# Neural substrates of orthographic processing: Are they specific to written language?

## Introduction

The neural substrates of written language processing have been of interest since the time of Dejerine in the late 19th century. Lesion-deficit studies of individuals with acquired alexia/agraphia, as well as functional neuroimaging research with healthy, literate adults, offer the means to test and refine hypotheses regarding critical brain regions involved in reading and spelling. With regard to reading, a large number of neuroimaging studies have been conducted that confirm the findings of Cohen and colleagues (2000, 2002) that the left mid fusiform gyrus (BA 37) plays a special role in reading. Consistent activation in this area during a wide range of reading tasks has lead to its designation as the "visual word form area (VWFA)." This region has also been shown to be engaged during spelling tasks in healthy adults (Nakamura et al., 2000, 2002; Beeson et al., 2003), further supporting the idea that this cortical region is specialized for orthographic processing. Some researchers have questioned whether this cortical area is truly specialized for the processing of written words, however, because the region is also engaged during language tasks that do not involve orthographic processing (e.g., naming pictures, naming colors) (Price and Devlin, 2003, 2004). An alternate view to the hypothesis of a specialized VWFA is the primary systems hypothesis, which claims that reading is supported by three central processing components (vision, phonology, and semantics). There is general consensus that spoken and written language processing rely on common semantic and phonological representations, however, the nature of orthographic representations has been less clear. According to the primary systems hypothesis, orthographic processing is supported by brain regions responsible for visual object recognition that develop early in life rather than a specialized brain region dedicated to reading or spelling (Patterson & Lambon Ralph (1999; Lambon Ralph & Patterson, 2005). In other words, the generic visual processing system is engaged as one learns to read and spell and ultimately supports orthographic processing. The purpose of this study was to seek confirmation (in the same cohort of individuals) that common visual processing regions do indeed support reading, spelling, and a non-orthographic language task such as picture naming.

## Methods

Fourteen healthy, right-handed native English speakers participated in two fMRI experiments involving a total of three imaging protocols.

Procedures & stimuli: Exp.1 was conducted to confirm findings from imaging studies of reading regarding recruitment of left mid fusiform for reading tasks, and to localize the "VWFA" in individual participants. The experiment was block-designed and consisted of 3 conditions: reading irregular words, reading pronounceable nonwords, and viewing checkerboards. The contrasts of interest were reading irregular words vs. viewing checkerboards and reading nonwords vs. viewing checkerboards. Each block lasted 12 seconds and consisted of 8 items per block. Each item was presented for 1000 ms with an ISI (inter-stimulus interval) of 500 ms. 84 irregular words of 4-7 letters in length and 84 pronounceable nonwords of 4-7 letters were used.

Experiment 2 included reading, spelling, and spoken naming of items that were matched in terms of lexical features (i.e., imageability, concreteness, and frequency). Our spelling task involved written naming of pictured items. Two block-design protocols were implemented: one for reading and one for written/spoken naming. The reading protocol consisted of 2 conditions:

reading words and viewing checkerboards. The reading words vs. viewing checkerboards contrast was intended to reveal cortical activation associated with visual word form processing in reading. 96 words of 4-7 letters were presented. The same parameters (i.e., block duration, number of items per block, stimulus duration, and ISI) were used as in Exp.1.

The written/spoken naming protocol consisted of 4 conditions: written naming of pictures, spoken naming of pictures, copying scribbles, and viewing checkerboards. Sequences of 3 or 4 pictures were presented in each block for the written and spoken picture naming, respectively. In the spoken picture naming condition, subjects named the presented items silently, and this condition was contrasted with viewing checkerboards. In the written picture naming condition, the task was to write the names of the presented pictures, so that it required retrieval of the name as well as the spelling of the word. This condition was contrasted with viewing checkerboards, but was also contrasted with the task of copying simple scribbles in order to remove regions of activation specific to motor control of the pen.

Stimuli were presented during the same epoch time (12 secs) as in the reading protocol with no ISI. An iconic instruction appeared at the beginning of every block to indicate whether it was a spoken naming or a writing task. 36 picture items were selected for each of the written- and spoken-naming conditions. Three types of scribbles (i.e., circular, vertical, and horizontal) were used for the scribble-copying condition.

Image acquisition: Functional images were acquired on a GE 3T whole-body MRI system using a spiral in-out acquisition protocol with the following parameters: matrix= 64 x 64, TR= 2400 ms, TE= 30 ms, FOV= 22 cm, flip angle= 90, number of slices= 26, slice thickness= 5 mm.

Image analysis: Images were reconstructed and then analyzed in SPM5 (http://www.fil.ion.ucl.ac.uk/spm). All images were motion corrected and spatially normalized to the standard MNI (Montreal Neurological Institute) EPI template. Normalized images were resliced to 2 x 2 x 2 mm voxels and smoothed with an isotropic 8 mm FWHM Gaussian kernel.

## Results

Across the three fMRI protocols, all three contrasts of interest for reading (reading irregular words vs. viewing checkerboards, reading nonwords vs. viewing checkerboards, and reading words vs. viewing checkerboards) yielded significant activations in the left inferior temporo-occipital region (Fig. 1a-1c). The cortical activation observed in the reading tasks overlapped with the coordinates reported for the VWFA by Jobard et al. (2003) based on a meta-analysis of 35 neuroimaging studies (MNI: x = -44, y = -58, z = -15). The same cortical region was also activated during written and spoken naming (Fig. 1d-1f). It should be noted, however, that written naming resulted in stronger cortical activation overall, so those contrasts were thresholded at a more stringent level for display in Figures 1 and 2. In addition to activation in the inferior temporo-occipital region, all three tasks of interest (reading, spelling, and spoken naming) yielded activation in the frontal region as shown in Fig. 2.

## Conclusion

The reading, spelling, and spoken naming tasks included in this study resulted in strikingly similar patterns of cortical activation. Common areas of activation included left frontal cortex often associated with phonological processing, and activation in left inferior temporo-occipital cortical region in the vicinity of the VWFA as identified from meta-analyses of reading studies. These findings support a common neural substrate for reading and spelling in the left mid fusiform area, but further suggest that this region is not necessarily specialized for orthographic processing. The common activation associated with the reading, spelling, and naming tasks suggests that this area is involved in the processing of visual stimuli of all types, and that orthographic representations simply represent one type of complex visual stimuli. From a developmental perspective, it follows that orthographic processing skills rely on cortical regions that were initially critical for object recognition. Taken together, our findings are consistent with the primary systems hypothesis for written language processing.

## References


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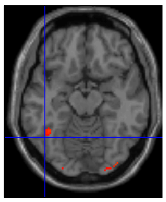
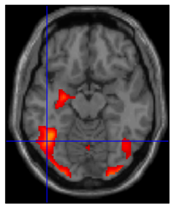
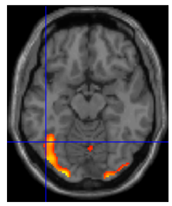
Figure 1. Axial sections showing activation on reading, written picture naming, and spoken picture naming tasks: (1a) reading irregular words vs. checkerboards, (1b) reading nonwords vs. checkerboards, (1c) reading words vs. checkerboards, (1d) written picture naming vs. copying scribbles, (1e) spoken picture naming vs. viewing checkerboards, (1f) written picture naming vs. viewing checkerboards. Crosshairs indicate the coordinates reported for the visual word form area (VWFA) by Jobard et al. (2003) (x = -44, y = -58, z = -15). All contrasts except written picture naming thresholded at p < .05 FDR; written picture naming contrasts at p <.005 FDR.



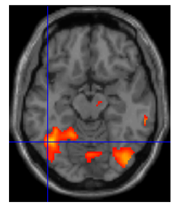
1a. reading irregular words vs. checkerboards



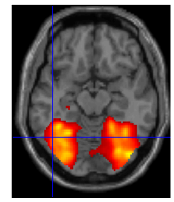
1b. reading nonwords vs. checkerboards



1c. reading words vs. checkerboards



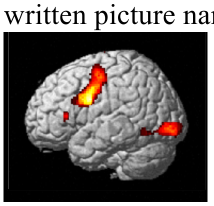
1d. written picture naming vs. copying scribbles



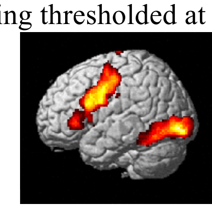
1e. spoken picture naming vs. checkerboards

1f. written picture naming vs. checkerboards

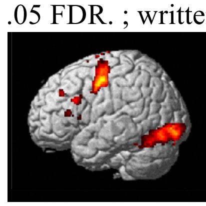
Figure 2. Activation patterns across reading, written picture naming, and spoken picture naming: (2a) reading irregular words vs. checkerboards, (2b) reading nonwords vs. checkerboards, (2c) reading words vs. checkerboards, (2d) written picture naming vs. copying scribbles, (2e) spoken picture naming vs. viewing checkerboards, (2f) written picture naming vs. viewing checkerboards. All contrasts except written picture naming thresholded at p < .05 FDR. ; written picture naming contrasts at p <.005 FDR.



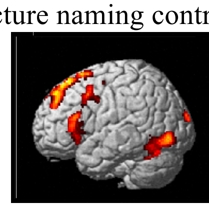
2a. reading irregular words vs. checkerboards



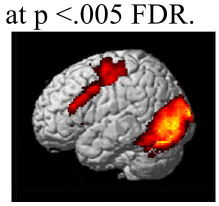
2b. reading nonwords vs. checkerboards



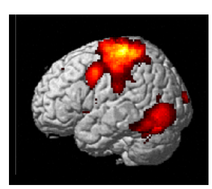
2c. reading words vs. checkerboards



2d. written picture naming vs. copying scribbles



2e. spoken picture naming vs. checkerboards



2f. written picture naming vs. checkerboards