Depth-Dependent BOLD as a Measure of Directed Connectivity During Language Processing

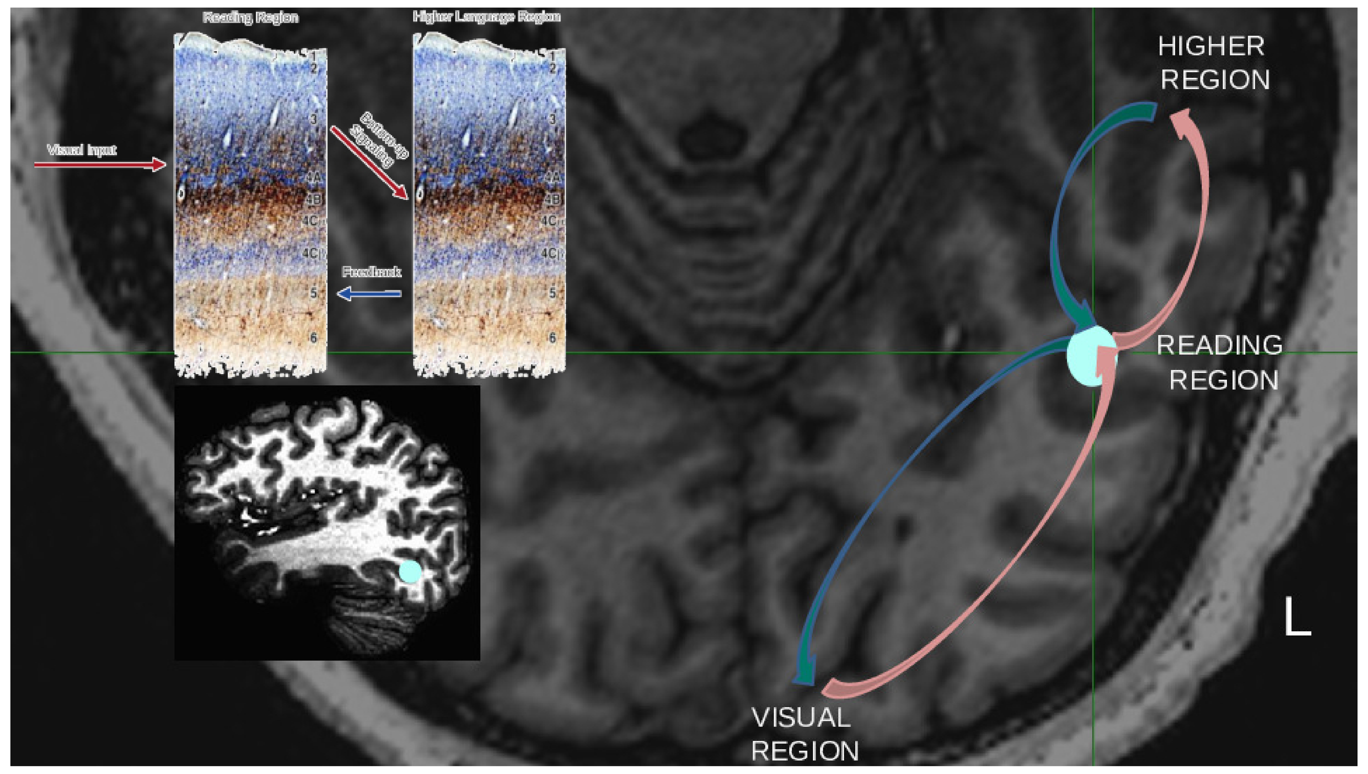
Daniel Sharoh[1], Tim van Mourik[1], Lauren J. Bains[1], Katrien Segaert[2], Kirsten Weber[3], Peter Hagoort[1,3], David G. Norris[1,4]

[1] Donders Institute for Brain Cognition and Behaviour, Centre for Neuroimaging; [2] University of Birmingham, School of Psychology; [3] Max Planck Institute for Psycholinguistics, Nijmegen; [4] Erwin L. Hahn Institute

DONDERS INSTITUTE

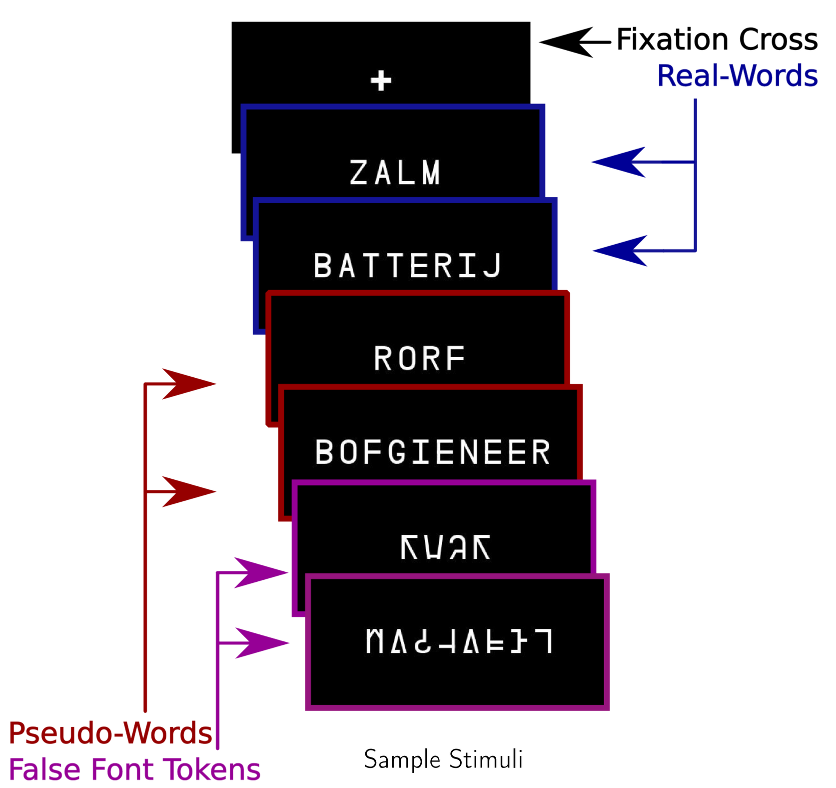
Introduction

- The input/output topology of neocortical circuits is known to be organized with respect to cortical laminae,[4] and blood supply has been shown to be regulated at this level[1,8]
- A growing body of evidence suggests high-field MRI is capable of resolving laminar specific BOLD responses[5,6,8,9]
- This work demonstrates whole brain, laminar connectivity during a reading task.
- Noninvasively disentangles directed information streams through the brain during reading, on the basis of cortical depth dependent BOLD in the left ventral occipitotemporal sulcus (vOT)



Forward (red) and back (blue) propagating information through vOT. Inset shows depth-dependent model of information flow, with bottom-up information targeting middle layer and feedback targeting deep layers. vOT is shown as the pale blue dot.

Task Procedure

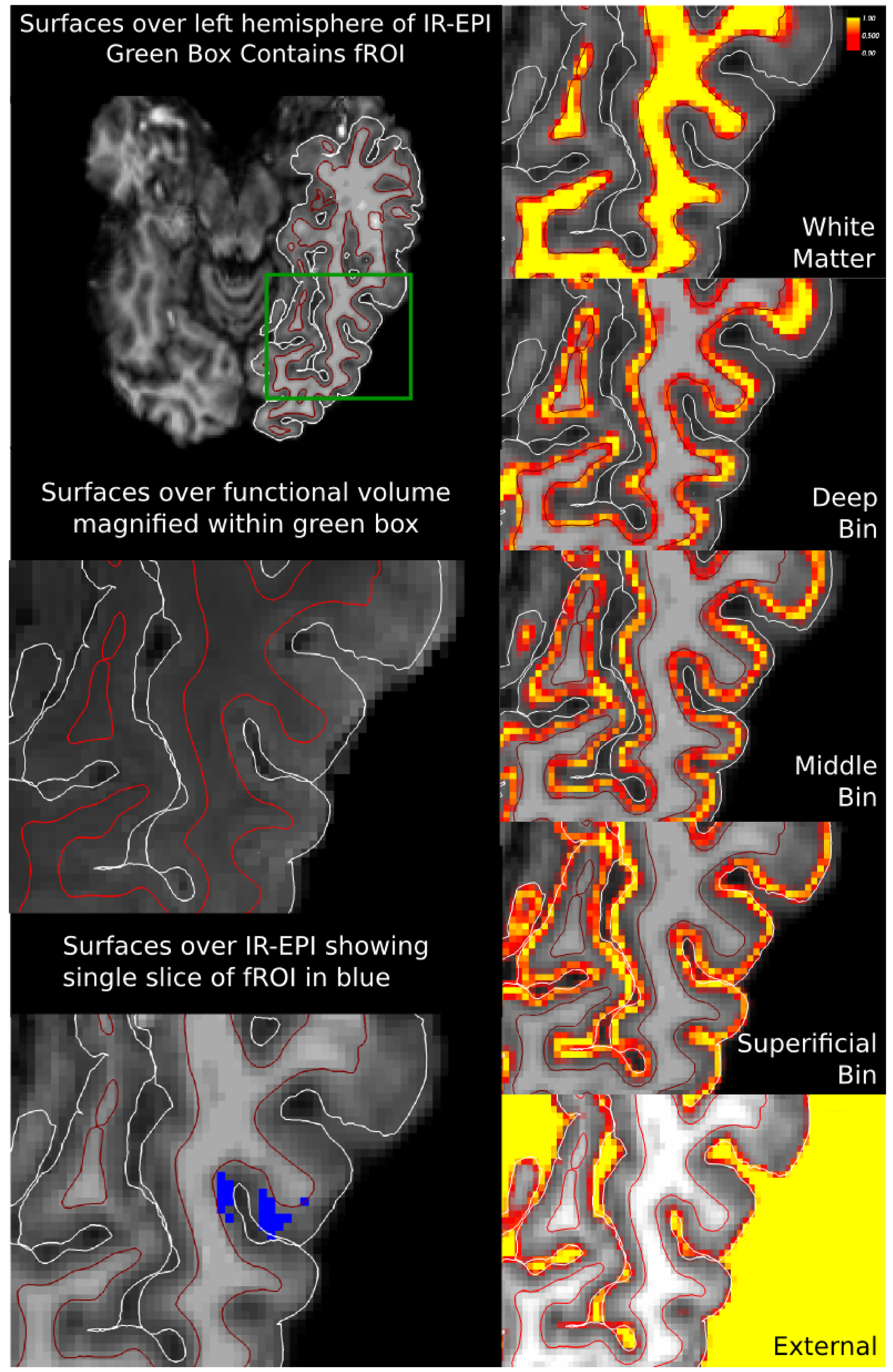


Sample Stimuli

- Event-related fMRI experiment
- Item by item visual presentation
- 800ms/item presentation time
- Word, pseudo-word and false-font stimuli
- 60 items per run×12 runs

- Occasional lexical decision task to monitor participant attention
- Distinct top-down information for words and pseudo-words should lead to differential layer-response
- Early visual cortex thought to be sensitive to length manipulation; allows for investigation of potentially different bottom-up load

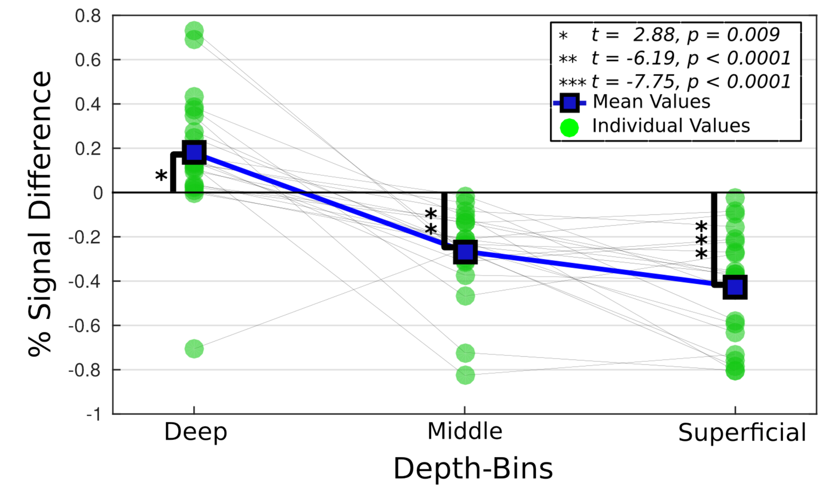
Acquisition and Analysis Procedure



Layering shown over different acquisitions for a single subject.

- Data acquired on Siemens 7T scanner at Erwin L. Hahn Institute
- Segmentation and depth parcellation performed on inversion recovery(IR)-EPI
- Depth parcellation follows level-set method of Waehnert et al.[10,11]
- Single subject laminar signal extracted using spatial GLM on fROIs[10]
- Individual fROIs selected by weighted contrast of T-scores for words and pseudo-words against false-fonts

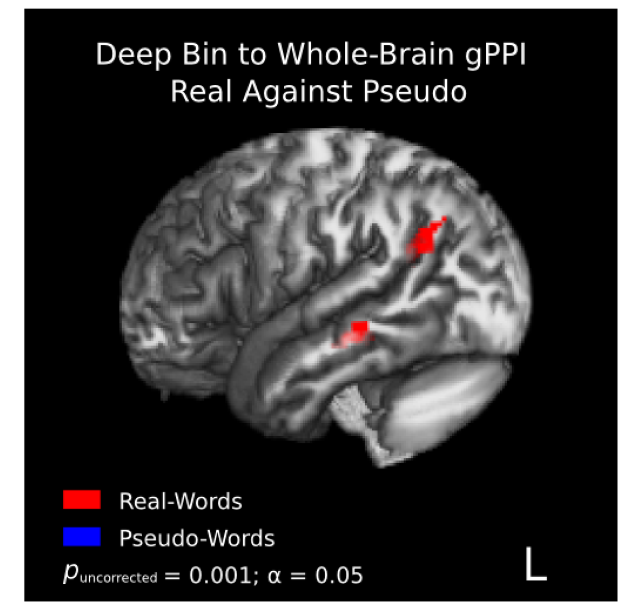
Depth-dependent task responses



Real - Pseudo T-Scores (n=22) for group shown at each depth-bin.[12]

- Deep bin positive for words > pseudo-words
- Evidence of deep-bin sensitivity to top-down lexical information
- Distinct from overall response in the region

vOT Depth-dependent connectivity during task

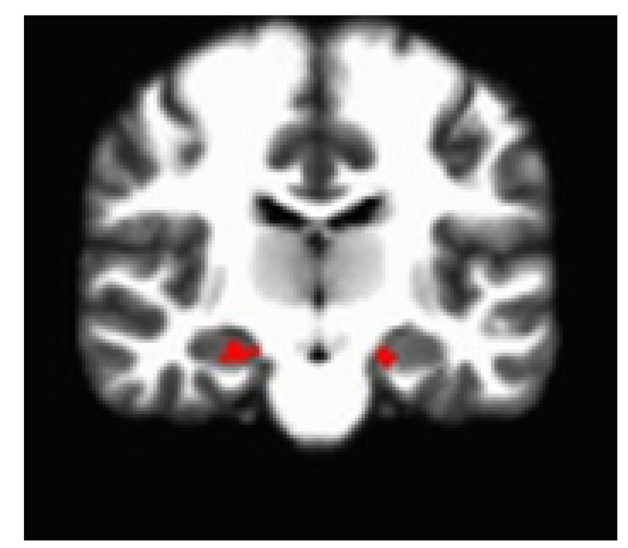


Surviving clusters from whole brain gPPI connectivity, seeding from the deep bin of vOT (n=21) No significant clusters for the middle bin or pseudo-words.[12]

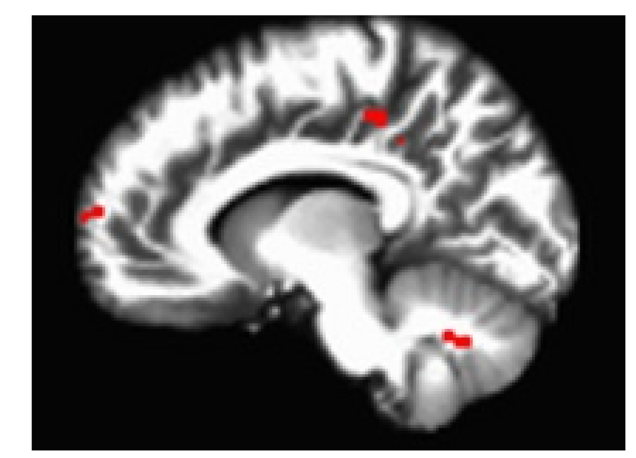
- Deep bin shows unique interactions uncommon to the middle bin as a function of the word > pseudo-words contrast
- Deep-bin was shown to respond to top-down lexical information and shown to interact with language critical regions related to lexical retrieval.

- Depth-dependent connectivity results are direct evidence for top-down connectivity from language critical regions to vOT for lexicality contrast.
- Support characterization of vOT as feed-forward/back hub in reading network.

Preliminary V1 gPPI connectivity using item length contrast



Depth (F-statistic, n=19) modulates V1 connectivity to bilateral (para)hippocampus. Left shown on image right, correction performed as in previous figure.



Depth × lexicality interaction modulates frontal, cerebellar and cingulate regions.

- Depth, lexicality modulate V1 connect. to brain as function of length
- Bilateral hippocampus most sensitive to depth. Frontal, cerebellar and cingulate regions sensitive to depth × lexicality interaction
- Bilateral anterior temporal and left middle temporal regions (not shown) are also sensitive to interaction.

References

[1] Adams DL., et al. Cereb Cortex; 25 (10): 3673-3681, 2015
[2] Bastos A., et al. Neuron; 76(4): 695-711, 2012
[3] Chen Y., et al. J Cogn Neurosci; 27(9): 1738-51, 2015
[4] Douglas & Martin. Annual Review of Neuroscience; 27: 419-451, 2004
[5] Kok P., et al. Current Biology; 26, 371-376, 2016
[6] Koopmans PJ., et al. Human Brain Mapping; 31:1297–1304, 2010
[7] Polimeni JR., et al., Neuroimage; 52(4): 1334-1346, 2010
[8] Poplawsky AJ., et al., J. Neuroscience; 35 (46): 15263-15275, 2015
[9] Trampel R., et al., Proc. of the 20th Meeting of ISMRM 20, 663, 2012
[10] van Mourik, in preparation
[11] Waehnert et al., Neuroimage; Jun 2: 210-20, 2013
[12] Sharoh et al., PNAS, 2019

LANGUAGE in INTERACTION

NWO Netherlands Organisation for Scientific Research

Radboud University

Radboudumc