Predicting Typicality Effect from Brain Activation Patterns in Healthy Adults and Individuals with Aphasia: a Multi-Voxel Pattern Analysis

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Introduction

Semantic representation in healthy adults: left-lateralized in frontal, temporal parietal, and prefrontal regions[1]; *Controlled semantic cognition* (CSC)[2] : ATL, PFC, pMTG, IPS, pre-SMA, ACC/mPFC.

Semantic representation in individuals with aphasia (PWA): distributed network[3].

Category-specific representation: anatomically distinct[4]; distributed[5]; continuous[6].

Feature-specific representation: *Typicality effect* - Faster and more accurate access to *typical* than *atypical* exemplars in healthy adults[7]; Inconsistency in PWA[8]; Hierarchical theory of object processing: early visual regions and higher temporal regions in healthy adults[9].

Searchlight-based multi-voxel pattern analysis (MVPA)[10]: reduce overfitting; no *a priori* region specification is needed;

Objectives

1. Which brain regions show neural encoding of semantic typicality associated with behavioral performance in healthy adults? *Hypothesis: above-chance (50%) classification accuracy in the visual and temporal regions.*

2. Which brain regions show neural encoding of semantic typicality associated with behavioral performance in PWA? *Hypothesis: different neural regions; above-chance (50%) classification accuracy.*

Methods

Subjects

- 21 PWA due to left MCA infarct (7F, mean age = 60.76 ± 10.64 y, mean months post onset = 65.71 ± 102.13, mean lesion volume = 104,647 ± 69,682.17 mm3); 18 neurologically healthy adults (8F, mean age = 59.86 ± 10.50 y)

Standardized Language Assessments

Test	Mean (SD)
BNT	24.4 (20.0)
PALPA51 (HI-LI)	3.2 (2.5)
PAPT	47 (5)
WAB-AQ	61.6 (27.1)

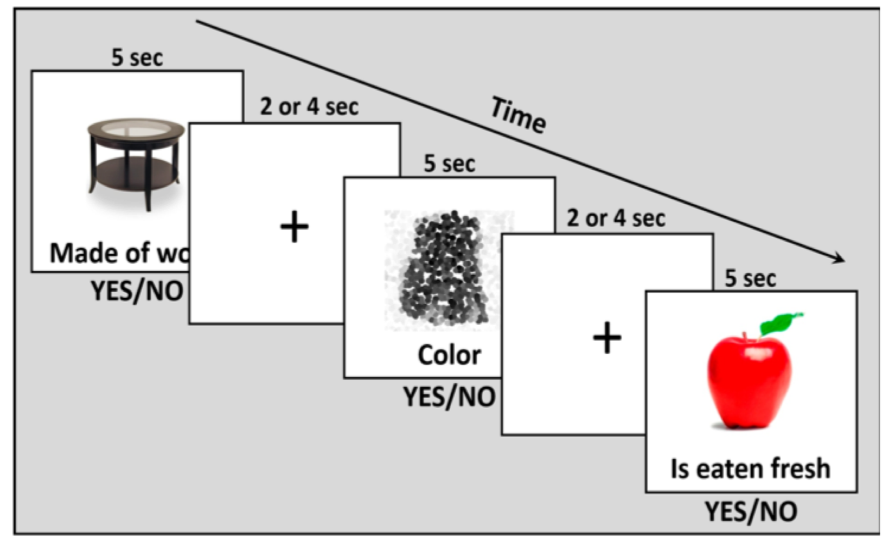
BNT: Boston Naming Test; **PALPA:** Psycholinguistic Assessment of Language Processing in Aphasia Word Semantic Association (PALPA51; HI: Hight Imageability; LI: Low Imageability); **PAPT:** Pyramids and Palm Trees; **WAB-AQ:** Western Aphasia Battery Aphasia Quotient

fMRI Task Stimuli and Procedure

Picture stimuli: 36 color photos (half typical, half atypical) in each category: *birds, vegetables, furniture, clothing, fruits*; 36 scrambled pictures; split across two runs

- Each subject: fruits + two other categories (counterbalanced across subjects)
- Semantic features: Core, prototypical, and distinctive

Task: semantic features verification



fMRI Data Acquisition

3.0 T Siemens Trio Tim using 20-channel head + neck coil; **T1:** TR = 2300 ms, TE = 2.91 ms, 176 sagittal slices, 1 x 1 x 1 mm voxels, 256 x 256 matrix, FOV = 256 mm, flip angle = 9º, fold-over direction = AP; **T2*- weighted EPI:** TR = 2570ms, TE = 30ms, 40 axial slices, 3mm slices interleaved with 2 x 2 x 3 mm voxels, 80 x 78 matrix, FOV = 220 x 220 mm, 40 axial, flip angle = 90º

Methods

Data Analysis

Behavioral: 1) linear mixed-effects model (accurate RTs); 2) logistic mixed-effects model (accuracy; 1 = accurate, 0 = inaccurate); *Fixed factors:* typicality, group, category, typicality-by-group; *random intercept:* subject

fMRI Data Preprocessing (SPM12[11])

1) Slice timing
2) Spatial realignment with 4th degree B-spline
3) Coregistration
4) Structural segmentation
5) Spatial and functional normalization to the MNI space; high-pass filter with a cutoff of 1/128 s
6) *Spatial smoothing with 4mm Gaussian kernel (for univariate analysis)

fMRI Univariate Analysis (SPM12)

% spared tissue: spared volume / total volume

1) 1st-level GLM: typical, atypical, scrambled
   - **Typical > Atypical**
   - **Atypical > Typical**

   Onsets and durations convolved with the canonical HRF and its temporal derivative
2) 2nd-level: one-sample *t* test ($p < .001$); corrected for multiple comparison (FDR at $p < .05$)

Searchlight MVPA

The Decoding Toolbox (TDT[12]); Radius = 9mm

Input: beta values (unsmoothed)

Classifier: LSVM with leave-one-run-out cross validation (LORO-CV): $g\ (w_1x_1 + w_2x_2 \ldots w_yx_y)$

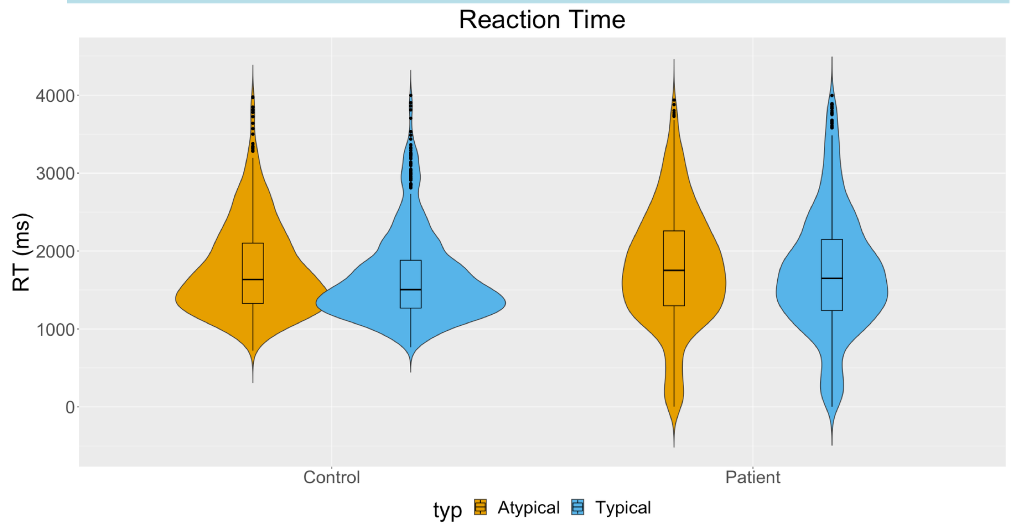
Output: individual's accuracy map (-50 to 50)

Group-level: smoothing with 6mm FWHM; one-sample *t* test ($p < .001$), corrected for multiple comparisons (FWE at $p < .05$)

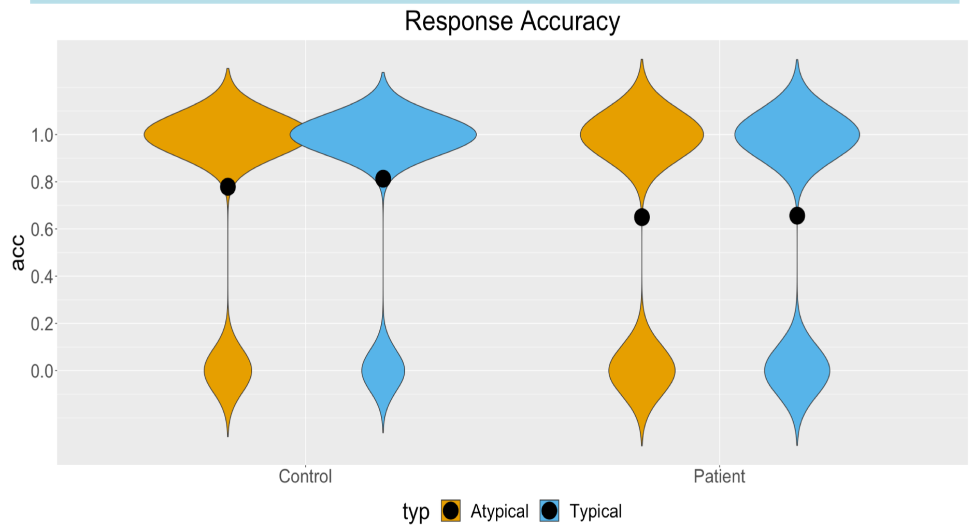
Results

Behavioral

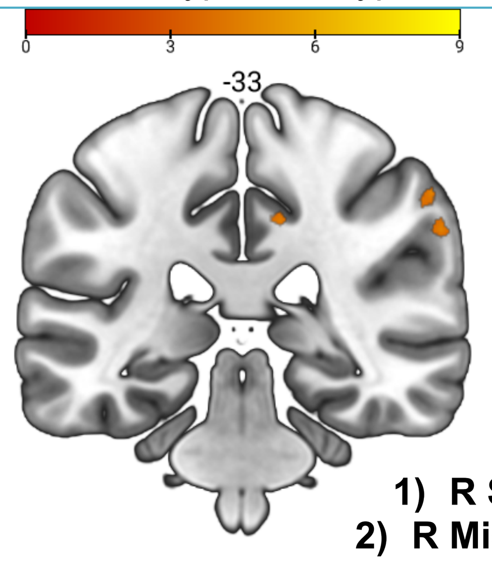
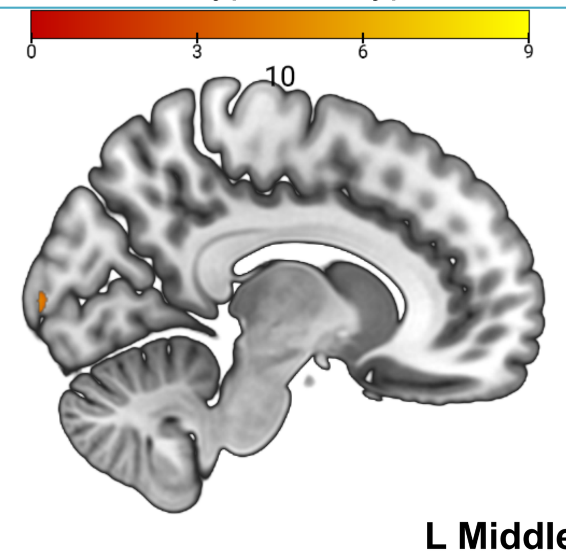
Main effect of ***typicality*** (β = 106.61, SE = 29.11, $p < .01$)



Main effect of ***typicality*** (β = -.34, SE = .14, $p < .05$)
Main effect of ***group*** (β = -.98, SE = .40, $p < .05$)



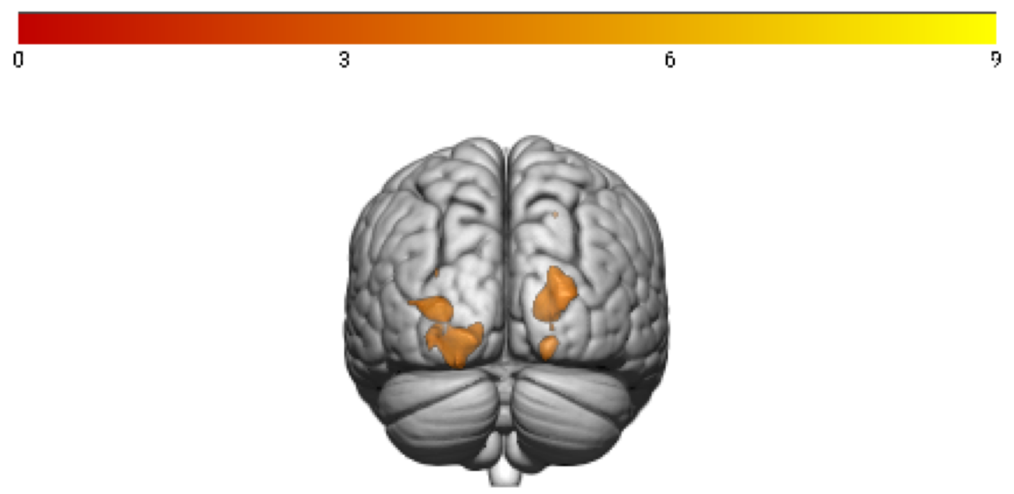
fMRI Univariate (uncorrected at p < .001; extent size k ≥ 10)

	Typical > Atypical	Atypical > Typical
Healthy	 1) R Supramarginal 2) R Middle Cingulate	 L Middle Occipital
PWA	No significance	No significance

Results

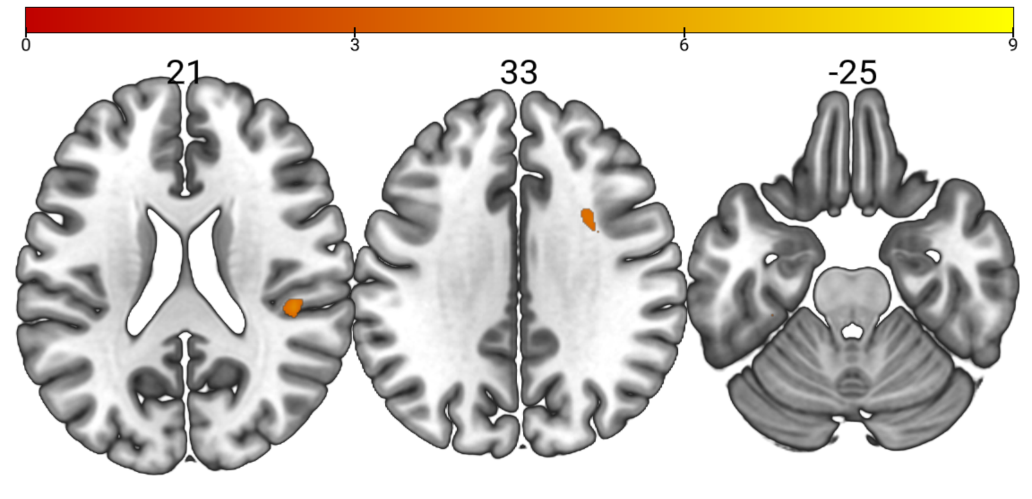
Searchlight MVPA

Healthy — Cluster-level FWE correction at $p < .05$



1) **LMOG (*t* = 5.57) extending into L Lingual (*t* = 5.39)**
2) **R Calcarine (*t* = 5.31) extending into R SOG (*t* = 5.03)**

PWA — Uncorrected at $p < .001$



1) **R Rolandic Operculum (*t* = 5.14)**
2) **L Fusiform (*t* = 3.74)**

Post-hoc brain-behavior analysis (PWA):

1) *Spearman's* rank correlation between behavioral language performance (total RTs, accurate RTs, % PAPT, WAB-AQ) and classification accuracies in LMOG and R Calcarine in all PWA (N = 21), Anomic (N = 9), and Broca's (N = 9); ROI classification in PRoNTo 2.1[13], binary LSVM with LORO-CV
   - significant correlation between ***accurate RTs and classification accuracy in LMOG*** (ρ = .77, $p < .05$) in ***Anomic*** PWA
2) Linear regression predicting LMOG classification accuracy from behavioral measures: main effect of ***accurate RTs*** (β = .08, |t| = 2.77, SE = .03, $p < .05$) in the ***Anomic*** Group.

Discussion

1. **Which brain regions show neural encoding of semantic typicality associated with behavioral performance in healthy adults?**
   - Neural representation of typicality is built by the visual system at an intermediate processing stage[9].
   - *LMOG:* shape discrimination of objects[14]; *R Calcarine:* processing certain semantic categories[15].
2. **Which brain regions show neural encoding of semantic typicality associated with behavioral performance in PWA?**
   - Similar behavioral typicality effect as healthy adults, but different neural representations.
   - Maybe semantic typicality does not directly modulate the neural representation of typical and atypical stimuli in early visual processing due to a damaged semantic network post-stroke[9].
   - Visual cortex (LMOG) is still associated with accurate processing of semantic typicality in less severe PWA, but comes at a cost with longer processing time, suggesting not as automatic as in healthy adults.

Future studies: functional/structural connectivity between the visual cortex and semantic network in PWA.

Selected References

[1]Binder, J. R., Desai, R. H., Graves, W. W., & Conant, L. L. (2009). Where is the semantic system? A critical review and meta-analysis of 120 functional neuroimaging studies. *Cerebral cortex, 19*(12), 2767-2796.

[9]Iordan, M. C., Greene, M. R., Beck, D. M., & Fei-Fei, L. (2016). Typicality sharpens category representations in object-selective cortex. *NeuroImage, 134,* 170-179.

[10]Kriegeskorte, N., Goebel, R., & Bandettini, P. (2006). Information-based functional brain mapping. *Proceedings of the National Academy of Sciences, 103*(10), 3863-3868.

[12]Hebart, M. N., Görgen, K., & Haynes, J.-D. (2015). The Decoding Toolbox (TDT): a versatile software package for multivariate analyses of functional imaging data. *Frontiers in Neuroinformatics, 8*,88.

Acknowledgements

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