Individual-specific functional architecture and activation patterns in medial prefrontal cortex

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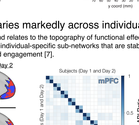
Background

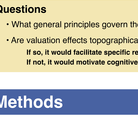
BOLD activity in ventromedial prefrontal cortex (vmPFC) is modulated by the subjective value of prospects and outcomes during decision making.

Meta-analyses show robust, domain-general valuation effects [1, 2]



vmPFC is also implicated in other cognitive functions — memory, prospection, affect, self-referential thought — and is part of the default network.

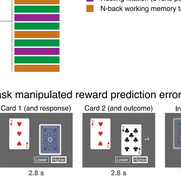
Effects of multiple cognitive variables are spatially overlapping in group-average and meta-analytic data [3]. As a result, vmPFC activity *per se* does not specifically signify the engagement of valuation processes.



The organization of vmPFC varies markedly across individuals.

Sulcal morphology is idiosyncratic [4] and relates to the topography of functional effects [5].
The default network can be divided into individual-specific sub-networks that are stable across test-retest [6] and have different profiles of task-related engagement [7].

Graph partitioning identifies reproducible, individual-specific "Default network" and "Non-default network" communities using resting-fixation data [8].



Questions

- What general principles govern the individual-level functional topography of vmPFC?
- Are valuation effects topographically segregable from the default network in individual brains?

  If so, it would facilitate specific readout of the engagement of valuation processes from brain data.
  If not, it would motivate cognitive theories of shared processing demands.

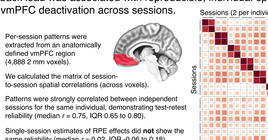
Methods

Participants (n=18) were scanned in 3 paradigms across 2 sessions.

Six-minute functional runs:

- Card-wagering task (6 runs per session)
- Resting fixation (3 runs per session)
- N-back working memory task (3 runs per session)

The card-wagering task manipulated reward prediction error.



35 trials per run

- Two independent decks, each with number cards 2 through 9, described as reshuffled after each trial.
- After viewing Card 1, wager whether Card 2 will be higher or lower.
  The ideal response was always bet "higher" if Card 1 was a 5 or below, and bet "lower" if it was a 6 or above.
- At Card 2, gain (or lose) points according to the size of the difference in the predicted direction.
- The **Expected Value** at Card 1 ranged from 0.5 points (for a 5 or a 6) to 3.5 points (for a 2 or a 9).
- The **Reward Prediction Error** (RPE) at Card 2 ranged from -3.5 to +3.5 in 1-point steps, independent of Expected Value or decision difficulty.

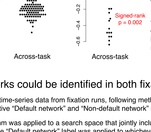
Acquisition parameters mitigated signal dropout and mislocalization.

- 3T Siemens Prisma, 64-channel head coil
- TR = 1.44 s, TE = 25 ms, SMS = 3
- Oblique axial slices and 1.75 mm slice thickness to reduce susceptibility-related dropout.
- Larger in-plane voxels (2.25 mm) and GRAPPA = 2 to reduce distortion.
- Field map images every 4 runs for distortion correction.

Results

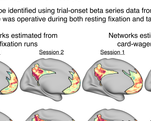
In whole-brain group analyses, N-back load and RPE each modulated vmPFC activity.

N-back task
2-back vs. 0-back



Card-wagering task
Parametric effect of RPE

Analyses used fMRIPrep for preprocessing, AFNI for subject-level GLMs, and FSL's *randomise* for group tests.



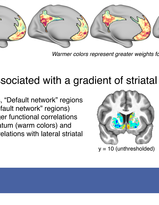
N-back load was associated with reproducible, individual-specific patterns of vmPFC deactivation across sessions.

Per-session patterns were extracted from an anatomically defined vmPFC region (4,888 2 mm voxels).

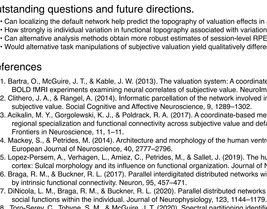
We calculated the matrix of session-to-session spatial correlations (across voxels).

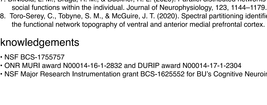
Patterns were strongly correlated between independent sessions for the same individual, demonstrating test-retest reliability (median $r = 0.75$, IQR 0.65 to 0.80).

Single-session estimates of RPE effects did **not** show the same reliability (median $r = 0.02$, IQR -0.06 to 0.18).



Load-related deactivation and RPE-related activation showed evidence of shared structure in participant-level vmPFC patterns.





Negative within-participant correlations (median = -0.33) imply that voxels negatively modulated by N-back load overlapped with voxels positively modulated by RPE.

Larger-magnitude within- than across-participant correlations imply shared individual-level topographic structure.

Interdigitated cortical networks could be identified in both fixation and task data.

Spectral partitioning was applied to time-series data from fixation runs, following methods from Toro-Serey et al. [8], to identify putative "Default network" and "Non-default network" subregions.

The unsupervised clustering algorithm was applied to a search space that jointly included medial PFC and posterior cingulate cortex (PCC). The "Default network" label was applied to whichever of the resulting communities predominated in a caudal region of PCC (see [8]).

Similar network communities could be identified using trial-onset beta series data from the card-wagering task, implying the same network structure was operative during both resting fixation and task performance.

Warmer colors represent greater weights for the Default Network.

Cortical networks were associated with a gradient of striatal connectivity.

In resting fixation runs, "Default network" regions (compared to "Non-default network" regions) tended to show stronger functional correlations with ventromedial striatum (warm colors) and weaker functional correlations with lateral striatal regions (cool colors).

Conclusions

- Individual-specific topographic patterns of task-evoked cortical activity were highly reproducible across independent sessions a week apart.
- To a degree, valuation-related activity shared topographic structure with the default network.
- Community detection identified parallel network architecture in both task and non-task data.

Outstanding questions and future directions.

- Can localizing the default network help predict the topography of valuation effects in a given individual?
- How strongly is individual variation in functional topography associated with variation in brain structure?
- Can alternative analysis methods obtain more robust estimates of session-level RPE effects?
- Would alternative task manipulations of subjective valuation yield qualitatively different activity patterns?

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Acknowledgements

- NSF BCS-1755757
- ONR MURI award N00014-16-1-2832 and DURIP award N00014-17-1-2304
- NSF Major Research Instrumentation grant BCS-1625552 for BU's Cognitive Neuroimaging Center