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Introduction to This Special Issue: The Cognitive Neuroscience of Reading

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That reading happens in the brain is obvious, but how this occurs has been a focus of scientific investigation for more than 100 years. This special issue of *Scientific Studies of Reading* highlights the great deal of progress that has been made recently in understanding the neurobiological foundations of basic processes in reading.

Until the last quarter of the 20th century, scientific understanding of the neural basis of reading came almost exclusively from studies of patients with focal brain lesions. The classic work of Déjerine (1891) demonstrated that lesions to the occipital cortex and splenium of the corpus callosum resulted in alexia without agraphia, or the inability to read with a spared ability to write, whereas lesions that included the inferior parietal lobe (angular gyrus) resulted in alexia with agraphia. These results provided an early suggestion that separate regions of the brain might be involved in different components of reading ability. Subsequent work in the 20th century extended these observations; in particular, much work has examined the syndromes of acquired phonological, surface, and deep dyslexia, which can occur following brain lesions (e.g., Coltheart, Patterson, & Marshall, 1980; Patterson, Marshall, & Coltheart, 1985). However, the limits of lesion approaches necessitate a relatively crude mapping of function to structure.

With the advent of safe and widely accessible functional neuroimaging techniques, cognitive neuroscientists have begun to examine the neural basis of reading at a number of different levels of analysis, and the articles in this issue highlight the diversity of approaches and techniques that have been brought to bear. Two broad

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classes of neuroimaging techniques are used in this work. Psychophysiological imaging techniques, such as event-related potentials and magnetoencephalography (MEG), measure the electrical or magnetic signals that are created by neural activity. These techniques can measure brain activity with high temporal resolution (down to the millisecond level), but their ability to localize activity in the brain is rather limited. Hemodynamic imaging techniques, such as positron emission tomography or functional magnetic resonance imaging (fMRI), measure the blood flow response that occurs when neurons are active. Because this blood flow response is relatively slow (peaking several seconds after the neural activity), these techniques are limited in their temporal resolution. However, they can provide much better spatial resolution than psychophysiological techniques (down to about 1 mm for fMRI).

HOW CAN NEUROSCIENCE INFORM THE SCIENCE OF READING?

Neuroimaging clearly produces pretty pictures of brain activation, but it is often asked whether neuroimaging can reveal anything about cognitive processes (such as reading) that is not already known. The articles in this issue demonstrate a number of ways in which this can occur. To highlight one example, there has been a long-standing debate over the role of phonological processing in skilled reading (reviewed by Frost, 1998), with one set of theorists offering online-processing data suggesting rapid activation of phonological representations and another set of theorists highlighting neuropsychological dissociations between phonological and lexical processing. As Sandak, Mencl, Frost, and Pugh outline, neuroimaging has provided converging evidence for the early phonology theory by showing that regions in the ventral visual stream (which have been thought to subserve the "direct" route from orthography to semantics) are sensitive to phonological variables. This finding also highlights the limitations of neuroimaging and the need for converging techniques. For example, fMRI cannot be used to determine when these phonological effects arise during processing; do they occur early in the visual recognition of words, or are they due to later feedback effects? To answer this question, one must use techniques such as EEG–MEG, which provide greater temporal resolution (at the cost of lower spatial resolution). Salmelin and Helenius outline how these techniques have been used to characterize the time course of early visual processes in reading and to show that these early processes are delayed in individuals with reading disabilities.

Another way that neuroimaging can inform the science of reading is by demonstrating common underlying neural mechanisms for tasks that appear to be quite different. Misra, Katzir, Wolf, and Poldrack use this approach to help explain why rapid automatized naming tasks, which involve rapid naming of single letters or other objects, are so strongly predictive of text reading skills. By showing that rapid naming of single letters engages many of the same neural systems as single-word reading, this work shows how simple tasks can be used to decompose the component processes of reading skills.

To fully understand the neural basis of skilled reading, it is also important to understand how reading skills are acquired during childhood. This is made difficult by the fact that the brain is still developing throughout the ages during which children acquire reading skills. Palmer, Brown, Petersen, and Schlaggar discuss a number of fundamental issues regarding how functional neuroimaging can be used to study the development of reading skills. In particular, they highlight several important methodological difficulties that arise with the use of neuroimaging techniques in children and show that these difficulties can be overcome to provide a fascinating picture of the developing brain as it acquires reading skills.

Whereas most neuroimaging studies of reading have focused on the single-word level, the goal of reading is comprehension, so it is also crucial to understand the neural systems involved in syntactic and semantic processing at the sentence level and higher. Caplan outlines a long-standing program of research using neuroimaging to understand sentence comprehension. This work highlights the oft-noted fact that reading is built on top of spoken language, noting that similar neural mechanisms appear to be involved in both written and spoken sentence comprehension.

The articles in this special issue demonstrate how functional neuroimaging techniques have provided novel insights into how reading works in the brain and how these processes may be disorganized in reading disorders. As highlighted in the commentary by Perfetti and Bolger, understanding how reading works in the brain is not a simple end goal but rather reveals new phenomena that will serve to constrain theories of reading. These articles also make clear that a full understanding of these processes is well off in the horizon, but it is our hope that they will inspire further collaboration between reading researchers and neuroscientists. It is precisely this kind of cross-discipline collaboration that defines cognitive neuroscience and that we believe will continue to inform our understanding of the psychology of reading.

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