Shared Neural Architecture for Navigating Space and Social Hierarchies

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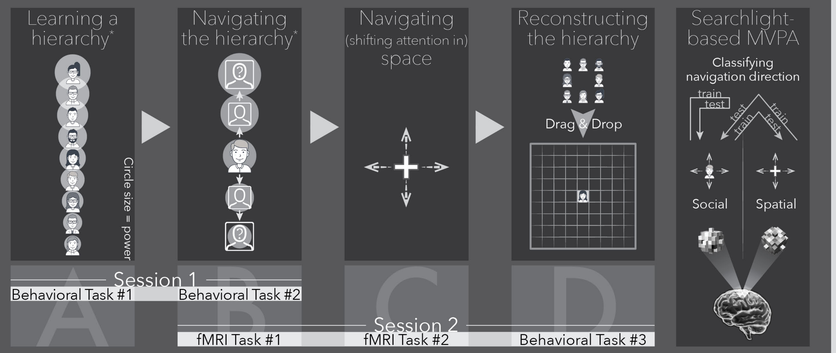
INTRODUCTION

Effectively navigating social groups requires tracking, encoding, and reasoning about the bonds, rivalries and hierarchies that comprise them. Yet, the neural mechanisms underlying these processes are not fully understood.

Several theories suggest that evolutionarily recent cognitive capacities, such as encoding and reasoning about complex social structures, might co-opt neural circuitry with evolutionarily older functions, such as encoding and navigating space[1-3].

We used multi-voxel pattern analysis (MVPA) of fMRI data to investigate the neural mechanisms involved in mentally navigating knowledge of social relations, and to test if common neural mechanisms support performing analogous mental operations on spatial and social contents.

METHODS



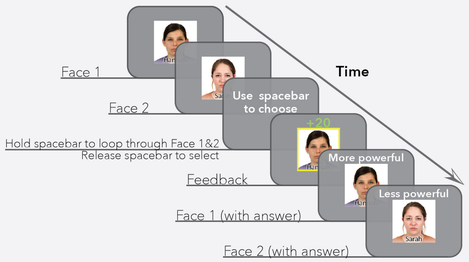
*Participants never saw the full hierarchy, but deduced it via trial and error.

Task A

HIERARCHY LEARNING

The hierarchy: 9 female or male faces[4] (matched to participants' gender).
Ostensibly members of the same organization (task and instructions adapted from prior work[5]).
Assignment of faces to positions in the hierarchy randomized across participants.

The learning task:



Participants learned each person's position in the hierarchy through trial and error.

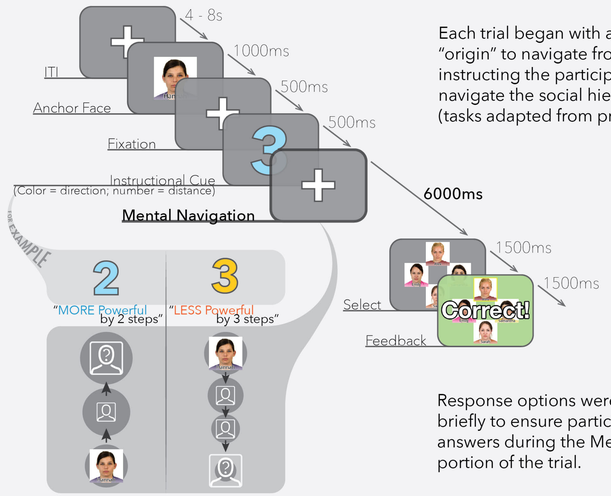
On each trial, they saw 2 people and selected who had more power in the organization.

Only one face was shown at a time to avoid biasing participants towards thinking about the hierarchy in spatial terms, or towards any particular mental mapping between locations in space and in the social hierarchy.

Task B C
fMRI

NAVIGATION

SOCIAL NAVIGATION — SHIFTING ATTENTION IN SOCIAL KNOWLEDGE



Each trial began with an anchor face (the "origin" to navigate from), followed by a cue instructing the participant how to mentally navigate the social hierarchy on that trial (tasks adapted from prior work[6]).

Response options were displayed very briefly to ensure participants arrived at their answers during the Mental Navigation portion of the trial.

SPATIAL NAVIGATION — SHIFTING ATTENTION IN SPACE

Participants were asked to follow a fixation cross with their eyes. The fixation cross moved in one of the 4 directions (up/down/left/right) in each trial.

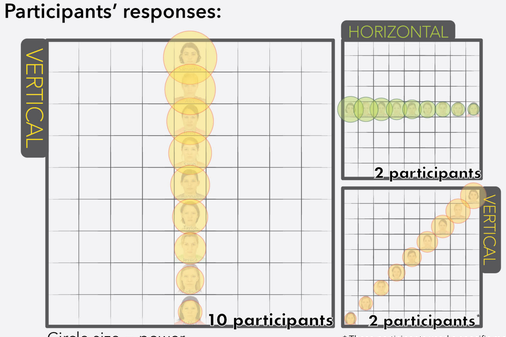
Task D

RECONSTRUCTING HIERARCHY

After scanning, participants organized the faces into whichever arrangement best represented their relative power in the organization.

This task probed the spatial organization of participants' mental representations of the hierarchy.

Participants' responses:

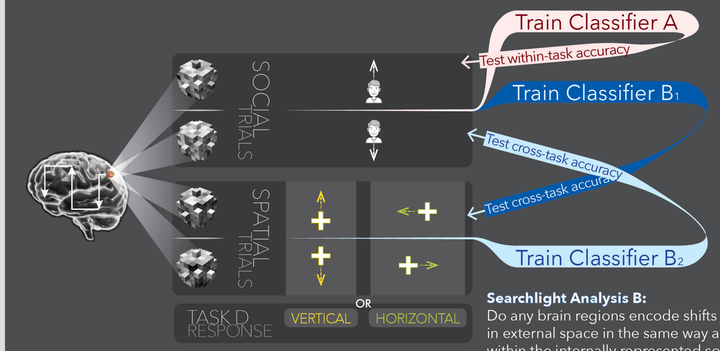


We later related multivoxel response patterns during *social navigation* to *vertical saccades* if a participant responded with a VERTICAL representation here, and to *horizontal saccades* if they indicated that their mental representation of the hierarchy was organized in a HORIZONTAL manner.

* These participants used a specific mnemonic strategy in the social navigation task. They assigned a number to each face, and then did arithmetic operations to find targets.

SEARCHLIGHT MVPA

Searchlight Analysis A:
What brain regions encode direction of mental navigation when reasoning about the social hierarchy?



Searchlight Analysis B:
Do any brain regions encode shifts of attention in external space in the same way as shifts of attention within the internally represented social hierarchy?

After standard preprocessing[7], voxelwise responses were estimated for each direction of social and spatial navigation during each run of the social and spatial navigation tasks, respectively.

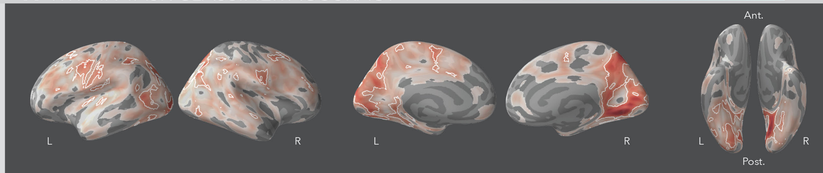
A linear SVM classifier was trained and tested in each searchlight sphere using PyMVPA[8], and accuracy maps were tested against chance across participants with AFNI[9] and visualized using PySurfer[10].

RESULTS

White contours indicate where classification significantly exceeded chance ($p < .05$, FDR-corrected)

A WITHIN-TASK CLASSIFIER ACCURACY

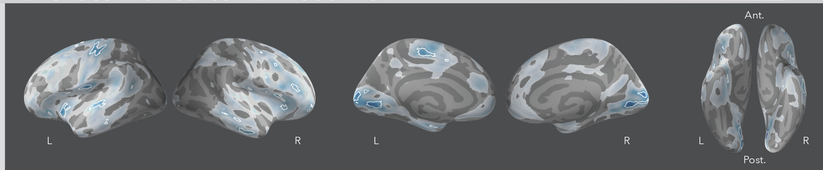
50% — 65%



Direction of mental navigation when reasoning about the social hierarchy was encoded in regions that also support representing (e.g., inferior parietal lobule, posterior parahippocampal gyrus) and shifting attention in (e.g., superior parietal cortex) space, as well as areas of early visual and middle temporal cortex that encode the direction of imagined visual motion[11].

B CROSS-TASK CLASSIFIER ACCURACY

50% — 65%



Shifts of attention in external space and within mental representations of the social hierarchy were encoded similarly in frontal and parietal regions implicated in shifting attention in external space*, early visual areas that encode the direction of imagined visual motion[11], and the anterior parahippocampal gyrus, which may analogously mediate spatial and abstract associations[12].

*Behavioral data suggested that participants did not systematically move their eyes during the social navigation task.

REFERENCES [1] Yamazaki et al. (2009). *F1000 Biol. Rep.* [2] Parkinson & Wheatley (2015). *Trends Cog. Sci.* [3] Lakoff & Johnson (1980). *Metaphors We Live By.* [4] Ma et al. (2015). *Behav. Res. Meth.* [5] Kumaran et al. (2012). *Neuron.* [6] Knops et al. (2009). *Science.* [7] Esteban et al. (2018). *BioRxiv.* [8] Hanke et al. (2009). *Neuroinform.* [9] Cox (1996). *Comp. Biomed. Res.* [10] https://github.com/nipy/PySurfer/ [11] Emmerling et al. (2016). *NeuroImage.* [12] Aminoff et al. (2014). *Trends Cog. Sci.*