Artificial neural networks reveal multivariate integration of information across different brain regions

Mengting Fang, Aidas Aglinskas, Yichen Li, Stefano Anzellotti
Department of Psychology and Neuroscience, Boston College

Introduction

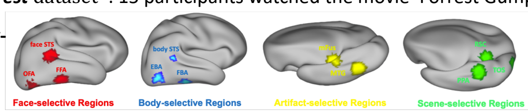
- Human visual cortex is organized into distinct category-selective regions that respond preferentially to objects from different categories (i.e. faces, bodies, artifacts, scenes).
- However, people often need to integrate information about multiple kinds of objects to make inferences about the world.

Question: How does the brain integrate the responses across multiple category-selective regions?
Our hypothesis: Multi-category integration occurs within a specific set of anatomically localized hubs.

Methods

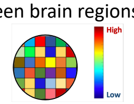
Studyforrest dataset[1]: 15 participants watched the movie 'Forrest Gump'.

Category-selective ROIs



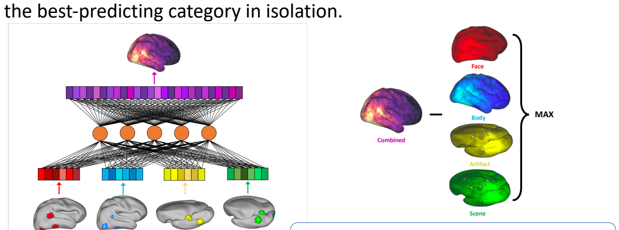
Multivariate **P**attern **D**ependence **N**etwork (**MVPN**)

- Capture multivariate pattern dependence[2,3] between brain regions;
- Train and test with independent data;
- Take advantage of linear artificial neural networks.



Exploring hubs for multi-category integration

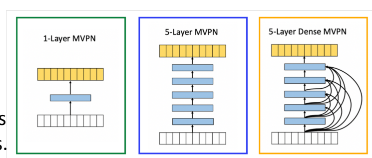
Integration hubs were defined as regions whose responses are better predicted by the response patterns across regions selective for multiple categories, than by the response patterns in the regions selective for the best-predicting category in isolation.



$$\Delta \mathrm{varExpl} = \mathrm{varExpl}_{all} - \mathrm{varExpl}_{max}$$

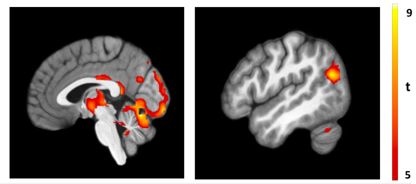
Computational architectures

MVPNs were trained with a variety of computational architectures to compare the predictive accuracy of different models and to assess the robustness of our findings.



Candidate Hubs for Multi-Category Integration

Statistical t-maps computed from ΔvarExpl across subjects using results from the 5-Layer Dense MVPN model.

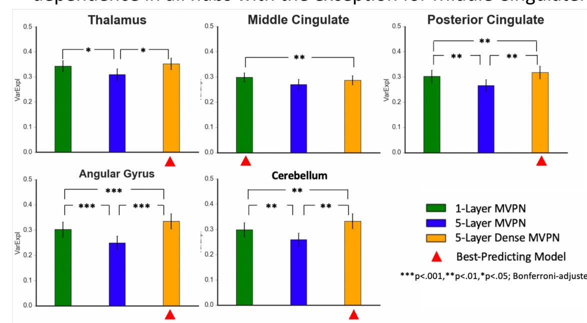


A set of five candidate hubs were identified across three network architectures.

Regions	MNI Coordinates												# vox
	1-Layer				5-Layer				5-Layer Dense				
	x	y	z	t	x	y	z	t	x	y	z	t	
Thalamus	-12	-27	14.4	9.05	-15	-24	14.4	7.74	-18	-21	21	7.38	77
Middle Cingulate	-6	-27	30.9	8.85	3	-24	30.9	6.39	-6	-30	27.6	6.97	81
Posterior Cingulate	3	-45	21	9.53	0	-45	17.7	6.23	3	-45	47.4	8.76	65
Angular Gyrus	-48	-66	24.3	8.54	-	-	-	-	-51	-66	24.3	9.61	46
Cerebellum	0	-69	-12	9.39	-6	-72	-25.2	5.94	0	-69	-12	10.14	66

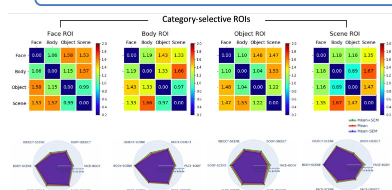
The locus of each hub was thresholded at p < 0.05; FWE-corrected for multiple comparisons.

- 1-Layer MVPN and 5-Layer Dense MVPN outperformed 5-Layer MVPN without dense connections.
- 5-Layer Dense MVPN provided the best model of the statistical dependence in all hubs with the exception for Middle Cingulate.

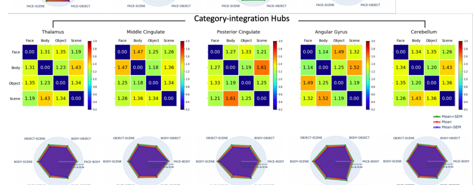


Representational Similarity Analysis

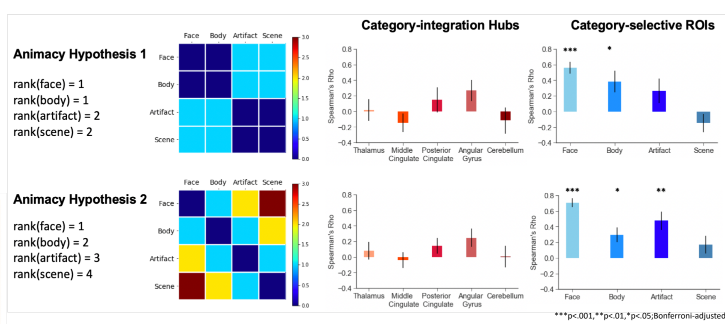
Do hubs inherit representational geometry from category-selective regions?



In category-selective regions, the similarity between the responses to different categories of objects largely depends on whether they are animate or inanimate.



By contrast, RSA revealed that the representational geometry in the hubs is not driven by animacy.



Conclusion

- We introduced MVPN, a technique that leverages a combination of neuroimaging, multivariate connectivity, and artificial neural networks to study how brain regions interact.
- Thanks to MVPN, we discovered a set of brain regions ('category-integration hubs') that integrate information about different kinds of objects, revealing a candidate mechanism for multi-category integration.
- Representations in category-integration hubs are not organized along the same dimensions as representations in category-selective regions.

Future Directions

- Test with non-linear artificial neural networks to find other regions that could contribute to the integration between categories as well.
- Integrate temporal information into the model to capture more complex relationships.

References

1. Hanke, M., Adelhöfer, N., Kottke, D., Iacovella, V., Sengupta, A., Kaule, F. R., ... & Stadler, J. (2016). A studyforrest extension, simultaneous fMRI and eye gaze recordings during prolonged natural stimulation. Scientific data, 3(1), 1-15.
2. Anzellotti, S., Caramazza, A., & Saxe, R. (2017). Multivariate pattern dependence. PLoS computational biology, 13(11), e1005799.
3. Anzellotti, S., & Coutanche, M. N. (2018). Beyond functional connectivity: investigating networks of multivariate representations. *Trends in cognitive sciences*, *22*(3), 258-269.