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Can neuroscience help predict learning difficulties in children?

Modern neuroimaging techniques such as magnetic resonance imaging (MRI) have significantly advanced our understanding of the neural bases of learning disabilities in children and raised the possibility of using these neural measures to improve the early diagnosis of learning disabilities.

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Executive summary

- Modern neuroimaging techniques such as magnetic resonance imaging (MRI) have significantly advanced our understanding of the neural bases of learning disabilities in children and raised the possibility of using these neural measures to improve the early diagnosis of learning disabilities.
- Studies have shown that neural measures often outperform behavioral measures in predicting learning outcomes in children with and without disabilities.
- Studies also indicate that subtle differences in brain activity and brain anatomy may be observed in children at risk for a learning disability before the onset of this learning disability.
- It is clear that much more research is needed before these techniques can be applied in clinical and educational settings, but current results are promising.

Introduction

Over the past 20 years or so, tremendous progress has been made in understanding the learning brain. Such progress has been mainly driven by the increasing use and availability of noninvasive imaging techniques that allow researchers to observe the brain activity of participants while they perform different types of tasks. Perhaps the most popular of these techniques is functional magnetic resonance imaging (fMRI) (see Figure 1). fMRI relies on the idea that a brain region at work necessarily consumes oxygen and therefore will demand increased blood flow (which comes with oxygenated hemoglobin) to compensate for this consumption. An fMRI scanner is able to detect these (very small) changes in blood oxygenation. It may thus tell researchers whether a brain area is involved in a given task. Although most fMRI studies investigate brain activity in adult participants, a number of studies have also explored brain activity in children. Therefore, the technique has allowed researchers to gain insights into the neural mechanisms that are involved in learning different types of skills through development and education, such as reading and arithmetic. Because fMRI can detect changes in brain activity in response to specific stimulations even without any behavioral response, it raises the intriguing possibility that the technique could be used one day to help predict learning difficulties in children even before these children may struggle. This could have tremendous implications for the early diagnosis and management of learning difficulties such as dyslexia (i.e., reading learning disability) and dyscalculia (i.e., math learning disability). Although much research still needs to be done, a few recent studies indicate that one can be hopeful about the potential relevance of fMRI techniques for predicting learning difficulties in the not-too-distant future. In this brief, we will review recent evidence supporting this claim in the domain of both reading acquisition and arithmetic learning.

Figure 1. A Magnetic Resonance Imaging (MRI) scanner

Neural prediction of reading outcomes in dyslexia

Dyslexia is a specific learning disability in learning to read that is not explained by low intelligence or poor educational opportunities[1]. The disability affects from 5% to 10% of children worldwide and can have important consequences on academic achievement and everyday life. Interestingly, some children with dyslexia (about one fifth) may develop compensation strategies for their deficit and will become typical readers by the time they reach adulthood[1]. However, many others are not able to compensate, and their reading difficulties will persist. Predicting whether a child will be able to compensate for her/his reading disability is of tremendous importance for designing interventions and selecting treatments. In a recent study, Hoeft and colleagues attempted to test whether fMRI could help predict how much reading progress a child with dyslexia will make in the near future[1]. Therefore, they recruited 25 teenagers diagnosed with dyslexia and tested their reading skills at the beginning of the study. Participants' brain activity was also measured with an MRI scanner while they had to judge whether two visually presented words rhymed. For example, participants could be presented with the words "bait" and "gate," in which case they had to answer that the words rhymed (despite having a different spelling). Two and a half years later, the participants were invited to come back to the lab, and their reading skills were again measured (but not their brain activity). Based on how much each participant improved with respect to her/his reading skill over this period of 2.5 years, the researchers categorized the participants as showing progress or not showing progress. They then tested whether brain activity measured 2.5 years earlier could predict which group a participant fell into. What the researchers found was quite striking. Based on brain imaging alone, it was possible to predict whether a participant made progress in reading with an accuracy of more than 90%. In fact, fMRI measures turned out to be better than behavioral measures at predicting reading gains in that study. Interestingly, what distinguished participants showing progress in reading from participants who did not show progress was activity in the frontal cortex, a region located in the anterior part of the brain. The researchers posited that this activity might reflect compensatory mechanisms that some dyslexics (i.e., those who show the most progress in reading) may be able to engage (see Figure 2).

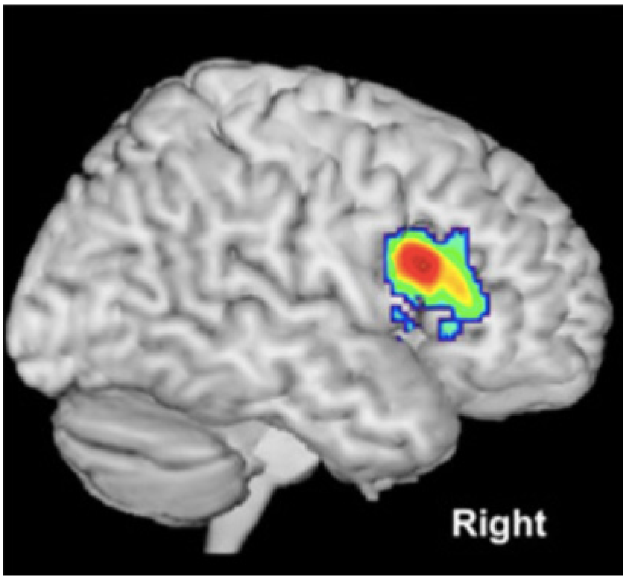

Figure 2. Children with dyslexia who show the most progress in reading activate a region in the right frontal cortex. The region is depicted here on a 3D representation of the brain. (Reproduced from Ref. [1])

Following this study, other studies have explored whether fMRI can detect differences between children at risk for dyslexia and children who are not at risk even before these children learn to read. For example, in one study, Raschle and colleagues recruited a group of 5-year-olds with a familial risk for dyslexia (each child in this group had at least one first-degree relative with a clinical diagnosis of dyslexia)[2]. The researchers presented these children with an auditory task in which they had to say whether two spoken words started with the same first sound or not. That task thus involved phonological processing, which is widely thought to be affected in dyslexic children. Critically, brain activity in these children was measured with fMRI while they were performing the task. Compared to a group of 5-year-olds with no familial risk of dyslexia (no child in this group had first-degree relatives with dyslexia), the researchers found that children at risk for dyslexia have less activity in a number of brain regions that are known to be important for learning how to read (see Figure 3). Therefore, brain activity differences between children at risk versus children not at risk for dyslexia may be detected even before these children struggle with reading. In a follow-up study, the researchers found that brain anatomy was also atypical in prereaders at risk for dyslexia[3]. Overall, these studies are interesting because they show the potential of brain imaging for detecting brain abnormalities in children before they struggle, thereby showing promise for future efforts to diagnose reading disabilities.

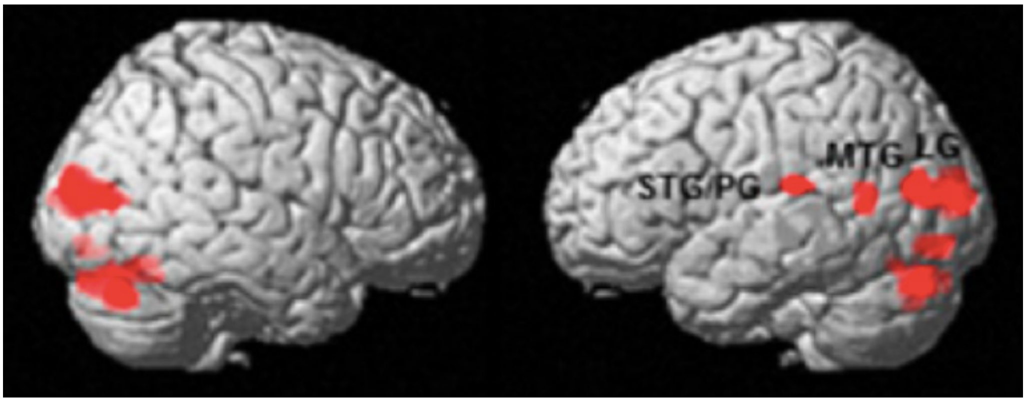

Figure 3. 5-year-old children at risk of dyslexia show less activity in several brain regions than children who are not at risk of dyslexia during a phonological task. The regions are depicted here on a 3D representation of the brain. (Reproduced from Ref. [2])

Neural prediction of arithmetic outcomes in dyscalculia

Dyscalculia is a specific learning disability affecting the acquisition of math skills. Like dyslexia, dyscalculia is not explained by low intelligence or poor educational opportunities and also affects about 5% to 10% of children[4]. In fact, children with dyslexia may often (but not always) also have dyscalculia, and vice versa. Dyscalculia is considerably less researched than dyslexia. Yet, a few recent studies suggest that brain imaging measures may also be useful in the future for the diagnosis and treatment of dyscalculia. For example, in a recent study, Iuculano and colleagues tested whether it may be possible to detect whether a child is dyscalculic or not by examining brain activity during arithmetic problem-solving[4]. Therefore, the researchers recruited 15 children with dyscalculia and 15 children without dyscalculia. All children, who were in their third grade of schooling, were asked to solve addition problems while their brain activity was measured in an fMRI scanner. Based on brain activity alone, the researchers were able to classify each participant into a dyscalculic and a nondyscalculic group with an accuracy of more than 80% (see Figure 4). Much like in the study by Hoeft and colleagues described above, the researchers also invited these children to come back to the lab 8 weeks later and asked them to perform the same addition problem-solving task. They also measured their brain activity at that time. Importantly, during the 8 weeks separating the two sessions, children were all involved in an intensive math tutoring program. As expected, there was some variability in the extent to which children benefited from that tutoring: While some exhibited large improvements in the addition problem-solving task, others exhibited smaller improvements (or no improvements). Critically, by simply looking at the difference in brain activity between the pre- and post-tutoring sessions, the researchers were able to predict performance gains in dyscalculic children. Interestingly, behavioral measures could not help in predicting such performance gains. Overall, these results are consistent with two other studies from the same group that showed that brain measures (either activity in brain regions or connectivity between regions) are a better predictor of math performance gains than behavioral measures alone[5,6]. Unfortunately, there is no study to date showing that fMRI can detect neural markers of dyscalculia before children experience difficulties, as is the case for reading and dyslexia[2]. But research on the neural bases of dyscalculia is still in its infancy, and significant progress on our understanding of this disability is likely to be made in the near future.

Some challenges along the way

The studies reviewed above allow one to be reasonably hopeful regarding the potential of neuroscience methods for the early diagnosis and treatment of learning disabilities. However, there are many challenges along the way before reaching this ultimate goal[7]. First, many of the studies reviewed here involve relatively small sample sizes, and the results need to be replicated and extended to larger populations. Second, studies need to more consistently evaluate the extent to which they can predict learning

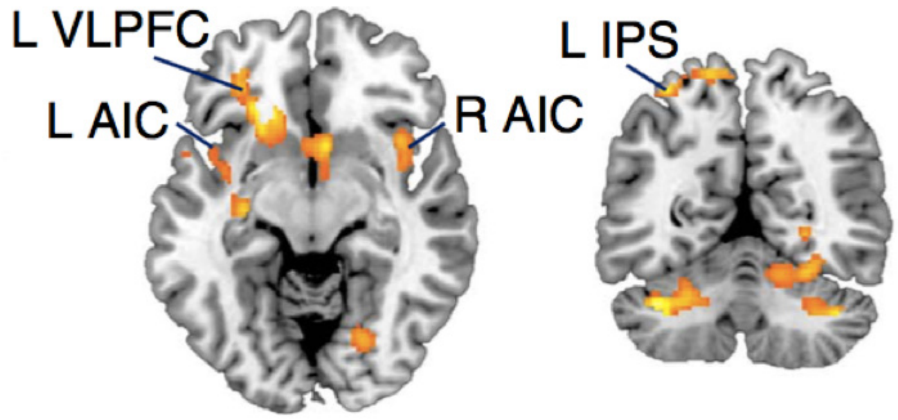

Figure 4. Compared to children without dyscalculia, children with dyscalculia activate several brain regions much more when performing an addition problem-solving task. These brain regions are displayed here on two pictures of the brain taken using a magnetic resonance imaging scanner. (Reproduced from Ref. [4]).

outcomes or detect neural markers of disabilities in a single individual (rather than in a group of subjects). Third, studies need to consistently show that neural measures either outperform behavioral measures or improve the efficiency of behavioral measures in predicting learning outcomes. Otherwise, they would not be particularly useful. Fourth, it may be argued that neuroimaging techniques are too costly and will never realistically be used in clinical practice to help diagnose children with learning disabilities or predict learning outcomes. Although it is true that fMRI is an expensive technique, it is difficult to predict what the future holds and the extent to which more affordable techniques may be developed. Techniques may also become increasingly mobile and easy-to-use outside of the lab. Finally, as pointed out by Gabrieli and colleagues[7], "any economic analysis […] ought to include the costs of current practices […] in which children must demonstrate academic failure before receiving educational intervention. The cost of a neuropsychological assessment and report for an individual child or adult, for example, often exceeds that of an MRI."

Conclusion

In sum, modern neuroimaging techniques have provided important new insights into the learning brain. These techniques have also contributed to a better understanding of learning disabilities in children. Recently, researchers have started to explore whether we could go beyond the use of neuroimaging techniques to improve our understanding of disabilities and use these methods to predict whether children may develop a learning disability (or to what extent children may improve their skills in the near future). These studies are still in their infancy, but they have already provided some interesting and promising results. For instance, studies have shown that neural measures often outperform behavioral measures in predicting learning outcomes in children with and without disabilities[1,5,8]. Studies also indicate that subtle differences in brain activity and brain anatomy may be observed in children at risk for a learning disability before the onset of this learning disability[2,3]. It is clear that much more research is needed before these techniques can be applied in clinical and educational settings. But there are also many reasons to be hopeful.

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