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Reading skill related to left ventral occipitotemporal cortex during a phonological awareness task in 5–6-year old children

Jin Wang[a,b,*], Marc F. Joanisse[c], James R. Booth[a,b]

[a] Department of Psychology and Human Development, Vanderbilt University, Nashville, TN, USA
[b] Department of Communication Sciences and Disorders, The University of Texas at Austin, Austin, TX, USA
[c] Department of Psychology & Brain and Mind Institute, The University of Western Ontario, London, Ontario, Canada

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ABSTRACT

The left ventral occipitotemporal cortex (vOT) is important in visual word recognition. Studies have shown that the left vOT is generally observed to be involved in spoken language processing in skilled readers, suggesting automatic access to corresponding orthographic information. However, little is known about where and how the left vOT is involved in the spoken language processing of young children with emerging reading ability. In order to answer this question, we examined the relation of reading ability in 5–6-year-old kindergarteners to the activation of vOT during an auditory phonological awareness task. Two experimental conditions: onset word pairs that shared the first phoneme and rhyme word pairs that shared the final biphone/triphone, were compared to allow a measurement of vOT's activation to small (i.e., onsets) and large grain sizes (i.e., rhymes). We found that higher reading ability was associated with better accuracy of the onset, but not the rhyme, condition. In addition, higher reading ability was only associated with greater sensitivity in the posterior left vOT for the contrast of the onset versus rhyme condition. These results suggest that acquisition of reading results in greater specialization of the posterior vOT to smaller rather than larger grain sizes in young children.

1. Introduction

Reading starts from visual input, and involves translating print to sound. The left ventral occipitotemporal cortex (vOT) is an important brain region in reading that connects the visual word form of the stimuli to higher-level language brain areas. Even though the precise function of the left vOT is under debate (Dehaene and Cohen, 2011; Price and Devlin, 2011), it is a brain region that has consistently been found to be more sensitive to visual words compared to other stimuli such as faces and tools (Cohen et al., 2002; Gauthier et al., 2000). It has also been suggested that the sensitivity of the left vOT to visual word forms of the stimuli follows a posterior to anterior gradient, with the posterior part more sensitive to smaller grain sizes, such as letters. On the other hand, the anterior part, which has classically been referred to as the putative visual word form area (pVWFA), is in fact more sensitive to larger grain sizes, such as bigrams or trigrams (Dehaene et al., 2005).

The specialization of the left vOT for recognizing visual word forms is related to the acquisition of reading skill. An early influential theory of reading acquisition (Frith, 1985) argues that reading acquisition proceeds from the alphabetic to the orthographic stage. Early reading is marked by the acquisition of letter-sound relationships to form the alphabetic principle. Later reading is marked by the accumulation of knowledge of spelling patterns that recur across words to form larger grain orthographic representations. fMRI studies also suggest a developmental progression of vOT's sensitivity to words from small grain sizes to large grain sizes. Brem et al. (2010) trained 6-year-old non-reading children to learn letter-speech sound correspondences by using the Graphogame, a phonics-intensive training program. After the training, the participants were asked to judge the modality of a stimulus in a multimodal task where both visually and auditorily presented words as well as false fonts and rotated speech sounds were presented as stimuli. They found that the posterior vOT (MNI, ± 46 −78 −12) showed greater activation to visually presented words compared to false fonts. In a study of older children, Brem et al. (2009) found that, similar to adults, 10-year-olds exhibited greater activation for visually presented words than symbol strings in the anterior left vOT in a repetition detection task, which required pressing a button after the immediate repetition of a stimulus. Taken together, these two studies suggest that young children utilize their posterior vOT to process visual words because they rely on letter-to-phoneme mapping, while older children and adults with more reading experience utilize their anterior vOT to process visual words because they rely on larger grain size information.

* Corresponding author at: Department of Psychology and Human Development, Vanderbilt University, Nashville, TN, USA.
E-mail address: jin.wang@vanderbilt.edu (J. Wang).

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Unlike reading, which starts from visual input, spoken language processing begins with auditory input. Even though perceptual information comes through the auditory modality, a number of fMRI studies have consistently found activation in the left vOT during various spoken language tasks. Yoncheva et al. (2010) found selective attention to speech, relative to attention to melody, was associated with an activation increase in vOT (sphere ROI, MNI −35 −58 −15) for skilled adult readers. Dehaene et al. (2010) examined activation during an auditory lexical decision task in groups of adults with different reading abilities, and found that the illiterate group showed no activation in vOT, but all literate groups did (peak, MNI −44 −50 −14). Cone et al. (2008) tested typically achieving children aged 9- to 15- years old, and found vOT's (peak, MNI −45 −51 −15) activation was greater for an auditory rhyme task than a pure tone task. They also found that an orthography-phonology conflicting (e.g. PINT-MINT) condition elicited greater activation in vOT (peak, MNI −54 −51 −15) than a non-conflicting (e.g. PRESS-LIST) condition, suggesting that orthographic representations are automatically activated in a spoken language task where all stimuli are only presented auditorily. Using the same auditory rhyme task, Desroches et al. (2010) found that typically achieving children showed significantly greater activation in vOT (peak, MNI −48 −51 −15) than those with reading difficulties. This is likely because reading acquisition drives the connection between oral and written language, resulting in the automatic activation of corresponding orthographic representations in vOT even during auditory tasks. The connections between phonological and corresponding orthographic representations may aid in the performance of a variety of spoken language tasks, including phoneme awareness ones (e.g. Castles et al., 2011). In sum, all of the above findings suggest that vOT can be activated in spoken language tasks that do not require access to corresponding orthographic information for correct performance, reflecting the automatic activation of corresponding orthographic representations, especially for those with higher reading abilities.

The above studies in older children and adults showed speech–related activation in the anterior left vOT, a brain region also sensitive to bigrams in written language. For younger pre-reading children, studies have also shown activation in the left vOT in auditory language tasks. Raschle et al. (2012) compared brain activation of pre-reading children aged 5–6 years with a familial history of developmental dyslexia (FHD +) versus children without a familial history (FHD-). Among these pre-reading children, only 2% were able to identify words. Children were asked to listen to two words and decide whether they started with the same initial sound. This onset task was compared to a control task that required the children to determine whether the two words were spoken by the same voice. In the comparison of the onset task to the control task, the FHD- children showed greater activation in the left vOT (peak, MNI −16 −86 −10) compared to the FHD+ children. This peak was in the lingual gyrus, which is more medial and posterior than the peaks in the studies of older children and adults. Powers et al. (2016) also used an onset task on 5-year-old children who could recognize less than 10 words. They found a positive correlation between home literacy environment and activation in the left vOT (peak MNI −36 −60 −20) in the onset compared to the control task. Hutton et al. (2015) found that, for even younger children aged 3–5 years, reading exposure, measured by a questionnaire assessing storybook reading, parental teaching and verbal interaction, was positively correlated with activation in the left vOT during a narrative story listening condition compared to a non-speech tone condition. This activation appeared to be located more posterior than the coordinates for older children and adults, but it is hard to determine as activation formed a large cluster that peaked in the angular gyrus. Finally, Dębska et al. (2016) found an effect of familial risk of dyslexia in the left vOT (peak, MNI −20 −68 −6) with decreased activation in FHD+ compared to FHD- in kindergarten children during an auditory rhyme task compared to a voice judgment task. In summary, these studies indicate that the posterior left vOT seems to be involved in spoken language processing in young children. Moreover, pre-reading children with better reading potential, such as an absence of familial history of developmental dyslexia or more reading exposure, showed greater activation in the posterior left vOT. Many early behavioral studies suggest more experience with learning to read changes the spelling-to-sound mapping from smaller grain size to larger grain size (e.g. Ziegler and Ferrand, 1998). Therefore, it is likely that the development of reading drives the connections between oral and written language, first at the phoneme-to-letter level and then at larger grain sizes such as the rhyme. In terms of the neural mechanism, recent fMRI evidence indicates the posterior vOT is engaged in spoken language more for young children, but the anterior vOT is engaged more for older children. However, little is known about whether this automatic activation of orthographic representations in the vOT during spoken language processing is related to reading skill and whether this vOT's activation depends on grain sizes.

In order to answer these questions, the current study used the fMRI technique to examine whether reading skills in 5- to 6-year-old children at the onset of literacy were associated with automatic activation in the left vOT during an auditory phonological task that only requires a sound based judgment. Based on previous neuroimaging studies, we hypothesized that higher reading skills would be associated with greater activation in the left vOT. We also aimed to determine whether activation in the left vOT depended on grain sizes. We employed a small grain size onset condition that only contained the same first phoneme for the paired auditory words, and a large grain size rhyme condition that contained the same biphone or triphone for the paired auditory words. Previous studies have shown phoneme awareness is a better predictor of reading skill than the awareness of rhymes (Melby-Lervåg et al., 2012). Based on these behavioral studies, we hypothesized that the onset condition would be more difficult and more strongly correlated with reading skills, as compared to the rhyme condition. Based on the transition from alphabetic to orthographic reading (Frith, 1985), we expected that the young children in our study at their onset of literacy would be at the alphabetic stage due to little reading experience, and hypothesized that higher reading skills would be associated with greater sensitivity to the onset compared to the rhyme condition in the posterior left vOT that is presumably sensitive to smaller grain sizes, i.e. letters. Because the young children in our study are unlikely to be at the orthographic stage, we did not expect greater sensitivity for the rhyme compared to the onset condition in the anterior left vOT that is presumably sensitive to larger grain sizes, i.e. bigrams and trigrams.

2. Experimental procedures

2.1. Participants

Fifty-nine children (mean age = 5.9, range 5.5–6.5 years-old, 33 girls) were included in our study. Children were recruited from the Austin, Texas metropolitan area. Informed consent form was obtained from the parents. The Institutional Review Board approved all of the following procedures.

Participants were given developmental history questionnaires completed by their parents and a series of screening tests. The screening tests included the 5-handedness questions in which the children needed to pretend they write, draw, pick, open, and throw something, and the Diagnostic Evaluation of Language Variation (DELV) Part 1 Language Variation Status (Seymour et al., 2003). All the children met the following inclusionary criteria: (1) primarily right-handed, defined as performing at least 3 out of 5 items using their right hand; (2) Mainstream English speakers, defined as scoring above 8 out of 15 mainstream English items on DELV. (3) no diagnosis of Attention Deficit Hyperactivity Disorder (ADHD), neurological disease, psychiatric disorders, learning disorder or specific language impairments as reported in the developmental history questionnaire completed by their parents; (4) normal hearing and normal or corrected-to-normal vision as reported in the developmental history questionnaire completed by their parents.