



Dyslexia and the Brain

Researchers are continually conducting studies to learn more about the causes of dyslexia, early identification of dyslexia, and the most effective treatments for dyslexia.

Developmental dyslexia is associated with difficulty in processing the *orthography* (the written form) and *phonology* (the sound structure) of language. As a way to understand the origin of these problems, neuroimaging studies have examined brain anatomy and function of people with and without dyslexia. These studies are also contributing to our understanding of the role of the brain in dyslexia, which can provide useful information for developing successful reading interventions and pinpointing certain genes that may also be involved.

What is brain imaging?

A number of techniques are available to visualize brain anatomy and function. A commonly used tool is magnetic resonance imaging (MRI), which creates images that can reveal information about brain anatomy (e.g., the amount of gray and white matter, the integrity of white matter), brain metabolites (chemicals used in the brain for communication between brain cells), and brain function (where large pools of neurons are active). Functional MRI (fMRI) is based on the physiological principle that activity in the brain (where neurons are “firing”) is associated with an increase of blood flow to that specific part of the brain. The MRI signal bears indirect information about increases in blood flow. From this signal, researchers infer the location and amount of activity that is associated with a task, such as reading single words, that the research participants are performing in the scanner. Data from these studies are typically collected on groups of people rather than individuals for research purposes only—not to diagnose individuals with dyslexia.

Which brain areas are involved in reading?

Since reading is a cultural invention that arose after the evolution of modern humans, no single location within the brain serves as a reading center. Instead, brain regions that subserve other functions, such as spoken language and object recognition, are redirected (rather than innately specified) for the purpose of reading (Dehaene & Cohen, 2007). Reading involves multiple cognitive processes, two of which have been of particular interest to researchers: 1) grapheme-phoneme mapping in which combinations of letters (graphemes) are mapped onto their corresponding sounds (phonemes) and the words are thus “decoded,” and 2) visual word form recognition for mapping of familiar words onto their mental representations. Together, these processes allow us to pronounce words and gain access to meaning. In accordance with these cognitive processes, studies in adults and children have demonstrated that reading is supported by a network of regions in the left hemisphere (Price, 2012), including the occipito-temporal, temporo-parietal, and inferior frontal cortices. The occipito-temporal cortex holds the “visual word form area.” Both the temporo-parietal and inferior frontal cortices play a role in phonological and semantic processing of words, with inferior frontal cortex also involved in the formation of speech sounds. These areas have been shown to change as we age (Turkeltaub, et al., 2003) and are altered in people with dyslexia (Richlan et al., 2011).

What have brain images revealed about brain structure in dyslexia?

Evidence of a connection between dyslexia and the structure of the brain was first discovered by examining the anatomy of brains of deceased adults who had dyslexia during their lifetimes.

Dyslexia and the Brain – Page 2

The left-greater-than-right asymmetry typically seen in the left hemisphere temporal lobe (*planum temporale*) was not found in these brains (Galaburda & Kemper, 1979), and ectopias (a displacement of brain tissue to the surface of the brain) were noted (Galaburda, et al., 1985). Then investigators began to use MRI to search for structural images in the brains of research volunteers with and without dyslexia. Current imaging techniques have revealed less gray and white matter volume and altered white matter integrity in left hemisphere occipito-temporal and temporo-parietal areas. Researchers are still investigating how these findings are influenced by a person's language and writing systems.

What have brain images revealed about brain function in dyslexia?

Early functional studies were limited to adults because they employed invasive techniques that require radioactive materials. The field of human brain mapping greatly benefited from the invention of fMRI. fMRI does not require the use of radioactive tracers, so it is safe for children and adults and can be used repeatedly which facilitates longitudinal studies of development and intervention. First used to study dyslexia in 1996 (Eden et al., 1996), fMRI has since been widely used to study the brain's role in reading and its components (phonology, orthography, and semantics). Studies from different countries have converged in findings of altered left-hemisphere areas (Richlan et al., 2011), including ventral occipito-temporal, temporo-parietal, and inferior frontal cortices (and their connections). Results of these studies confirm the universality of dyslexia across different world languages.

What about genes, brain chemistry, and brain function?

Several genetic variants are associated with dyslexia, and their impact on the brain has been investigated in people and mice. Using animals that have been bred to have genes associated with dyslexia, researchers are investigating how these genes might affect development of and

communication among brain regions (Che, et. al., 2014; Galaburda, et al., 2006). These investigations dovetail with studies in humans. Differences in brain anatomy (Darki, et al., 2012; Meda et al., 2008) and brain function (Cope et al., 2012; Pinel et al., 2012) have been observed in people who carry dyslexia-associated genes, even those people who have good reading skills. In addition to these investigations at the anatomical, physiological, and molecular levels, researchers are trying to pinpoint the chemical connection to dyslexia. For example, brain metabolites that play a role in allowing neurons to communicate can be visualized using another MRI-based technique called *spectroscopy*. Several metabolites (for example, choline) are thought to be different in people with dyslexia (Pugh et al., 2014). Researchers continue to explore the connections between these findings and are hopeful that what they learn will help to determine the causes of dyslexia. This is a difficult aspect of research because differences in the brains of people with dyslexia are not necessarily the cause of their reading difficulties (for example, it could also be a consequence of reading less).

Changes in Reading, Changes in the Brain

Brain imaging research has revealed anatomical and functional changes in typically developing readers as they learn to read (e.g. Turkeltaub et al., 2003), and in children and adults with dyslexia following effective reading instruction (Krafnick, et al., 2011; Eden et al., 2004). Such studies also shed light onto the brain-based differences of those children with dyslexia who benefit from reading instruction compared to those who fail to make gains (Davis et al., 2011; Odegard, et al., 2008). Neuroimaging data have also been used to predict long-term reading success for children with and without dyslexia (Hoeft et al., 2011).

Cause versus Consequence

An important aspect of research on the brain and reading is to determine whether the findings are the cause or the consequence of dyslexia. Some of

the brain regions known to be involved in dyslexia are also altered by learning to read, as demonstrated by comparisons of adults who were illiterate but then learned to read (Carreiras et al., 2009). Longitudinal studies in typical readers reveal anatomical changes with age, some of which are related to development (Giedd et al., 1999) and others to the firming up of language skills (Sowell et al., 2004) in correlation with improvements in phonological skills (Lu et al., 2007). As such, researchers are teasing apart the brain-based differences that can be observed before children begin to learn to read from differences that may occur as a consequence of less reading by people with dyslexia. For example, researchers have found altered brain anatomy (Raschle, et al., 2011) and function (Raschle, et al., 2012) in pre-reading children with a family history of dyslexia. Future studies using longitudinal designs (i.e., long term), will inform the timeline of these changes and clarify cause and consequences of anatomical and functional differences in dyslexia.

Summary

The role of the brain in developmental dyslexia has been studied in the context of brain anatomy, brain chemistry, and brain function—and in combination with interventions to improve reading and information about genetic influences. Together with results of behavioral studies, this information will help researchers to identify the causes of dyslexia, continue to explore early identification of dyslexia, and determine the best avenues for its treatment.

References

- Carreiras, M., Seghier, M. L., Baquero, S., Estévez, A., Lozano, A., Devlin, J. T., & Price, C. J. (2009). An anatomical signature for literacy. *Nature*, *461*(7266), 983–986. doi:10.1038/nature08461
- Che, A., Girgenti, M. J., & Loturco, J. (2014). The Dyslexia-Associated Gene *Dcdc2* is required for spike-timing precision in mouse neocortex. *Biological Psychiatry, in press*. doi:10.1016/j.biopsych.2013.08.018
- Cope, N., Eicher, J. D., Meng, H., Gibson, C. J., Hager, K., Lacadie, C., ... Gruen, J. R. (2012). Variants in the *DYX2* locus are associated with altered brain activation in reading-related brain regions in subjects with reading disability. *NeuroImage*, *63*(1), 148–156. doi:10.1016/j.neuroimage.2012.06.037
- Darki, F., Peyrard-Janvid, M., Matsson, H., Kere, J., & Klingberg, T. (2012). Three Dyslexia Susceptibility Genes, *DYX1C1*, *DCDC2*, and *KIAA0319*, affect temporo-parietal white matter structure. *Biological Psychiatry*, *72*(8), 671–676. doi:10.1016/j.biopsych.2012.05.008
- Dehaene, S., & Cohen, L. (2007). Cultural recycling of cortical maps. *Neuron*, *56*(2), 384–398. doi:10.1016/j.neuron.2007.10.004
- Eden, G. F., Jones, K. M., Cappell, K., Gareau, L., Wood, F. B., Zeffiro, T. A., ... Flowers, D. L. (2004). Neural changes following remediation in adult developmental dyslexia. *Neuron*, *44*(3), 411–422.
- Eden, G. F., VanMeter, J. W., Rumsey, J. M., Maisog, J. M., Woods, R. P., & Zeffiro, T. A. (1996). Abnormal processing of visual motion in dyslexia revealed by functional brain imaging. *Nature*, *382*(6586), 66–69. doi:10.1038/382066a0
- Flowers, D. L., Wood, F. B., & Naylor, C. E. (1991). Regional cerebral blood flow correlates of language processes in reading disability. *Archives of Neurology*, *48*(6), 637–643.
- Galaburda, A. M., & Kemper, T. L. (1979). Cytoarchitectonic abnormalities in developmental dyslexia: a case study. *Annals of Neurology*, *6*(2), 94–100. doi:10.1002/ana.410060203
- Galaburda, A. M., Sherman, G. F., Rosen, G. D., Aboitiz, F., & Geschwind, N. (1985). Developmental dyslexia: four consecutive patients with cortical anomalies. *Annals of Neurology*, *18*(2), 222–233. doi:10.1002/ana.410180210
- Galaburda, A. M., LoTurco, J., Ramus, F., Fitch, R. H., & Rosen, G. D. (2006). From genes to

- behavior in developmental dyslexia. *Nature Neuroscience*, 9(10), 1213–1217. doi:10.1038/nn1772
- Giedd, J. N., Blumenthal, J., Jeffries, N. O., Castellanos, F. X., Liu, H., Zijdenbos, A., ... Rapoport, J. L. (1999). Brain development during childhood and adolescence: A longitudinal MRI study. *Nature Neuroscience*, 2(10), 861–863. doi:10.1038/13158
- Gross-Glenn, K., Duara, R., Barker, W. W., Loewenstein, D., Chang, J. Y., Yoshii, F., ... Sevush, S. (1991). Positron emission tomographic studies during serial word-reading by normal and dyslexic adults. *Journal of Clinical and Experimental Neuropsychology*, 13(4), 531–544. doi:10.1080/01688639108401069
- Hoefl, F., McCandliss, B. D., Black, J. M., Gantman, A., Zakerani, N., Hulme, C., ... Gabrieli, J. D. E. (2011). Neural systems predicting long-term outcome in dyslexia. *PNAS*, 108(1), 361–6. doi:10.1073/pnas.1008950108
- Krafnick, A. J., Flowers, D. L., Napoliello, E. M., & Eden, G. F. (2011). Gray matter volume changes following reading intervention in dyslexic children. *NeuroImage*, 57(3), 733–741. doi:10.1016/j.neuroimage.2010.10.062
- Lu, L. H., Leonard, C. M., Thompson, P. M., Kan, E., Jolley, J., Welcome, S. E., ... Sowell, E. R. (2007). Normal developmental changes in inferior frontal gray matter are associated with improvement in phonological processing: a longitudinal MRI analysis. *Cerebral Cortex*, 17(5), 1092–9. doi:10.1093/cercor/bhl019
- Meda, S. A., Gelernter, J., Gruen, J. R., Calhoun, V. D., Meng, H., Cope, N. A., & Pearlson, G. D. (2008). Polymorphism of DCDC2 reveals differences in cortical morphology of healthy individuals—A preliminary voxel based morphometry study. *Brain Imaging and Behavior*, 2(1), 21–26. doi:10.1007/s11682-007-9012-1
- Pinel, P., Fauchereau, F., Moreno, A., Barbot, A., Lathrop, M., Zelenika, D., ... Dehaene, S. (2012). Genetic variants of FOXP2 and KIAA0319/TTRAP/THEM2 locus are associated with altered brain activation in distinct language-related regions. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, 32(3), 817–825. doi:10.1523/JNEUROSCI.5996-10.2012
- Price, C. J. (2012). A review and synthesis of the first 20 years of PET and fMRI studies of heard speech, spoken language and reading. *Neuroimage*, 62(2), 816–847.
- Pugh, K. R., Frost, S. J., Rothman, D. L., Hoefl, F., Tufo, S. N. D., Mason, G. F., ... Fulbright, R. K. (2014). Glutamate and choline levels predict individual differences in reading ability in emergent readers. *The Journal of Neuroscience*, 34(11), 4082–4089. doi:10.1523/JNEUROSCI.3907-13.2014
- Raschle, N. M., Chang, M., & Gaab, N. (2011). Structural brain alterations associated with dyslexia predate reading onset. *Neuroimage*, 57(3), 742–749.
- Raschle, N. M., Zuk, J., & Gaab, N. (2012). Functional characteristics of developmental dyslexia in left-hemispheric posterior brain regions predate reading onset. *Proceedings of the National Academy of Sciences of the United States of America*, 109(6), 2156–2161. doi:10.1073/pnas.1107721109
- Richlan, F., Kronbichler, M., & Wimmer, H. (2011). Meta-analyzing brain dysfunctions in dyslexic children and adults. *Neuroimage*, 56(3), 1735–1742. doi:10.1016/j.neuroimage.2011.02.040
- Richlan, F., Kronbichler, M., & Wimmer, H. (2013). Structural abnormalities in the dyslexic brain: A meta-analysis of voxel-based morphometry studies. *Human Brain Mapping*, 34(11), 3055–3065. doi:10.1002/hbm.22127
- Rumsey, J. M., Andreason, P., Zametkin, A. J., Aquino, T., King, A. C., Hamburger, S. D., ... Cohen, R. M. (1992). Failure to

Dyslexia and the Brain – Page 5

activate the left temporoparietal cortex in dyslexia. An oxygen 15 positron emission tomographic study. *Archives of Neurology*, 49, 527–534.

Sowell, E. R., Thompson, P. M., Leonard, C. M., Welcome, S. E., Kan, E., & Toga, A. W. (2004). Longitudinal mapping of cortical thickness and brain growth in normal children. *The Journal of Neuroscience*, 24(38), 8223–8231.

doi:10.1523/JNEUROSCI.1798-04.2004

Turkeltaub, P. E., Gareau, L., Flowers, D. L., Zeffiro, T. A., & Eden, G. F. (2003). Development of neural mechanisms for reading. *Nature Neuroscience*, 6(7), 767–773. doi:10.1038/nn1065

The International Dyslexia Association (IDA) thanks Guinevere F. Eden, Ph.D., for her assistance in the preparation of this fact sheet.

“promoting literacy through research, education and advocacy”™

The International Dyslexia Association · 40 York Road · Fourth Floor · Baltimore · MD · 21204
Tel: 410-296-0232 · Fax: 410-321-5069 · E-mail: info@interdys.org · Website: <http://www.interdys.org>

© Copyright 2015, The International Dyslexia Association (IDA). IDA encourages the reproduction and distribution of this fact sheet. If portions of the text are cited, appropriate reference must be made. Fact sheets may not be reprinted for the purpose of resale.