Mapping receptive fields using stimuli with third- and fourth-order statistics: black blobs better than random

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INTRODUCTION

Because neurons in visual cortex do not act as simple linear filters, mapping receptive fields can be challenging and depends very much on the stimuli used. Random black-and-white checkerboard stimuli (with no correlations) are only modestly effective. Naturalistic stimuli are somewhat more effective, but it is unclear what aspects of those stimuli underlie the improvement.

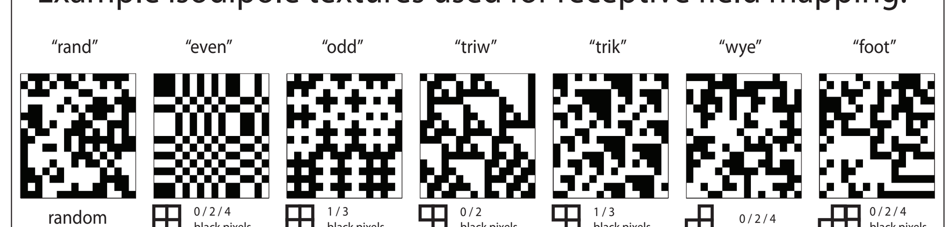
How do receptive field maps in V1 depend on higher-order spatial correlations in the stimuli?

METHODS

Physiology:
- Anesthetized and paralyzed macaques
- Extracellular single unit recordings using tetrodes

Stimuli:
- Seven different types of binary checkerboards
- Random, third- or fourth-order correlations
- No second order correlations("isodipole textures")

Example isodipole textures used for receptive field mapping:

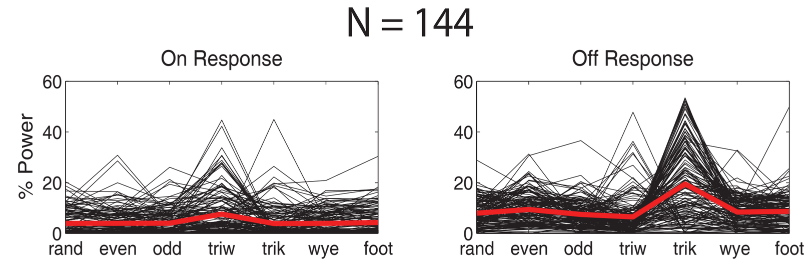


- 1024 examples of each type (two repetitions each)
- Stimuli presented for 320 ms
- Different types of stimuli randomly interleaved

Analysis:
- Reverse correlation for each stimulus type using 320ms bins

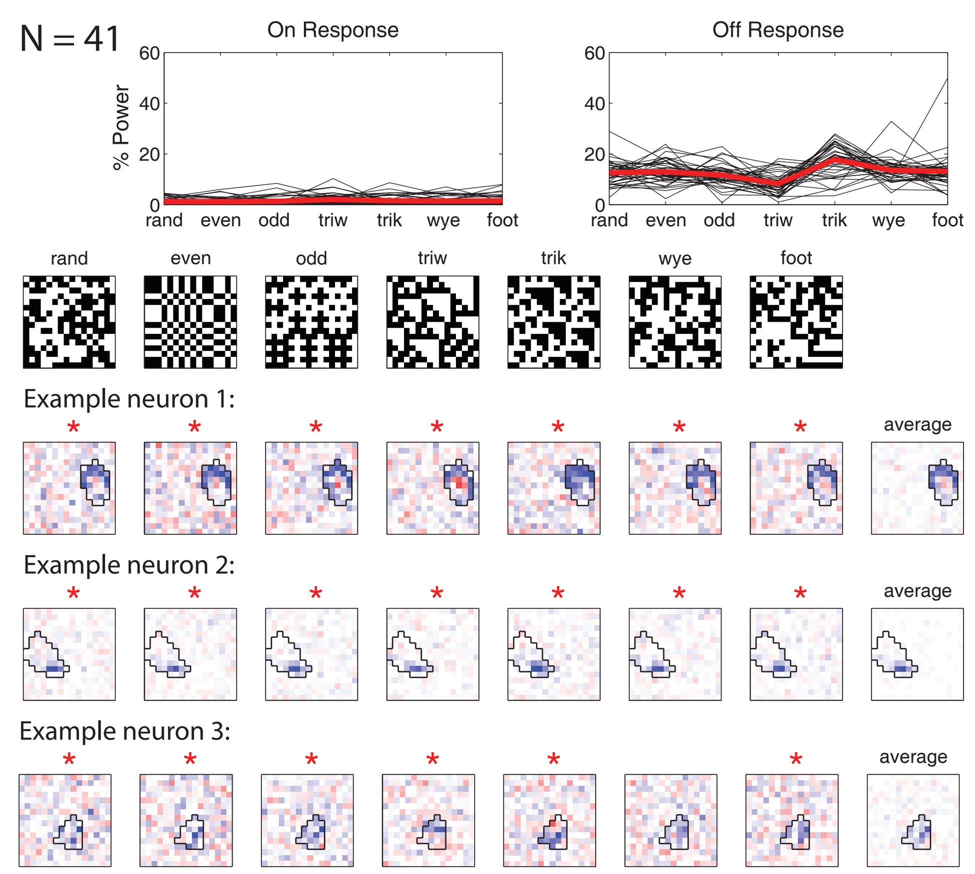
Receptive Field Maps:
Red pixels (positive values) signify increased firing rate to white checks (on-response), blue pixels (negative values) signify increased firing rate to black checks (off-response). The black line denotes the Region Of Interest: enclosing all pixels with a statistically significant response compared to a shuffled response (t-test, alpha = 0.05, corrected for multiple-comparisons) for at least one map and/or the average map. Isolated significant pixels that are more than 2 pixels away from the main response were deleted. Asterisks denote that there is at least one significant pixel for that particular stimulus type.

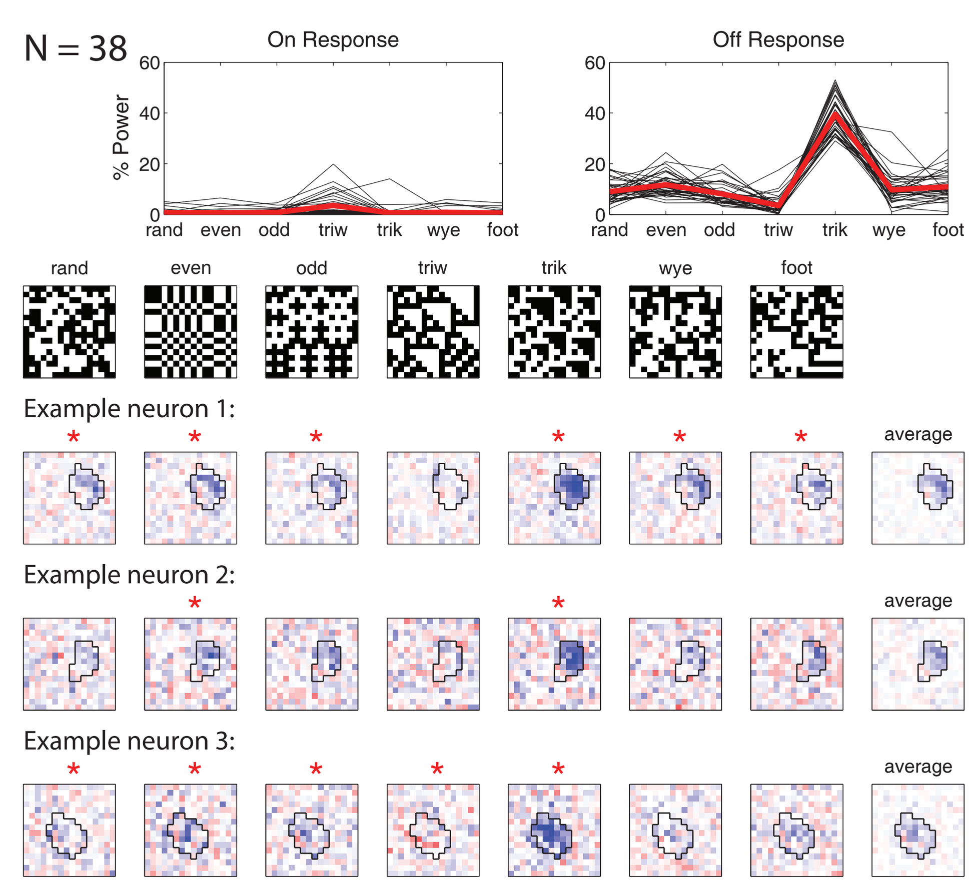
Relative power of on- and off-responses for different stimulus types:
To quantify how strongly the neurons respond to the different types of stimuli, we computed the power of the response within the Region Of Interest. We did so separately for the on- and off-response. Then we normalized those values by the sum of the on- and off-power over all maps. This gives us a profile of relative power of on- and off-responses for each neuron.

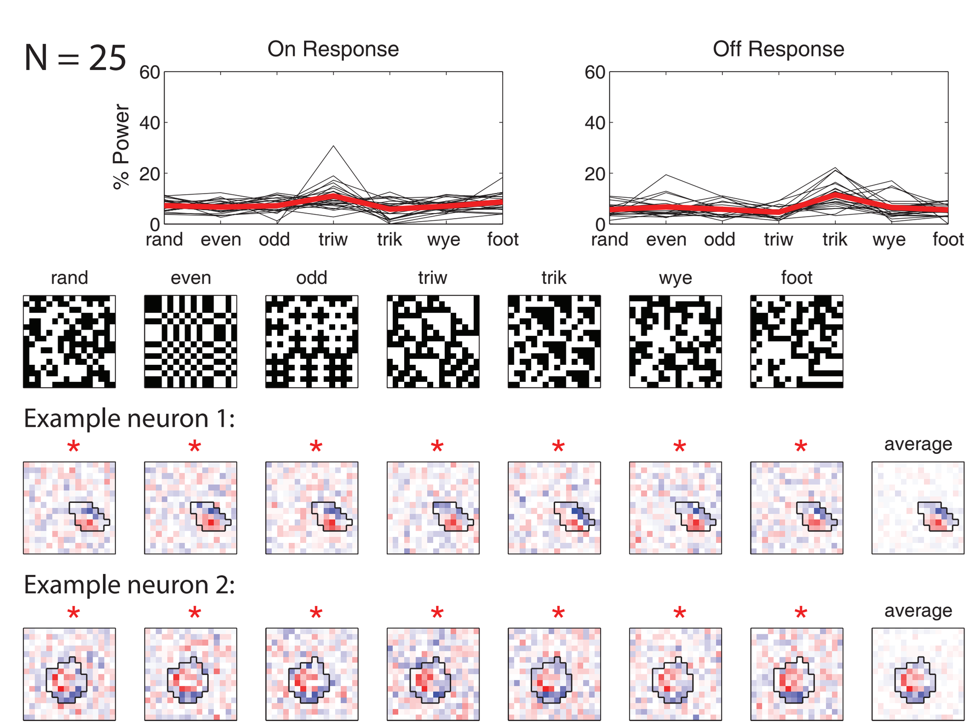


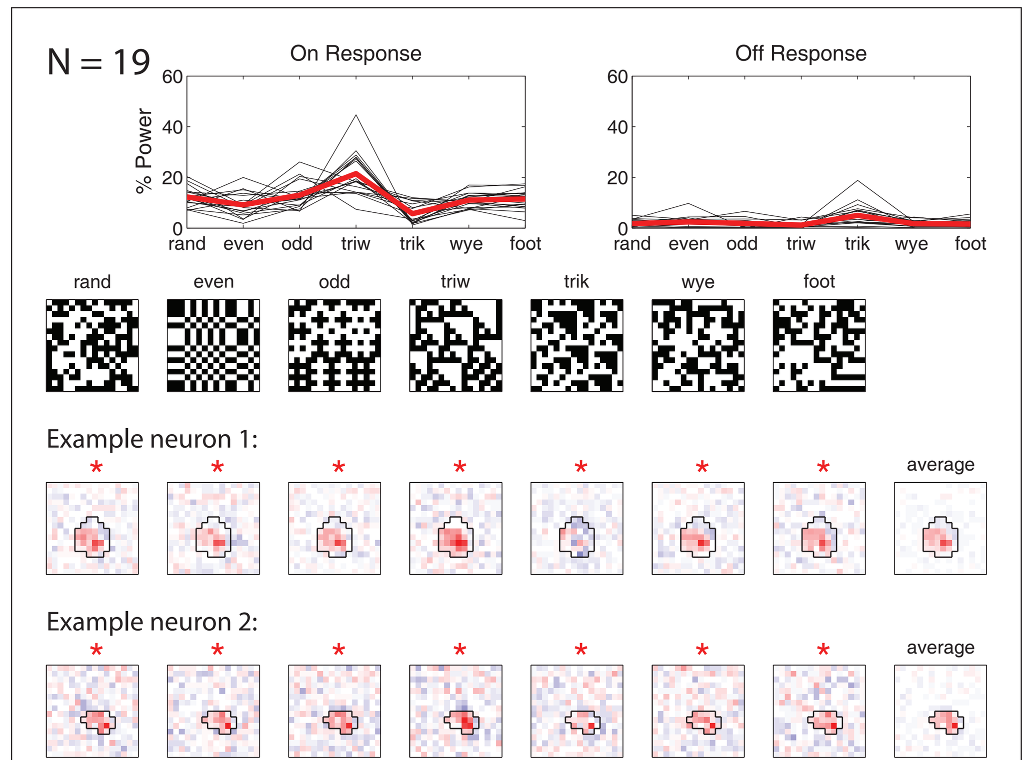
Profile types observed:

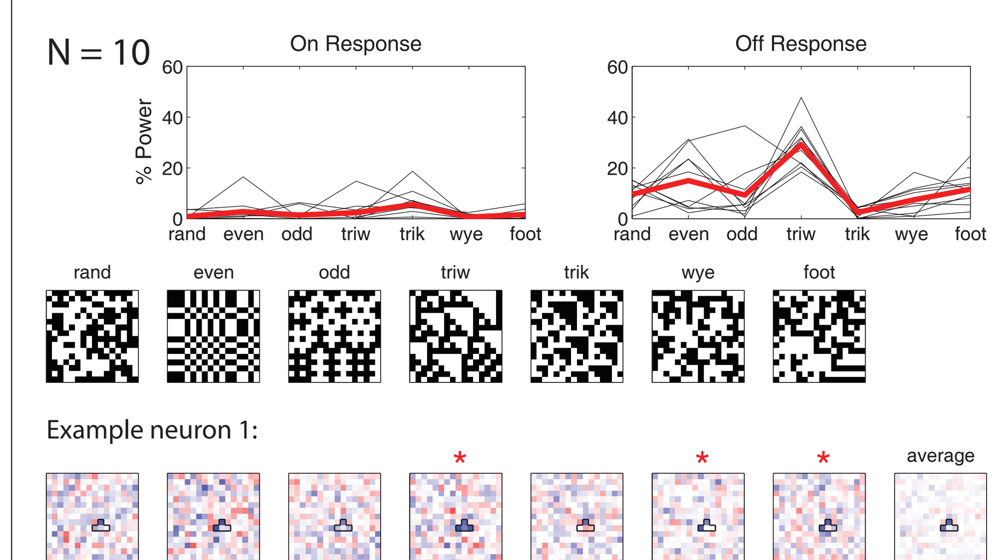
There is a continuum of profiles we observe, but for easier representation, we clustered them into several groups:

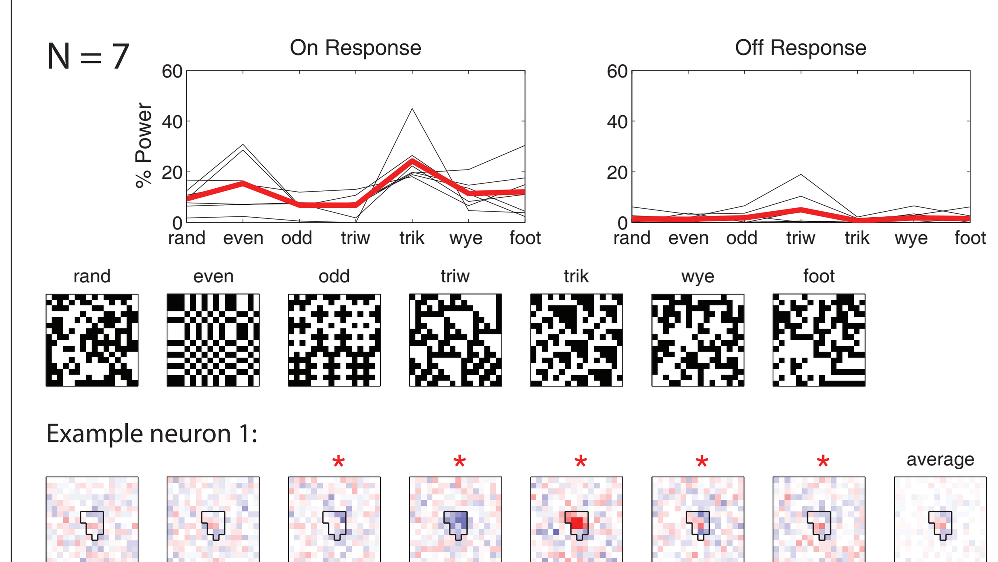


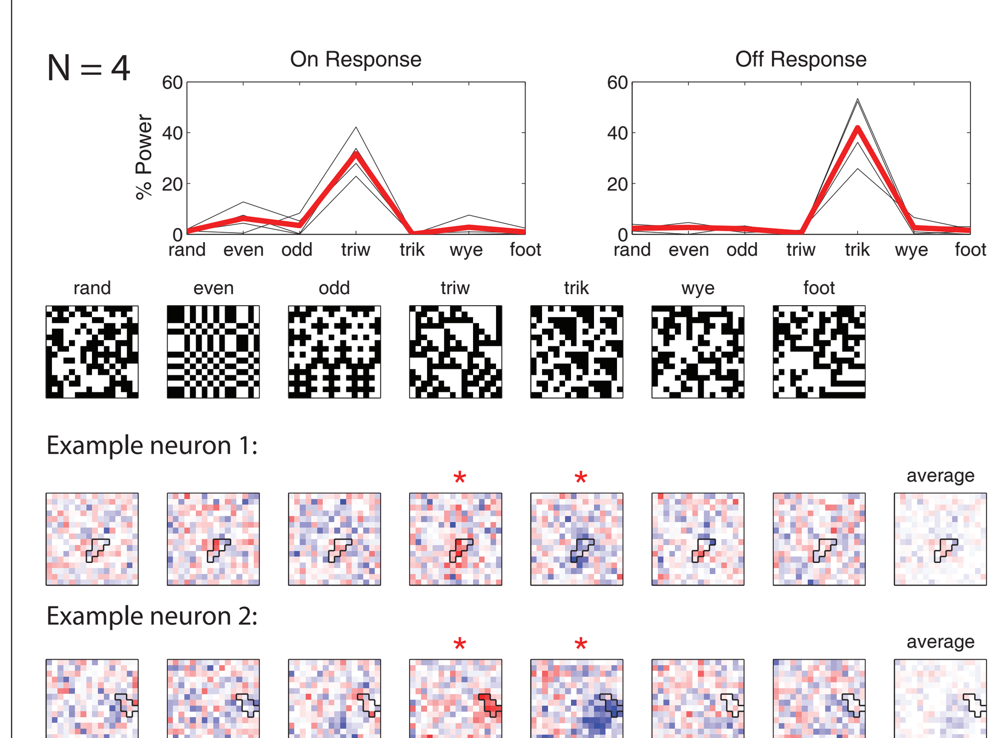




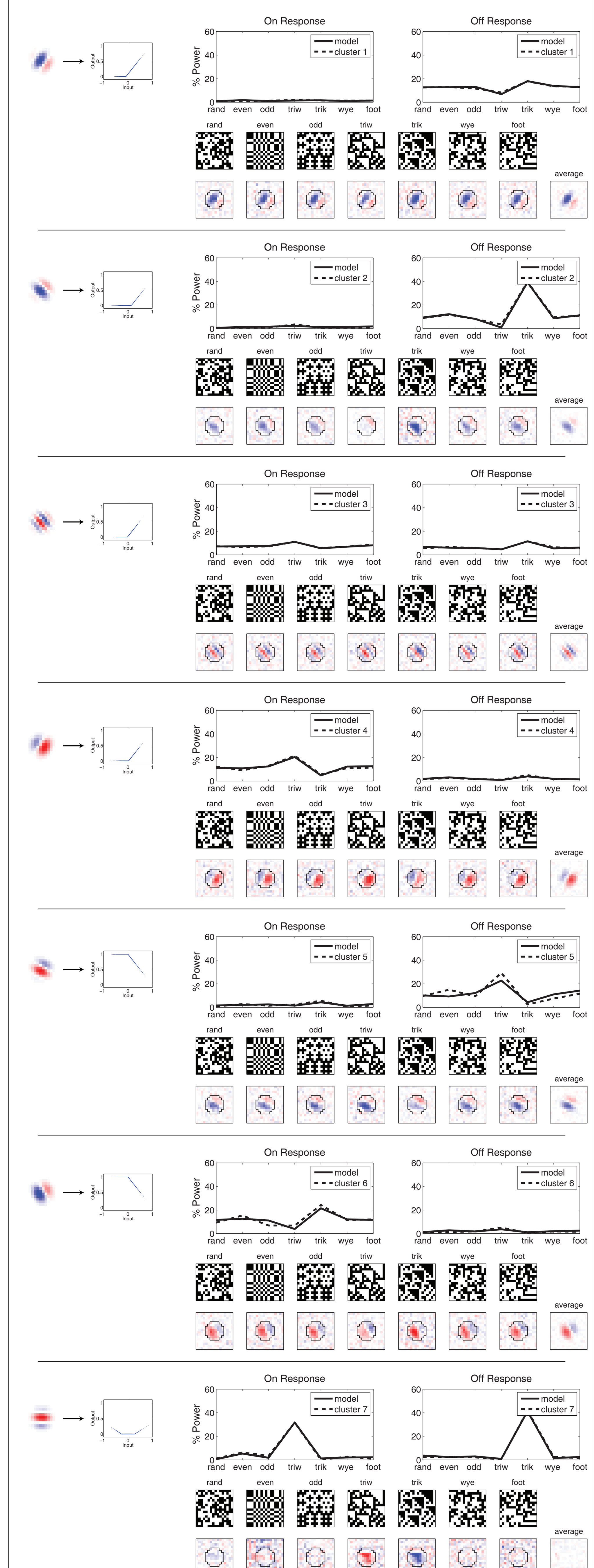








LN Models:



Results in Numbers:

- Out of 134 neurons with at least one significant map, 71 (53%) had a significant map for the random stimulus, while 106 (79%) had a significant map for the black blobs.
- The relative power of the responses was largest for the black blobs (23.5%), followed by the white blobs (14.2%), and followed by the "even" stimulus (13.5%).
- Out of all 144 neurons, 102 (71%) had a stronger map for the black blobs than for the white blobs.
- Out of all 144 neurons, 104 (72%) had more off-pixels than on-pixels in the average map over all stimulus types.
- Out of the 63 neurons without a significant map for random stimuli, 49 (78%) had a map for black blobs, 32 (51%) had a map for "even" stimuli and 31 (49%) had a map for white blobs.

SUMMARY

- Introducing statistical structure into random stimuli approximately doubled the number of neurons that could be mapped.
- Stimuli containing third-order correlations that produced black blobs were the major contributors. They resulted in more cells with significant maps than any other type of stimulus, and also produced the strongest maps.
- Of all stimuli tested, the most pronounced maps were obtained with stimuli whose third order correlations produced black or white blobs, and with "even" stimuli.
- There were more neurons with a stronger map for the stimuli with black blobs than for those with white blobs. This is consistent with an overall prevalence of off-subfields and with previous studies (1).
- Stimuli enriched in black blobs enhanced the off-subfields, while the stimuli enriched in white blobs enhanced the on-subfields. Simulations showed that this behavior is consistent with a linear filter followed by a half-wave rectification.

CONCLUSIONS

In sum, stimuli with black blobs on a random background are the most efficient for eliciting maps, because they enhance off-subfields, which are most prevalent. Using white blobs on a random background is most efficient for mapping on-subfields. Adding stimuli with "even" fourth-order correlations to these two sets leads to significant maps in more additional neurons than any of the other stimulus types we tested. We conclude that the use of these three stimulus types is an effective strategy for augmenting standard approaches for mapping receptive fields.

References:
(1) Xing D, Yeh CI, Shapley RM. Generation of black-dominant responses in V1 cortex. J Neurosci. 2010

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