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Individual differences in involvement of the visual object recognition system during visual word recognition

Sarah Laszlo[a,b,*], Elizabeth Sacchi[a]

[a] Department of Psychology, Binghamton University, United States
[b] Program in Linguistics, Binghamton University, United States

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ABSTRACT

Individuals with dyslexia often evince reduced activation during reading in left hemisphere (LH) language regions. This can be observed along with *increased* activation in the right hemisphere (RH), especially in areas associated with object recognition – a pattern referred to as RH compensation. The mechanisms of RH compensation are relatively unclear. We hypothesize that RH compensation occurs when the RH object recognition system is called upon to supplement an underperforming LH visual word form recognition system. We tested this by collecting ERPs while participants with a range of reading abilities viewed words, objects, and word/object ambiguous items (e.g., "SMILE" shaped like a smile). Less experienced readers differentiate words, objects, and ambiguous items less strongly, especially over the RH. We suggest that this lack of differentiation may have negative consequences for dyslexic individuals demonstrating RH compensation.

1. Introduction

Specific reading impairment (also called dyslexia) is, by far, the most common learning disorder, with estimates of incidence reaching 12% of the population (e.g., Lindgren, De Renzi, & Richman, 1985). Given the fundamental necessity of literacy in our society, low levels of reading achievement can lead to a variety of difficulties in daily life that persist across the lifespan (e.g., Boetsch, Green, & Pennington, 1996), in addition to the obvious scholastic disadvantages. Consequently, there is a large literature addressed to understanding the cognitive and neural problems that are associated with dyslexia. In the cognitive domain, focus is on understanding what particular sub-skills of reading seem to be especially critical for the acquisition of expert reading skills. Phonological awareness (i.e., a metalinguistic awareness of the sound structure of the language referring to the ability to identify and manipulate the phonological units of words – for example, phonemes, syllables, and rhymes) is frequently highlighted as an especially strong candidate (see extensive review in National Reading Panel, 2000). Extensive behavioral work has further demonstrated that reading is a complex process that can be impaired due to problems with a number of subskills in addition to phonological awareness, such as visual attention (e.g., Bosse, Tainturier, & Valdois, 2007), orthographic analysis (e.g., Stanovich & West, 1989; Stanovich, West, & Cunningham, 1991), vocabulary knowledge (review in NRP, 2000), and fluent recognition of text (e.g., Rashotte & Torgesen, 1985),

In the neural domain, a large number of studies have focused on understanding how the brains of individuals with dyslexia differ from those of individuals who read normally. Results from this work suggest several common characteristics of the functional brain organization of dyslexics. First, dyslexics seem to evince reduced functional connectivity in the left cerebral hemisphere (e.g., Keller & Just, 2009; Steinbrink et al., 2008). This reduced connectivity seems to be related to, second, reduced left hemisphere activation during phonological processing tasks, especially in the left inferior frontal gyrus and temporo-parietal areas (e.g., Hoeft et al., 2007; Keller & Just, 2009; Shaywitz & Shaywitz, 2005; Temple et al., 2003). Reduced activity in the LH is also observed in the occipitotemporal system during word reading or reading related tasks (e.g., Paulesu et al., 2001) – though not all changes in LH activation in dyslexia are reductions; activation in the left inferior frontal gyrus has been shown to increase in some dyslexic individuals (Pugh et al., 2010; Shaywitz et al., 1998) Finally, seemingly in *compensation* for reduced LH effectiveness, poor readers – even those that are not dyslexic – have been shown to exhibit *more* activation in right hemisphere occipitotemporal (OT) regions (Shaywitz & Shaywitz, 2005) than better readers. Right hemisphere

* Corresponding author at: Department of Psychology, 4400 Vestal Parkway East, Binghamton, NY 13902, United States.
E-mail address: cogneuro@alum.mit.edu (S. Laszlo).

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compensation is in its extreme in alexia, where seemingly compensatory activity in the right OT fusiform gyrus has been observed when the left OT fusiform region is actually damaged (e.g., Cohen et al., 2003). Here, we are interested in two, related, questions. First, *why is RH OT cortex specifically*, of all the brain, a region that is frequently observed to contribute to RH compensation in dyslexia? Second why is this RH OT compensation seemingly maladaptive? That is, why do children who use the RH OT more during reading demonstrate *lower* reading ability than children who use it less? Why is its use not *helping* to address connectivity/activation problems in the LH analog? That is, it is certainly imaginable that, in the face of an abnormally developing LH, use of the RH could be beneficial, with individuals who use it more demonstrating stronger reading ability than those that use it less. However, this is not what is observed (Shaywitz & Shaywitz, 2005), and beginning to understand *why* additional use of the RH does not seem to protect reading skill in the face of problems in the LH is one goal of this paper.

1.1. Why the RH OT cortex?

When RH OT compensation occurs, why does it occur in RH OT cortex specifically, and not in a RH analogue of any of the other LH regions involved in the reading network (a number of which are involved in normal reading already)? When the LH network is actually damaged, as in alexia, for example, compensation can instead take place in the RH fusiform gyrus (Cohen et al., 2003). It is our hypothesis that the typical function of the RH OT cortex is related enough to the typical function of the LH OT cortex to be recruited to assist a sparsely connected LH – to a greater degree than other RH analogues of LH language regions. We will argue that the reason that RH OT cortex, in particular, is recruited in RH compensation is that this compensation reflects recruitment of the visual *object* recognition system for dealing with visual *wordforms*.

There is a fairly strong literature suggesting that the LH OT cortex is involved in the decoding of visual word forms into more abstract orthographic features (e.g., Cohen & Dehaene, 2004; Dehaene & Cohen, 2011). Though there is spirited debate pertaining to how *specifically* the LH OT is involved in orthographic analysis (Price & Devlin, 2003, 2011), especially regarding how and whether this region might perform other functions, the evidence is strong that it does at least contribute to orthographic analysis. The result of orthographic analysis is the extraction of abstract orthographic features from visual percepts; these representations can then be processed at higher linguistic levels such as semantics or lexicality (see Grainger & Holcomb, 2009; Laszlo & Federmeier, 2014; Laszlo & Plaut, 2012).

The RH OT seems to undertake a related function with related results, but in a different domain. Specifically, we note that this region seems to be involved in visual object recognition (e.g., Grill-Spector, Kourtzi, & Kanwisher, 2001; Haxby et al., 1991; Spiridon & Kanwisher, 2002). Visual object recognition involves the extraction of more abstract representations from visual percepts – representations that may include or eventually be linked with category labels or other verbal information (see review in Tarr & Vuong, 2002). Thus, while in the LH OT visual percepts are converted to abstract features for further processing, in the RH OT a similar process seems to take place, only based on visual objects instead of visual wordforms. Clearly, the functions of the two regions are related. In fact, it is likely that the specialization of the LH OT for orthographic analysis and the specialization of the RH OT for object recognition are only *relative* specializations, with both areas likely being involved to some extent with both processes (e.g., Price & Devlin, 2003; Seghier & Price, 2011) This is consistent with findings in the literature that demonstrate that the RH OT system is called upon to support the LH OT system for text processing in various situations, such as when text is presented vertically instead of horizontally (Cai, Paulignan, Brysbaert, Ibarrola, & Nazir, 2010) or in children who have not yet learned how to read (Maurer, Brem, Bucher, & Brandeis, 2005). Indeed, it is thought that the RH's visuospatial expertise is partially responsible for its heightened involvement in processing Chinese text relative to English and other alphabetic scripts (e.g., Liu, Dunlap, Fiez, & Perfetti, 2007). It is thought that this heightened RH involvement may be due to the "global" (low spatial frequency) nature of the processing that takes place in logographic languages as opposed to "local" (high spatial frequency) information more critical for decoding of alphabetic languages (e.g., Mei et al., 2014).

Here, we will directly test the possibility that RH OT involvement in text processing represents use of the object recognition system to support the LH word recognition system, and whether degree of use of the RH OT in this role varies according to individual reading ability. We will do this by recording ERPs while participants who vary in their vocabulary, verbal fluency, and exposure to print view words, objects, and word/object ambiguous items (e.g., the word SMILE shaped like a smile, see Fig. 1 for examples and Appendix 1 for the full set). This experimental design enables the exploration of several questions. First, do individual weaker readers display less specialization for print than stronger readers, as evidenced by less differentiated responses to the words and objects? Second, how do individuals respond to the novel, ambiguous items, and how does reading ability impact the processing of those items? Third, how do any observed reading ability effects interact with hemisphere of processing? We will explore each of these questions in our analysis.

1.2. Characteristics of RH use in reading

Individuals who evince more RH OT activation also tend to be weaker readers (Shaywitz & Shaywitz, 2005), and consequently, strengthening LH reliance is a stated target of multiple reading interventions (Richards & Berninger, 2008; Shaywitz et al., 2004). But more broadly, involvement of the RH in language comprehension is not only not maladaptive, it is normal and essential. Thus, as we consider hemispheric asymmetries in print specialization and how those interact with reading ability, it is important to note that RH involvement in reading is not always a sign of disorder – in fact the RH is clearly involved in many advanced reading functions in normal readers, such as integrating incoming text with sentence or discourse context (e.g., Federmeier, 2007; Federmeier & Kutas, 1999; Wlotko & Federmeier, 2007), resolving lexical and semantic ambiguities (Kandhadai & Federmeier, 2008, 2010), and interpreting non-literal language, as in jokes (Coulson & Williams, 2005). Further, in reading disorders besides dyslexia, such as alexia, RH compensation is associated with recovery (e.g., Cohen et al., 2003).

Indeed, the apparent over-activation of the RH OT in dyslexia may only be an artifact of comparing its activity with an *under*-activating LH analog (see Shaywitz & Shaywitz, 2008) – that is, it may not be that the RH OT is actually working more at an absolute level in dyslexic individuals than in normally developing readers; rather it may just be working *proportionally* more. Similarly, the finding that individuals who rely more on the RH OT system during reading also are poorer readers (Shaywitz & Shaywitz, 2005) could potentially be explained with the suggestion that increased RH reliance is always or mostly associated with *greater problems in the LH*, meaning that RH compensation is not the *cause of* poorer reading ability but only a *symptom* of the underlying problems in the LH. Nevertheless, it is still the case that many established reading remediations aim to increase reliance on LH areas during reading, precisely because overuse of the RH is *seen as* maladaptive