Dynamic brain connectivity supports visual and semantic processing during object recognition

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Introduction:

Object recognition requires the rapid transformation of sensory signals into detailed, meaningful representations.

Currently, we lack mechanistic details of how this happens. Specifically, we know little about how feedforward, feedback and recurrent dynamics between regions contribute to recognition.

Here we re-analysed existing MEG data (Clarke et al, 2015; Bruffaerts et al., 2018) of participants performing a basic level naming task, and asked:

1. How do visual and semantic representations of objects evolve over time?
2. How do visual and semantic properties of objects relate to feedforward and feedback information flow across the brain?

Methods:

- 36 Participants
- Basic-level naming during MEG
- 302 images of common animals and objects

Analysis 1. Representational Similarity Analysis

- Gradiometers used for sensor-level RSA
- Neural RDMs from spatio-temporal patterns
  - 204 sensors x 60 ms time window
- Neural RDMs calculated for each time point between -200 ms to 800 ms
- Each correlated with visual and semantic measures:
  - CORnet-s (4 layers; V1, V2, V4, IT)
  - Semantic feature norms (Devereux et al., 2014)

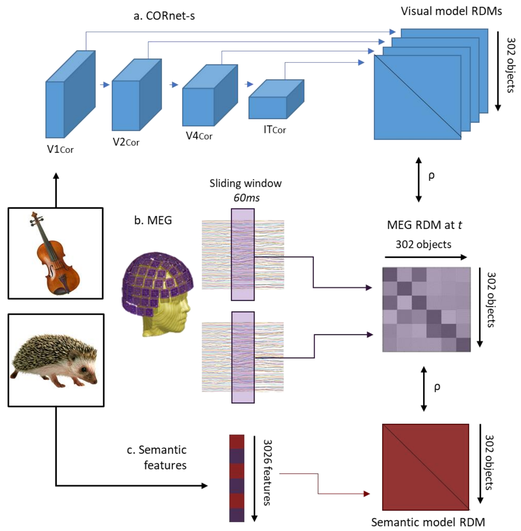
Analysis 2. Representational Connectivity Analysis

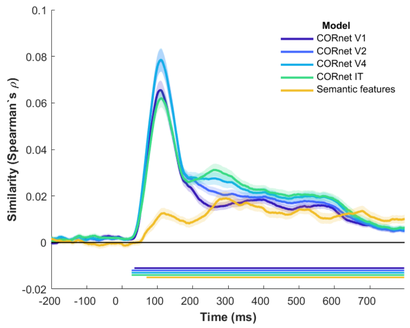
- Tests if shared representations across regions relate to a specific model RDM by establishing the contribution of earlier source representations to current model fit in target region (Karimi-Rouzbahani et al., 2021)

Statistics

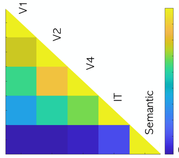
- RFX analysis using cluster-based permutation testing

Representational Similarity Analysis



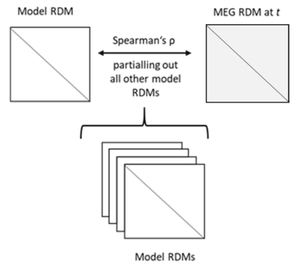


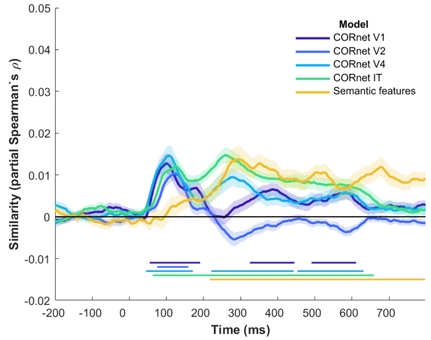
- CORnet-s models show early effects, peaking near 100 ms
- Semantic effects delayed, peaking 200-300 ms



- However, CORnet-s layers are highly correlated.

Partial correlations RSA was used to show unique effects of CORnet-s and semantic models



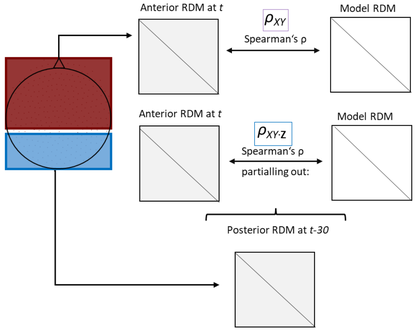


- CORnet-s layers show unique effects, peaking near 110 ms
- CORnet-IT peak now 200-300 ms, prior to semantic peak effects ($p<0.05$)

→ RSA shows CORnet-s early layers (V1-4) peak near 100 ms, before higher-level visual effects (CORnet-IT) and semantic effects at 200-300ms

Representational Connectivity Analysis

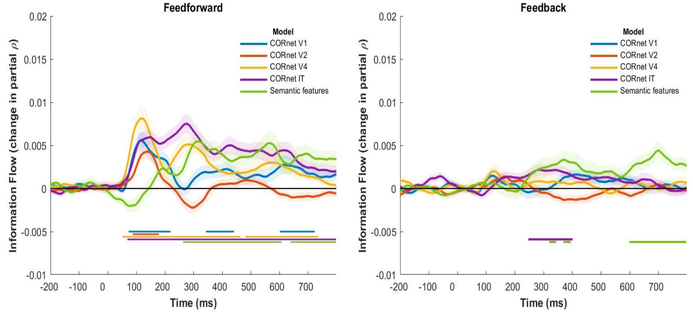
- Important to understand how FF and FB dynamics help support object recognition
- We look at broad posterior and anterior regions
- We ask how FF and FB dynamics relate to model RDM effects
- Additionally partial out all other models



Feedforward flow (t) = ρ_{XY} - $\rho_{XY \cdot Z}$

Feedforward RCA

- Early CORnet-s models (V1-4) show early FF effects, peaking near 100 ms
- Higher-level CORnet-IT FF effects begin early, but peak near 200-300 ms
- Semantic FF effects delayed, beginning and peaking after CORnet-IT



Feedback RCA

- No effects of early CORnet-s models (V1-4)
- Higher-level CORnet-IT FB between 250 and 400 ms
- Semantic FB effects slightly delayed, between 300 and 400 ms

Conclusions:

- Rapid transition of object representations captured by visual, higher-level/intermediate, semantic models incrementally
- Feedforward sweep reflects visual, intermediate, and semantic representations within 300ms
- Feedback is captured uniquely by models of high-level visual and semantic information and confined to later time-points

Visual information is transformed into semantic representations through an interplay of bi-directional information flow

References

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