Population codes in V1 and MT are optimised for the structure of natural images

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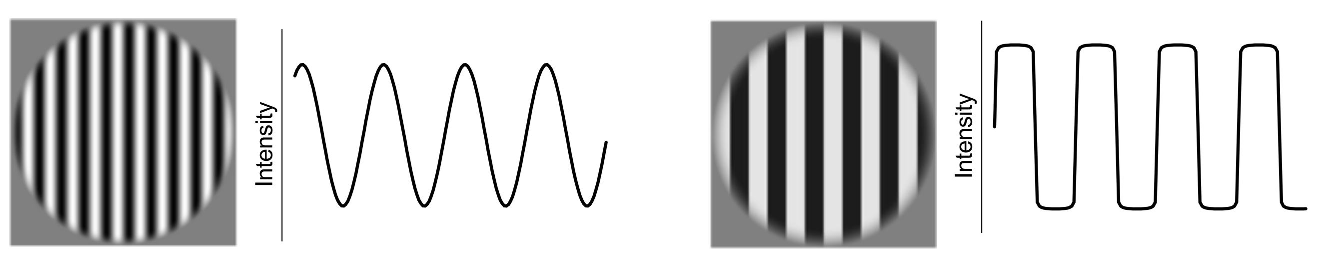
Many neurons in the primary visual cortex (V1) project to the middle temporal area (MT). In V1, motion representations are tightly coupled to the physical properties of the stimulus. In MT, a more robust, stimulus invariant, representation of motion direction is computed.

Here we examine how stimulus representations in networks of neurons in two cortical areas depend on stimulus structure.

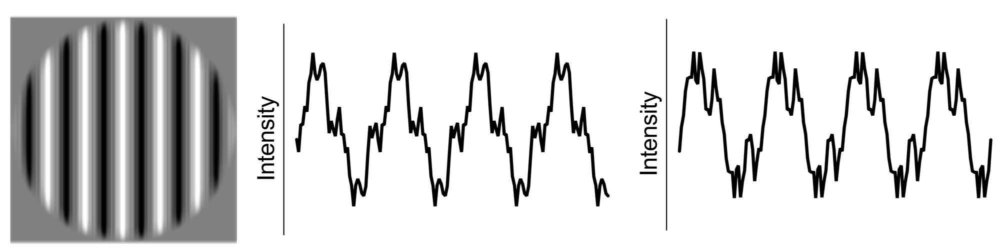
Manipulating stimulus structure

Sine wave
narrowband

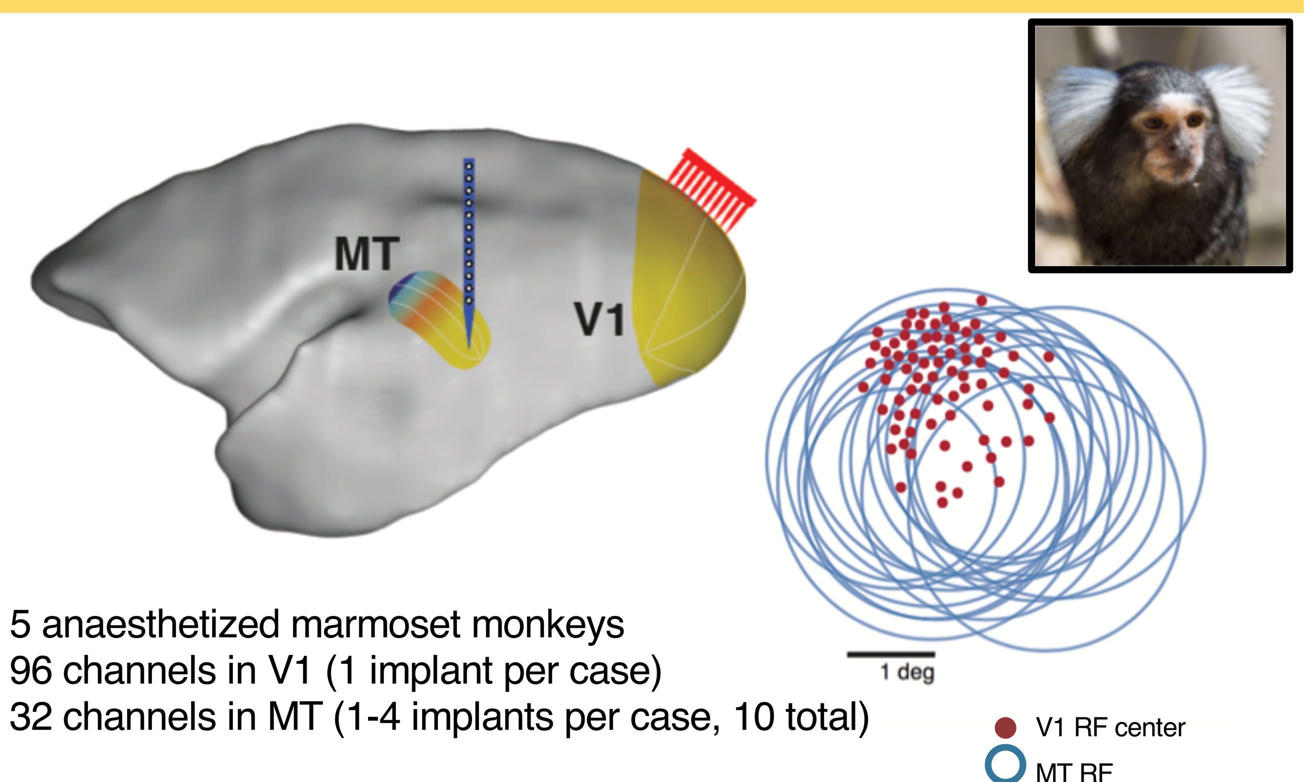
Square wave
broadband, structured



Phase-randomized square wave
broadband, unstructured



Population electrophysiology



5 anaesthetized marmoset monkeys
96 channels in V1 (1 implant per case)
32 channels in MT (1-4 implants per case, 10 total)

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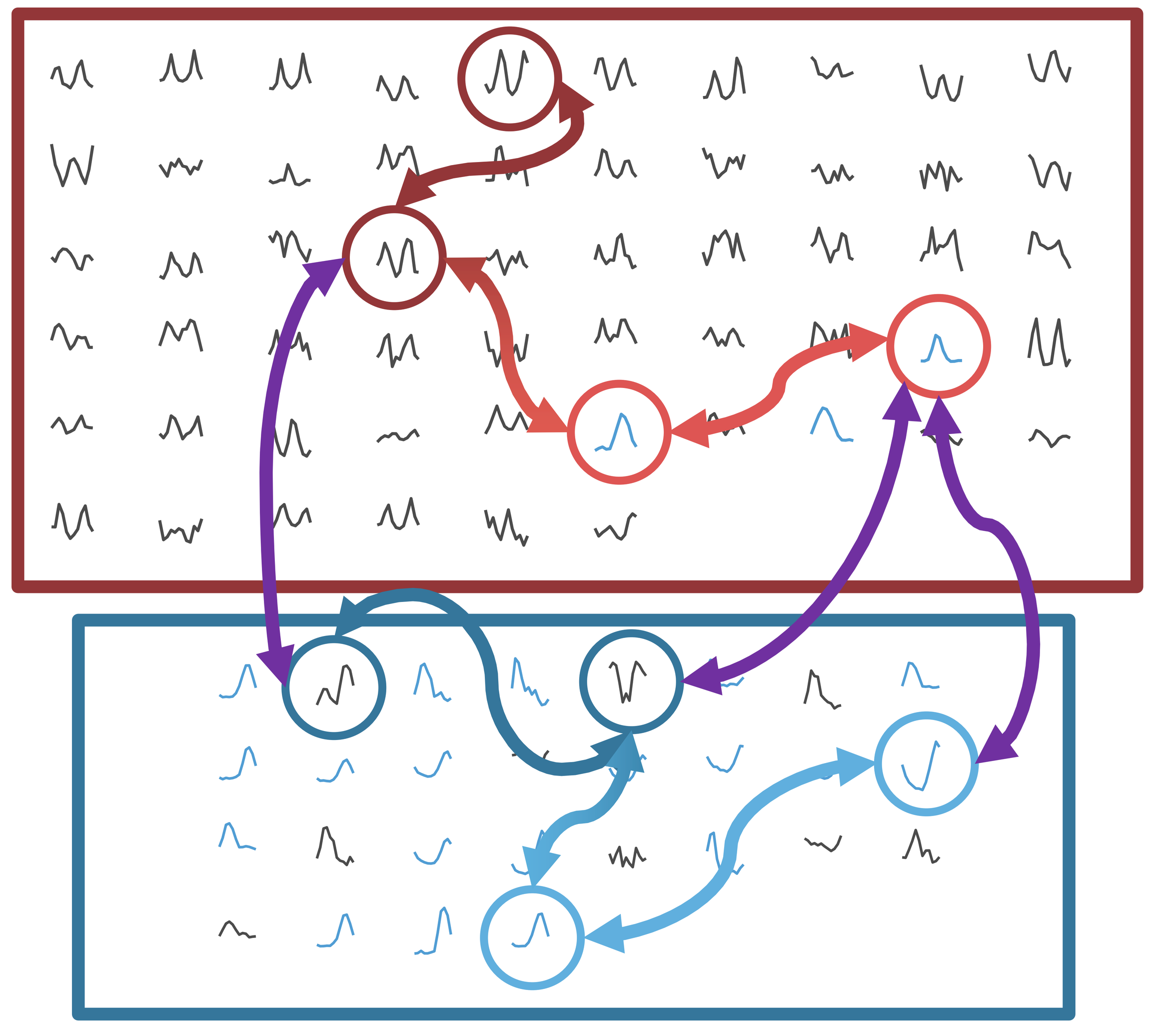
Networks in aggregate, or based on direction selectivity

Tuned, visual units were categorized as orientation (OS) or direction (DS) selective

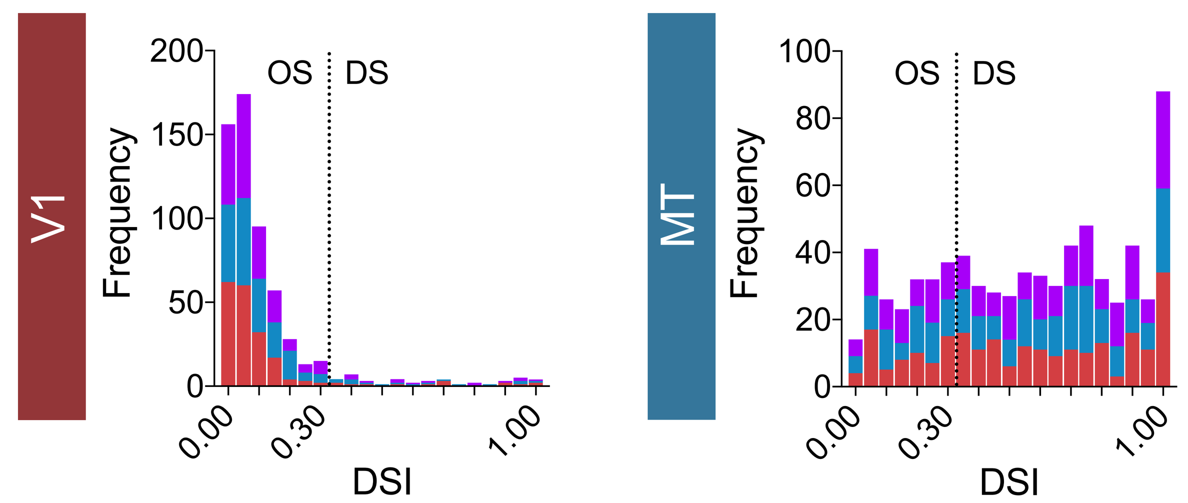
V1-OS = 178 units
V1-DS = 18 units

MT-OS = 95 units
MT-DS = 185 units

Tuning curves from 56 simultaneously recorded V1 multiunits

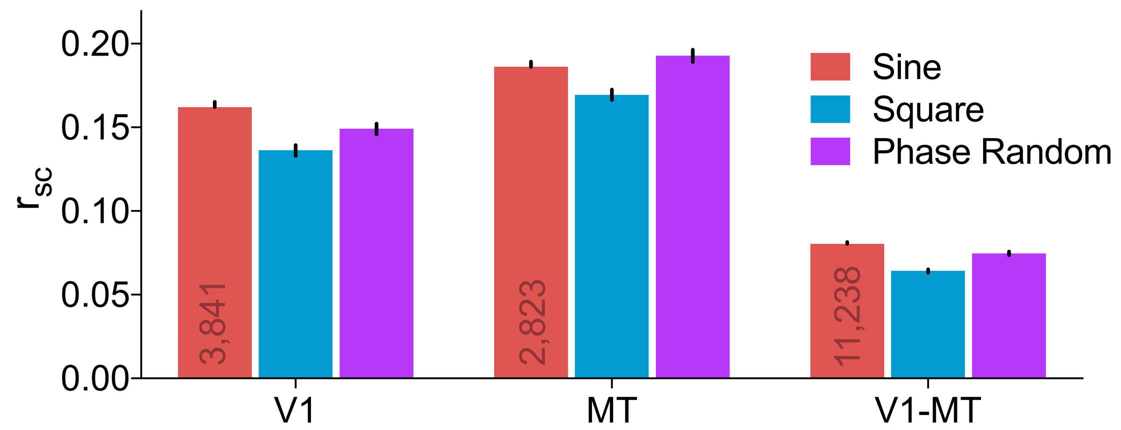


Tuning curves from 28 simultaneously recorded MT multiunits



Naïve network (all pairs)

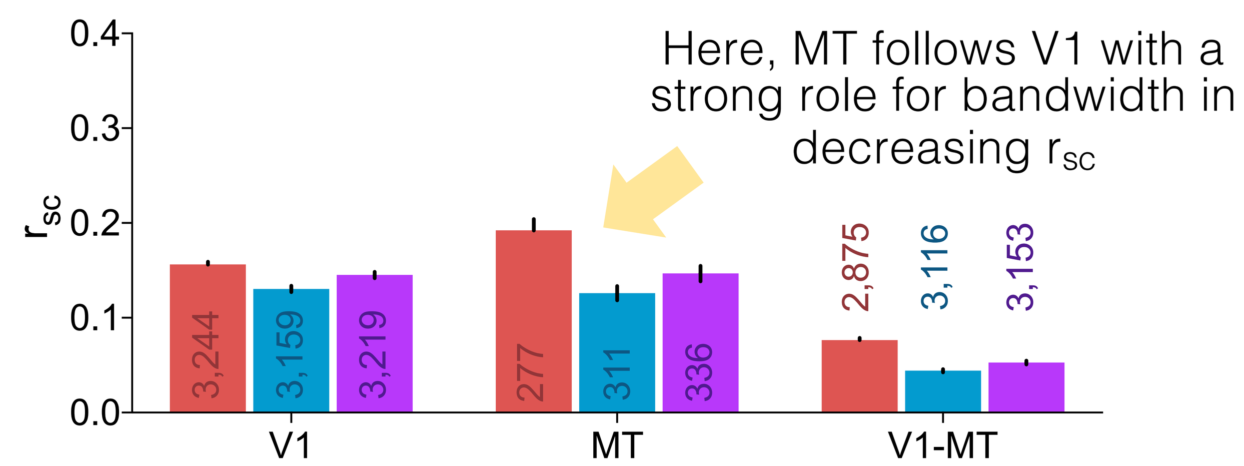
Correlations are higher within than between areas



All differences are statistically significant unless otherwise indicated.

OS networks

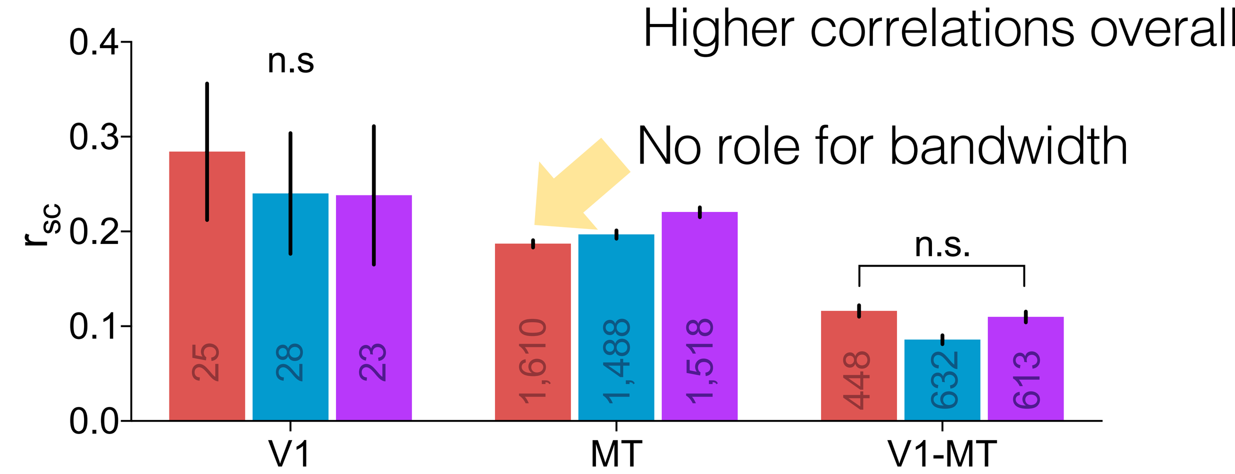
Here, MT follows V1 with a strong role for bandwidth in decreasing r_{sc}



DS networks

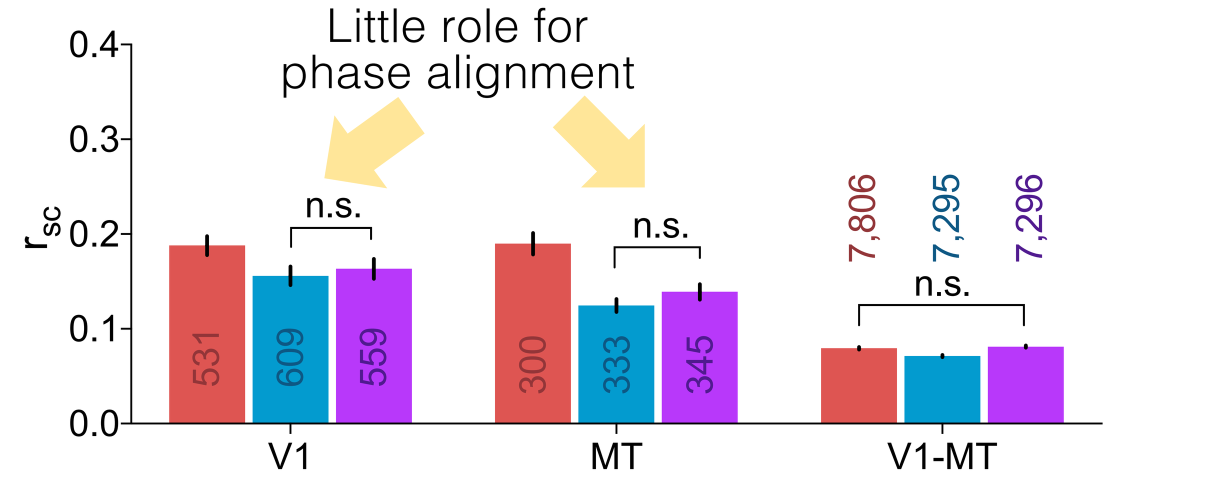
Higher correlations overall

No role for bandwidth



DS-OS networks

Little role for phase alignment



Summary

In V1 and between V1-MT, **sine wave** correlations are highest, followed by **phase-randomized square waves**, and **square waves**.

In MT, **phase-randomized square waves** produce the highest correlations.

Populations within and between both areas are sensitive to the **phase alignment** of the stimulus, but only populations in V1 are particularly sensitive to the **bandwidth**.

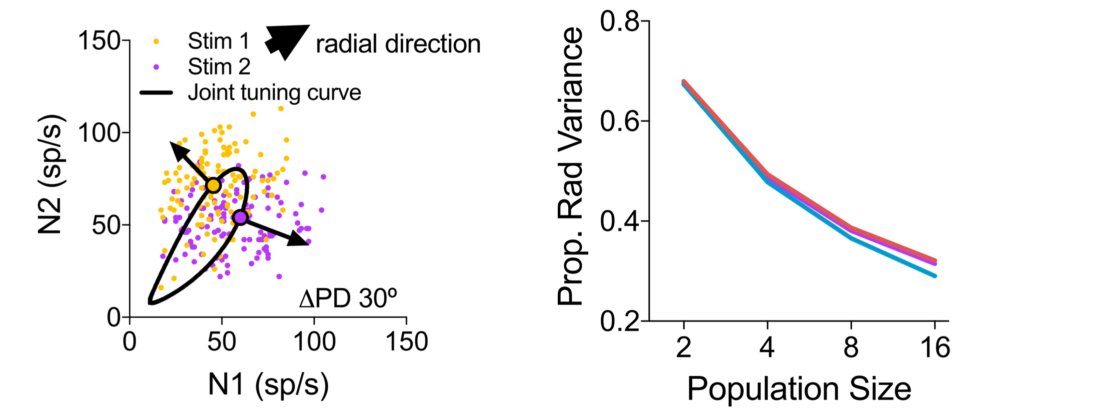
In orientation, but not direction, selective networks, correlations between MT neurons are reduced by greater **bandwidth**.

Overall, correlations are higher in networks of direction selective neurons.

Phase alignment reduced correlations within DS and OS networks, there is less evidence that it reduces correlations between them.

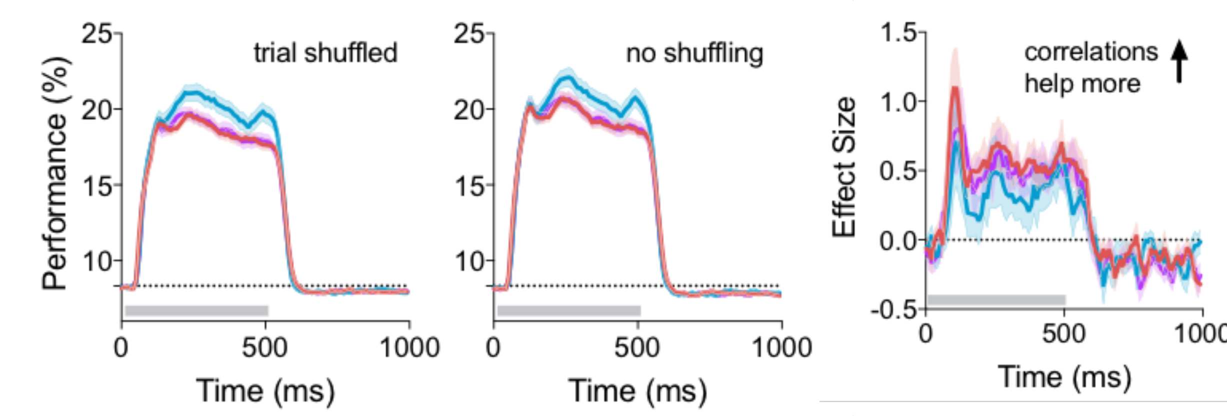
Must correlations hinder?

Measuring the proportion of radial variance is one way to estimate how much of the variability is in a direction that facilitates stimulus representation.



Radial variance is lowest when stimuli have the most structure, predicting the least facilitation.

To examine the representation quality directly, measure direction decoding in small (n=20), simultaneously recorded, MT populations.

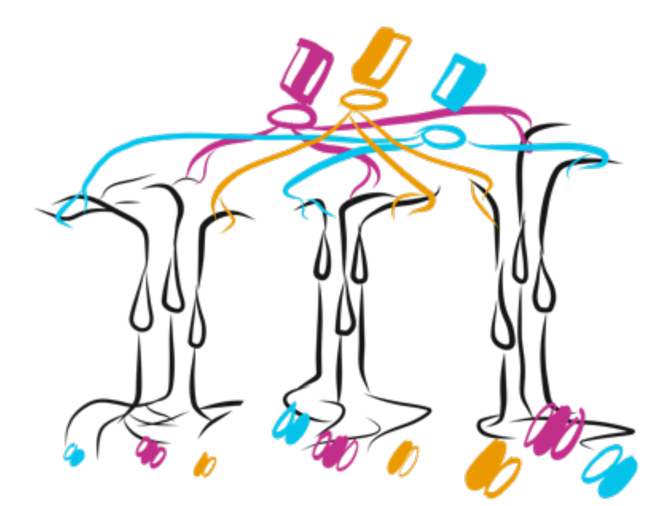


In both correlated and uncorrelated populations, square-wave stimuli are represented best.

For all stimulus types, correlated variability facilitates decoding, however, the correlations that are present in the **sine wave** and **phase randomised** stimuli facilitate decoding more than those present in **square wave** stimuli.

What mechanisms?

Normalisation pools that are specific for phase and orientation, but span many spatial frequencies



Lower correlations may be promoted by …