Hierarchical effects of contrast and motion coherence in human visual cortex

Dan Birman[1*], Justin Gardner[1]

[1]Department of Psychology, Stanford University

[*]Corresponding author email: danbirman@stanford.edu

Summary

Human contrast discrimination performance tracks neural responses in visual area V1[1].

Here we look at how motion coherence discrimination might rely on early visual cortical regions:

- Which regions have a neural response of sufficient magnitude and of the correct shape[2]?
- Can motion coherence discrimination be explained by a simple model of signal detection readout, like for contrast?

Area V1 is sensitive to contrast, and tracks behavior.

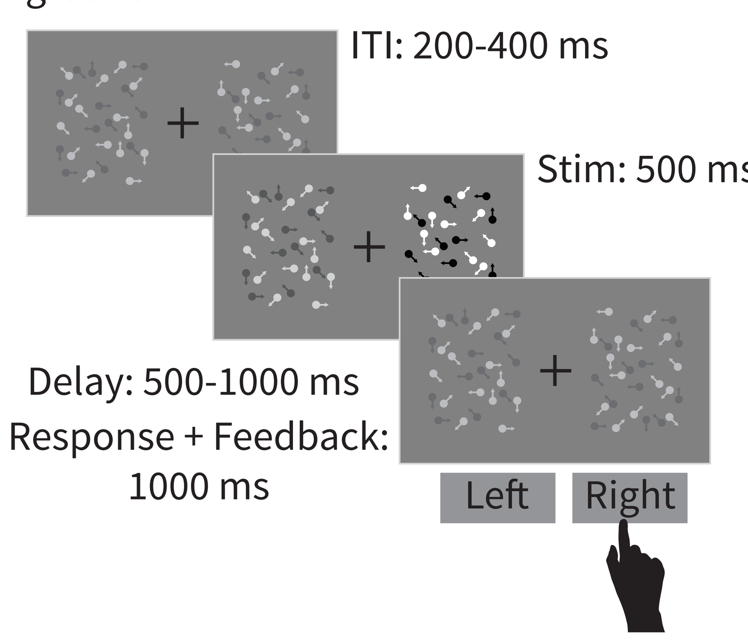
What areas do this for motion coherence?

Methods

Behavior was collected from XX subjects performing a 2-alternative forced choice discrimination task, (below left, mean XXXX trials). On separate blocks subjects attended contrast or motion. Independent fMRI data was recorded from 11 subjects at 3T (EPI, 0.5 s TR, whole brain, 7 slice at mux 8) while shown stimuli of varying length (250 - 4000 ms), and strength (25-100% contrast, 0-100% coherence). Responses were averaged in visual areas mapped with retinotopy[3]. The behavior and fMRI were used to jointly constrain a model of the underlying neural responses (below and right).

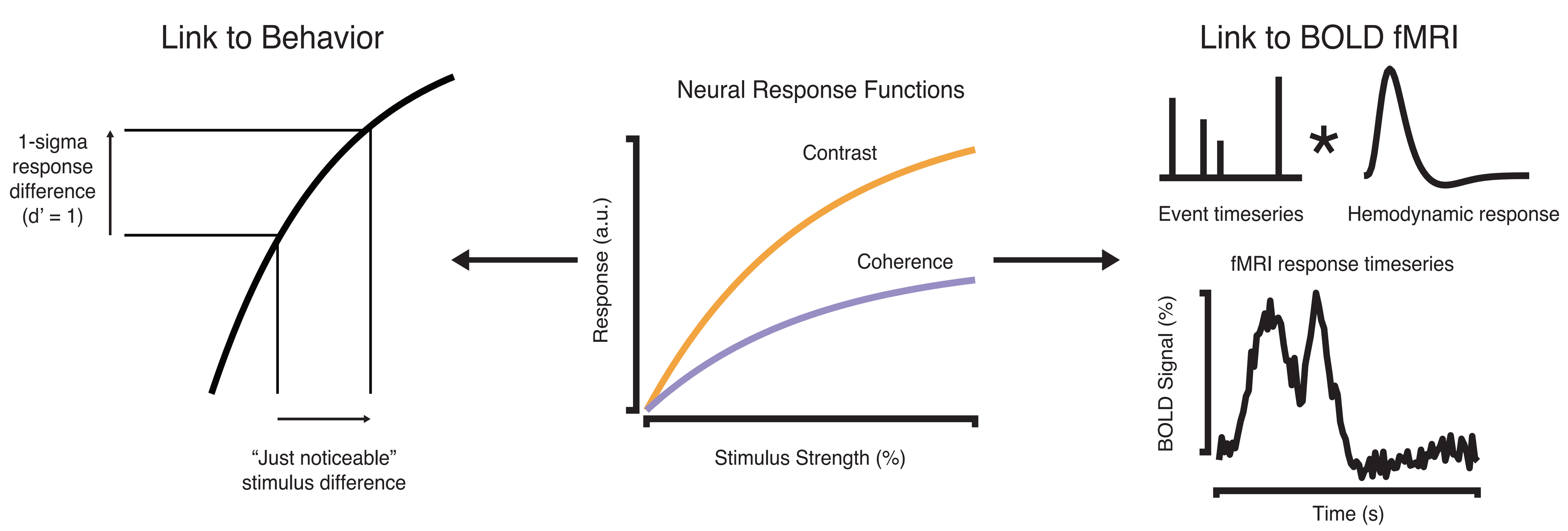
Behavioral task

Dot stimulus: 21 dots/deg, 3 deg/s 25% contrast, 0% coherence, constant in background.



Linking Model

The neural response function is linked to behavior via signal detection theory and to fMRI by convolving a stimulus timeseries with a parameterized hemodynamic response function.

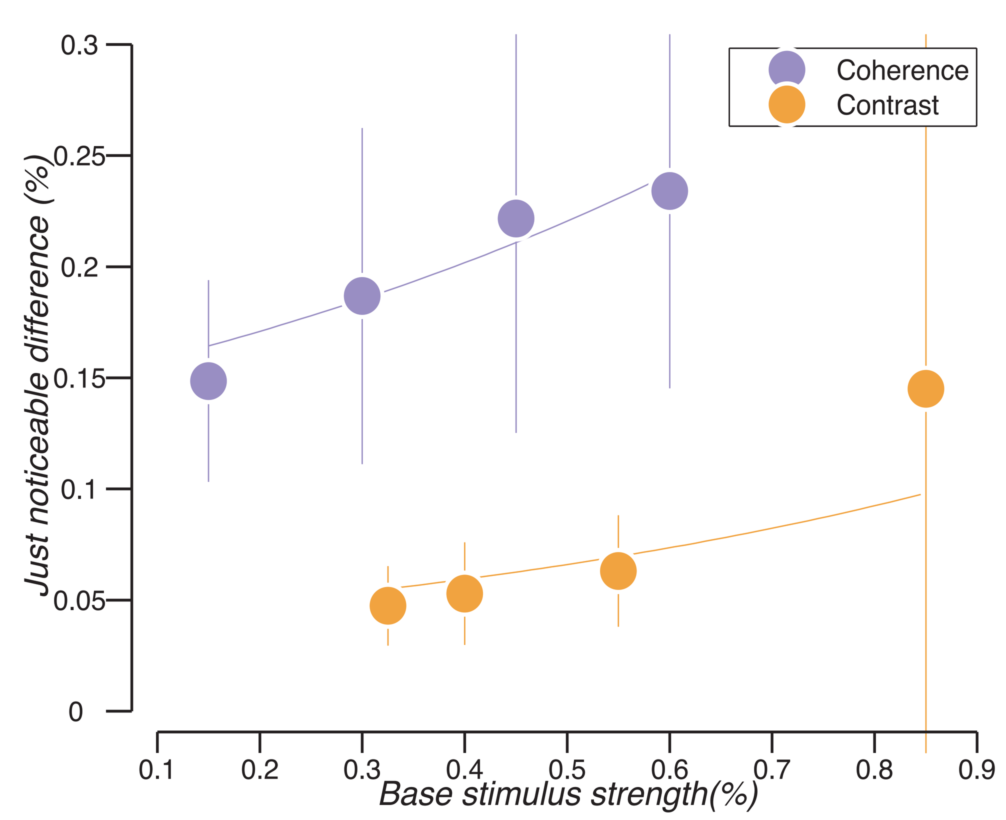


Discrimination performance

We found that subjects' "just noticeable difference" (JND) increased with base stimulus strength, as expected[1] if a non-linear neural response is used to perform signal detection.

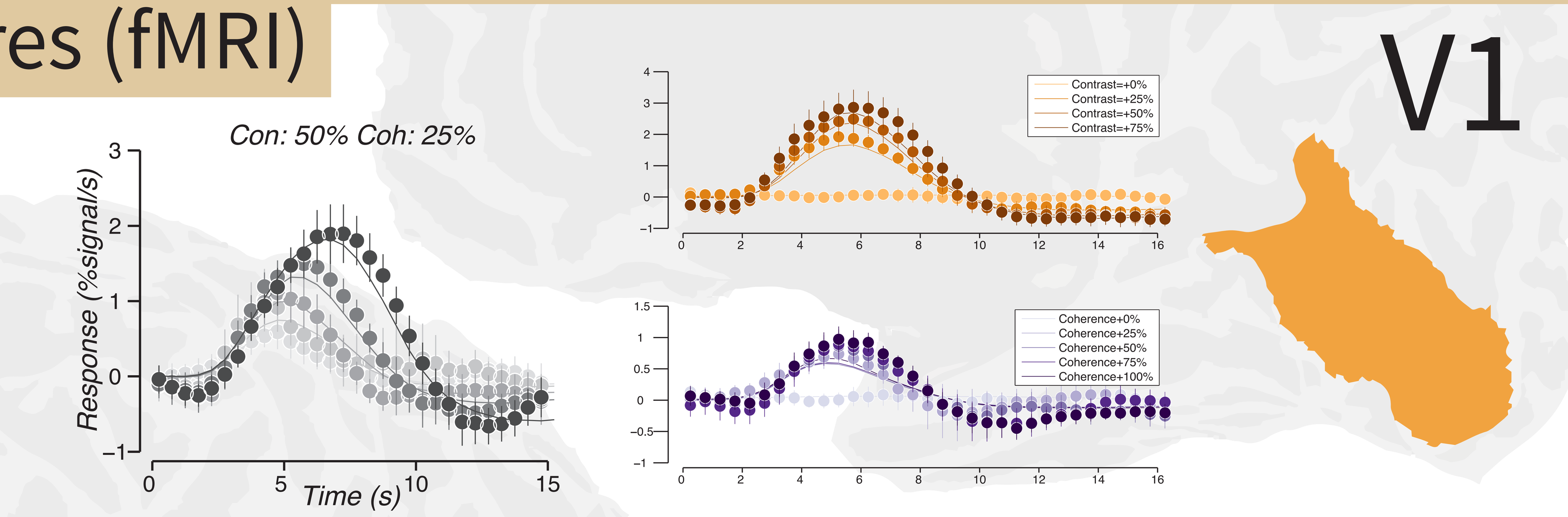
But previous work has suggested that the neural response to motion coherence should be *linear*, which would result in a flat JND line.

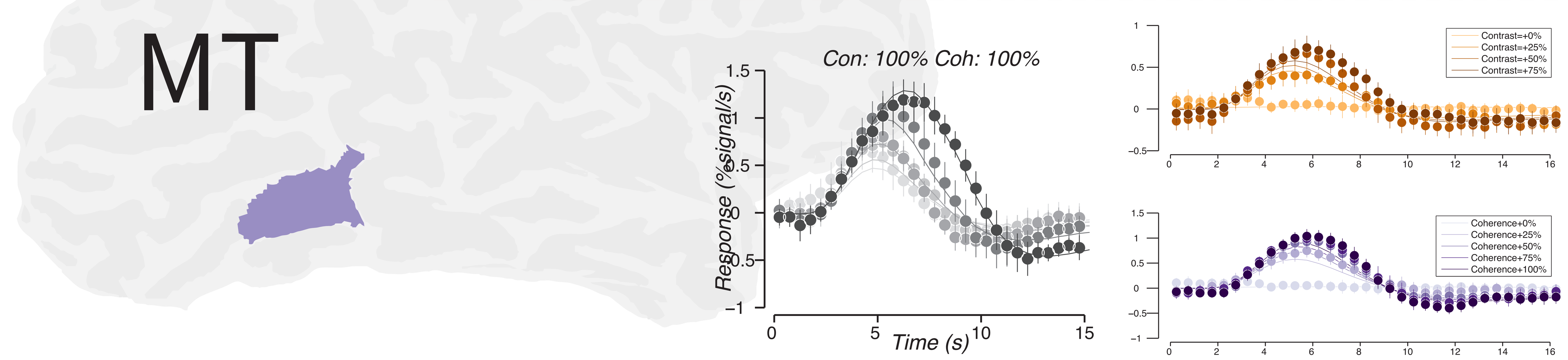
Just noticeable differences for contrast and motion coherence discrimination



Neural Measures (fMRI)

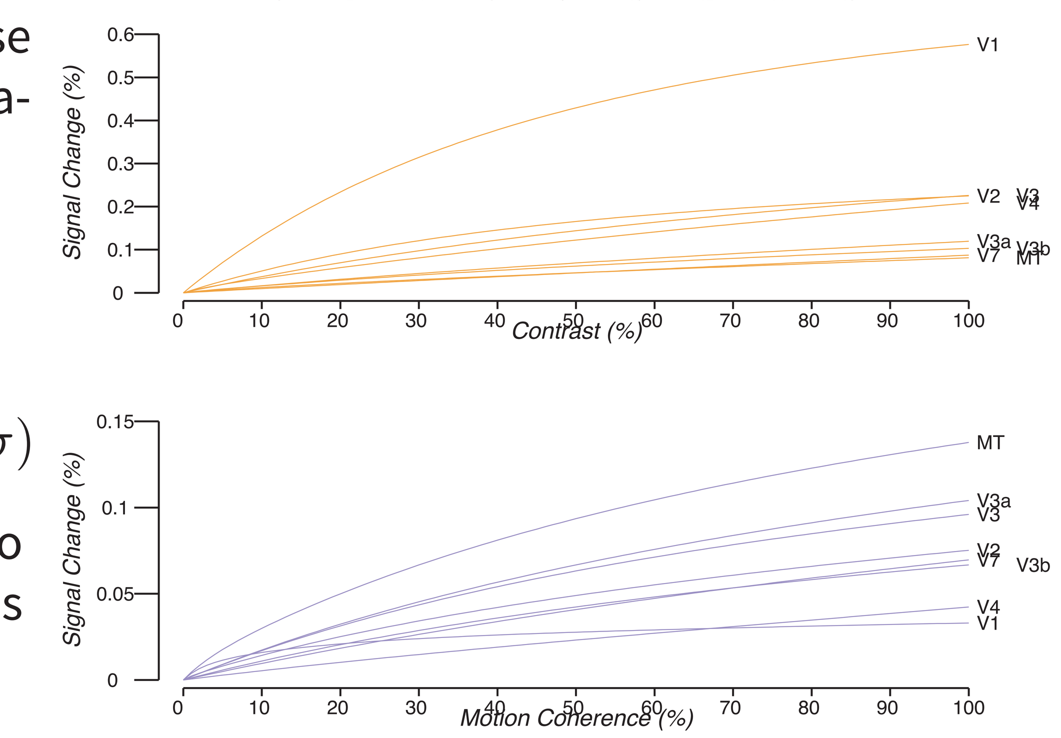
We show here example fMRI responses from two visual cortical regions. We tested areas V1, V2, V3, V4, V3a, V3b, V7, and MT to see whether they were sufficient to explain discrimination performance.





For each stimulus feature in each cortical area we fit a neural response function, an exponential of the stimulus strength *s* with two free parameters *alpha* (magnitude) and *kappa* (shape):

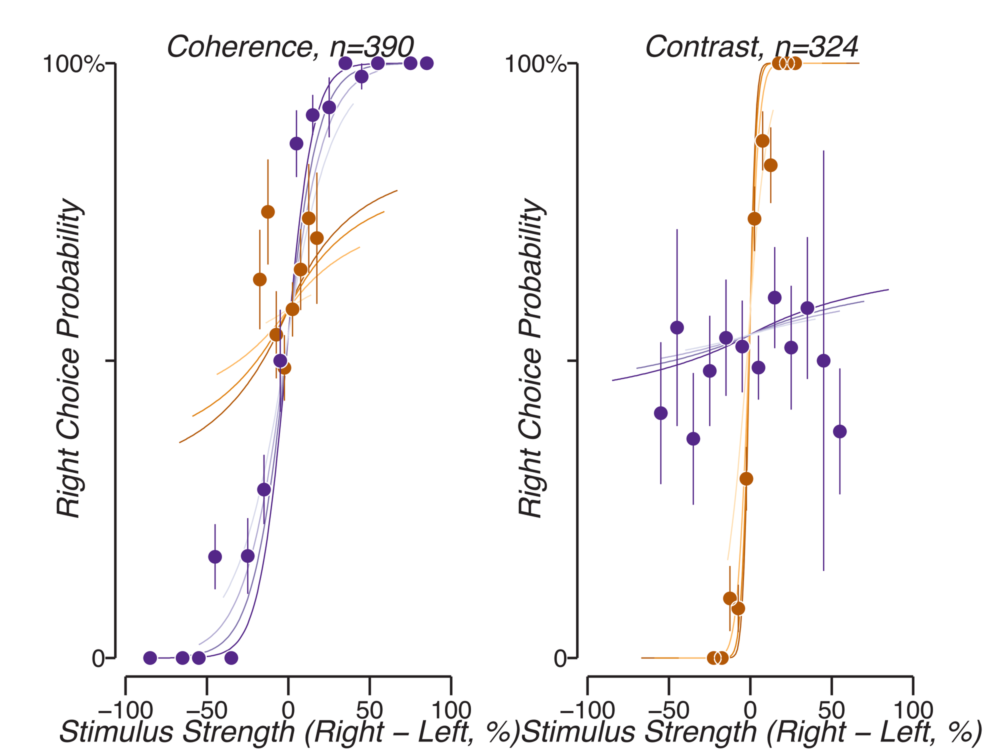
$$R_{neural}(s) = -\alpha e^{-\kappa s}$$



We linked the neural responses to behavior using signal detection:

$$P(right|R_{neural}) = 1 - \Phi(R_{neural}(s_{right}) - R_{neural}(s_{left}), \sigma)$$

In our linking function Phi is the cumulative normal and sigma is fit to maximize the likelihood of the behavioral data. In our data sigma was XX+-XX%, similar to values in previous results[4] (XX%).



The complete model (eqn. X) constrained by the neural responses functions in V1 and MT and using the sigma parameter fits....... ?

Conclusion

Jointly fitting motion coherence and contrast discrimination to the neural responses of MT/V3a and V1 respectively is sufficient to explain behavioral performance on a 2-AFC attention task. Contrary to expectations this requires a non-linear representation of motion coherence.

1. Boynton, G. M., Demb, J. B., Glover, G. H., & Heeger, D. J. (1999). Neuronal basis of contrast discrimination. Vision research, 39(2), 257-269.
2. Rees, G., Friston, K., & Koch, C. (2000). A direct quantitative relationship between the functional properties of human and macaque V5. Nature neuroscience, 3(7), 716-723.
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