Brain and Language 175 (2017) 64–70

Contents lists available at ScienceDirect

Brain and Language

journal homepage: www.elsevier.com/locate/b&l

Neural correlates of the lexicality effect in children

Yael Weiss[a,*], James R. Booth[b]

[a] Department of Psychology, University of Texas at Austin, Austin, TX 78712, USA
[b] Department of Psychology and Human Development, Vanderbilt University, Nashville, TN 37203, USA

ARTICLE INFO

Keywords:
Lexicality
Pseudowords
Reading
fMRI
Children
Brain development

ABSTRACT

The comparison of words and pseudowords has been extensively used in adult neuroimaging studies to inform neurocognitive models of reading but has rarely been used to inform models of reading acquisition. Using a rhyming judgment task, the current study examined age-related differences in the spelling to sound mapping mechanisms involved in word and pseudoword reading. We hypothesized a developmental increase in specialization of the brain mechanisms engaged for word and pseudoword processing. Consistent with adult studies, children in the current study demonstrated a greater activation for words as compared to pseudowords in the anterior left ventral occipito-temporal cortex (vOT). Inconsistent with adult studies, children also showed greater activation for words as compared to pseudowords in the mid-posterior left vOT, indicating a robust semantic influence on orthographic processing in young readers. Furthermore, our results did not indicate a lexicality by age interaction for 8- to 13-year-old children, suggesting that the adult-like specialization in the left vOT only appears later in development.

1. Introduction

Cognitive models of visual word recognition aim to describe the ability to read both familiar words and pseudowords (pronounceable nonwords). Both word and pseudoword processing encompass integration of phonological and orthographic information. However, words differ from pseudowords both because they are orthographically familiar and because they possess semantic value (Cattinelli, Borghese, Gallucci, & Paulesu, 2013). The comparison of words and pseudowords has been extensively used in the adult neuroimaging literature to inform neurocognitive models of reading, but this contrast has rarely been used to inform models of reading acquisition. In the current study, we examined age-related differences in the spelling to sound mechanisms involved in word and pseudoword reading. We hypothesized a developmental increase in specialization of the brain mechanisms engaged for word and pseudoword processing.

1.1. Lexicality effect on brain activation of adult readers

Neuroimaging meta-analysis studies that examine the lexicality effect (the difference between words and pseudowords) on adults' brain activation suggest that the familiarity and the lexical status of written stimuli affect the degree to which different reading-related brain regions are involved (Cattinelli et al., 2013; Jobard, Crivello, & Tzourio-Mazoyer, 2003; McNorgan, Chabal, O'Young, Lukic, & Booth, 2015; Mechelli et al., 2005; Protopapas et al., 2016; Pugh et al., 2001, 2010; Taylor et al., 2013). Pseudowords as compared to words show greater activation in regions that are associated with spelling to sound mapping, such as the supramarginal gyrus (SMG) and inferior parietal lobule (IPL) (Graves, Binder, Desai, Conant, & Seidenberg, 2010; Jobard et al., 2003), and phonological processing, such as the superior temporal gyrus (STG) and dorsal inferior frontal gyrus (IFG) (Fiez & Petersen, 1998; Richlan, Kronbichler, & Wimmer, 2011; Turkeltaub, Gareau, Flowers, Zeffiro, & Eden, 2003). Familiar words, on the other hand, show greater activation in regions that are associated with semantic processing or the integration of phonological/ orthographic information with semantic information, such as the angular gyrus (AG), inferior and middle temporal gyri (ITG and MTG), and ventral IFG (Fiebach, Friederici, Müller & Cramon, 2002; Jobard et al., 2003). In sum, neuroimaging studies with adults indicate a dissociation between word and pseudoword brain activation. While pseudoword reading is more likely to engage spelling to sound mapping mechanisms, real word reading is more likely to engage ortho-lexical and semantic processing mechanisms. However, the engagement of one mechanism or the other seems to depend on the specific task. While lexical decision tasks tend to increase engagement of semantic and ortho-lexical processing mechanisms, naming tasks tend to increase engagement of spelling to sound mapping mechanisms (Carreiras, Mechelli, Estévez, & Price, 2007; McNorgan et al., 2015). The current study incorporated a phonological rhyming judgment task that is likely to

* Corresponding author.
E-mail address: ylweiss@gmail.com (Y. Weiss).

http://dx.doi.org/10.1016/j.bandl.2017.09.006
Received 30 January 2017; Received in revised form 25 September 2017; Accepted 25 September 2017

enhance engagement of spelling to sound mapping mechanisms for both words and pseudowords (Pattamadilok et al., 2017). Using a single task that focuses on the conversion of orthography to phonology enables us to examine the lexicality effect on these mechanisms with no explicit requirement to access meaning-based representations (Booth & Burman, 2005).

Neuroimaging studies with adults provide extensive evidence that the left ventral occipito-temporal (vOT) cortex is crucial to written word recognition in different orthographies (Dehaene, Cohen, Morais, & Kolinsky, 2015; Richlan et al., 2011). Studies with adults further show a dissociation for words and pseudowords in different parts of the left vOT, including the left fusiform gyrus (FG) and ITG. Pseudowords show a greater activation as compared to words in the mid-posterior part (MNI: $-50 < Y < -70$) (Bruno, Zumberge, Manis, Lu, & Goldman, 2008; Cattinelli et al., 2013; Jobard et al., 2003; McNorgan et al., 2015; Mechelli, Gorno-Tempini, & Price, 2003; Price & Mechelli, 2005; Taylor et al., 2013). This region includes the putative visual word form area (VWFA) and is associated with sub-lexical bigrams and single letter coding (Dehaene, Cohen, Sigman, & Vinckier, 2005; Kronbichler et al., 2004). In their interactive account of the left vOT, Price and Devlin (2011) suggest that the mid-posterior left vOT is involved in the integration of low-level orthographic stimuli with high-level semantic and phonological processing. The greater activation for pseudowords as compared to words in the mid-posterior part of the left vOT in adult readers can be explained by a greater prediction error from the top-down processes for the phonologically and semantically unfamiliar pseudowords. Real words, on the other hand, show greater activation as compared to pseudowords in the anterior part of the left vOT (MNI: $-30 < Y < -50$) (Cattinelli et al., 2013; Jobard et al., 2003; McNorgan et al., 2015; Price & Mechelli, 2005; Taylor et al., 2013). This region is associated with coding of larger orthographic units (morphemes, small words, and up) (Dehaene et al., 2005). The greater activation for words as compared to pseudowords in the anterior part of the left vOT is attributed to the role of this region in modality independent semantic processing (Price, 2000, 2012). Alternatively, it may reflect the role of the left anterior vOT in processing a higher level visual information and function as an orthographic lexicon, which contains whole word orthographic representations (Boukadi et al., 2016; Ludersdorfer et al., 2016). Both alternatives can explain the greater engagement of the anterior left vOT for word as compared to pseudoword reading (Taylor et al., 2013).

1.2. Developmental changes in the ventral occipito-temporal cortex

Neuroimaging studies with young children suggest that similar to adults, they are able to engage the left vOT in word recognition (Gaillard, Balsamo, Ibrahim, Sachs, & Xu, 2003; Houdé, Rossi, Lubin, & Joliot, 2010; Martin, Schurz, Kronbichler, & Richlan, 2015), even before formal reading instruction (Bach et al., 2010; Maurer et al., 2007; Raschle, Zuk, & Gaab, 2012). Furthermore, a left vOT dysfunction was found for both dyslexic children and adults (Richlan et al., 2011), and in children at-risk for dyslexia prior to reading onset (Vandermosten, Hoeft, & Norton, 2016), indicating an early involvement of the region in reading. Similar to adults, typically reading, but not dyslexic, children showed the posterior-to-anterior gradient of increasing selectivity for larger orthographic units in the left occipito-temporal cortex (Brem et al., 2009; Olulade, Flowers, Napoliello, & Eden, 2013, 2015). However, neuroimaging studies found age-related changes in sensitivity to word reading in the left vOT, with adult-like patterns appearing only by the age of 15 years (Ben-Shachar, Dougherty, Deutsch, & Wandell, 2011; Olulade et al., 2013). A direct comparison between children and adult activation revealed that word selectivity in children occurs more posteriorly than in adults. For children (7- to-13-year-old), word activation was greater than false font activation in regions near the middle fusiform gyrus (MNI: $x,y,z = -36, -42, -23$ and $x,y,z = -42, -50, -14$), while for adults greater word activation was found in anterior fusiform gyrus (MNI: $x,y,z = -38, -26, -20$ and $x,y,z = -40, -34, -22$), associated with semantic processing (Olulade et al., 2013). These findings suggest a greater semantic influence on the mid-vOT activation for children as compared to adults. This interpretation is consistent with models of reading development suggesting that greater reading experience facilitates spelling to sound mapping mechanisms, improves word recognition efficiency and in turn, reduces the reliance on semantic information (Booth & Burman, 2005; Harm & Seidenberg, 2004; Plaut & Booth, 2000; Stanovich, 1980). Consistent this hypothesis, Price and Devlin (2011) described three reading acquisition phases in the top-down effects on the left vOT. In pre-readers, activation in the left vOT is low because the stimuli are not yet familiar and cannot elicit the top-down activations. In the beginning stage of learning to read, activation in this region is the highest due to increased prediction error from the top-down processes that are yet to be efficient. In experienced readers, activation in this region decreases due to more efficient top-down processes and decreased prediction error. This model predicts that the top-down influence of semantics in beginning readers should be larger than the top-down influence in experienced readers.

1.3. Lexicality effect on brain activation of children readers

One indication of a specialization in the left vOT is the dissociation of greater activation for word reading in the anterior part and a greater activation for pseudowords in the mid-posterior part, as found in adults (Cattinelli et al., 2013; Jobard et al., 2003; McNorgan et al., 2015; Price & Mechelli, 2005; Taylor et al., 2013). Examining the lexicality effect on activation along the left vOT cortex in young readers has the potential to shed light on the developmental specialization in this region. Greater activation for words suggests a reliance on semantic information, while a greater activation for pseudowords suggests a reliance on phonological and sub-lexical processing. Alternatively, this pattern for pseudowords could be explained by increased prediction error from phonological and semantic top-down processes.

To date, only one functional Magnetic Resonance Imaging (fMRI) study has directly examined the main effect of lexicality on brain activation in children using a single task design, and this was in German speaking children (van der Mark et al., 2009). A few other studies used different tasks to examine phonological and semantic activation differences in children, using pseudowords and real words (Backes et al., 2002; Liebig et al., 2017). However, to the best of our knowledge, no fMRI study has directly examined the lexicality effect on brain activation in English speaking children, or examined age-related differences in the brain mechanisms involved in familiar word versus unfamiliar pseudoword processing using a single task. Consistent with the lexicality effect found in studies with adults, German speaking children (age 9.7–12.5 years) showed greater activation for word reading in left AG, and greater activation for pseudoword reading in left IFG and IPL, when performing a phonological lexical decision task (van der Mark et al., 2009). These results indicate that children at this age already show a specialization within these regions similar to adults. However, in contrast to findings from the meta-analyses with adults (Cattinelli et al., 2013; McNorgan et al., 2015; Taylor et al., 2013), this study showed a greater activation for pseudowords as compared to words in the left anterior FG (MNI: $x,y,z = -42, -42, -21$). Furthermore, their ROI analysis revealed the same pattern (pseudoword > word activation) along the entire left vOT. Studies with German speaking adolescents and adults, which incorporated the same phonological lexical decision task, also found greater activation for pseudohomophones as compared to words in the left anterior FG (MNI: $x,y,z = -45, -48, -15/-18$) (Kronbichler et al., 2007; Schurz et al., 2014). This effect was interpreted as indicating an increased demand on lexical search in this region for pseudohomophones. In contrast with the finding from German, adult English readers showed a lexicality