

Responses of the cortical reading network:

An fMRI Region-of-Interest Investigation

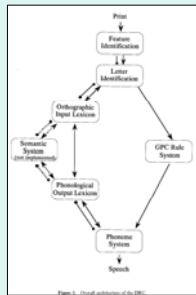
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Introduction

Neuroimaging and the Dual-Route Cascade Model

Neuroimaging can be used to constrain models of cognitive processes. The Dual Route Cascade (DRC) model of reading (Coltheart et al. 2001) has accommodated dissociations in both neuropsychological (acquired) and developmental dyslexia/alexia (e.g. "surface" vs. "phonological" dyslexia). However, neuroimaging studies have been inconsistent in their support of the DRC (Mechelli et al. 2003, Jobard et al. 2003). One reason for this inconsistency may be that while the neural correlates of the DRC's different routes (GPC vs. lexical search; see below) may be discrete in the brain, both routes are predicted to be activated in response to a legal letter-string stimulus, though only one route may be successful. Since both routes would be activated, but possibly to different degrees in all conditions, traditional "whole-brain" neuroimaging paradigms that rely on cognitive subtraction cannot detect difference degrees of activation (inferred from changes in the BOLD signal) across conditions.



The Dual-Route Cascade Model

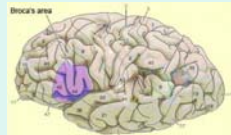
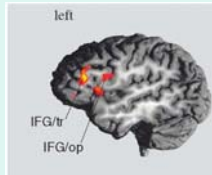
According to this model, word reading can be accomplished by two distinct routes. One of these is referred to as the graphophonological, or 'direct' route; processing by this route is understood as the application of grapheme-to-phoneme conversion (GPC) rules to the visual stimulus (after it has undergone early visual analysis, been recognized as a letter string, etc.). The other route is referred to as the lexicosemantic or 'indirect' route; processing by this route is by a search through the mental lexicon for a "match" to the stimulus.

Why pseudowords?

Pseudowords can only be read by the GPC route, though they may trigger an unsuccessful lexical search.

The Inferior Frontal Gyrus

The left inferior frontal gyrus (LIFG) has long been known to play a part in language tasks. A functional division is suspected within the LIFG between two of its components, the pars opercularis (LIFG-op, roughly Brodmann's area 44) and pars triangularis (LIFG-tr, roughly Brodmann's area 45).



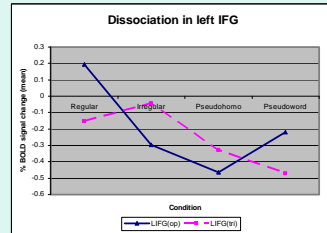
Whole-brain studies have only revealed a single dissociation. While **pars triangularis** activity is found in *both* word and pseudoword reading, the **pars opercularis** is more likely to be found active in grapheme-to-phoneme conversion.

Task

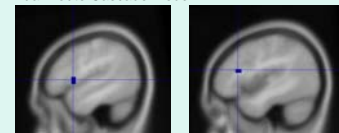
- Participants:** 6 healthy right-handed native English speaking volunteers aged 21-28; 3 female, 3 male
- Homophone Decision (see below)
- Training outside scanner
- 4 presentations of each condition in scanner
- Order of conditions counterbalanced across presentations
- Stimuli:** 20 pairs per each condition – four conditions: (1) regular, (2) irregular, (3) word/nonword pseudohomophone and (4) nonwords were employed. Each condition was presented four times, and the presentation order was counter-balanced. Baseline conditions included fixation and false-font viewing.

Results

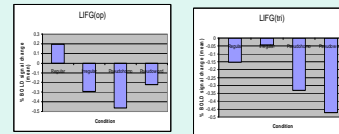
Imaging Results



This chart shows changes in BOLD signal across the experimental conditions. The solid line corresponds to the pars opercularis and the dashed line to the pars triangularis. What is striking is the almost opposite patterns shown by two areas. From this data they appear to be differentially recruited depending on the type of stimuli. Although they are quite near each other, the LIFG(op) and LIFG(tr) appear to play different roles in word reading and belong to different "routes" of the Dual Route Cascade model.

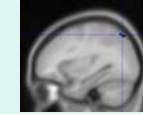


LIFG(op): Pars opercularis LIFG(tr): Pars triangularis

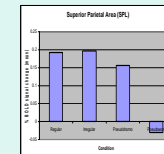


Superior Parietal: A surprising Empirical ROI

One unexpected but robust finding was involvement of the superior parietal area (SPL). Previous studies have found SPL responsive to writing tasks (Menon and Desmond 2001) and to tasks involving Chinese logographs (Lin et al. 2007).



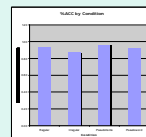
Across conditions, SPL displayed a "preference" for real words, behaving like a putative Visual Word Form Area.



Behavioral Results

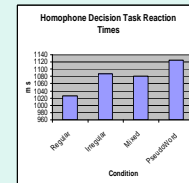
Accuracy

Response-tracking revealed that participants were able to perform the task with a high degree of accuracy. Some variation was observed among participants, but for the most part this was in a quite limited range. No remarkable differences in accuracy were observed across conditions.



Reaction Time

As predicted, mean reaction time for Regular words was shortest and for Pseudowords was longest. Also as predicted, the reaction time for irregular words was longer than for Regular words. Inter-participant differences were more pronounced in RTs than in accuracy across conditions.



Conclusion

A more complete understanding of the cognitive structures underlying reading may lead to more effective interventions for reading difficulties. Neuroimaging allows us to search for neural correlates of cognitive functions (which may or may not be localized cortically) and thereby constrain our theories about reading and other tasks.

In this study, by using the Region-of-Interest imaging analysis technique, we found evidence that might more strongly support the Dual Route Cascade model of reading than previous single dissociation findings.

Specifically, our findings support the notion that subparts of the left IFG may serve different routes: the pars opercularis underlies grapheme-to-phoneme conversion and the pars triangularis the lexical search. Previously pars triangularis activity has been found in both word and pseudoword conditions; although this finding is consistent with a parallel lexical search strategy (predicted by DRC), it can be interpreted several different ways.

However, our demonstration of different sensitivities in LIFG(op) and LIFG(tr) to words and pseudowords is most parsimoniously explained by the DRC.

One limitation of the current study was a small number of participants, so a clear hope for future study is to replicate these findings with a larger sample.

Another direction for future study should be to see if more precise quantitative fMRI methods confirm these results and add nuance; however, such an approach may call for significant changes in the paradigm.

A final suggestion for future investigation is use of a technique that can reveal temporal information across different cortical areas involved, such as dynamic causal modeling (DCM).

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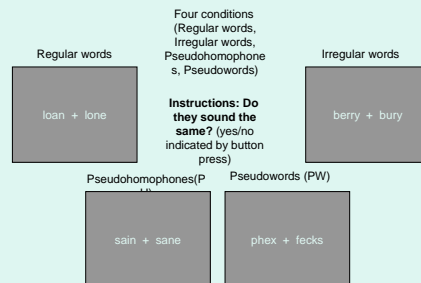
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Methods

Task: Homophone Decision



Imaging

- Procedure:** Each participant was run on two fMRI scans of the experimental task, each lasting approximately 14 min. and high-resolution anatomical image, lasting 4 min.
- fMRI acquisition:** Siemens 3-T scanner (Trio). Standard imaging procedure (gradient echo pulse sequence, TR: 2 sec.)
- fMRI data analysis:** using SPM5, images were first corrected for head motion, and smoothed. Each condition was contrasted against the baseline per subject to determine the regions of interest (ROIs). These regions of interest were visualized by coregistering the functional results with the anatomical images. MarsBar was employed to examine the time-course of each ROI across the conditions.