One of the most exciting developments in cognitive neuroscience is the possibility of performing *in vivo* (in the living body) functional brain imaging to elucidate the neurobiological basis of complex cognitive skills. Neuroimaging technology allows neuroscientists to study the regions of the brain that we use for diverse activities, such as committing a telephone number to memory, recollecting directions needed to find our way through a city, or learning a complex sequence of finger movements that result in a tune played on the piano.

Experimental situations are created within the imaging environment, such as in an MRI scanner, allowing investigators to record changes in subject’s brain during the performance of a specific task. For example, participating subjects may be asked to read single non-words (pronounceable words that do not exist in the English language) that appear on a visual display. When brain activity from this condition is contrasted to one when the real words are presented, it is possible to identify those regions associated with phonological decoding, while keeping other factors such as visual and auditory stimulation constant. In this way it is possible to determine the functional anatomy of the brain for diverse tasks in normal and disordered brain function. The combination of imaging technology and behavioral observation promises to provide a better understanding of the cognitive and sensory processes that support our daily activities, including what is considered one of our most valuable skills: the ability to learn how to read.

This article addresses functional brain imaging techniques only. Functional brain imaging techniques capitalize on the known relationship between increased neuronal firing (in response to an action or a thought process) and increased cerebral blood flow and blood volume. Some specific techniques include: (1) Xenon: a gas that is inhaled and detected by probes placed around the head, (2) Positron Emission Tomography (PET): tracer elements are introduced into the brain and imaged as they emit photons, and (3) Functional Magnetic Resonance Imaging (fMRI): a procedure that takes advantage of the different magnetic properties of hemoglobin in the blood stream. In fMRI studies areas of brain activity are associated with net increase in oxygenated hemoglobin, and serve as a marker of neuronal activity. fMRI is not invasive because unlike Xenon imaging and PET, the hemoglobin serves as our own endogenous contrast agent.

### Neuroimaging technology allows neuroscientists to study the regions of the brain that we use for diverse activities

In the late 1980s and early 1990s, researchers utilizing brain imaging methods such as positron emission tomography (PET) investigated the brain basis of typical and atypical reading in adults. With the advent of functional magnetic resonance imaging in 1991, (fMRI) it has recently become possible to perform these studies non-invasively, meaning that no radiation or contrast agents are required. Since this has provided researchers with the opportunity to study children safely and gain a better understanding of cognitive development, there has been an upsurge in the number of studies utilizing brain imaging. The non-invasive nature of fMRI has also made it possible to design more complex experiments. These may incorporate many more conditions within one testing sessions or consist of repeated data acquisitions. An example of such a design may involve collecting fMRI data before and after an intervention procedure and in children this would not be allowable with more invasive imaging technologies such as PET.

Much of what we know to date about the brain organization of vision, audition, and motor skills is based on animal studies. A great deal of this knowledge is applicable to humans and has been confirmed by neuroimaging studies performed on people. For example, we know from brain imaging studies performed in the 1990s that humans, like monkeys, process visual attributes such as faces and objects in a similar region of the brain, located at the back of the temporal lobe, near where light perception begins. Likewise, information about the perception of moving features is preferentially processed in other portions of the brain that reside higher up, in the more posterior aspects of the brain’s hemispheres.

Attributes that are unique to humans such as language and reading cannot be studied in animal models. Instead, our knowledge of the biological basis of reading prior to the advent of brain technology was largely due to studies of adult patients who, as a result of a stroke, had lost specific aspects of the reading process. These observations lead to the “dual route” theory of reading, which has prevailed in the reading literature for many years. This model posits that simple, commonly encountered words and words that do not follow regular pronunciation rules (exception words such as “yacht”), are processed in the brain by a “direct route.” On the other hand, novel regular words that have to be sounded out phonologically engage an “indirect route.” These conclusions emanated from studies of patients who were able to name exception words despite their inability to phonologically decode words. Other patients were noted to have the opposite problem, and exhibited preserved non-word reading abilities but struggled with the reading of exception words.

Although these patient observations increased our understanding of reading and reading disorders, they are insufficient when it comes to explaining developmental dyslexia. This is not surprising, as problems that stem from developmental changes in the brain may be quite different from those resulting from stroke, as observed in adults who were once skilled readers. Indeed, neuroanatomical differences were found by Albert Galaburda and his colleagues during autopsies of in-
Functional brain imaging studies have reliably revealed several areas in the brain that appear to work differently in individuals with dyslexia compared to good readers.

Argued for a link between the ability to process auditory input and perceive phonemes. These contrasting theories continue to be debated in the research literature and have recently influenced diverse approaches to the treatment of dyslexia.

It has also become clear that the experience of reading itself changes the brain; functional brain imaging studies of Portuguese illiterates have shown that the brain’s representation of phoneme processing is modified by a person’s print experience. The anomalous activity underlying developmental reading disability has been shown to be consistent across different cultures. Paulesu and colleagues have identified common areas of activation in the brains of English, French and Italian individuals with dyslexia. These important discoveries suggest that the basic pathophysiology of dyslexia can be isolated despite some variations found in the phonological structure of diverse languages and in societal attitudes toward learning disabilities.

While the introduction of imaging technology has revolutionized neuroscience, it is important to recognize the limitations as well as the benefits of these tools. Researchers have been asking the question: “How can brain imaging be used to advance the identification and treatment of developmental dyslexia?” Although data sets portrayed as colorful images may seem appealing and valid, the true knowledge gained from these studies depends on the strength of the hypotheses and the rigor of the research designs. Therefore, the utility of brain imaging is just as dependent on scientific quality as any other research approach. It necessitates the same scrutiny that would be applied in trying to understand other investigative avenues that could potentially lead to the alleviation of reading problems.

What role does brain imaging play in the understanding of treatment approaches? The non-invasive advantage of fMRI allows for the study of dyslexia in younger children, thereby getting closer to early identification and treatment for the disorder and preventing the resultant manifestation caused by a lifetime of reading difficulties. fMRI also offers the potential for discovering the neurophysiological correlates of reading intervention at an early age. A better understanding of brain regions that are positively altered by the successful treatment of reading problems could help fine tune interventions and make them more effective.

Following the established standards applied during observational investigations on the efficacy of reading intervention, studies employing functional brain imaging must be designed with sufficient rigor to provide meaningful results. For these to be applied in the field, these studies need to contain several elements: a sample of students with dyslexia that is receiving an experimental treatment and an appropriately matched control group of students with dyslexia. The control group...
can be either “active” or “passive”, meaning this group may or may not receive another type of intervention which does not contain the components thought to bring about improved reading (unlike that administered to the treatment group) and hence serves to control for the placebo effect. Preferably both are included in the study.

Studies should also be conducted by randomly assigning students to the different treatment arms (intervention, active control, passive control). This may seem counterintuitive to a clinician whose goal is to assign a child to the type of intervention that seems most beneficial for that student. However, to prevent bias in the same way that trials are performed in medicine, students need to be randomly assigned to the treatment and control groups and their progress must be monitored by an observer who is unaware of their group assignment (that is they are blind until the study is complete).

The treatment and control groups, matched on their reading deficit prior to the intervention, are then compared at the end of an intervention to see if the group that received treatment made significant gains compared to the active or passive control group. The advantages of including an active control group is that it controls for confounds associated with receiving an intervention, for example receiving attention by those administering the intervention. However, it is not always possible to find a suitable placebo treatment that is closely matched to the actual intervention, or often it provides an ethical conflict.

It is important not only to investigate gains in performance which is highly correlated to the intervention, but also to see if the effects generalize to reading comprehension, fluency, and accuracy. For example, for an intervention that concentrates on improving an individual’s phonological awareness skills it is considerably more consequential if word reading, context reading, and reading speed are also increased.

Applied in combination with all of the above described components, brain imaging technology can significantly add to the information gained from intervention studies. Brain imaging can contribute by assessing the neurophysiological correlates of successful reading intervention. To do this, the treatment and control groups need to be scanned prior to and after the intervention. If regions of the brain emerge that have been significantly changed only in the treatment group when contrasted to the control group (in an analysis that compares the pre- with post-intervention data) the results are meaningful. Unfortunately, initial reports have failed to employ these appropriate control groups and the results are, therefore, not conclusive. As more studies are completed it will be possible to establish which findings hold up and can be reproduced. It is always important that findings be replicated by scientists who are not associated with a commercial product being investigated.

While the number of tasks studied during the imaging experiment are often limited, it is possible to correlate brain activity from the study with other aspects of reading assessed during behavioral observation (e.g. phonemic awareness, fluency, working memory, orthographic processing). Efforts are underway to investigate several different intervention approaches in conjunction with brain imaging to evaluate their impact on a wide range of reading skills. These results will need to be made available to consumers in an accessible and responsible way to allow parents to make informed decisions about which avenues to pursue for their child.

In conclusion, brain imaging has recently begun to play an important role in characterizing the neural mechanisms of reading. Imaging studies will eventually advance the identification and treatment of developmental dyslexia. The most prominent contributions of fMRI involve investigations that focus on the biological basis, early identification, and the most effective treatment for dyslexia. The goal of these efforts is to aid early identification before reading failure ensues and to provide practical and reliable treatments.

References: