Modelling Probability Effects as Differences in Neuron Tuning

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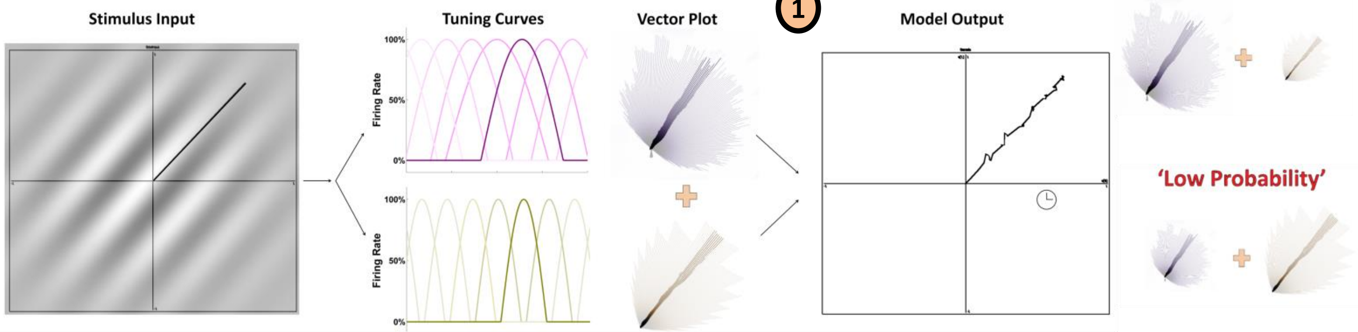
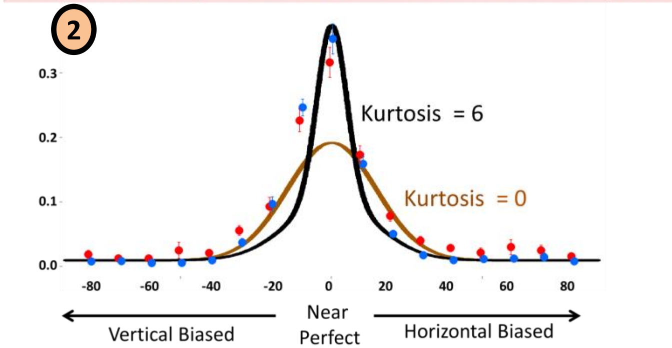
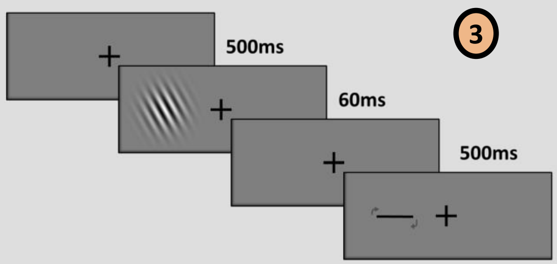
Can orientation probability effects be due to neural tuning differences ?



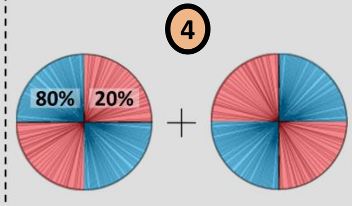
Proportion of angular errors from true stimulus orientations



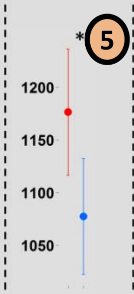
Orientation Estimation Task



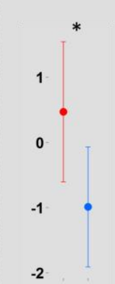
Probability Distribution



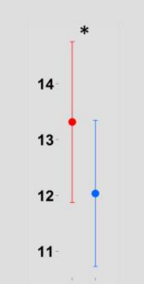
RT



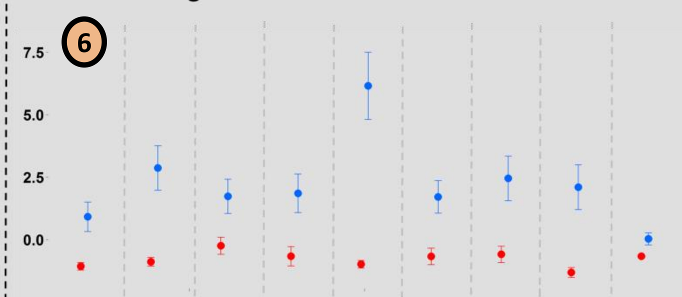
Bias#



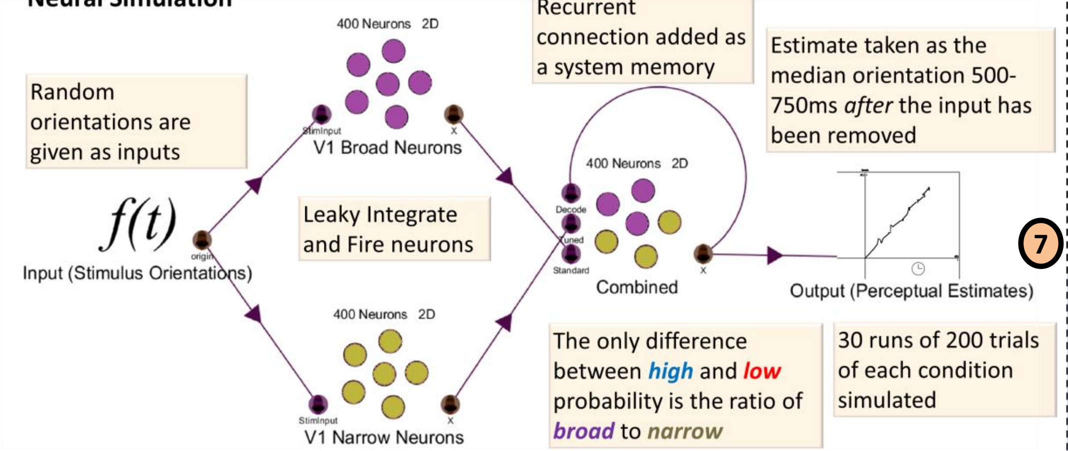
Mean Error



Kurtosis of angular errors across stimulus orientations^



Neural Simulation[N]



Random orientations are given as inputs

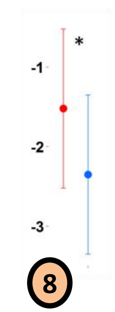
Leaky Integrate and Fire neurons

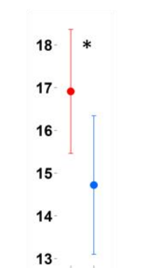
Recurrent connection added as a system memory

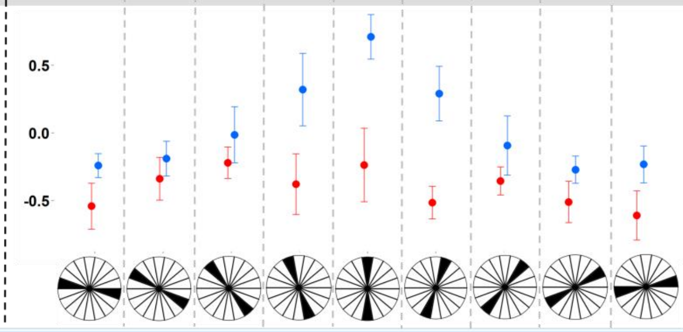
Estimate taken as the median orientation 500-750ms *after* the input has been removed

The only difference between ***high*** and ***low*** probability is the ratio of ***broad*** to ***narrow***

30 runs of 200 trials of each condition simulated







Conclusions

- **Behavioural effects sufficiently modelled just by changing neural tuning bandwidths**
  - **Orientation effects : Differential neural tuning across preferred orientations ˜**
  - **Probability effects : Relative tuning across neural subpopulations**

* *p* <.05

^ Significant main effects of orientation, probability, and two way interaction, for both behavioural and model data, all *ps* <.05

\# Negative bias indicates an overestimation towards the vertical meridian. Broader tuning for vertical-preferring neurons in the broad population induces this bias.

N Stewart, T.C., Tripp, B., Eliasmith, C. (2009). Python scripting in the Nengo simulator. *Frontiers in Neuroinformatics, 3*, 7.

˜ Li, B., Peterson, M. R., & Freeman, R. D. (2003). Oblique effect: a neural basis in the visual cortex. *Journal of Neurophysiology, 90(1),* 204-217.

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1 *Can probability effects be due to neural tuning differences?* Here we seek to investigate whether tuning differences in the V1 neurons can result in the probability effects seen in orientation estimation tasks. Our model has an input orientation which is fed into two populations of V1 neurons, each of which has their own preferred direction. The difference between the two populations is that one is more broadly tuned than the other. When the tuning is broader, each neuron fires to a greater range of orientations deviating from its preferred orientation. Activity from these two populations are combined in a weighted manner. What we aim to examine is whether changing these weights might replicate the type of estimation errors that participants make for high versus low-probability tilts.

2 We looked at the distribution of errors in participants' estimates in one such orientation task. There is a higher proportion of responses nearer the true orientation for the high-probability tilts (shown in blue) than for the low (shown in red), and higher proportion of responses further away from the true orientation for the low-probability tilts. This difference is well-captured by a measurement of the kurtosis of the distribution, with the high-probability tilts having a more kurtotic error distribution. Probability seems to alter the shape of the distribution of estimation errors, and this is what we want to model.

3 In the task, participants were shown a gabor for 60ms, and asked to orientate a line using keyboard buttons, to match the orientation as accurately as they could. We can a trial-by-trial measure of error by comparing the estimated orientation against the presented one.

4 Participants were not told of this, but there was a probability distribution in the tilts. Half the participants saw that when the gabors appeared on the left, they are more likely left tilting, and the reverse on the right. This was counterbalanced across participants.

5 Although no participant could accurately report the probability distributions, traditional behavioural measures did show a significant effect of probability. Participants were faster in matching high-probability tilts, and also made smaller errors on average. Additionally, the high probability tilts also tended to be estimated more vertically than they should have.

6 There is a higher kurtosis for high than low probability orientations, but this difference is particularly exaggerated then the gabor was vertically orientated. High-probability vertical tilts are best represented. These behavioural effects are consistent across even more complex probability conjunctions. It has been suggested that V1 neurons with different preferred directions have different tuning widths. Given the interaction of the probability effect with this 'orientation effect', it might suggest that probability is also affecting V1 tuning widths.

7 Therefore, in addition to the relative weighting between broad and narrow populations, we also added orientation differences in tuning into our model to test for the interaction effect. We had thirty runs of this simulation, simulating 200 trials of each 'probability' condition. Note that the *only* difference between probability conditions was the weight of how each population influences the output. In the 'high probability' simulation, the weight is higher for the broad neuron population, but is lower in the 'low probability' simulation.

8 Just this simple change in the weights enables the model to replicate the probability effects, not only in terms of the mean errors made, but also in the shape of the error distributions. As in the behavioural data, the more precise 'high-probability' simulation also results in a more kurtotic distribution of errors than for the low-probability tilts. Additionally, making the V1 neurons preferring the near-vertical orientations broader than the rest not only causes the vertical bias , but also causes the interaction where high-probability vertical tilts are best represented.

<u>Summary</u>

- Computationally, a simple change in the influence of broad versus narrowly tuned neuron populations is *sufficient* to account for the probability effects, not only in terms of mean accuracy, but also in the shape of the error distributions made.
- Vertical-preferring neurons might have broader tuning curves. Modelling this causes both vertical bias and the interaction between orientation and probability, further supporting the tuning hypothesis.
- Mechanistically, it could be that probability effects seen at the behavioural level are due to sensitivity changes that develop across feature-selective neuron populations.