Abstract letter position sensitivity in the VWFA: Representational Similarity Analyses in EMEG source space

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Introduction

Human left ventral occipitotemporal (VOT) cortex shows functional specialisation for the processing of orthographic features (letters, bigrams) required for skilled reading, with the "visual word form area" (VWFA) claimed to play a critical role [1]. It remains unclear, however, what are the specific computational functions subserved by the VWFA and the precise time-course of these contributions.

Here we present source-localised combined MEG + EEG (EMEG) data, providing millisecond temporal resolution and fine-grained spatial resolution, and use Representational Similarity Analysis (RSA) to ask four basic questions about VWFA function during visual word perception:

- Does orthographic processing in VWFA abstract away from low-level visual detail?
- If VWFA is sensitive to abstract letter identities, are these computed in a word-level position-sensitive format?
- Does the lexical status of potential word forms affect processing in the VWFA?
- How far is position-sensitivity in the VWFA driven by retinotopic letter position and how far by abstract letter position?

To test these questions we construct four sets of RSA model, manipulating pixel-level overlap between letter strings, position specificity, lexical status, and retinotopic vs abstract letter position.

Methods

Stimuli

- visually-presented words and pseudowords (100 ms), all 4 (first set of models) or 4, 6 & 8 (second set of models) letters in length and morphologically simple
- occasional lexical decision on 10 % of items

Acquisition and Source Reconstruction

- concurrent MEG-EEG data acquired with 306-channel Vectorview system and 70-channel EEG cap
- epochs from -100 to 500 ms from word onset
- three-layer boundary element model using FreeSurfer from individual structural MRIs
- L2 minimum norm estimation (MNE) for source reconstruction
- regions of interest (ROIs) defined anatomically in FreeSurfer; two functional ROIs: 1. visual word form area (VWFA) - defined using Talairach coordinates (-43, -54, -12 [1]) with radius ten vertices, 2. V8 - visuotopic label (Freesurfer)

Multivariate pattern analysis

- searchlight-based Representational Similarity Analysis (RSA) in source space [2, 3]
- analysis extracts pattern of neural activity across voxels, and correlates pattern at each source location to theoretical models
- cluster-based permutation statistics used to reveal significant spatio-temporal clusters

Representational Similarity Analysis (RSA) models

a) visual model based on pixel-level overlap between word images:

e.g. pill – plum

b) orthographic models based on the number of shared letters:

i) position-specific models
1 shared letter bake – beak

ii) position-nonspecific models
4 shared letters bake – beak

c) orthographic models for words with varying length with two alignment types:

i) relative to a central fixation point ('retinotopic')
2 shared letters raft – paradise

ii) left-aligned (abstract position)
1 shared letter raft – paradise

Results I - Visual and Orthographic Models

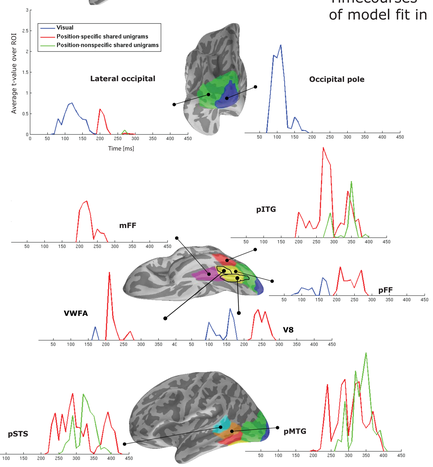
Significant clusters (p<.05 cluster level) for visual and orthographic models using words matched for length - maximum fit of each model.

Visual model:
70 - 180 ms
p = .041
fit at 110 ms

Position-nonspecific model:
260 - 400 ms
p = .032
fit at 350 ms

Position-specific model:
190 - 420 ms
p = .001
fit at 210 ms

Timecourses of model fit in ROIs:



- The **pixel-overlap visual model** fits early (from 70 ms) and primarily in posterior occipito-temporal regions.
- The **position-specific model** fits later (from 190 ms) in posterior and middle fusiform (with peak fit in the VWFA between 200-250 ms) and continuing in lateral temporal regions.
- The **position-nonspecific model** fits only later (from 260 ms), primarily in lateral temporal areas associated with lexical representation, and with no VWFA fit.

Focusing on the strong fit of the position-specific model in VWFA at 200-250 ms, we asked two further questions:

II. Is VWFA fit modulated by the **lexicality** of the 4-letter strings involved? To test this we compared the real word model with a new model mixing 138 real words and 69 pseudo-words (e.g., bect, fump).

III. Is position-specificity in the VWFA driven primarily by **visual field position** (retinotopy) or by **abstract position** in the word, independent of visual field location?

Results II - Words and Pseudowords

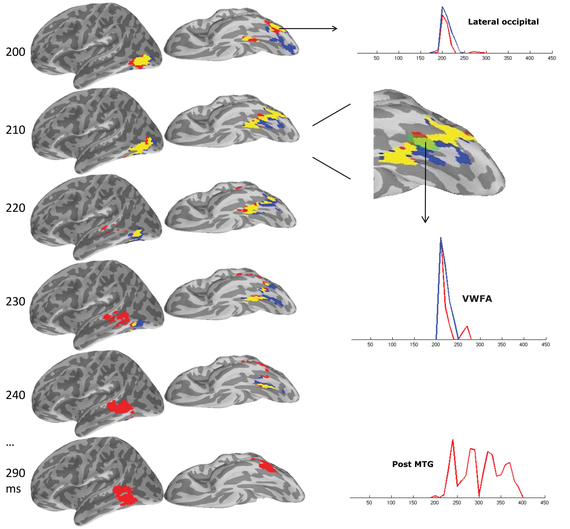
Dissociating lexical and non-lexical effects: word and word+pseudoword datasets for position-specific model.

Real words:
190 - 420 ms
p = .001

Words + pseudowords:
180 - 280 ms
p = .045

Real words
Words + pseudowords
Overlap

Timecourses in selected ROIs:



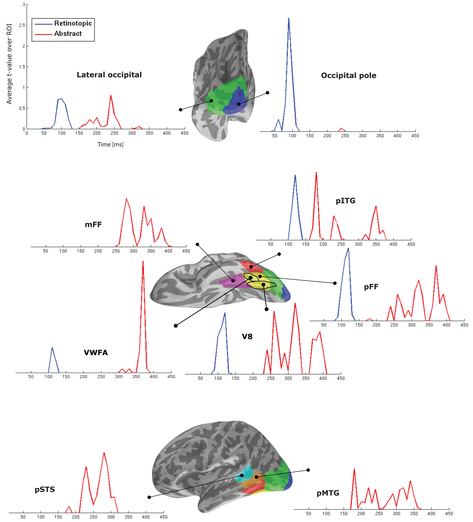
When **pseudowords** are included, early activation involving VWFA is unaffected, again peaking in VWFA at 210 ms, but the more dorsal and anterior activations, presumably related to lexical representations, are no longer seen.

Results III - Letter position sensitivity

Letter position models for words varying in length (4, 6, 8 letters) either center-aligned ('retinotopic') or left-aligned ('abstract').

'Retinotopic' model:
50 - 130 ms
p = .023
fit at 90 ms

'Abstract' model:
160 - 400 ms
p = .002
fit at 280 ms



The **retinotopic** model fits data in occipito-temporal regions (50-130 ms) similarly to the visual model. The **abstract** letter position model is similar to the position-specific model in ventro-lateral temporal cortex but with late VWFA fit (350-400 ms).

Conclusions

- RSA successfully delineates separate regions in the ventral processing stream, with left occipital cortex showing strong early fit to a pixel-level **visual** model (70-180 ms) and to a **retinotopic** letter position model (50-130 ms).
- Processes in VWFA are transiently sensitive (200-250 ms) to abstract letter identities in **position-specific word-level** format but not to the lexical status of these strings.
- **Lexical** effects are seen later, in left inferior and middle temporal areas, where we also see apparently lexically dependent **position-nonspecific** effects.
- The contrast between letter-position models driven by **retinotopic letter position** and by **abstract letter position** suggests that position-specific effects in the ventral stream are primarily driven by letter position referenced to abstract word-form.
- The **late VWFA peak** (at 370 ms) for abstract letter position relative to the **210 ms peak** for the length-matched position specific model suggests a continuing role for spatial position in the visual field at the level of the VWFA.
- **RSA analyses in EMEG source space** are able to directly identify the role of **VWFA** in processing abstract word-form representations, transiently activated as feed-forward orthographic processes sweep through the fusiform gyrus to lexical destinations in posterior temporal cortex.

References

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