Sound Training Rewires Dyslexic Children's Brains For Reading

December 2007 by Nadine Gaab, Ph.D.

Introduction by Garrison W. Cottrell, Ph.D.

This week's article was written by Nadine Gaab, a newly-appointed Assistant Professor at Children's Hospital at Harvard Medical School. Dr. Gaab was a postdoctoral researcher in the NSF-funded Temporal Dynamics of Learning Center with Dr. Paula Tallal of Rutgers.

While many young cognitive neuroscientists are using the emerging technology of fMRI, which allows us to see how brain areas are activated by various stimuli, Dr. Gaab is one of the few who has made a substantial, creative and lasting contribution to the technology itself. One of the limitations of fMRI for investigating issues involving sound, such as spoken language or music processing, is the very loud noise generated by the scanner. When the subject is inside the scanner, the noise sounds like 100 garbage trucks backing up in synchrony (WAH, WAH, WAH...). As part of her Ph.D. research, Dr. Gaab developed the idea of sampling brain activation between the noise bursts. This technique, called "sparse temporal sampling" has been a major technological advance, and allows researchers for the first time to use sound stimuli in the scanner. While at Stanford, Nadine was able to work with Gary Glover, one of the major figures in the development of fMRI technology, to further quantify the advantages of this procedure not only for auditory experiments, but much more broadly. The studies reported in this issue demonstrate the value of Gaab's sparse temporal sampling procedure by demonstrating a major difference in the brain responses of dyslexic children versus typical readers when presented with rapidly changing auditory stimuli.

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A spublished brain-imaging study[1] suggests that children with developmental dyslexia struggle with reading because their brains do not process fast-changing sounds properly. Moreover the study found that with the help of computerized sound training, the children with developmental dyslexia were able to literally rewire their brain. This resulted in more accurate sound processing and hence better language and reading.

A major problem for the estimated 5 to 17 percent of children with developmental dyslexia is that they often confuse letters and syllables when they read, which suggests that their internal association between letters and their corresponding sounds is weak. In the 1970's it was proposed by Paula Tallal that this deficit is caused by an underlying problem with accurately perceiving and distinguishing different fast-changing sounds. In order to differentiate between the sounds of a word, the brain needs to perceive fast sound alterations at the millisecond (one thousandth of a second) time scale. Tiny differences in the time at which the vocal chords start vibrating make the difference between "ba" and "pa" for example. The vocal chords start vibrating just before your lips open for "ba," and just after for "pa." You can see this yourself if you hold your throat while repeating "ba, ba, ba" versus "pa, pa, pa." (Make sure you're alone or people will think you're crazy!) You can feel that your vocal chords vibrate continuously as you say "ba". However, as you say "pa" there is no vibration until you get to the vowel "a" part of the syllable. If a child cannot capture these subtle timing details, he or she will have problems distinguishing between speech sounds and, therefore, he or she may be more prone to confuse these syllables even before learning to read. With an imprecise internal sound map, it will be difficult for the child to establish a map of which letters go with which sounds, and this can lead to difficulty learning the phonetic basis for reading.

In this study, together with my colleagues Elise Temple (Dartmouth University) and John Gabrieli (MIT), we used functional magnetic resonance imaging (fMRI) to examine how the brains of 9- to 12-year-old children with developmental dyslexia, and typical readers responded to fast and slow changing sounds. The fMRI enabled us to observe brain activity in response to short sound intervals in which the acoustic properties changed either rapidly (over tenths of milliseconds – as in spoken words) or relatively slowly (hundreds of milliseconds). The sounds were not actual language, but resembled the vocal patterns found in speech. In addition to the brain imaging, standardized language and reading tests were administered both before and after using a neuroplasticity-based[2] training program called Fast ForWord Language, designed in part by Tallal, a co-author on the study.

Although previous studies pointed out that children with developmental dyslexia have trouble discriminating between brief acoustic stimuli, this is the first to use functional magnetic resonance imaging (fMRI) to observe their brains' response to fast and slow changing sounds.

The results indicated that the brains of children with developmental dyslexia responded similarly to fast and slow changing sounds, even though they were not required to pay attention to these changes in this experiment. The same brain regions responded to both sets of stimuli. In contrast, the brains of typical reading children showed differences in 11 brain regions when listening to fast compared to slow sounds. This suggests that, unlike typical readers, the brain of a child with dyslexia is not representing fast and slow sound changes differently.

After the initial fMRI, the dyslexic children went through eight weeks of daily one-hour sessions (about 60 hours total) of the remediation program Fast ForWord Language (Scientific Learning Corporation, Oakland). This program involves no reading and uses both nonverbal sounds such as chirps and whistles as well as speech sounds in the form of syllables, words and sentences. Users must discriminate between paired sounds, syllables or words, such as choosing which sound rose or dropped in pitch or which picture represents the word they just heard, when presented with words that sound very much alike (such as big vs pig). The training exercises are individually adaptive to each mouse click the child makes. Each begins at an easy level, but then gradually increases in difficulty based on the child's responses.

The repetitive exercising of the intervention program had an effect on the brains of children with developmental dyslexia. After training the children listened again to the fast and slowly changing sounds while in the fMRI scanner. After training, the children with dyslexia showed brain activity much more like that of the typical-reading group. Furthermore, the dyslexic children's reading scores as a group improved significantly after training (even though the training did not involve reading per se), moving them into the low end of the typical reading range. Hence the initially described differences in brains of children with developmental dyslexia and typical readers can be changed through intensive training. How long this effect lasts remains to be seen in follow-up studies.

Heartened by the promising findings of these results, we hope to be able to use fMRI to identify developmental dyslexia before the children begin to read. If developmental dyslexia could be diagnosed at a young age, it would enable educators to remediate the kids very early and would spare them from frustration and low self-esteem. To come closer to this goal, I am designing a new study for which we are currently recruiting preschoolers whose family members have developmental dyslexia. (Learn more about the study.)

Acknowledgments:

Elise Temple, PhD, of Dartmouth College's Department of Education, was the senior author of the study, which was funded by the Haan Foundation, the M.I.T. Class of 1976 Funds for Dyslexia Research, and the NSF Temporal Dynamics of Learning Center.

John Gabrieli, PhD (Department of Brain and Cognitive Sciences, MIT); Gayle Deutsch (Stanford University) and Paula Tallal (Rutgers University) co-authored this study.

Fast ForWord Language (www.scientificlearning.com) was developed by Paula Tallal, Ph.D and Steve Miller, Ph.D of Rutgers University and Michael Merzenich, PhD, and William Jenkins, Ph.D of the University of California, San Francisco.

Nadine Gaab is a newly-appointed Assistant Professor at Children's Hospital at Harvard Medical School. Dr. Gaab was a postdoctoral researcher in the NSF-funded Temporal Dynamics of Learning Center with Dr. Paula Tallal of Rutgers. She has received superb academic training both in Europe (Germany and Switzerland) as well as in the US (Harvard, Stanford, MIT). She received a Master's of Science in Psychology from the University of Trier, Germany and a Ph.D in Psychology/Neuropsychology from University of Zurich, Switzerland, receiving the highest distinction of "Summa cum laude" for her doctoral thesis. Throughout her doctoral as well as post-doctoral training, Nadine has worked with leaders in the emerging field of cognitive neuroscience (Lutz Jancke, Gottfried Schlaug, John Gabrieli and Paula Tallal), as well as in her specialty area of functional magnetic resonance imaging (fMRI) (Gary Glover). She has continuously received funding for her training and research, including several prestigious fellowships for graduate training at the Harvard Medical School (German National Merit Foundation; German Academic Exchange Council) and specialty training courses at King's College London, Princeton and Harvard.

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[1] October, 2007; Gaab et al; (2007) "Neural correlates of rapid auditory processing are disrupted in children with developmental dyslexia and ameliorated with training: An fMRI study,"; *Restorative Neurology and Neuroscience* 25, 295-310

[2] “Neuroplasticity” refers to changes in brain organization that occur through learning. “Neuroplasticity-based” in this context means that the training is in accord with neuroscience studies of how brain areas reorganize in monkeys through training.