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Changes in Brain Function in Children with Dyslexia after Training

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Introduction

Developmental Dyslexia

Developmental dyslexia is defined simply as difficulty reading despite the intelligence, motivation, and education necessary for successful reading [1]. Its prevalence is still an active area of research but has been estimated at any where between 5 and 17% of the population, therefore representing a very large national and international concern [1]. Studies have shown that the reading deficits of children with developmental dyslexia have persisted into adolescence and even adulthood. The disorder cannot be explained as a simple developmental lag [1]. A number of different methods have suggested a neurobiological basis for the disorder, but the fundamental cause (or causes) remains unknown and is an active area of research on many fronts [2, 3]. It is important to note that there are many risk factors for difficulties in reading that are not biological. For example, home literacy environment and socio-economic status can predict reading ability [4]. These factors can and should be addressed in educational and social policy. The biological basis for dyslexia is considered when those risk factors have been accounted for and a reading deficit remains.

Importance of Phonological Awareness

A developing consensus among many researchers is that developmental dyslexia is characterized by difficulties in phonological processing, specifically phonological awareness which is the ability to identify and manipulate the sound structure of words [1, 4]. Individuals with dyslexia have impaired phonological skills, including the ability to distinguish rhyming sounds, count the syllables of words, and sound out novel or "pseudo-words" (e.g., "stroat" or "traim"). Phonological awareness skills are thought to be a required foundation for both normal-reading and dyslexic children to benefit from phonics instruction.

Auditory Processing

In addition to a deficit in phonological processing, individuals with dyslexia have been shown, by some researchers, to have a more fundamental deficit in auditory processing, specifically auditory processing of rapid auditory sounds that are entering the nervous system in the 10's of milliseconds [5, 6]. This deficit in processing rapid auditory stimuli is thought to impact language and subsequently reading because some of the sounds in language, or phonemes, differ only in frequency changes that occur in the first 40-50 ms of the sound. The idea behind the rapid auditory processing hypothesis of developmental dyslexia is that without this ability to detect rapid auditory signals the child is unable to distinguish certain phonemes and develops an inadequate or "fuzzy" understanding of the phonology or sounds of his/her language. This inadequate understanding of the sounds of the words in the language is especially problematic when the child learns to read and is required to map letters onto their appropriate sounds.

Functional Brain Imaging

With the advent of new technology that allows us to visualize brain function in adults and children, researchers have begun to explore brain function and possible dysfunction in adults, and more recently children with developmental dyslexia. There are a few methods available to measure brain function in children. The type used in the current study is called functional magnetic resonance imaging or fMRI. FMRI is a variant of traditional MRI, which is used for visualization of any soft tissue inside the body (including the structure of the brain and spinal cord).

While MRI allows us to see the structure of the brain, fMRI allows us to see the *function* of the brain. The technique is based on the fact that when you think, see, or imagine there is an increase in brain function (neurons firing) in specific and localized parts of the brain.

Increased brain function causes an increase in blood flow. The increase in blood flow, brings about an increase in oxygen, that can be measured by fMRI. More oxygen occurs naturally in areas of the brain that are working harder. The technique is entirely noninvasive (it requires no injections or imaging contrasts) and can be used safely in children.

Brain Function in Dyslexia

Studies of brain function in dyslexia using this and other techniques have shown people with dyslexia seem to have a neural disruption in phonological processing as well as the behavioral deficit described earlier. A number of studies, using different methods and subject groups, have found that when people with dyslexia are asked to do some tasks that require phonological processing they have less brain function (as compared to normal reading controls) in a specific brain area. This decreased activity is localized to a part of the brain on the left side called the temporo-parietal cortex, a region of the brain located a little behind and above the ear [2]. (See figure.) This decrease in brain function has been shown in adults with dyslexia and even non-English speaking adults with dyslexia.

More recently, children with dyslexia have also been shown to have decreased activity in this brain region, suggesting that the disruption may be fundamental to the disorder and not an effect of years of compensation. What has not been known is the extent to which this decrease in brain function could be changed with training or education.

The Current Study

The current study [7] was designed to test whether this decrease in activity could be changed in children with dyslexia. We hypothesized that we might be able to see changes in brain function in children with dyslexia after remediation and we expected two types of changes. One type of change we might see would be a normalizing of the activity in the left temporo-parietal region discussed above. We might see increases in activity in this region, bringing the dyslexic brain closer to the normal-reading brain. We also expected that we might see increased activity in other regions of the brain, perhaps reflecting a compensatory effect of the training on brain function.

Methods

Training program

The training program used in the study was Fast ForWord Language (www.scilearn.com), which focuses on auditory processing and oral language through an intensive and adaptive computer program [8, 9]. One unique feature of the program is a focus on training children to discriminate rapid auditory signals. It also emphasizes other aspects of oral language, including auditory attention, memory, phonological processing, and listening comprehension. The training lasted approximately 8 weeks and included 100 minutes a day, 5 days a week.

Experimental Design

The study included children 8-12 years old with dyslexia (ñ=20) who underwent fMRI scans before and after training. In addition, 12 normal-reading children underwent two fMRI scans about 8 weeks apart to control for any practice effects, normal development, and scan–rescan effects. The children performed a phonological processing task while undergoing fMRI. The task was a simple rhyming task. Each child was shown two letters and asked to push a button if the names of the two letters rhymed with each other (e.g., “T” and “D” rhyme, whereas “G” and “K” do not). This was compared to a matching task where the child simply indicated if the two letters were the same letter (e.g., “P” and “P”). The rhyming task was designed to require phonological analysis of the letters’ names, but was simple enough for a poor or beginning reader to perform.

By comparing the brain function during the rhyming task with the brain function during the matching task, we could focus on the brain function specifically associated with phonological analysis rather than orthographic processing of letters or other task demands (like pushing a button, being in an MRI machine, etc.).

Results

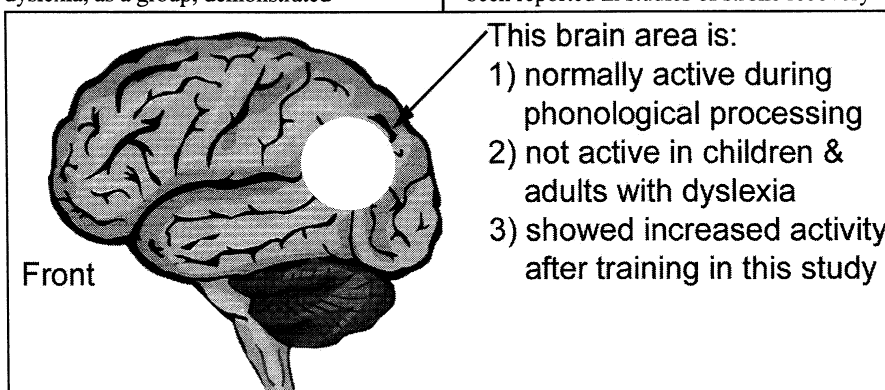
Reading and Language Ability

We found that the children with dyslexia, as a group, demonstrated improved performance on reading measures after the training program. Their performance on the Woodcock Johnson Reading Master subtests improved significantly and, as a group, was now in the normal range. (WJR-MT scores: Word Identification: pre training = 78.2, post training = 86.0, $p<0.0005$; Word attack: pre training = 85.5, post training 93.7, $p < 0.0001$; Passage Comprehension: pre-training = 83.3, post training = 88.9, $p < 0.001$). Similar improvements were seen in oral language measures (CELF-3: receptive: pre training = 92.5, post training = 101.3, $p < 0.001$; expressive: pre training = 95.0, post training = 102.2, $p < 0.006$).

Brain Function

In our analysis of brain function, we found a number of brain areas that showed changes, after training, in the children with dyslexia. In line with our expectations, we did see an increase in the left temporo-parietal cortexes in the children with dyslexia after training. This region was near the region which had been shown to be under-active in these children compared to normal reading children. This increase in brain function had a normalizing effect, in that it brought the brain function of children with dyslexia closer to that of normal-reading children. This normalization was not complete however; the children with dyslexia did not reach normal levels of activity in this region.

In addition, we saw increased activity in a number of regions not normally involved in phonological processing. These regions included parts of the right side of the brain which are mirror images of the normal left-sided language processing areas. These increases may reflect more of a compensatory effect of the training, where the right side of the brain gets involved to help the damaged left side. Right-sided help for language in people who have left-sided damage has been reported in studies of stroke recovery



where increased right-sided activity was associated with improved language after stroke.

In summary, we found a partial amelioration of the disrupted brain function seen in children with dyslexia after training; they showed partial normalization of activity in the left temporo-parietal cortex. In addition, we saw compensatory effects of training, especially in increased activity in the right side of the brain.

Conclusion

This study was the first to use fMRI to explore possible changes in brain function after behavioral training in children with dyslexia. The training used was Fast ForWord Language, a training program that focuses on oral language and auditory processing. After training, the children with dyslexia improved in reading and language ability. In addition, after training, the children with dyslexia showed changes in brain function. These changes in brain function were both "normalizing" and "compensating."

Normalization of brain function in children with dyslexia included increased brain function in the left temporo-parietal cortex, above and behind the left ear. After training there was increased activity in this region, which had been shown to be under-active in children and adults with dyslexia. "Compensating" effects of the training included increased activity in regions of the brain that are were not normally active during such tasks. These increases were seen especially in the right side of the brain, in mirror images to the traditional left-sided language areas, perhaps reflecting a tendency by the right side of the brain to compensate for the left side's inability to function fully. This study shows that the brain dysfunction seen in dyslexia can be affected by behavioral training.

The implications of this study are numerous. First, this study shows that it is possible to study the brain effects of training in human children. Previous research on brain plasticity had been largely limited to animal research. This study opens up the possibility for further research that explores different interventions and educational strategies. Second, this study shows that a specific remediation program, Fast ForWord Language, resulted in changes in brain function in children with dyslexia while improving their reading ability. Finally this study shows that previously reported brain dysfunction in dyslexia can be at least partially ameliorated. These results should help give hope to the individuals struggling with dyslexia and their families and teachers. Dyslexia is not simply a matter of a child not "trying hard enough." This brain research has shows us that the biological aspects of dyslexia can be changed and at least partially normalized.

Please see the actual scientific article for more detail on this study: Temple, E., et al., *Neural deficits in children with dyslexia ameliorated by behavioral remediation: Evidence from fMRI.* Proc Natl Acad Sci U S A, 2003. 100(5): p. 2860-2865.

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