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Investigating the role of noise correlation in auditory coding: is correlated neural activity really detrimental to stimulus discrimination?

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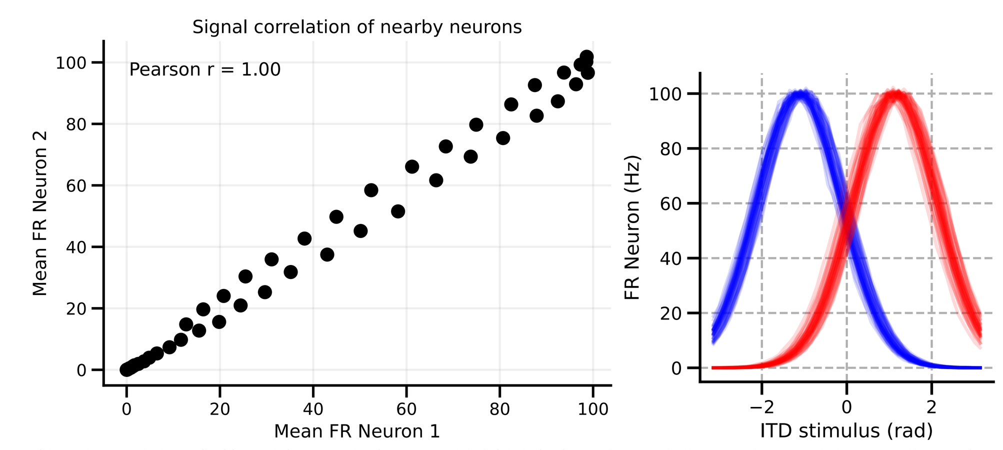
Introduction

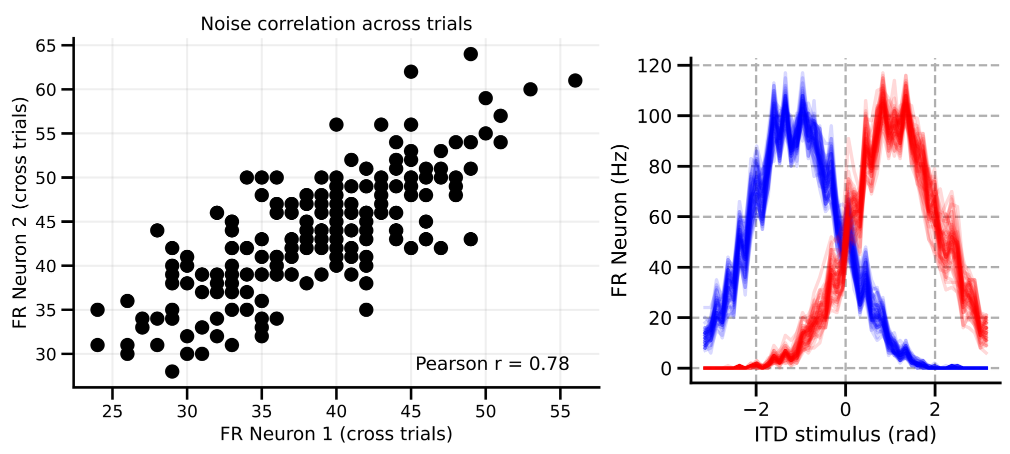
Mammals mainly employ Interaural Time Differences (ITD) for locating low frequency sounds. The firing rate of cells in mammal inferior colliculus (IC) is correlated to ITD, as reflected in ITD tuning curves. These curves span ITD space forming a neural population code, in such a way that the discriminability of frontal ITDs is maximized, which can be quantified by the neural Fisher Information (FI).

Inferior colliculus cells have similar ITD tuning curves, i.e. they present high ***signal correlation***. Previous work investigating the coding of ITD in collicular populations assumed that neuronal activity was uncorrelated across trials, i.e. disregarded ***noise correlation*** − which is not supported by experimental evidence.

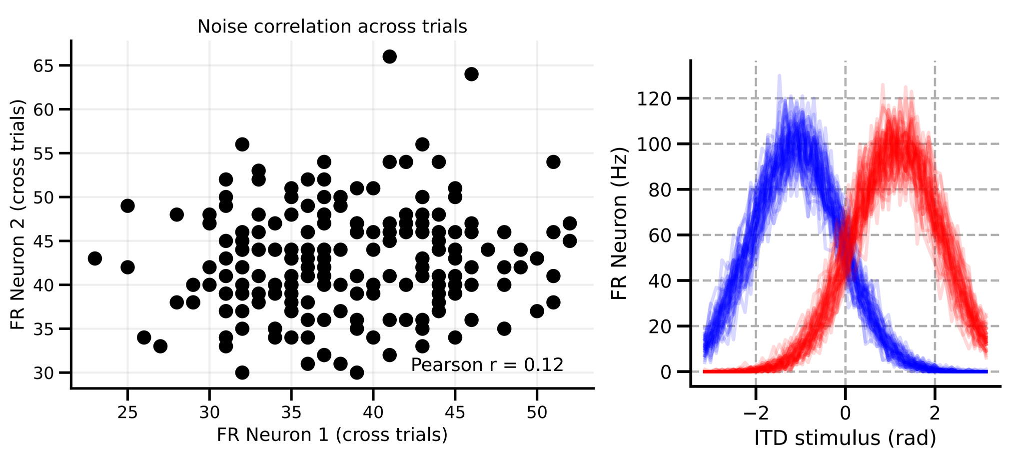
This study investigates how noise correlation influences neural FI, in particular whether it is detrimental to ITD discriminability.



Signal correlation (left) and firing rate for each trial (right). Signal correlation is always high regardless of noise correlation.



High noise correlation (left) and firing rate for each trial (right).



Low noise correlation (left) and firing rate for each trial (right).

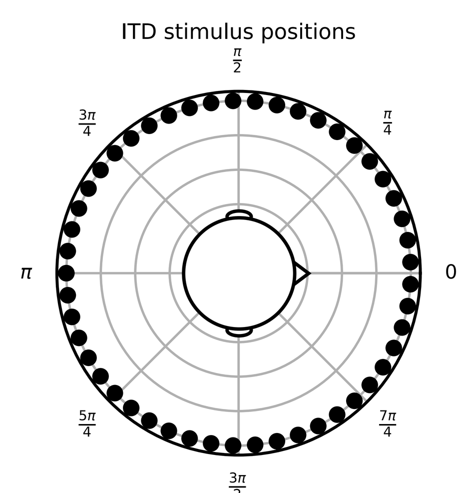
Methods

We simulated a neuronal population with gaussian ITD tuning curves with parameters based on experimental data for mammal inferior colliculus cells, keeping signal correlation constant across all simulations.

We then generated Poisson spike trains whose rate followed ITD tuning curves, while imposing varying levels of noise correlation.

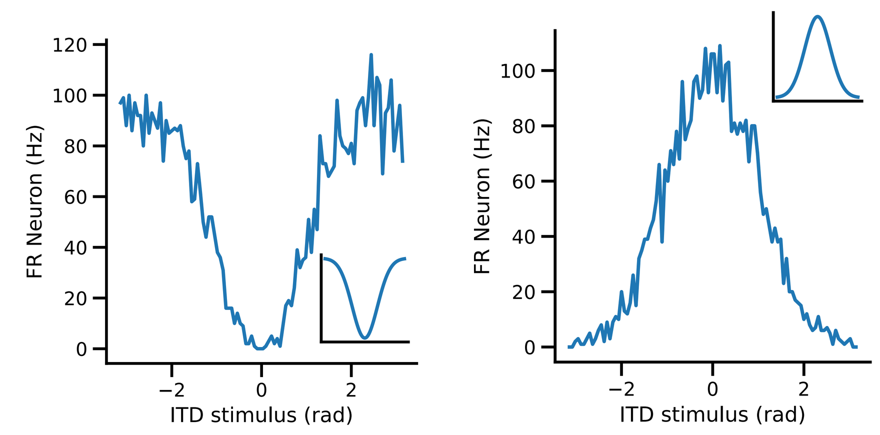
Finally, we employed a linear approximation to calculate the neural Fisher Information for each noise correlation value.

1 Define positions for generating ITD stimulus



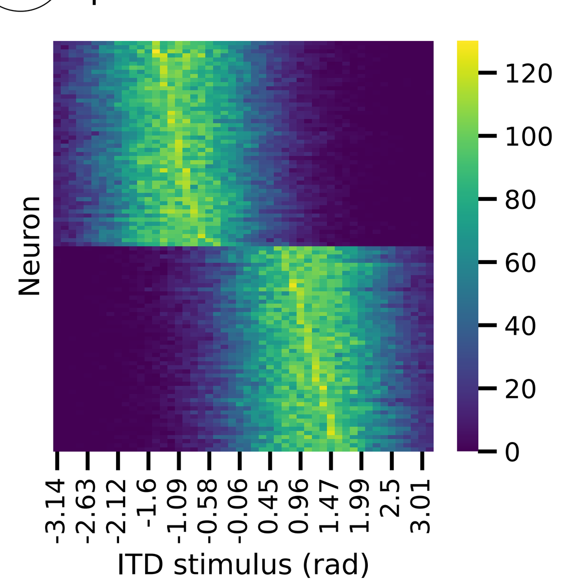
We evenly distributed 50 stimuli around the head. We are going to simulate IC neuron FR curves for each ITD for a low-frequency sound.

2 Estimate the parameters for the tuning curves



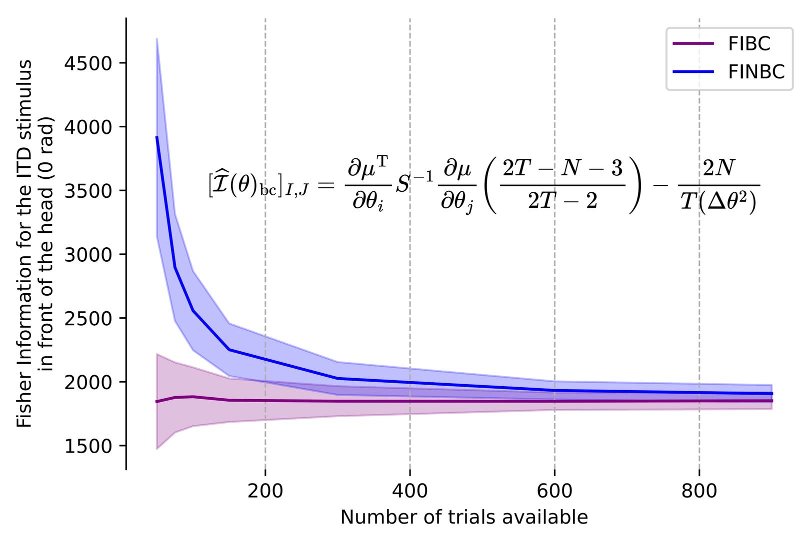
Previous studies showed that tuning curves (average firing rates) are Gaussian-like, and spike trains are generated by Poisson process whose firing rate is given by the tuning curve as a function of ITD. The peak FR of the neuron's "*favorite*" ITD (best ITD) is approximately 100 Hz. These tuning curves can be Through- or Peak-type, meaning that the valley or the peak will be located on the best ITD.

3 Generate trial experiments with controled pairwise noise correlation across trials



Evidence suggests that the neuron population is symmetrically distributed around the center into two clusters of best ITD. We generated a population of 100 with best ITD of ± 0.7 rad, based on previously published empirical studies. The neurons of each cluster have their favorite ITD sampled from a normal distribution centered at the best ITD.

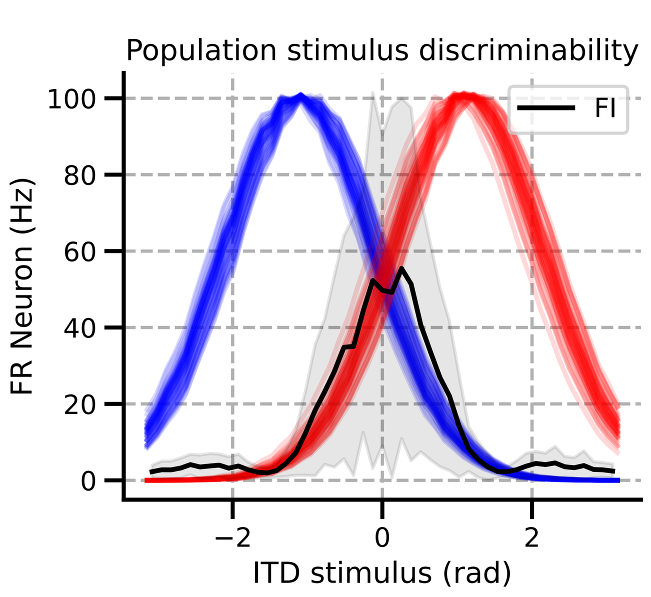
4 Calculate the linear Fisher Information of the population



$$[\widehat{\mathcal{I}}(\theta)_{\mathrm{bc}}]_{I,J} = \frac{\partial \mu^{\mathrm{T}}}{\partial \theta_i} S^{-1} \frac{\partial \mu}{\partial \theta_j}\left(\frac{2T-N-3}{2T-2}\right) - \frac{2N}{T(\Delta\theta^2)}$$

Fisher Information is costly to estimate and biased for small samples. Here, we use a linear estimation (*bias-corrected*, FIBC) that shows a faster estimation of FI. We simulated 200 trials.

5 Visualize the Fisher Information curves



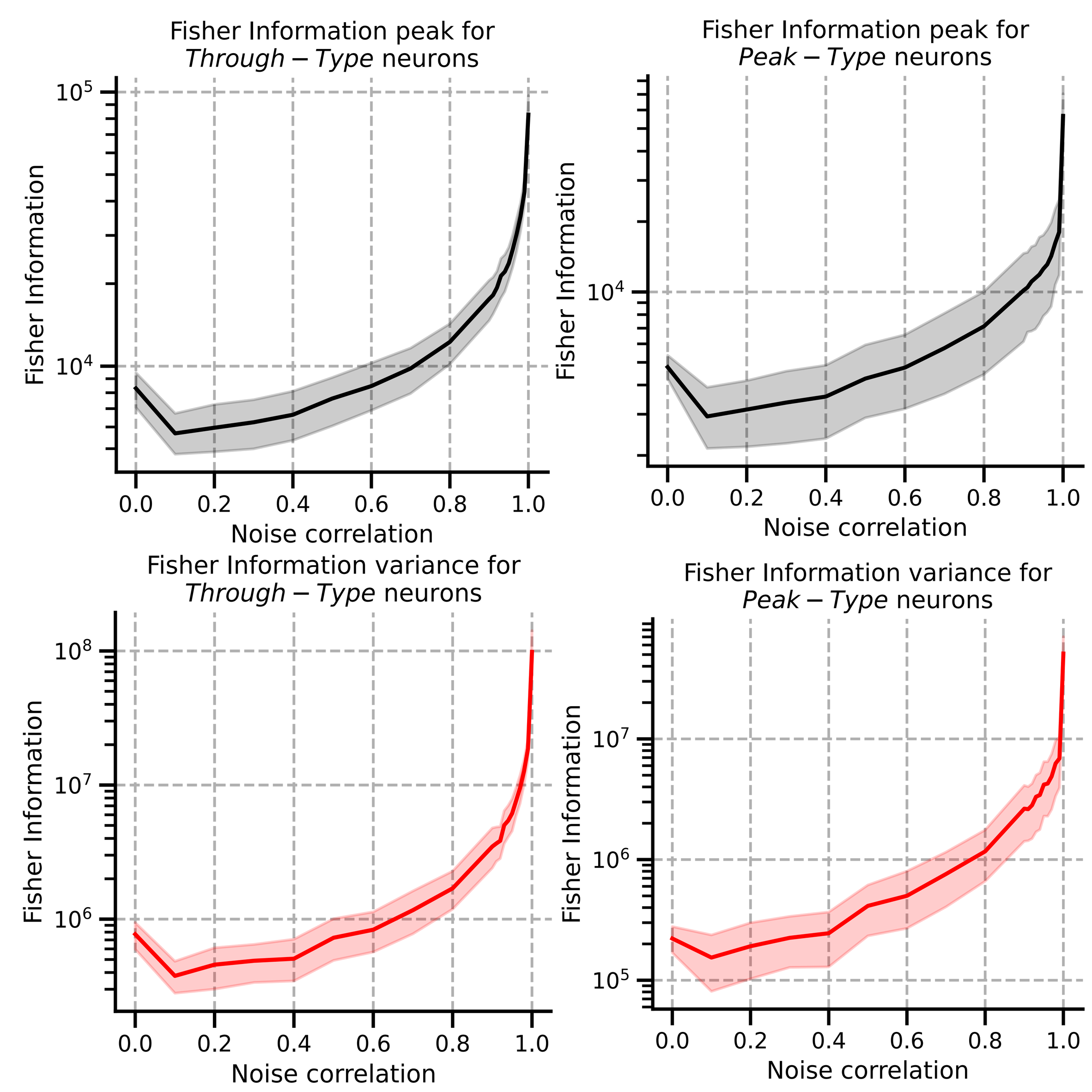
6 Repeat the experiment for each neuron type (Through- and Peak-type) and different noise correlations (between [0, 1] with 0.1 step and [0.9, 1.0] with 0.01 step).

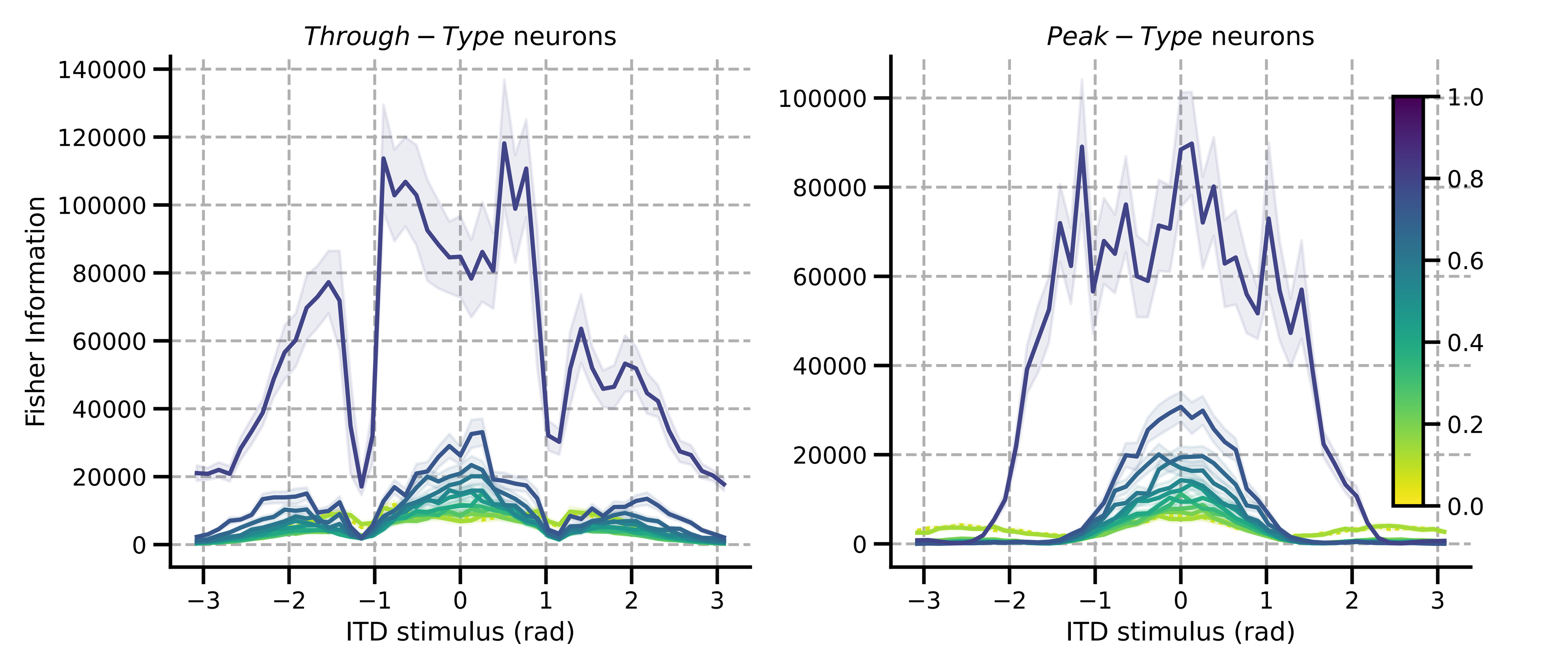
Results

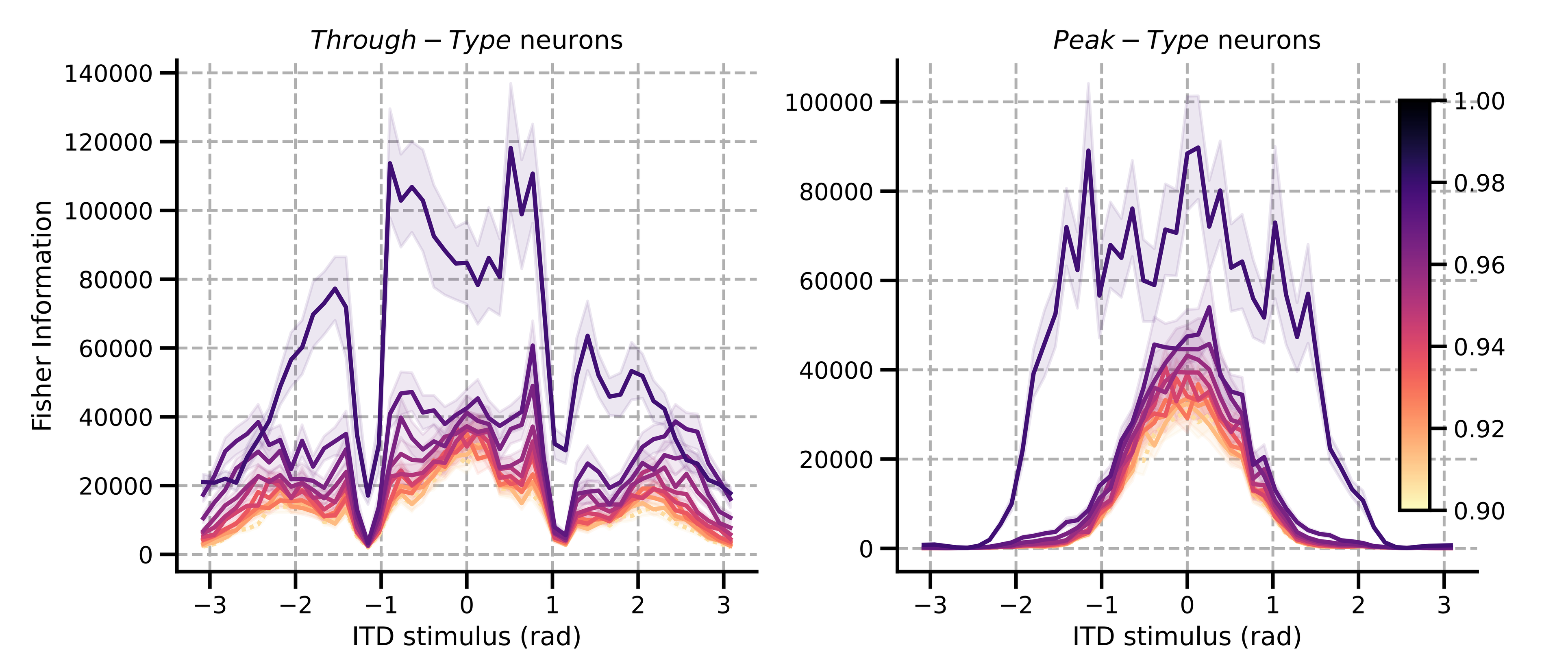
Even though the overall shape of Fisher Information curves remained similar, increased noise correlation led to higher neural Fisher Information across all ITD values − a counterintuitive result given that redundancies are usually thought to decrease the accuracy of population codes.

The average Fisher Information peak across noise correlations shows an initial drop between 0.0 and 0.1 controlled correlation, followed by a monotonic increase.

Through-type and peak-type neuron populations respond differently to an increase in noise correlation, with the latter leading to broader tuning curves at maximum noise correlation.







Conclusions

Noise correlation significantly influences neural Fisher Information. Fisher Information relates to the maximum information that an ideal observer can extract, which is the maximum information the stimulus carries for inferring the sound location.

The discriminability curves show a peak at their center, aligned with the region of highest discriminability experimental findings for humans.

Furthermore, theoretical results based on uncorrelated neural activity are not such crude approximations because noise correlations are known to be present in neural systems.

Future studies should investigate whether this hypothesis holds for experimental data, *e.g.*, by analyzing multi-unit neuronal recordings instead of simulated spike trains.

References

[1] Larry F Abbott and Peter Dayan. The effect of correlated variability on the accuracy of a population code. Neural computation, 11(1):91–101, 1999.

[2] Alessandro Barbiero and Pier Alda Ferrari. Simulation of correlated poisson variables. Applied Stochastic Models in Business and Industry, 31(5):669–680, 2015.

[3] Michael V. Beckert, Rodrigo Pavão, and José L. Peña. Distinct correlation structure supporting a rate-code for sound localization in the owl's auditory forebrain. eNeuro, 4(3), 2017.

[4] Nicol S. Harper and David McAlpine. Optimal neural population coding of an auditory spatial cue. Nature, 430(7000):682–686, August 2004.

[5] Ingmar Kanitscheider, Ruben Coen-Cagli, Adam Kohn, and Alexandre Pouget. Measuring fisher information accurately in correlated neural populations. PLOS Computational Biology, 11(6):1–27, 06 2015.

[6] Rodrigo Pavão, Elyse S Sussman, Brian J Fischer, and José L Peña. Natural itd statistics predict human auditory spatial perception. eLife, 9:e51927, oct 2020.

[7] Ian H. Stevenson, Brian M. London, Emily R. Oby, Nicholas A. Sachs, Jacob Reimer, Bernhard Englitz, Stephen V. David, Shihab A. Shamma, Timothy J. Blanche, Kenji Mizuseki, Amin Zandvakili, Nicholas G. Hatsopoulos, Lee E. Miller, and Konrad P. Kording. Functional connectivity and tuning curves in populations of simultaneously recorded neurons. PLOS Computational Biology, 8(11):1–14, 11 2012.