

NEUROSCIENCE

Social networks in the brain

Functional magnetic resonance imaging and social network analysis show that on viewing familiar individuals in a small social network, the brain activates regions critical for inferring mental states and intentions, as well as regions associated with spatial navigation and psychological distance.

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The past decade has seen increasing recognition that a driving force behind human brain evolution may have been the complex demands of living in social groups¹. As a fundamentally social species, humans form complex social networks that foster competition or cooperation where we must track not only our own direct relationships but indirectly monitor and understand others' relationships as well. Traditionally, different fields have approached the study of human social groups in different ways. Sociologists quantify the structure of real-world social networks. Social psychologists ask how we judge individuals or groups and how status differences influence behaviour. And neuroscientists identify brain systems for recognizing social cues or thinking about mental states. To have a complete, multi-level understanding of our social nature², however, these approaches must be integrated to explain how group-level phenomena — like network status — are supported by specific neural systems.

Writing in this issue of *Nature Human Behaviour*, Parkinson *et al.*³ join a small but growing number of studies (for example, refs^{4,5}) taking such an approach. Using sociometric methods, the network structure of a cohort of 275 MBA students was measured based on questions such as who they spent free time with in social activities and whose homes they had visited. A 24-person subset later viewed 2-second silent videos of network members in a functional magnetic resonance imaging (fMRI) scanner. Videos were selected to depict individuals who systematically varied along two key indices of network membership: (i) eigenvector centrality (EC), which refers to how interconnected an individual is with others that are highly interconnected; EC may reflect social prestige and sociometric popularity (that is, being liked in the aggregate by your group), and (ii) geodesic distance, which is the path with the fewest intermediaries between any two individuals (for example, two unconnected individuals sharing a



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common friend have a geodesic distance of two). A third variable, constraint, which measures how much an individual connects others who themselves are not highly connected, was allowed to vary freely; low-constraint individuals may 'broker' the flow of information through a network from one subgroup to another⁴.

This innovative design was combined with representational similarity analysis (RSA; ref. ⁶) to ask what brain systems represent our knowledge of network members' status. RSA identifies brain regions whose pattern of activity across sets of voxels approximates the relational structure of features in stimulus inputs — in this case, the three indices of network membership noted above. The combination of a real-world affiliation-based network studied with this technique makes this paper particularly novel: in humans, studying affiliation-based status is important because everyone is part of such groups, dominance hierarchies are less important as compared with other species, and prior

imaging work on social status has focused primarily on hypothetical hierarchies (for example, ref. ⁷) or stylized status cues⁸, or if they studied real-world affiliation networks, used univariate analyses to identify brain systems tracking a single network index (for example, sociometric popularity⁵ or brokerage⁴).

Parkinson *et al.* found large swaths of brain that are sensitive to EC, most notably, regions comprising the 'mentalizing' network (for example, medial prefrontal cortex (mPFC), precuneus, posterior cingulate cortex) critical for inferring mental states and intentions, as well as a left ventrolateral prefrontal region associated with retrieving semantic information from memory⁹. Prior work dovetails with this finding by showing that these regions support retrieving and keeping in mind social knowledge (for example, about a person's personality or status), which may foster social interactions^{4,5,10–12}.

By contrast, geodesic distance was associated specifically with temporal-parietal cortices, including an anterior inferior parietal lobule (IPL) region nearly identical to one previously associated with spatial navigation and the experience of psychological distance, consistent with the idea that the coding of our distance from others in groups may have co-opted systems for representing physical distance¹³.

Two regions were most strongly related to the processing of an individual's constraint — superior temporal and supplementary motor regions previously related to processing biological motion and action understanding¹⁴. The significance of these exploratory findings remains to be determined, although the authors' interpretation that such activity may reflect greater attention to the potentially influential social cues displayed by high-brokerage individuals is plausible, and consistent with brokers themselves engaging mentalizing regions more when getting ready to influence others⁴.

Together, these data suggest that merely perceiving group members engages neural

systems that represent their group-level status — notably, regions whose functions may help prepare us to interact effectively. That said, any ground-breaking study raises as many questions as it answers, and it is useful to consider directions for future work.

One question is what triggers retrieval of social knowledge when encountering group members. The authors emphasize the spontaneity of retrieval insofar as participants were not explicitly instructed to think about the attributes of their MBA compatriots. This doesn't mean retrieval was implicit/automatic, however. It could be, but to demonstrate this, activation must be shown to be unaffected by manipulations of attention/resources. The fact that post-scan participant ratings of EC, distance and constraint correlated highly with sociometric measures suggests that participants may have explicitly attempted to retrieve social information of their own.

Another question concerns the relative absence of activation in regions associated with affective valuation. As emphasized in animal¹⁵ and recently in human⁵ work, affect systems may help us to learn about others by encoding the good/bad consequences of interacting with them, potentially motivating

interactions with those we expect will like and aid us (such as sociometrically popular or high-EC individuals). Here, a region that is key for computing subjective value¹⁶ — the ventromedial PFC (vmPFC) — tracked EC. Future work could determine when and to what extent affect regions represent differences in the expected and experienced values of interacting with group members.

Finally, this raises the question of what motivated the network of relationships studied here, which were based on time spent together informally. In principle, many relationship dimensions not measured here — including liking, trust and power/dominance, each of which can be used to define network relations — could motivate spending time together. Given that we simultaneously exist in several social networks where ties may be based on both affiliative and agonistic interactions, it will be interesting to determine if the patterns of brain activation found in this study hold true across all network types. □

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References

1. Dunbar, R. I. *Ann. Hum. Biol.* **36**, 562–572 (2009).
2. Ochsner, K. in *Social Psychology: A Handbook of Basic Principles* (eds Kruglanski, A. & Higgins, E. T.) 39–66 (Guilford Press, 2007).
3. Parkinson, C., Kleinbaum, A. M. & Wheatley, T. *Nat. Hum. Behav.* **1**, 0072 (2017).
4. O'Donnell, M. B., Bayer, J. B., Cascio, C. N. & Falk, E. B. *Soc. Cogn. Affect. Neurosci.* **12**, 61–69 (2017).
5. Zerubavel, N., Bearman, P. S., Weber, J. & Ochsner, K. N. *Proc. Natl Acad. Sci. USA* **112**, 15072–15077 (2015).
6. Nili, H. *et al. PLoS Comput. Biol.* **10**, e1003553 (2014).
7. Kumaran, D., Melo, H. L. & Duzel, E. *Neuron* **76**, 653–666 (2012).
8. Chiao, J. Y. *et al. Neuropsychologia* **47**, 354–363 (2009).
9. Amodio, D. M. & Frith, C. D. *Nat. Rev. Neurosci.* **7**, 268–277 (2006).
10. Satpute, A. B., Badre, D. & Ochsner, K. N. *Cereb. Cortex* **24**, 1269–1277 (2014).
11. Ferrari, C. *et al. Cereb. Cortex* **26**, 156–165 (2014).
12. Meyer, M. L., Spunt, R. P., Berkman, E. T., Taylor, S. E. & Lieberman, M. D. *Proc. Natl Acad. Sci. USA* **109**, 1883–1888 (2012).
13. Parkinson, C. & Wheatley, T. *Trends Cogn. Sci.* **19**, 133–141 (2015).
14. Spunt, R. P. & Lieberman, M. D. in *Dual-Process Theories of the Social Mind* (eds Sherman, Y., Gawronski, B. & Trope, Y.) Ch. 19 (Guildford Press, 2014).
15. Tremblay, S., Sharika, K. M. & Platt, M. L. *Trends Cogn. Sci.* **21**, 265–276 (2017).
16. Clithero, J. A. & Rangel, A. *Soc. Cogn. Affect. Neurosci.* **9**, 1289–1302 (2014).

Competing interests

The authors declare no competing interests.