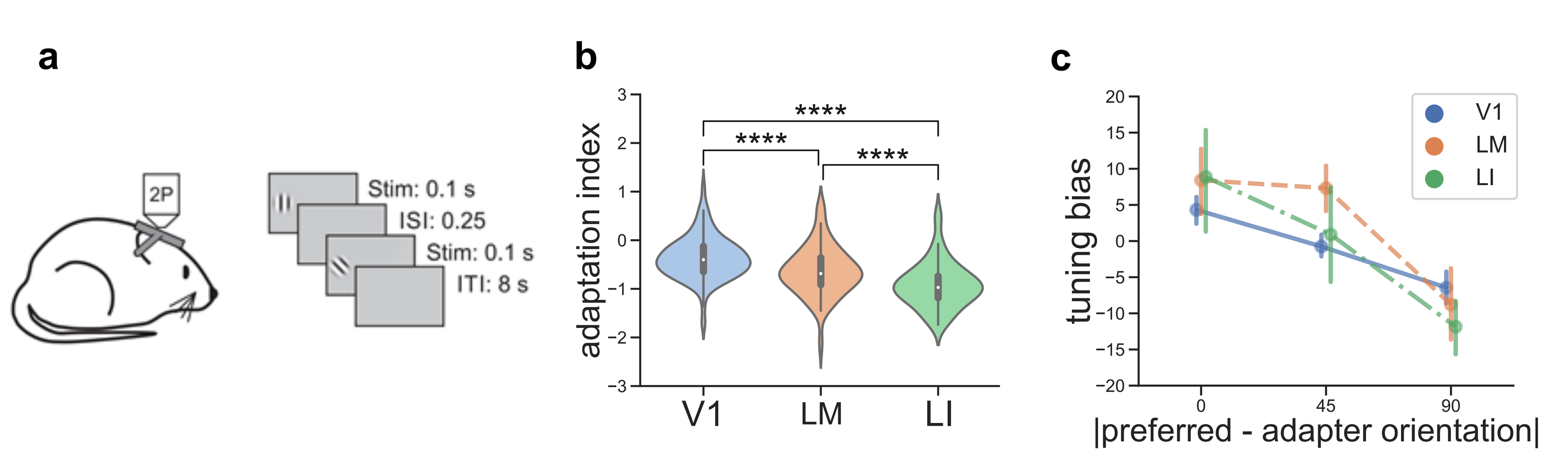


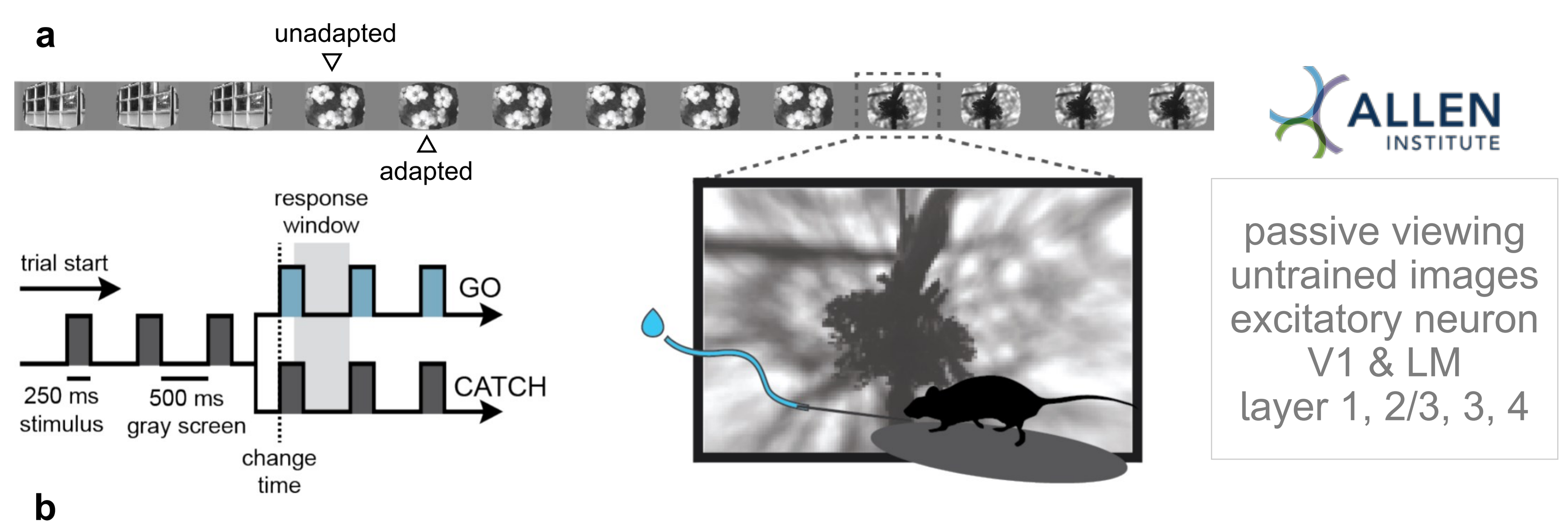
Fig 2. Adaptation magnitude and tuning bias is magnified along ventral visual pathway.

a. Schematics of two-photon imaging of visual area neuronal population and visual stimuli.

b. Adaptation magnitude increases from V1 to LM to LI. Adaptation index is defined as (target_response - adapter_response) / adapter_response. **** indicates p < 0.0001.

c. Adaptation generates an increasing tuning bias along the ventral stream. Surprisingly, as the difference of preferred vs adapter orientations increase, the bias becomes more attractive than repulsive.

Results



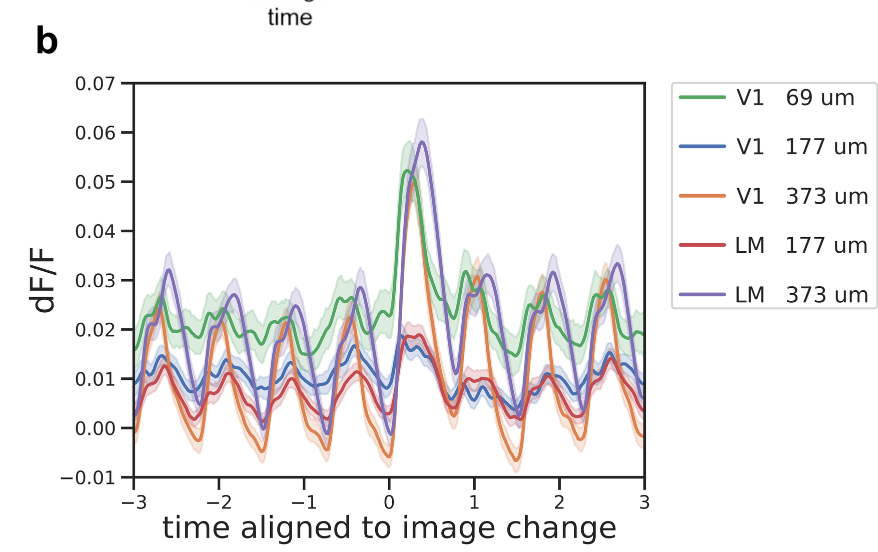


Fig 3. Adaptation in Allen Institute Visual Behavior dataset.

a. Change detection task. Stimuli are presented during a behavior session. Lower left shows "go" trials where the stimulus identity changes and the mouse must lick to earn a water reward, and "catch" trials where the image identity doesn't change. Lower right shows the behavioral setup, with stimuli displayed to the right eye of the mouse, a lick spout for response detection and water reward delivery, and a running wheel.

b. Adaptation occurs in excitatory neurons across different layers in V1 and LM in a passive viewing session using untrained images.

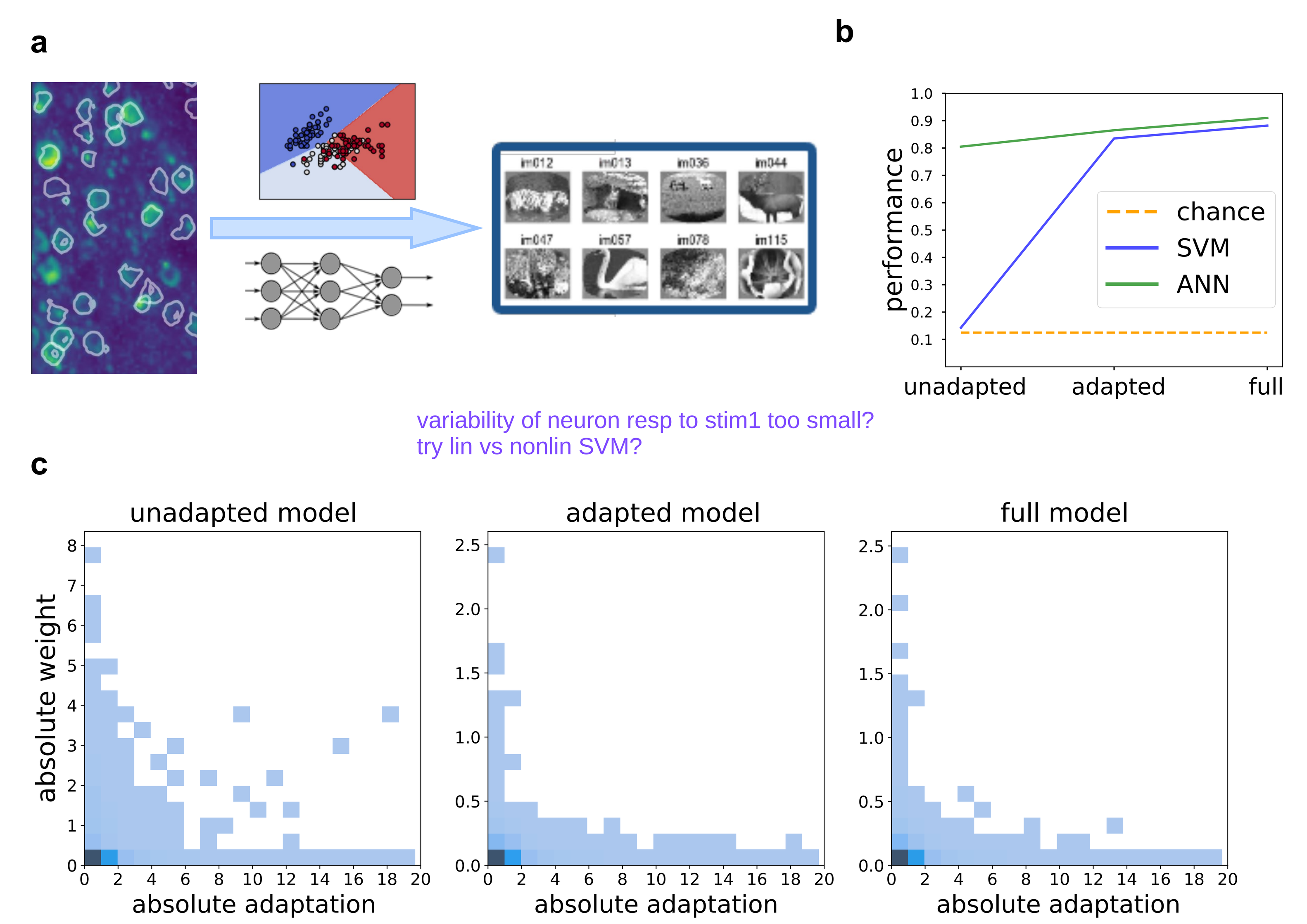


Fig 4. Decoding natural image identity from (un)adapted neural response reveals that less adapted neurons contribute more to linear decoding.

a. Image identity (8) are decoded from neuronal population response (unadapted, adapted, or full dataset) using either a linear support vector machine (SVM) or a shallow fully connected artificial neural network (ANN).

b. Multiclass SVM linear decoder optimized by grid search and elastic net regularization can decode image identity from adapted but not unadapted response. Training by adapted trials achieves comparable performance to training by full dataset, while training by unadapted trials yields almost chance performance.
In contrast, ANN with a single hidden layer as nonlinear decoder can decode image identity from both adapted and unadapted response.

c. Neurons with smaller absolute adaptation magnitude contribute more absolute weight to the SVM decoder, regardless of which subset of data SVM is trained on. Absolute adaptation magnitude is defined as |(target_response - adapter_response) / adapter_response|. Inset: distribution of absolute adaptation among cells, showing that the vast majority of neurons have an absolute adaptation lower than 2, with the median being 0.65.

Results

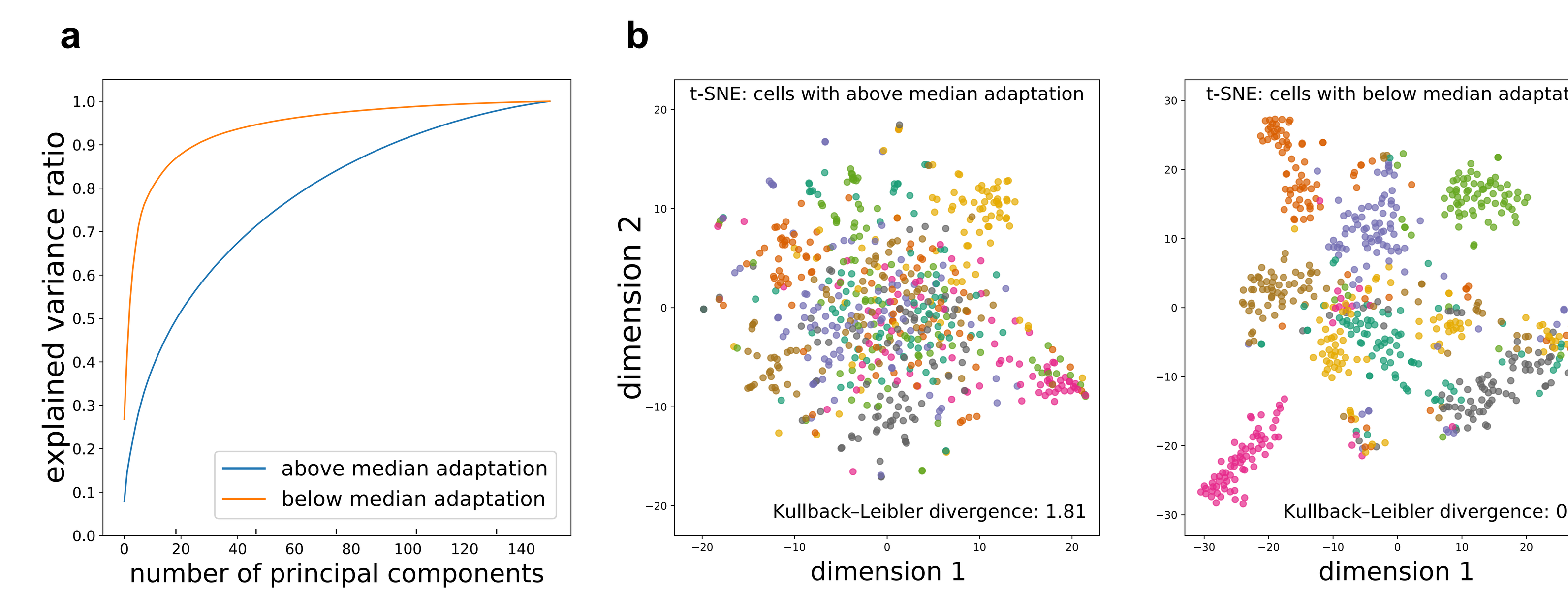


Fig 5. Less adapted neurons encode image identity in a lower dimensional space, visualized by linear and nonlinear dimensionality reduction techniques.

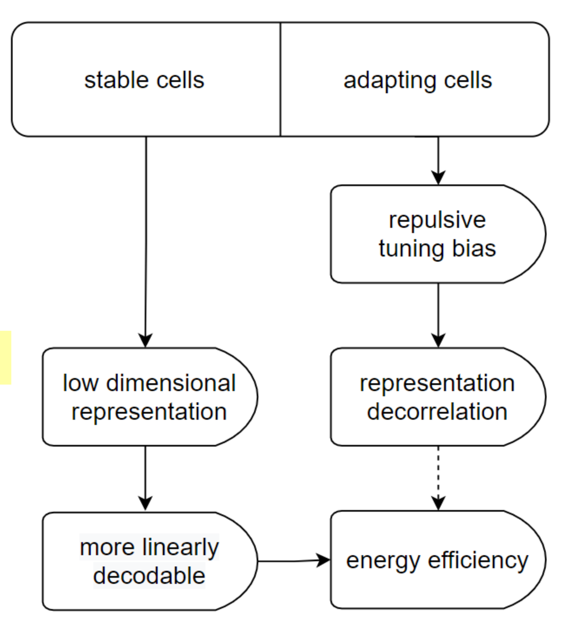
a. Principal component analysis plot shows that for cells with below-median adaptation magnitude, fewer principal components are needed to reach a high explained variance ratio.

b. t-SNE indicates that responses of neurons with below-median adaptation magnitude cluster by image identity, while neurons with above-median adaptation do not.

Conclusions & Future Directions

Conclusions

1. Rapid adaptation is magnified along the ventral stream in mice (V1-LM-LI) , resulting in an increasing repulsive tuning bias away from adapter
2. Neural representation post adaptation is more linearly decodable, possibly due to less adapted neurons encoding natural images in a lower dimensional space



Future Directions

? Reconstruct gratings and natural images from un/adapted neural response to quantify representation decorrelation caused by adaptation

? Calculate mutual information per spike, sparseness, and selectivity of neural response to investigate whether adaptation increases energy efficiency

? Investigate the identity of less adapted cells (area, depth, signal-noise ratio), and whether conclusion 2 generalizes

? Probe with hundreds of natural images to build convolutional neural network based models to predict adaptation given a stimulus image, in order to estimate what feature evokes most adaptation along the ventral stream

References

Credit: Caitlin Lienkaemper (dimensionality reduction analysis), Max Gagnon (nonlinear decoder structure)

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